Mitigating Risks and Vulnerabilities in the Energy-Food-Water Nexus in Developing Countries



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Mitigating Risks and Vulnerabilities in the Energy-Food-Water Nexus in Developing Countries

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AUTHORS

Jeremy Wakeford
Candice Kelly
Sasha Mentz Lagrange

PREPARED FOR THE

United Kingdom Department
for International Development

CONTRIBUTORS

Tarak Kate
Florian Kroll
Luke Metelerkamp

BY THE

Sustainability Institute and School of Public Leadership
Stellenbosch University, South Africa

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The **Sustainability Institute** (SI) was established in 1999 as an educational institution to advance learning for sustainable living. Located in the Lynedoch Eco-Village near Stellenbosch, it focuses on combining practice with theory in a way that integrates ecology and equity in support of a sustainable South Africa, with special reference to reducing and eradicating poverty. The SI has built a name for itself through its Masters Programme in Sustainable Development Planning and Management, offered in partnership with the SPL at Stellenbosch University. SI Projects is a business unit of the SI that offers its clients sustainability expertise shaped by the insights generated through the Masters programme and the latest research conducted by its students and associates.

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ABOUT THE AUTHORS

Dr Jeremy Wakeford is an economist specialising in energy and sustainability. He holds Masters degrees in economics from the University of Cape Town and Cambridge University, and a PhD in sustainable development and planning from Stellenbosch University (South Africa). He is an Extraordinary Senior Lecturer in the School of Public Leadership at Stellenbosch University and was formerly a Senior Lecturer in economics at the University of Cape Town. Dr Wakeford recently took up a position as macroeconomist at Quantum Global Research Lab, a think tank specialising in models of inclusive growth and sustainable development for African countries. Dr Wakeford has extensive research experience in the field of energy economics. He is the author of a book on the implications of global oil depletion for South Africa, and co-editor of a forthcoming volume on the green economy in South Africa.

Dr Tarak Kate holds a MSc and PhD in botany, and for the last 22 years has specialised in appropriate technology, organic recycling, sustainable agriculture, renewable energy, and waste utilisation. His work primarily helps small farmers in India with holdings of less than two acres to maximise the returns from their land. Central to his programme is an emphasis on a bio-diversification, geared to the needs of local farmers, that comprises sericulture, pisciculture, animal rearing, poultry farming, crop cultivation, land banking and watershed management on land previously cultivated for staple and cash crops.

Candice Kelly is currently conducting doctoral research on the change agents leading food system transition in South Africa. She is also involved in the running of the Southern African Food Lab, a prominent multi-sectoral collaboration working on innovations for food security in South Africa. Prior to this, Candice ran the Sustainable Agriculture programme of the Sustainability Institute, which developed a sustainable food systems stream within the MPhil in sustainable development. She continues to run the Food Security and Globalised Agriculture module, and to supervise and mentor students researching food systems. Prior to completing her own MPhil at the Sustainability Institute, Candice's Business Science degree in finance allowed her to work in a number of corporate settings.

Florian Kroll is a food security specialist with a particular focus on urban food security in Africa, food systems resilience analysis, policy advice, programme monitoring and evaluation, as well as social innovation. He is affiliated with the Wits Siyakhana Initiative at the School of Geography, Archaeology and Environmental Studies at Wits University, has worked with the African Centre for Cities at the University of Cape Town, is a US International Visitor Leadership Programme alumnus and is also a member of various research and advocacy networks including the SA Food Lab and the African Food Security Urban Network.

Sasha Mentz Lagrange holds a Master's degree in international relations and action abroad from Sorbonne University, Paris and a Master's degree in sustainable development planning and management from the University of Stellenbosch. Over the past six years, she has worked in the field of sustainable development with a specific interest in resilient agricultural practices, renewable energy, climate change adaptation and mitigation in Africa. Sasha was a consultant for the United Nations Development Programme Africa Adaptation Programme between 2010 and 2013 and currently works as an independent researcher and development practitioner for the Sustainability Institute and other research institutions.

Luke Metelerkamp has been based at the SI in Stellenbosch since 2009 and now heads up the SI Food System Centre. His research focus is on localisation of food systems and past research clients include Ernst & Young, the World Wildlife Fund, the German Corporation for International Cooperation, and the United Kingdom Department for International Development. Luke is also a lecturer for Stellenbosch University's MPhil in sustainable development. He holds an MPhil in sustainable development, a BA in applied design and is currently enrolled for a PhD at the University College of London.

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Abbreviations

AfDB	African Development Bank
BERL	Bioenergy Resources Limited
BP	British Petroleum
CAC	Campesino – a – Campesino
DAFF	Department of Agriculture, Forestry & Fisheries
DoE	Department of Energy
DFID	Department for International Development [United Kingdom]
DME	Department of Minerals and Energy
DWA	Department of Water Affairs
EIA	Energy Information Administration
ETHCO	Ethanol Company of Malawi
FSSA	Fertilizer Society of South Africa
FISP	Fertilizer Input Subsidy Programme
FAO	Food and Agriculture Organization [United Nations]
FDI	Foreign Direct Investment
GCIS	Government Communication and Information System
GDP	Gross Domestic Product
GNI	Gross National Income
GoM	Government of Malawi
IPCC	Intergovernmental Panel on Climate Change
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
LIC	Low-income country
LMIC	Lower-middle-income country
MERA	Malawi Energy Regulatory Agency
NSO	National Statistical Office
NGPL	Natural gas plant liquids
OCHA	Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing Power Parity
PV	Photovoltaics
REEEP	Renewable Energy and Energy Efficiency Partnership
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
SIDS	Small Island Developing States
SI	Sustainability Institute
SPL	School of Public Leadership
TFEC	Total final energy consumption
UNDESA	United Nations Department of Economic and Social Affairs

UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environment Programme
UNPD	United Nations Population Division
UN-SE4ALL	United Nations Sustainable Energy for All programme
UMIC	Upper-middle-income country
US$	United States Dollar
WEF	World Economic Forum
WDI	World Development Indicators
WFP	World Food Programme
WHO	World Health Organization
WTO	World Trade Organization
WWAP	World Water Assessment Programme
ZAR	South African Rand

Units of Measurement

Bpd	Barrels per day
cm	Centimetres
g	Grams
GW	Gigawatts
ha	Hectare
Kcal	Kilocalories
kg	Kilogram
km	Kilometre
km^2	Kilometers squared
kWh	Kilowatt hours
M^3	Cubic metres
Ml	Megalitre
mm	Millimetres
Mt	Megatonne
MW	Megawatts
mWh	Megawatt hour
PJ	Petajoules
TWh	Terawatt hours
TJ	Terrajoule

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part 0.

INTRODUCTION

Key Messages

- In an increasingly resource-constrained world, the energy-food-water 'nexus' – defined as the interconnections among these three systems that are vital for human survival – is emerging as increasingly important in the discourse on sustainable development.
- The key nexus linkages are as follows:
  - Energy inputs are required at all stages of the food system value chain, including crop and livestock production, processing and storage, distribution, food preparation, and disposal of food waste.
  - A number of agricultural crops are converted into bioenergy.
  - Water is essential for agricultural production, food processing and waste disposal.
  - Energy is critical at many stages of the water system value chain, including abstraction, desalination, treatment, construction of storage infrastructure, pumping, and waste-water treatment.
  - Water is required for the extraction and processing of fossil fuels, generation of hydroelectricity and geothermal power, cooling within thermal power stations, and production of bioenergy.
  - Certain energy industries and high-input agricultural production can have adverse impacts on water and soil quality.
- Treating energy, food and water systems independently of each other can result in critical system linkages and vulnerabilities being underappreciated and can possibly lead to the formulation and implementation of ineffectual or even counterproductive policies and measures.
- The overarching aims of this study are: (1) to understand the dynamic interactions occurring among energy, food and water systems with a view to identifying the key vulnerabilities and risks facing developing countries in terms of nexus security; and (2) to inform planning and policy in developing countries to mitigate these risks and to promote economic efficiency, social equity and environmental sustainability in food, energy and water provision to their citizens via a transition to more sustainable and resilient systems.
- The analysis is conducted at a global scale and also within three country case studies that represent agrarian, industrial and 'ecological' socioecological regimes.

INTRODUCTION

0.

0.1 Rationale for the Study

Geopolitical security and stability were among the prevailing international concerns of the 20th century. By and large, the availability of primary resources and environmental 'space' for waste and emission absorption was not perceived as a significant hindrance to global economic growth and development. However, resource constraints and global climate change have emerged as central challenges in the 21st century, with concerns being raised that humans have transgressed certain 'planetary boundaries' (Rockström, Steffen, Noone, Persson, Chapin, Lambin, Lenton, Scheffer, Folke et al. 2009), with potentially severe implications for human civilisation.

The issues of energy, food and water security have also risen to global prominence as they affect increasing numbers of people in an interconnected world. All individuals and societies rely on energy, food and water to survive and prosper, and yet there are hundreds of millions of people who lack reliable access to these basic necessities in sufficient quantities and of adequate quality. Some 1.3 billion people lack access to electricity, including those living in most of sub-Saharan Africa and large parts of South and East Asia, while a further 1.2 billion have unreliable access (World Bank 2013). Over 780 million people lack reliable access to potable (clean and safe) water for drinking and sanitation (World Bank 2013). And it is estimated that 805 million people experience chronic undernourishment, representing 13.5% of the combined population of developing countries (Food and Agriculture Organization [FAO] 2014).

Furthermore, it is anticipated that demand for energy, food and water will grow strongly in the coming half-century, driven by three main factors. First, the world population is projected to increase to 9.6 billion by 2050, with more than half of that growth set to occur in Africa (United Nations 2013). Second, the global economy is expected to quadruple in size by mid-century, with rising living standards in developing countries leading to increasing volumes and more resource-intensive patterns of consumption (Organisation for Economic Co-operation and Development [OECD] 2012).

Third, a continuing process of urbanisation, particularly in Africa, is likely to raise resource demands since urban areas are typically more resource-hungry than rural areas (United Nations Environment Programme [UNEP] 2013; Parnell & Pieterse 2014). As a result, the demand for energy is expected to increase by 80%, food by 60% (OECD-FAO 2014) and water by 55% (International Renewable Energy Agency [IRENA] 2015) by 2050.

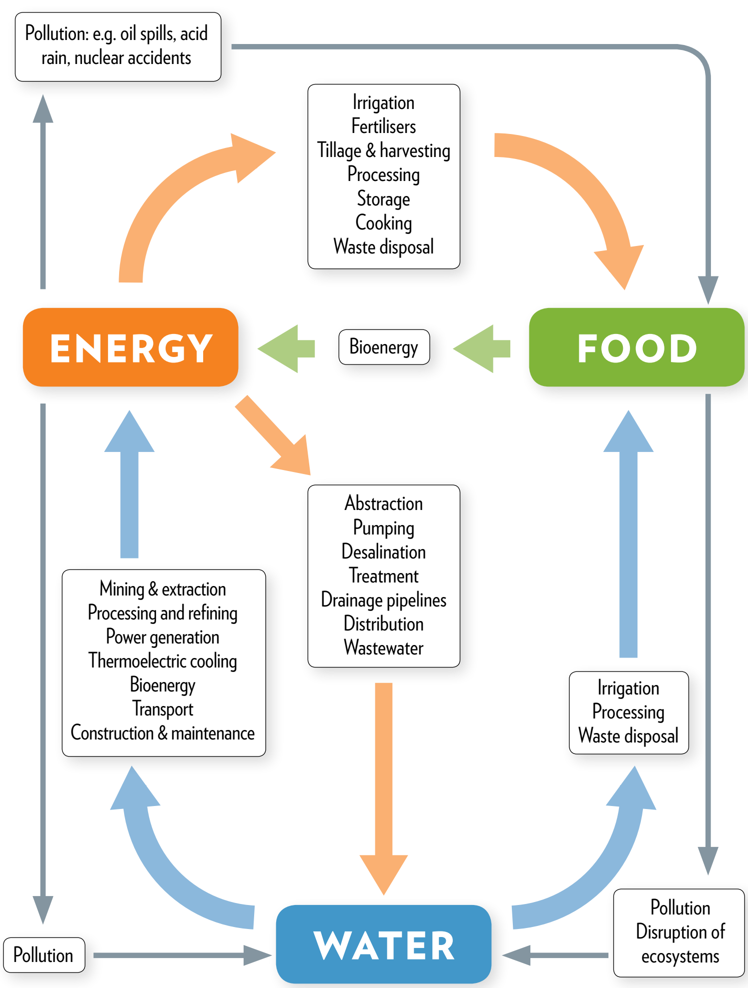
Most of this increased demand is projected to occur in developing countries, especially in burgeoning urban areas. The lack of availability or poor quality of certain key resources, including fossil fuels, water and land, will increasingly constrain the ability to meet this demand (Fischer Kowalski & Swilling 2010; Sorrell, Spiers, Bentley, Brandt & Miller 2010; UNEP 2014). At the same time, the climate is changing – global average temperatures are rising and extreme weather events are increasing in frequency with implications for energy, food and water systems (Intergovernmental Panel on Climate Change [IPCC] 2014).

However, the crucial point is that it is not just that energy resources, food and water are becoming economically scarcer (i.e. demand growing more rapidly than supply, resulting in higher prices), but that the interconnections and interdependencies of these three fundamental requirements for human life are emerging as increasingly important. The energy-food-water 'nexus' is defined as the interconnections between energy, food and water systems.

In this report, 'systems' are understood in terms of their entire value chains (including production, processing, storage, distribution, consumption and waste disposal elements) and supporting infrastructures. Some of the main interdependencies are as follows (and summarised in Figure 0-1):

- Energy inputs are required at all stages of the food system value chain, including electricity to pump water for irrigation, for cold storage of agricultural produce and refrigeration of processed food; diesel fuel to power tractors for tillage and harvesters; fossil fuel-based synthetic fertilisers and pesticides to produce crops and antibiotics to treat livestock; electricity and heat energy required for food processing; fuel for transporting and distributing food products; heat energy required for cooking; and fuel for transporting food waste to disposal sites.
- Energy is critical at many stages of the water system value chain, including extraction from lakes, rivers and aquifers; desalination; water treatment; construction of dams and reservoirs for water storage, and pipelines and pumping for distribution; and waste-water treatment.

Figure 0-1: An overview of the energy-food-water nexus



SOURCE: Adapted from IRENA (2015, fig. 1.1, p.24)

- Energy generation also depends on water for the extraction of fossil fuels; construction of energy infrastructure; processing of coal and refining of oil; generation of hydroelectricity and geothermal power; cooling within thermal power stations, concentrated solar power plants and nuclear reactors; and production of bioenergy.
- A number of agricultural crops (such as corn, sugar and palm oil) are converted into bioenergy, which may lead to competition between food and fuel production for scarce land and water resources.
- Water is essential not only for agricultural production, but also for food processing and waste disposal.
- Agricultural production and food processing may negatively affect water quality via pollution and interference with ecosystem services that are critical for the hydrological cycle, and excessive water demands from the food system may limit the availability of water for other uses.
- Energy industries have many impacts on food production and water quality; for example, via rising carbon-dioxide emissions driving global climate change and the effect of pollution, such as oil spills, sulphur dioxide emissions, acid mine drainage and nuclear radiation accidents, on soil fertility and water quality.

In recent years, spurred on by the oil and food price spikes of 2007-2008, the energy-food-water nexus has emerged as an important focus within international development, sustainability and policy discourses. Increasingly, it is understood that treating energy, food or water systems and security (see definitions in Table 0-1) independently of each other can result in critical system linkages and vulnerabilities being underappreciated and can possibly lead to the formulation and implementation of ineffectual or even counterproductive policies and measures. A key milestone in this regard was a conference organised by the German Federal Government and held in Bonn in 2011, which led to the creation of a nexus information hub: http://www.water-energy-food.org.

Several multilateral agencies have recently commissioned reports on aspects of the nexus: for example, the United Nation's Food and Agriculture Organization (FAO) has examined the relationship between food and energy within the context of climate change (FAO 2011a); the World Bank has a programme investigating the nexus between energy and water (Rodriguez, Delgado, DeLaquil & Sohns 2013; World Bank 2013); and the

Table 0-1: **Definitions of food, energy and water security**

FOOD SECURITY	"... all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO 2014).
ENERGY SECURITY	"... the uninterrupted availability of energy sources at an affordable price" (International Energy Agency [IEA] n.d.).
WATER SECURITY	"... the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN-Water 2013a).

International Renewable Energy Agency (IRENA) produced a report considering the role of renewable energy sources and technologies to address challenges within the energy-food-water nexus (IRENA 2015).

0.2 Aims, Research Questions and Scope

This research report was commissioned and funded by the United Kingdom's Department for International Development (DFID) to contribute to this emerging nexus field of enquiry, with a particular emphasis on developing countries in the Global South. The overarching aims of the study are to:

- Understand the dynamic interactions occurring among energy, food and water systems with a view to identifying the key vulnerabilities and risks facing developing countries in terms of food, energy and water security.
- Inform planning and policy in developing countries to mitigate these risks and to promote efficiency, equity and environmental sustainability in food, energy and water provision to their citizens via a transition to more sustainable and resilient systems.

A subsidiary objective is to present foundational frameworks and methodologies that stakeholders can build on to conduct more detailed assessments of country-specific vulnerabilities of their energy, food and water systems, and to formulate more nuanced and tailored strategies to boost the resilience of these systems. As such, the report is intended to serve as a reference work for policymakers, planners and researchers, primarily those working in developing countries, but also for those working in multilateral agencies and for the international aid community.

The three major research questions are as follows:

- What are the key issues, including global and national drivers, which we might see in the coming 5 to 10 years, in the linkages between energy and water use and food security in developing countries?
- What are the main risks and vulnerabilities faced by different types of developing countries with regard to the energy-food-water nexus?
- What strategies, policies and measures can governments in developing countries adopt to reduce energy-related risks to food security and to make energy-food-water systems more resilient and sustainable?

The energy-food-water nexus clearly comprises a multidimensional, complex set of issues operating at various scales from the global to national to local levels. This study cannot address all of the aspects involved, but rather seeks to identify the most salient factors that bear on the research questions. As per the directive given by DFID in the terms of reference, the primary emphasis in this report is on energy-food linkages and particularly the dependence of food systems on energy. Somewhat less attention is given to water issues, although these form a critical part of the overall picture. A particular focus will be placed on how vulnerable food systems could become more resilient to energy shocks by making more efficient use of energy and by substituting renewable inputs for non-renewable ones (including energy). Where appropriate, generic recommendations will be made, but in many instances these will need to be tailored to suit local conditions.

0.3 Methodology

Energy, food and water systems lie at the interface between social and ecological systems. Coupled social-ecological systems are 'complex' in that they are composed of many, non-homogeneous components that interact along multiple pathways (Cilliers 2008). These interactions can be dynamic and non-linear, and they encompass positive and negative feedback loops, thresholds and tipping points. Crucially, these interactions give rise to the emergent properties of the system; the properties are not contained within the individual components themselves (Cilliers 2008). This principle is recognised in this nexus research via the focus on the interactions among the energy, food and water systems, each of which is complex in its own right. Thus the appropriate methodological paradigm for this research is a complex systems perspective. Because complex systems are open systems, identifying the boundaries is generally difficult. Furthermore, it is recognised that there will always be a gap between the complex system itself and the model or framework that is trying to describe and understand it (Cilliers 2008).

This study is based primarily on three types of research method. The first is a desktop literature review that draws on relevant academic articles, reports and policy documents concerning the energy-food-water nexus both globally and in specific developing countries that are used as case studies. The second is a quantitative analysis of data on vulnerability indicators together with risk assessment for energy, food and water security. The third is the use of policy analysis to derive recommendations for mitigating risks and vulnerabilities. These methods are elaborated on below.

Analysis of energy-food-water system typologies with case studies

Part 1 of the report analyses energy-food-water system typologies and presents illustrative case studies. The group of nations commonly referred to as 'developing countries' spans a wide spectrum in terms of their stage of development and the sophistication or complexity of their economies and societies. The World Bank (2015a), for instance, categorises developing countries into three income bands according to their per capita Gross National Income (GNI) measured in United States Dollars (US$) in 2014:

- Low-income countries: US$1 045 or less
- Lower middle-income countries : US$1 046 – $4 125
- Upper middle-income countries: US$4 126 – $12 736.

Consequently, developing countries exhibit a great degree of variability in the key characteristics and components of their energy, food and water systems – arguably more so than their developed country counterparts, which have all reached a minimum threshold of industrial development. For this reason, a typology that divides developing countries – or at least major parts of them – into different categories can yield more nuanced analysis and more relevant policy recommendations. However, instead of using the crude income bands, this study uses a typology that correlates with this World Bank categorisation, but which is more pertinent to energy, food and water systems.

Socio-metabolic regimes

The typology employed here draws on a relatively new field of research that considers the interactions between human societies and natural systems within integrated social-ecological systems (Fischer-Kowalski 1998; Fischer-Kowalski & Haberl 2007). A central concept in this literature is the 'metabolism' of a society, which refers to the ways in which energy and materials (including water, minerals and biomass) are used to satisfy collective human needs and wants, analogous to the way an individual human's physical metabolism processes inputs of food, water and minerals. Three historical socio-metabolic regimes have been identified; each one is based on a particular way of obtaining and using energy and materials and exhibits increasing levels of societal complexity (Sieferle 2001; Fisher-Kowalski & Haberl 2007). A fourth regime appears to be emerging.

- Hunter-gatherer societies rely on 'passive' solar energy, which is captured via photosynthesis in plant biomass, without intentional intervention by humans in the energy-conversion process. These societies are therefore limited in their population size and their ability to accumulate possessions (and to pollute their surroundings) by the available resource density. The typical form of social organisation is mainly nomadic bands and small tribes possessing very few artefacts and having very little division of labour. This category is not analysed in this report because only a few, isolated hunter-gatherer societies remain in existence today.

- The agrarian regime, also sometimes termed pre-industrial or traditional, is based on 'active' use of solar energy, which involves deliberate intervention by humans in the process of transforming solar energy, using biotechnologies and mechanical devices to exploit cultivated plants and livestock.
- Land-based ecosystems and the organisms they contain are transformed or exploited in such a way as to yield the maximum utility for humans. Agriculture and forestry are the major sources of the primary energy needed to meet human needs and must generate a positive net energy balance. Although there is greater division of labour than in hunter-gatherer societies, it is limited by the need for most of the population (typically 80-90%) to engage in agriculture and forestry to produce a surplus to sustain the non-agricultural population. Nonetheless, the first permanent settlements and complex human societies emerged in the agrarian era. Subsistence agriculture in Malawi is used as a representative case study of the agrarian regime within a developing country context.
- The industrial socio-ecological regime is based on the exploitation of fossil fuels (coal, oil and natural gas), and first emerged in England in the mid-18th century. Societies falling within this regime are highly mechanised with extensive transport networks and are predominantly urbanised. Agriculture is also mechanised and involves the application of fossil fuel derivatives in the form of synthetic fertilisers and pesticides. The exploitation of fossil fuels overcame the constraints on growth inherent in the agrarian regime and allowed for a massive increase in both population size and the rates of material and energy consumption per person, as well as increasing specialisation. South Africa, whose economy and food system is powered by coal and oil, is used as a case study of the industrial regime within a developing country context.
- There are signs of a fourth socio-metabolic regime, which has tentatively been labelled 'sustainable', emerging in various parts of the world (Fischer-Kowalski & Haberl 2007). This regime is (projected to be) based (largely) on renewable energy sources and agroecological or organic food-production systems. Since 'sustainable' is a contested term, this report uses the term 'ecological' instead, to refer to a greater concern for and emulation of ecological systems and processes (such as closed-loop production systems that use waste streams as inputs). A case study of an emerging example of this regime, particularly with reference to the food system, is drawn from Cuba.

As mentioned, the socio-metabolic regime perspective correlates to some extent with the three income-based categories of developing countries. Low-income countries are centred mostly within the agrarian regime, as evidenced by the high percentage of the working population that is engaged in traditional, subsistence agriculture. Lower middle-income countries have typically begun the agrarian-industrial transition, moving into various manufacturing industries, but retaining a large, traditional agricultural sector. Upper middle-income countries have in general progressed further towards the industrial metabolism and are typically more highly dependent on fossil fuels. It should be noted, however, that while some individual developing nations may fit largely within one or other of the stylised types, some countries are transitioning from one type to another, and therefore exhibit elements of two (or even three) types.

Quantitative and qualitative assessment of risk and vulnerability

Part 2 of the report involves two types of risk and vulnerability assessment. First, a qualitative analysis of risks is made on the basis of the issues and drivers identified in Part 1. This is done at a global level and for each of the three system typologies. Second, a range of key quantitative national-level indicators of food, energy and water security for a sample of developing countries are presented and analysed.

This section makes use of secondary data derived from various agencies including the FAO, International Energy Agency (IEA), and World Bank. Key indicators are presented as graphics to help stakeholders quickly identify individual country rankings.

Policy analysis

Policy analysis is employed in Part 3 of the report to derive recommendations for national and local-level policy responses to boost the resilience of energy, food and water systems and to reduce risks and vulnerabilities related to the nexus. A set of generic strategies, policies and measures are put forward that are broadly applicable to all countries. In addition, lessons are drawn from the experiences of the three case study countries, and more specific policy recommendations are given for each. It is recognised that there are overlaps among the recommendations for the three typologies, but that important distinctions are nevertheless warranted. Other countries will have to adapt the recommendations to fit their particular circumstances.

0.4 Structure of the Report

The report is structured in three major parts, each of which addresses one of the three principal research questions stated above.

- Part 1 scopes the most pertinent issues and drivers for developing countries in the energy-food-water nexus. It begins with a global level analysis and then focuses on three case studies, each of which delves into greater detail for a certain type of socio-ecological system, based on metabolic flow characteristics.
- Part 2 provides a qualitative assessment of nexus-related risks and vulnerabilities facing developing countries, and presents and analyses empirical data on energy, food and water security indicators for a selection of developing nations.
- Part 3 draws out generic policy recommendations from the case study typologies as far as possible, recognising that each region and country has its own distinctive characteristics and circumstances that may affect the way in which the energy-food-water nexus plays out in that particular context. The final section presents the main conclusions and identifies scope for research topics that could be investigated in greater detail.

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Oil pollution, Niger delta

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Pivot irrigation, Vanrhynsdorp, South Africa

part 1.

SCOPING THE ISSUES AND DRIVERS IN THE ENERGY-FOOD-WATER NEXUS IN DEVELOPING COUNTRIES

Key Messages

- Energy, food and water systems need to be understood in terms of their entire value chains, including production, processing, storage, distribution, consumption and waste disposal stages, and their supporting infrastructures.
- Energy and food systems operate on global scales because of integrated global markets that allow trading in certain energy carriers and food commodities. Water is mainly a regional commodity, but there are substantial flows of 'virtual' water embedded in certain internationally traded goods, especially food products.
- The nexus manifests differently in urban versus rural environments, partly because different components of energy, food and water systems – or different stages of their respective value chains – tend to be located predominantly in either rural or urban areas.
- The nexus is subject to several major drivers. Demand-side drivers include population growth, economic growth, rising affluence, shifting consumption patterns, urbanisation and globalisation. Supply-side drivers include the depletion of conventional fossil fuel reserves (resulting in increasing reliance on more polluting unconventional oil and gas resources), and the degradation of soils, fresh water supplies and ecosystems. Climate change is anticipated to exert increasing pressure on water resources and have destabilising impacts on agricultural production and certain forms of energy generation.
- Malawi illustrates a largely agrarian regime that depends mainly on low-productivity, rainfed agriculture and biomass energy, with low rates of access to electricity, adequate nutrition and improved water sources.
- South Africa illustrates an industrial regime that depends heavily on fossil fuels to power high-input, mechanised agriculture and industries, and complex water supply infrastructures. The fossil energy-intensive food and energy systems pose severe threats to the quality of water resources they depend on.
- Cuba illustrates aspects of an emerging 'ecological' regime that includes extensive agroecological farming and growing use of renewable energy sources, but has weaknesses in terms of reliance on imported grains and liquid fuels.
- Notwithstanding the sometimes stark differences between the three case study countries, they all illustrate extensive nexus linkages and interconnections, and share many of the same fundamental drivers influencing their energy, food and water systems.

1.

SCOPING THE ISSUES AND DRIVERS IN THE ENERGY-FOOD-WATER NEXUS IN DEVELOPING COUNTRIES

This first part of the report addresses the following research question:

> *What are the key issues, including global and national drivers that we might see in the coming 5 to 10 years, in the linkages between energy and water use and food security in developing countries?*

The energy-food-water nexus is by its very nature a highly complex and interconnected set of issues, which can be approached in a number of different ways. A structured analytical framework is followed in the report to ensure that the investigations are systematic and consistent. For each of the three systems, the following are identified and discussed:

- A general introduction to the system.
- Linkages among the systems, in terms of dependencies and spill-over effects of one system on the other two systems; these linkages are in turn analysed according to a life-cycle or value-chain model that includes primary resource dependence, production, processing, storage, distribution, consumption and waste streams (see Table 1-1).
- Key drivers influencing the system in question, including economic, social, geopolitical, environmental and technological factors.

This analytical framework (see the box on the following page) is applied at two levels. First, since all developing countries are to some extent or other connected to the world economy, a global analysis of energy, food and water systems is presented (section 1.1). However, this will be limited in depth given the scope of the report and its primary focus on developing countries. Second, in order to capture more specific issues relevant to individual developing countries, a typology comprising three generic socio-ecological system types is used to gain a more granular understanding of the issues facing countries at different stages of development. As mentioned in the introduction, this typology comprises what we term agrarian, industrial and ecological socio-ecological systems (sections 1.2 through 1.4). Section 1.5 presents the conclusions of Part 1 and highlights the main similarities and differences among the case studies.

Analytical Structure for Part 1

The following structure is used for each major section (Global, Malawi, South Africa, Cuba):

ENERGY SYSTEM

- Overview
- Linkages & dependencies
  – Water for energy
  – Food for energy
  – Impacts of energy on water and food
- Drivers
  – Economic
  – Social
  – Geopolitical
  – Environmental
  – Technological

FOOD SYSTEM

- Overview
- Linkages & dependencies
  – Energy for food
  – Water for food
  – Impacts of food on water
- Drivers
  – Economic
  – Social
  – Geopolitical
  – Environmental
  – Technological

WATER SYSTEM

- Overview
- Linkages & dependencies
  – Energy for water
  – Impacts of water on energy and food
- Drivers
  – Economic
  – Social
  – Geopolitical
  – Environmental
  – Technological

NOTE: The colour-coded icons reflected in the upper margin area indicate the relevant system under discussion.

Energy: Food: Water:

1.1 Global Analysis of the Energy-Food-Water Nexus

Energy and food systems operate on global scales. This is fundamentally because of integrated global markets that allow international trading in certain energy carriers (particularly oil, but also liquefied natural gas and coal), as well as in a wide range of food commodities (notably grains such as wheat, maize and rice, as well as soya beans and meat products). Other energy types (such as solar and wind power, and some forms of biomass energy) may be traded on a regional basis, but are not truly global commodities. This is also strictly true in the case of water, although there are substantial 'virtual' flows of water that is embedded in food products (and other manufactured goods) that are traded globally. The globalisation of energy and food systems implies the need for a global-level analysis of the nexus to set the context for the more detailed case studies that follow.

Before discussing each system in detail, two cross-cutting issues deserve mention, as they are recurring themes throughout the report. An important concept for understanding nexus interactions (and resulting risks) is that of 'societal teleconnections', defined as "human-created linkages that link activities, trends, and disruptions across large distances, such that locations spatially separated from the locus of an event can experience a variety of impacts from it nevertheless" (Moser & Hart 2015:13). Put more simply, impacts and vulnerabilities do not only result from local causes; they can come about due to long-distance relationships, such as the embeddedness of individual countries within the world trading system. "Conceptually, societal teleconnections arise from the interactions among *actors* [e.g. consumers, producers, policy-makers], and the *institutions* [e.g. social norms, rules and regulations] that guide their actions, affecting the movement of various *substances* [e.g. energy, food products, and water and energy embedded in food] through different *structures* [e.g. energy, water, transportation and communication infrastructures] and *processes* [e.g. human needs, markets, globalization]" (Moser & Hart 2015:13, italics in original). Examples of societal teleconnections that are of particular relevance to the nexus include: (1) international trade; (2) energy systems; (3) food systems; (4) geopolitical alliances; and (5) financial systems. The various ways that

Table 1-1: Main life-cycle elements in energy, food and water systems

BASIC ELEMENTS OF SYSTEM	ENERGY SYSTEM	FOOD SYSTEM	WATER SYSTEM
PRIMARY RESOURCES	▪ Biomass ▪ Fossil fuels, uranium ▪ Wind, solar, hydro, geothermal	▪ Soils, nutrients (Nitrogen, Phosphorous and Potassium (N, P, K), lime), manure, water, energy	▪ Precipitation, rivers, lakes, aquifers
PRODUCTION	▪ Extraction of primary fuels and minerals ▪ Machinery, drilling rigs, etc.	▪ Pesticides ▪ Machinery, tractors, human labour, draught animals	▪ Water abstraction from surface and groundwater sources
STORAGE	▪ Pumped storage, hydro schemes, batteries	▪ Grain silos, refrigeration plants	▪ Reservoirs, dams, water tanks
PROCESSING	▪ Oil refining, gas to liquids, coal to liquids ▪ Power generation	▪ Food processing and manufacturing	▪ Treatment, purification, ▪ Desalination
DISTRIBUTION	▪ Oil and gas pipelines ▪ Electricity transmission	▪ Roads, railways, ports ▪ Shops, markets	▪ Pipelines, pumps, reticulation systems
CONSUMPTION	▪ Energy access ▪ Pricing structures ▪ Health implications of energy sources	▪ Calorific intake, nutritional content, dietary patterns, cultural preferences, nutrition and health	▪ Water access ▪ Pricing structures ▪ Health implications of water quality
WASTE	▪ Mining waste ▪ Greenhouse gas emissions from fossil-fuel combustion ▪ Spent uranium fuel	▪ Nutrient flows, on-farm agri-waste, food waste ▪ Eroded soils, siltation ▪ Embodied water ▪ Embodied energy ▪ Greenhouse gases	▪ Water-borne sewage systems ▪ Treatment of waste water

shocks get transmitted via these teleconnections across space to individual countries is explored in Part 1 in discussions about nexus drivers (e.g. globalization and geopolitics), and in Part 2 in the context of nexus risks and vulnerabilities. Ways to mitigate these teleconnection risks are dealt with in Part 3.

The second cross-cutting issue is that the energy-food-water nexus manifests differently in urban versus rural environments. This is partly because different components of energy, food and water systems – or different stages of their respective value chains – tend to be located predominantly in either rural or urban areas. Rural areas tend to be the location for much of the 'up-stream' end of these value chains, for example mining or extraction of fossil fuels, generation of hydropower, cultivation of biofuels, or harvesting of biomass for energy; agricultural production (aside from urban agriculture); and water abstraction and storage in dams and reservoirs. Land is a central issue in the rural nexus, and in particular the various – and sometimes competing – uses to which it can be put. Addressing food security in rural areas often relates to people's access to land, water and other productive inputs (although incomes and food prices are more important in some, typically more developed, countries). Another key issue is the use of water for irrigation – in most countries the largest source of water demand. A further concern is the possible degradation of ecosystems or pollution of soils and water arising from energy extraction and agriculture. Some storage facilities (e.g. grain silos) may be located in farming areas; where these are absent, post-harvest food losses are a significant concern.

Some energy processing might occur in rural areas, such as the conversion of coal to electricity in plants located close to coal fields; and similarly some food processing (such as milling of grains) may take place in in small rural towns. More commonly, though, processing of energy (e.g. in oil refineries) and food (e.g. in abattoirs and factories), and treatment and desalination of water, occurs in cities and towns. Urban areas also generally have more extensive infrastructure (powerlines, roads and pipes) for the distribution of energy, food and water, and more intensive consumption patterns. For example, the bulk of electricity and liquid fuels typically gets consumed in urban areas (even in predominantly rural societies, where electrification rates are generally low); cities depend more on transport systems and fuels, since they rely on resources (including water) from the hinterland. Dealing with the wastes and emissions from the energy, food and water systems is a major issue in urban areas, and this also requires infrastructure and entails nexus linkages.

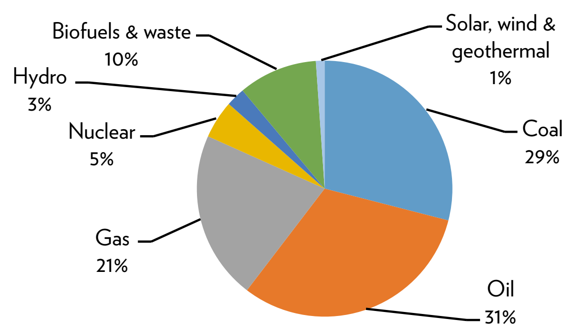
To be sure, there are exceptions to these generalisations about the spatial differentiation of nexus issues. The importance of the rural/urban divide in individual countries depends on its regime (agrarian or industrial), resource patterns, technologies employed, and the urbanisation rate. Moreover, rural and urban areas are inextricably linked through supply chains: cities and towns ultimately derive most of their raw materials (including agricultural produce), energy and water from rural areas; and processed food products and energy (e.g. electricity or petroleum fuels) flow back from cities to the hinterland.

1.1.1 Energy system

The global energy system comprises a range of energy sources (oil, gas, coal, biomass, nuclear power, hydroelectricity, solar, wind and tidal power), the infrastructures that are used to extract and deliver them to societies (e.g. mining equipment, drilling rigs, pipelines, tanker ships, refineries, electricity grids, etc.) and the markets, institutions and regulations that govern their flows.

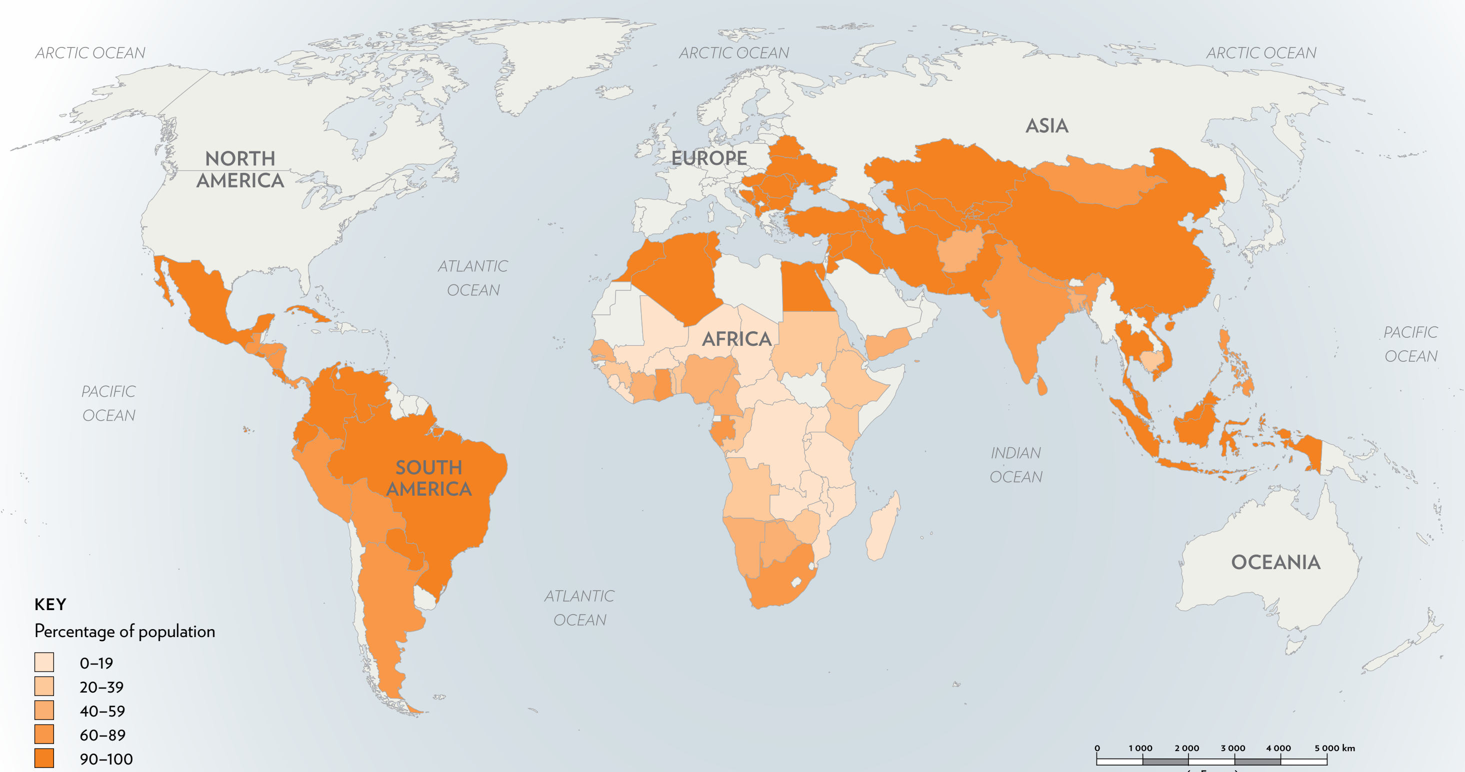
The world depends on fossil fuels for more than 80% of its primary energy supply (see Figure 1-1), with oil supplying the largest share (31%). Renewables, including biomass and hydroelectricity, contribute just 14% of primary energy, and nuclear power 5%. When it comes to final energy carriers, the world remains highly dependent on petroleum fuels, which account for 41% of total final energy consumption (TFEC) and over 90% of transport sector energy (International Energy Agency [IEA] 2015). The agriculture, forestry and fishing sector is responsible for just 2.2% of TFEC and 3.1% of total petroleum consumption.

Figure 1-1: Shares of world primary energy supply by source, 2012



SOURCE: IEA (2015)

Figure 1-2: Access to electricity in selected developing countries, 2010



SOURCE: Based on data from World Bank (2015b)

Linkages and dependencies

As noted in the introduction, energy systems are connected to food and water systems both through dependencies on them as inputs and through externalities (i.e. negative impacts of energy on the other systems); these are discussed in turn.

Water for energy systems

The energy system requires substantial water inputs at various stages of the energy production and consumption chain (Rodriguez et al. 2013). First, water is used in the primary extraction phase of fossil-fuel mining and production. Larger volumes of water are required for extraction of unconventional resources. For example, large quantities of water are used to produce synthetic oil from tar sands, for enhanced oil recovery (where water is injected into conventional oil wells) and in the hydraulic fracturing process used to extract oil and gas from shale basins. Even larger quantities of water are required to produce bioenergy crops such as maize, sugar cane, soybeans and so on. However, some biofuels may utilise 'green water' that accumulates in soils from rainfall, as opposed to 'blue water' that is provided through infrastructure (see Table 1-6 in section 1.1.3). Another important distinction is between 'consumptive' use of water, i.e. water that is not returned to the source (e.g. because of evaporation or embodiment in a product) and non-consumptive use; agriculture is typically consumptive (Hoff 2011). Table 1-2 illustrates the very wide range in water usage associated with different types of fuels.

Table 1-2: Water inputs for production of various energy sources

ENERGY TYPE	CONVENTIONAL OIL AND GAS	OIL SANDS	BIOFUELS
Water requirements (litres [l]/gigajoule)	1-10	100-1 000	10 000-100 000

SOURCE: Hoff (2011); World Economic Forum [WEF] (2011)

Second, water is needed to process or shift energy from one form to another. For example, water is consumed during oil refining and coal washing to prepare it for use in power stations. Furthermore, several types of electricity generation rely on water. Water is used directly to generate hydroelectricity and some forms of geothermal power (where the heat is transmitted through underground water); although (some of) this water may be recycled or used for other purposes. Several major developing countries (such as China, India and Brazil) are rapidly expanding their hydropower capacity (REN21 2014) and a number of African nations have plans to use the continent's large untapped hydro potential, notably the Democratic Republic of Congo. Hydropower reservoirs can result in significant loss of water through evaporation, although they may help to provide water storage for subsequent use by other sectors. Thermal power stations (including coal-, oil- and gas-fired steam turbines, nuclear plants and concentrated solar power plants) require large amounts of water for cooling, although the amount of water per unit of electricity varies considerably by technology type (Rodriguez et al. 2013). Even solar photovoltaics (PV) and collectors may require water for cleaning to maximise efficiency, although negligible amounts per unit of energy compared with most other energy sources.

Table 1-3 shows water usage for different power generation technologies (litres per kilowatt hour (l/kWh)). Once again, bioenergy has particularly high water demand compared to other sources. Nevertheless, strict comparisons of water productivities across energy types are complicated by the fact that some of the water uses are consumptive, while others make the water available for other uses after the process (Hoff 2011). For example, biofuels consume much of their water withdrawal for irrigation, while hydropower discharges much of its water intake, making it available for other uses (Rodriguez et al. 2013).

Table 1-3: Water consumption in electricity generation

	SOLAR PV	CONCENTRATING SOLAR POWER	GAS	COAL/OIL/NUCLEAR	HYDRO-POWER	BIOFUELS
cubic metres/megawatt hour (m^3/MWh) (approximate)	0	2	1	2	60 (variable)	180 (variable)

SOURCE: Hoff (2011)

Third, water is consumed indirectly in the manufacture and construction of all kinds of energy infrastructure, including refineries, power plants, pipelines and power grids. Water is also required to operate and maintain such infrastructure.

A few statistics highlight the dependence of energy on water at a global scale. Water withdrawals for energy production have been estimated at 583 billion cubic meters (m^3) in 2010, of which 66 billion m^3 represented consumptive use; i.e. it was not returned to the water source (IEA 2012). In proportional terms, about 15% of annual global freshwater withdrawals are attributed to the energy supply chain, with over 10% of this water consumed and not returned to the source (IRENA 2015). Nearly 90% of global electricity generation is water intensive (UN-Water 2014), and about 16% of world power generation is derived from hydropower (IEA 2015). Looking ahead, a projected 35% growth in energy demand by 2035 could result in an 85% increase in water consumption for energy use (World Bank 2013).

Food for energy systems

The direct dependence of the energy system on the food system relates to the conversion of certain food crops into bioenergy, especially liquid biofuels. An additional way in which energy systems may depend on food systems is through the use of food waste to generate bioenergy such as methane gas (biogas); however, the amounts involved are negligible at a global level. About 10% of the world's primary energy supply was derived from biomass in 2012 (IEA 2015), about 60% of which comprised traditional biomass including wood, animal dung and crop residues (REN21 2014). Of particular concern in a nexus context is the conversion of food crops into modern biofuels for transport, electricity and heating. Production of liquid biofuels has grown from 184 thousand barrels per day (bpd) of oil equivalent in 2000 to 1.32 million bpd in 2013 – a seven-fold increase (British Petroleum [BP] 2014).

Bioethanol, a substitute for petrol (gasoline), is produced from crops such as maize (corn), sugar cane, sugar beet and grain sorghum. The United States – the world's largest maize exporter – diverted a staggering third of its corn crop in 2010 to bioethanol production (Hoff 2011). By 2013, the United States' ethanol output totalled 571 000 bpd of liquid fuels – but this represented just 3% of the country's total liquid fuel consumption (BP 2014), while the maize used amounted to 16% of the global maize crop (IRENA 2015). In 2013, Brazil alone produced 317 000 bpd of ethanol from sugar cane (BP 2014), consuming approximately 57% of the country's sugar crop in the process (Sugaronline.com). Biodiesel, which is blended with or substituted for ordinary diesel, is derived from several plants including palm oil, canola, sunflower and soy beans. Europe is the world's largest market for biodiesel, with production running at 221 000 bdp in 2013 (BP 2014).

Significantly, the United Nation's *World Water Development Report 2014* states that "the demand for agricultural feedstocks for biofuels is the largest source of new demand for agricultural production in decades" (UN-Water 2014: 4).

Impacts of energy on water systems

In addition to consuming water, energy production and consumption can have a variety of negative impacts (externalities) on both underground and surface water quality. In particular, extracting fossil fuels poses significant threats to water quality. For example, mine tailings resulting from surface coal mining contain pollutants that can leach into groundwater, causing acid mine drainage (IRENA 2015). Oil and gas extraction results in large volumes of associated 'produced water', which is often costly and difficult to treat (UN-Water 2014). Furthermore, the oil industry is notorious for large oil spills in certain sensitive areas, such as the Niger River delta and Ecuador. The mining of Canada's tar sands poses water pollution threats on a large scale (Timoney & Lee 2009), while hydraulic fracturing for unconventional oil and gas recovery poses significant pollution threats to both surface and groundwater supplies (Vidic, Brantely, Vandenbossche, Yoxtheimer & Abad 2013). In general, oil and gas-related threats to water supplies are growing as the industry is forced by ongoing depletion to shift from the extraction of conventional to unconventional resources.

Various kinds of electricity generation can carry negative externalities for water quality. As the Fukushima nuclear disaster in Japan illustrates, accidents at nuclear power plants can pose a threat to water supplies. While historically rare, the impact of such disasters could be massive and the likelihood possibly increasing as the average age of the global nuclear fleet increases. The mining of rare earth metals for use in modern renewable energy technologies like wind turbines can also contaminate water supplies with radioactive materials (The

Guardian 2012). Thermal power plants can negatively affect water quality in two main ways (Rodriguez et al. 2013). First, air emissions from coal power plants can include pollutants and chemicals such as mercury, sulphur, and nitrogen oxides, which can compromise the quality of water sources and ecosystems downwind. Second, thermal pollution results when power stations return warm water to river systems, which can negatively affect aquatic ecosystems.

The largest impact of energy consumption on water at a global level stems from the fact that the combustion of fossil fuels is the primary driver of rising carbon dioxide emissions that are contributing to global climate change (IPCC 2014). Climate change poses significant threats to water systems, as discussed in section 1.1.3. Furthermore, acid rain can result from the sulphur dioxide emissions released through coal combustion.

Impacts of energy on food systems

Negative externalities emanating from energy systems and impacting on food systems mostly relate to contamination of water resources, as discussed above. However, pollution from extractive activities (whether for coal, oil, gas, uranium, or rare earth minerals) can also affect soil fertility. There is also an indirect effect of energy on agricultural production via the contribution of fossil-fuel combustion to greenhouse-gas emissions and climate change. Even new biofuel plantations may carry a negative carbon balance for many years (Fargione, Hill, Tilman, Polasky & Hawthorne 2009). The other major issue is the impact of bioenergy production on agricultural output, via the competition for limited land and water resources.

Drivers in the global energy system

The key drivers in the energy system are grouped in five categories: economic, social, geopolitical, environmental and technological factors.

Economic drivers

Economic growth is clearly a fundamental driver of energy demand, since energy has been closely correlated with economic growth and development throughout history and remains an essential input for all kinds of economic production (Hall & Klitgaard 2012). The World Bank estimates that developing countries will grow by 6% a year on average in the medium term (Rodriguez et al. 2013). The IEA projects that global energy demand will grow 37% by 2040, with all the net additional demand expected to come from developing countries (2014). More specifically, the IEA forecasts that global demand for oil could grow by 14 million bpd to 104 million bpd (a 16% increase) by 2040 (2014). Most of the net extra demand is projected to come from the transport sector in emerging economies.

However, it is not just economic growth that will drive up energy demand, but also rising living standards. Across the developing world, lifestyles are shifting towards more energy-intensive patterns of consumption. As sizeable middle-classes emerge, they purchase motor vehicles that are thirsty for fuel and a wide array of household appliances that are hungry for electricity. For example, the China Auto Association anticipates new commercial and passenger vehicles sales to top 25 million units in 2015 (Murphy 2015).

A related economic driver is the ongoing process of globalisation; i.e. the increasing integration of goods, factor and capital markets across the world and growing international flows of traded goods and services, as well as capital investment and technology. Globalisation has affected energy systems in various ways: by increasing the demand for energy-intensive transport for people and especially freight; by tying different countries' energy systems together through trade in fossil fuels, biofuels and electricity; and through heightened international transmission of energy (especially oil) price shocks.

Social drivers

Social drivers in the energy system relate to various demographic issues as well as equality of access to energy. Firstly, population growth implies greater demand for energy for residential, agricultural and commercial uses. The rate of population growth is particularly high in the Middle East and Africa (United Nations 2013). Some of the countries in these regions hold among the world's largest conventional reserves of oil and gas, and thus will be able to expand energy use (depending on government pricing policies), although this may erode energy exports. However, many African countries do not have indigenous fossil-fuel reserves and will have to rely on imports or on renewable energy sources.

A second important social driver is urbanisation. Half of the world's population now lives in cities, and the process of urbanisation is continuing in most developing countries, most notably in Asia and Africa (Parnell & Pieterse 2014). Urbanisation typically increases the demand for modern energy services such as electrical grid infrastructure and power generation, as well as liquid fuels for transport both for personal mobility and freight. Thirdly, access to energy is highly skewed across the globe, and there is a significant push to improve access to modern energy sources in Africa and other developing regions with the United Nations having declared the period 2014–2024 a "decade of sustainable energy for all" (SEA 2013); this in response to the fact that 1.2 billion people lack access to electricity and 2.8 billion do not have clean and safe cooking facilities (SEA 2013).

Geopolitical drivers

Geopolitics is another perennial driver in energy systems. This is most obvious in the case of political instability in key oil and gas-producing regions and countries. Geopolitical issues have resulted in several of the most serious oil price shocks in history, including the 1973, 1979 and 1991 price spikes. Klare (2012) has identified four "hot spot" regions that are especially vulnerable to oil-related conflict, namely the Persian Gulf in the Middle East, the East and South China seas, the Caspian Sea area and the Arctic. The current civil conflict in Syria and Iraq poses a significant risk of spreading to a wider regional conflagration, while the Israeli government continues to threaten to launch an attack on Iran's nuclear enrichment facilities. In addition, there are on-going civil conflicts in several important oil-exporting nations, such as Nigeria, Iraq and Libya, which pose a significant threat to the balance between world oil supply and demand in the medium term. Regarding natural gas, the major geopolitical risk is posed by the continued conflict in Ukraine, which is a key conduit for natural gas supplies from Russia and other former Soviet Union countries to European consumers.

Geopolitics also affects energy markets when certain countries engage in bilateral energy trade deals for strategic reasons (for example, Venezuela providing subsidised oil to Cuba, and China bartering infrastructure for oil with various African countries). Another form of cooperation involves regional power-pool agreements, which enable member countries to spread risks and trade energy across larger electric grid networks.

Environmental drivers

Environmental drivers influencing the global energy system can be divided into two categories, namely resource depletion and environmental degradation. Energy resource depletion is of greatest significance in the case of oil.

Data from the United States EIA show that conventional crude oil production – oil from wells accessed using typical drilling techniques – has been on a 'bumpy plateau' at around 74 million bpd since 2005 (Energy Information Administration [EIA] 2015a). Furthermore, the EIA has stated that conventional oil production peaked in 2008 and will gradually decline in the future as a result of rapid depletion of existing fields, whose production is declining at a rate of about 6% a year (IEA 2012). In recent years there has been a slight increase in production of all liquid fuels, which includes natural gas plant liquids (NGPLs), other liquids (coal-to-liquids, gas-to-liquids and biofuels) and refinery processing gains – mainly thanks to increased production of unconventional resources, including oil sands and shale (or 'light tight') oil. All of the net increase in world liquid fuel production over the past few years has effectively come from light tight oil in the United States, which has grown from almost nothing prior to 2008 to around 3 million bpd by the end of 2014 (Hughes 2014). The EIA projects that tight oil production will continue to increase for a few years and thereafter remain stable through the 2020s and 2030s. However, based on an independent analysis of an extensive industry dataset, Hughes (2014) projects that tight oil production in the two largest plays (Bakken and Eagle Ford), together representing 60% of tight oil output, will likely reach a peak around 2017. According to Hughes, overall tight oil supply is likely to decline quite steeply soon thereafter on account of the rapid observed decline rates, which range from 60% to 91% in the first three years (2014). Furthermore, data from the EIA show that world oil exports reached have been stagnant since 2005, implying that fast-growing net oil-importing countries like China and India have been out-competing poorer developing countries (and highly indebted Organisation for Economic Co-operation and Development (OECD) countries) (EIA, 2015a).

Not only is the quantity of oil available on world markets facing future constraints, but the quality of available oil (i.e. ease of access and refining) has been deteriorating for many years. This is principally because the oil deposits that are easier to access, typically discovered decades ago, are increasingly depleted and the frontier for new oil has moved into more remote areas, such as deep off-shore wells, polar regions and unconventional oil sources, that are more costly and technically more difficult to access and process (Gagnon, Hall & Brinker 2009). Thus the energy return on (energy) investment for oil, which measures the ratio of energy delivered by the process of oil exploration and extraction relative to the energy input, is diminishing in the world as a whole and in most countries (Guilford et al. 2011; Lambert, Hall, Balogh & Gupta 2012).

The outlook for world gas supplies is less constrained than that for oil. The IEA, for example, touted a possible 'golden age' for gas in a 2011 special report (IEA 2011). Gas reserves have been buoyed by large recent discoveries of conventional gas off the east coast of Africa, and the reserve-to-production ratio is currently 53 years (BP 2014). Furthermore, an assessment of the global potential for unconventional shale gas by the EIA (2013) suggested that technically recoverable resources could be one third as large as those of conventional gas. However, based on a comprehensive analysis of the United States shale gas industry, Hughes (2014) argues that the EIA projections are unrealistically high and that shale gas production in that country could peak around 2017. Shale gas development in other parts of the world has been constrained by various factors, including complex geology, environmental concerns, and a lack of infrastructure and technical skills. In view of this, the IEA has warned that the United States shale experience may not be replicated elsewhere (2013). While coal reserves are more abundant than oil reserves, there have been several studies suggesting that global coal production could reach a peak within a few decades (Patzek & Croft 2009; Mohr & Evans 2010; Rutledge 2011). However, in the case of coal at least it seems likely that constraints on production and consumption will emanate from pollution concerns before resource scarcity.

The highly polluting effects of coal combustion are well known, and include particulate matter, sulphur dioxide and, of course, carbon dioxide, the major greenhouse gas. Despite the failure thus far of the international community to reach a binding agreement to limit greenhouse gas emissions, it is still possible that this will occur within the coming decade or two. On the other hand, since China is responsible for half of the world's annual coal consumption (BP 2014), that country will likely determine the future course of coal use globally. As a result of dangerous levels of air pollution resulting mainly from coal combustion in many of China's major cities, the Chinese government recently announced plans to cap coal consumption by 2020 and accelerate the shift to alternative energy sources, including gas, nuclear and renewables (Wong 2014). In the United States, the second largest coal consumer, many coal-fired power stations have been closed in recent years due partly to environmental concerns and partly to cheap gas prices (Brown 2012). Coal consumption declined in the United States by 20% between 2007 and 2013 (BP 2014).

Anthropogenic climate change is largely caused by the burning of fossil fuels and therefore partly a product of the energy system as it is currently configured (IPCC 2014). However, climate change also affects the energy system in various ways (see IRENA 2015:33). First, erratic rainfall and river flows can disrupt the steady generation of hydroelectricity (as has been experienced in countries such as Pakistan and India in recent years). Second, droughts or floods can reduce bioenergy crop yields. Third, heatwaves and reduced river flows can cause problems with the efficiency and cooling of thermal power stations, as occurred in Europe in 2003. Fourth, extremes of temperature can raise the demand for energy for heating or cooling, and if this energy is derived from fossil fuels then it creates a positive feedback loop (albeit long-term). Fifth, storms and floods can damage energy infrastructure and cause power outages and disruptions to fuel supplies. Climate change also affects the energy system indirectly through mitigation policies, which aim to reduce fossil-fuel consumption and foster the development of renewable energy alternatives (Rodriguez et al. 2013). As discussed earlier, some of the renewables (such as biofuels and hydropower) are very water intensive and some may compete with food production. Moreover, some of the main technologies for carbon capture and storage are very water intensive (Hussey, Carter & Renhardt 2013).

Technological drivers

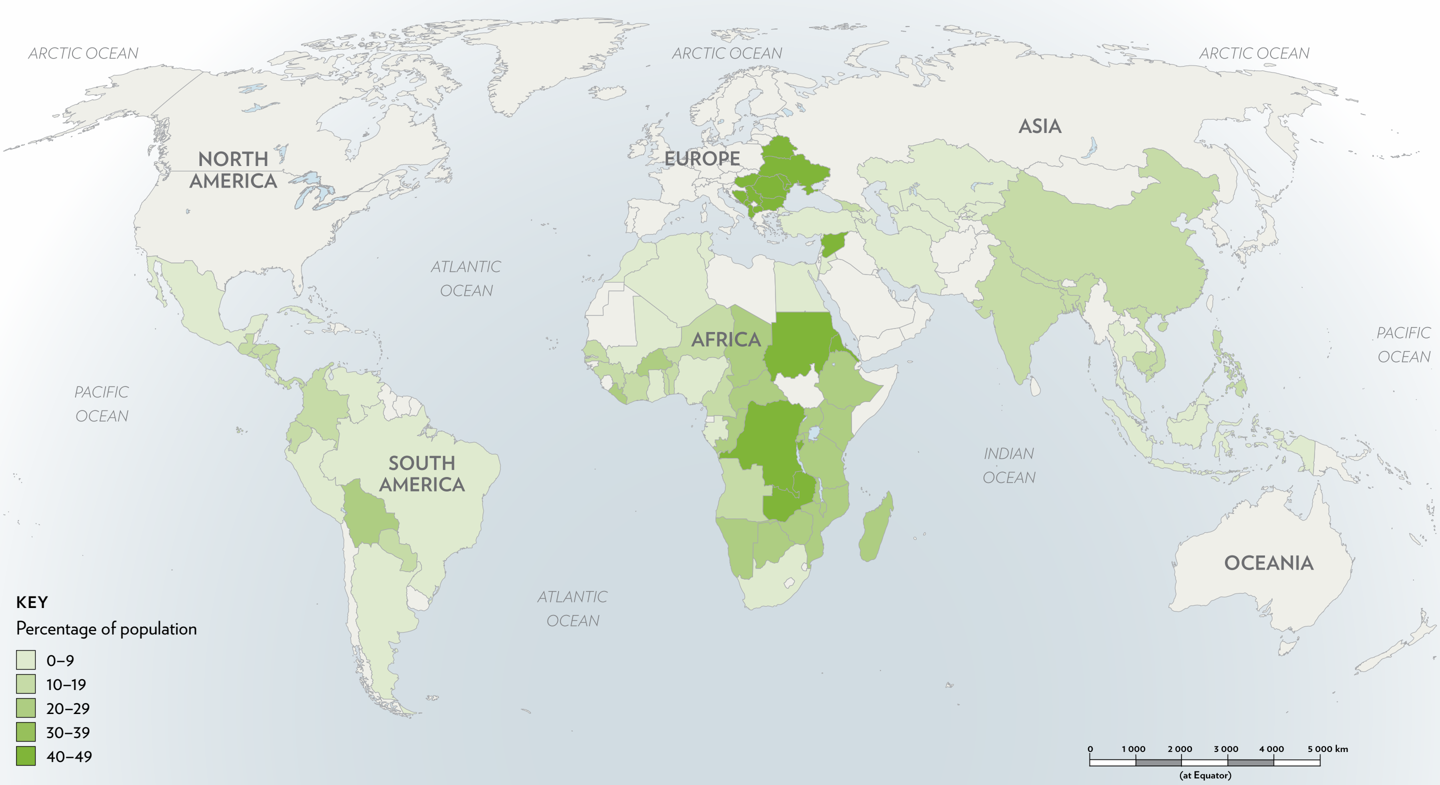
Technology is another important driver in the energy space. Technical progress can reduce the demand for energy by raising efficiencies in the production and consumption of energy. On the other hand, efficiency gains are often undermined by the so-called 'rebound effect', whereby the income saved through energy efficiency is spent on other energy-consuming activities or appliances (Berkhout, Muskens & Velthuijsen 2000). On the supply side, technological innovations can boost the availability of a variety of energy sources (from enhanced oil recovery to new ways of capturing renewable energy sources such as wave and ocean power). It can also lead to a reduction of energy costs, such as the sharply falling prices of solar PV panels in recent years (REN21 2014). As mentioned earlier, energy technology choices can have important implications for water use.

1.1.2 Food system

To understand the global food system and its linkages to the water and energy systems, one needs to understand the major shifts the food system has undergone in recent history. While the food system today is highly diverse and increasingly technologically advanced, there are key primary resources, provided 'free' by nature via ecosystem services, which can maintain all crop and animal production. In today's industrialised food system, these resources are often replaced or substituted by other, often fossil-fuel dependent, resources. Soils and water are arguably the primary inputs for the production of crops and livestock, and water is, so far, impossible to substitute or replace. Nutrients are essential to plant growth; the major nutrients provided to plants by healthy soil and air are nitrogen (N), phosphorous (P) and potassium (K). In addition, there are numerous other trace elements and minerals provided by soils, water and wildlife. Growing plants can also provide nutrients to the soil (e.g. nitrogen can be captured from the air by nitrogen-fixing plants and pulled into the soil to feed other plants), and when plants decompose, they return organic matter (carbon) and trace elements to the soil. Energy is another key input; before the fossil-fuel era, this was obtained via sunlight (for photosynthesis for the growth of crops), or human or animal power for preparation of soils, harvesting, processing and transport of food. Another primary input for certain crops is intervention from insects or birds to ensure pollination or the spread of seeds to ensure reproduction.

The food system transformed rapidly during the 20th century from reliance on the basic primary resourced mentioned above. Massive increases in output were attained from the development of modern, industrialised (i.e. fossil fuel-dependent) agriculture, allowing for a decrease in the number of hungry people, despite simultaneous rapid population growth (International Assessment of Agricultural Knowledge, Science and Technology for Development [IAASTD] 2009; Godfray, Beddington, Crute, Haddad, Lawrence, Muir, Pretty, Robinson, Thomas & Toulmin 2010). Additionally, the last century saw a steady decline in real food prices, and recently families in industrialised countries were

Figure 1-3: Prevalence of undernourishment in selected developing countries, 2013



SOURCE: Based on data from World Bank (2015b)

spending the lowest percentage of their total income on food in recorded history (Heinberg & Bomford 2009). Increased trade in both the inputs to and products of the system mean it is more globally interconnected than ever before (Hoff 2011). Mechanisation, industrialisation and globalisation have completely shifted the structure of the food system. In addition to the positive contributions mentioned above, this has also led, in some areas, to negative social issues, like loss of land, jobs and livelihoods and greater income inequality (IAASTD 2009). Thu (2009:14) discusses these rapid changes in the food system, focusing on the massive reduction of the percentage of the population involved in agriculture, and declares: "these changes, occurring within a single lifetime, may be as dramatic and far-reaching for the human world order as any change since the emergence of agriculture itself."

With nearly 795 million people suffering from hunger and undernutrition (FAO 2015e), 2 billion from 'hidden' hunger in the form of micronutrient deficiencies (Kennedy, Nantel & Shetty 2003) and 1.9 billion adults over 18 years old overweight and obese (World Health Organization [WHO] 2015), recent highly regarded reports have been calling for major changes to ensure long-term sustainability, bring about improvements in feeding the hungry and find ways to increase output to deal with anticipated population growth (IAASTD 2009; Foresight 2011).

The food system is broader than just agricultural production. The global food system comprises entire value chains for each crop, livestock or fish product, from inputs to waste. What makes a food-system approach different to the conventional value-chain approach is that it recognises the complexity of the system and overcomes the limiting linearity of the value-chain approach. The systems approach allows one to appreciate the interdependencies and effects of food on many other systems (Ericksen 2008).

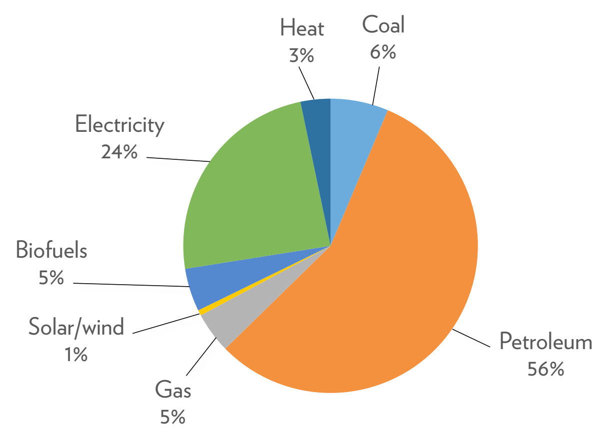
Linkages and dependencies

This section of the report examines the ways in which the food system is interlinked with and depends on the energy and water systems. It is organised according to the various stages of the food value chain, although the broader systemic perspective is incorporated in the discussion.

Energy for food systems

The food system depends on energy at virtually all stages of the value chain from inputs for production and processing right through to consumption and waste management. Figure 1-4 shows the contributions of various energy sources to total world energy consumption in agriculture. Oil is by far the most important energy source (56%), followed by electricity (24%). All in all, it has been estimated that the food system consumes some 30% of the world's energy (IRENA 2015). The specific linkages and dependencies are analysed in each stage of the value chain.

Figure 1-4: Shares of world energy consumption in agriculture by energy type, 2012



SOURCE: IEA (2015)

Inputs and production stage: The global food system starts in places most people do not associate with food: mines, factories, aquifers and power plants. The inputs needed for agriculture vary according to the type of production, as well as the particular approach to that type of production. For example, a farming system can be low-external input or high-external input, and fishing can be done through capture of wild fish or through aquaculture. Various production resources are used in addition to (or in place of) some of the primary resources provided by ecosystem services. These are discussed briefly below.

Synthetic nutrients: Different plant nutrients can be synthesised or mined and provided via fertilisers. Synthetic fertilisers were developed at the beginning of the 20th century, interestingly as a by-product of bomb manufacturing (Smil 1999), but large-scale agricultural application began with the 1950s 'Green Revolution', which aimed to increase yields through the use of 'improved' seeds and application of synthetic fertiliser and pesticides, along with irrigation. Today, natural gas is essential in the production of hydrogen and the energy needed to produce nitrogen fertilisers (Hoff 2011). "... the synthesis of nitrogenous fertilisers alone consumes approximately 1,400 TWh [terawatt hour]" of energy (UN-Water 2014:56). Producing nitrogen fertilisers uses half of the total energy used for primary production, with high-GDP countries using more energy and low-GDP countries less during this stage (FAO 2011a). Figure 1-5 shows the nearly continuous increase in global fertiliser use since 1950 (apart from the period 1989-1993, when the U.S. experienced a severe drought), and how it has followed a similar trend to – but risen even faster than – world grain production.

Seeds: While farmers have been saving and perfecting open-pollinated seeds for centuries, the Green Revolution was driven by the development of new high-yielding varieties of staple crops. These hybrid seeds produced crops that were faster-growing, took up less space and produced greater yields. High yields were achieved in specific conditions in terms of water and synthetic fertilisers applied in the correct amount and at the right time. Yields increased dramatically when the Green Revolution package of seeds, fertilisers and irrigation was introduced to fertile areas (IAASTD 2009). This 'package' increased the farm's reliance on fossil-fuels.

Pollination: In some parts of the world, bee colonies are transported considerable distances in order to pollinate crops. In the United States, for example, about 1 600 beekeepers follow migratory routes across the length and breadth of the country to provide pollination services to farmers growing a wide variety of crops (Jabr 2013). Between 3 000 and 6 000 truck-trailers are required to bring bee colonies to California from other states to pollinate 800 000 acres of almond trees each spring, in addition to local bee colonies. These essential pollination services thus depend on diesel fuel (Jabr 2013).

Farm machinery and processes: Farm processes have traditionally been powered by animal and human labour and sometimes renewable energy sources (e.g. windmills to pump water). However, as farms became mechanised in the Industrial Revolution their reliance on oil increased. Today, petroleum based fuels are needed to power tractors, combine harvesters and irrigation pumps, among other machines, and some farms use electricity for pumping water.

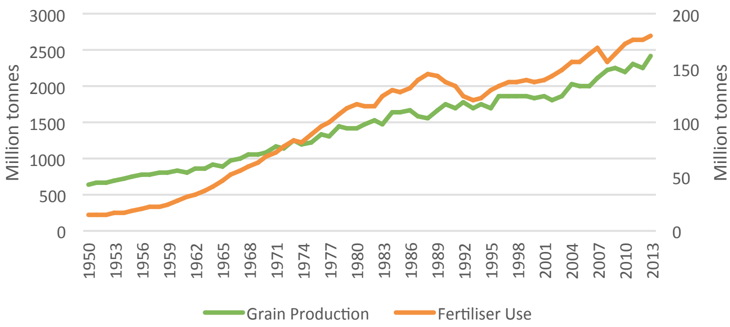
Pest and disease control: While this used to be done using methods such as removal by hand, intercropping, crop rotation and so on, there is now a heavy reliance on agricultural chemicals (pesticides, insecticides, herbicides and fungicides). This is partly due to the relative expense of labour compared to chemical inputs, but the need for such controls has increased with the use of monoculture cropping practices, which dominate large-scale commercial agriculture. These agro-chemicals are derived from petrochemicals (the waste stream from fuel refining) and require energy to manufacture.

Other inputs: Some other typical farm inputs are derived from petrochemicals, including, for example, plastic piping used for irrigation and plastic silage baling. These inputs, as well as others such as steel wire used for fencing and agricultural lime, also contain embedded energy that was consumed in their manufacture. Labour, another important agricultural input, requires energy in the form of food – although a large proportion of farm labour has been replaced by fossil fuel-powered machinery in industrialised countries and emerging markets (FAO 2011a).

In terms of animal production, concentrated animal feeding operations dominate livestock production in Europe and North America, and increasingly in Asia and Latin America (Nierenberg 2006). Significant amounts of animal feed are required to feed the thousands of animals packed tightly into small spaces with no access to pasture. This feed is mostly produced through large-scale crop production and is transported over long distances. The animals also require antibiotics because of the conditions in which they live and their unnatural diets, as well as dips and sprays (again derived from petrochemicals).

For the fishing industry, energy use differs depending on the sector. The fishing vessels of smaller fishing operations are often driven too fast and are not well-maintained, meaning they are inefficient energy users, while certain aquaculture operations (like shrimp farming) use large amounts of energy for pumping water (FAO 2011a). For fisheries as a whole, 550TWh are used as direct energy for powering boats, pumping water and aerating ponds; while the indirect energy contained in aquaculture feedstock amounts to 140TWh (UN-Water 2014).

Figure 1-5: World grain production and fertiliser use, 1950-2013



SOURCE: Earth Policy Institute (n.d.)

All of the above inputs require infrastructure: transport infrastructure to take inputs from mines to processors, and to get inputs to farms; processing plants to produce fertilisers and other agricultural chemicals; laboratories and research centres to develop new seeds and agricultural chemicals (and private or public funding to fund the research); land set aside for seed production; energy infrastructure to collect energy and distribute it to farming regions; and communications infrastructure to allow farmers to access market information. Constructing and maintaining all these infrastructure systems also requires energy inputs.

Processing stage: The processing, distribution and consumption stages use the most energy across the system (in both high- and low-GDP countries according to FAO 2011a); and, when added together with all the other stages beyond the farm gate, use 70% of the total (UN-Water 2014). Energy use between the farm and consumer's plate is estimated at four times the amount of energy used on the farm (Heinberg and Bomford 2009), with some estimating that processing alone uses three times the energy used on the farm (FAO 2011a).

Most crops and livestock require some form of storage and processing once harvested, killed or caught. There are different types of machinery, labour and storage facilities needed to process different crops and food products. Heating, cooling and electricity are the primary energy requirements (FAO 2011a). Most cereals, the key staple foods for the global population, require energy to be dried before storage (FAO 2011a). Fish products require large amounts of energy for processing: for ice, canning, freezing, curing and producing fishmeals and oils (FAO 2011a).

The transport infrastructure required to get produce from the farm to the processor needs energy – such as refrigerated tankers/trucks for milk and sensitive fresh produce and trucks to transport live animals to abattoirs for slaughter (or special shipping containers to transport these live animals overseas). In addition, packaging required for processed products has material, water and energy demands. Plastic packaging is ubiquitous in the food industry and is derived from petrochemicals, while aluminium is extremely energy intense to produce (FAO 2011a).

Distribution stage: Transport has been mentioned before: as more inputs are required by farmers and processors, and as more stages are added between the farm and the consumer, so transport requirements increase. Food retailers have increasingly taken control over their supply chains; most large food retailers now have centralised and regional distribution centres (Fernie,

Table 1-4: Energy intensities of various modes of freight transport

MODE	SHARE OF GLOBAL TRANSPORT (% OF TOTAL TONNE-KMS)	GLOBAL SHARE OF LOCAL DISTRIBUTION TRANSPORT (% OF TOTAL T KILOMETRE)	ENERGY INTENSITY OF TRAVEL MODE (MEGAJOULE/TONNE-KM)
Rail	29%	16%	8-10
Marine shipping	29%	Not applicable	10-20
Inland waterway	13%	19%	20-30
Road trucks	28%	62%	70-80
Trolley, cycle, tractor	No available data	3%	Varies
Aviation	1%	Not applicable	100-200

SOURCE: FAO 2011a:17

Sparks and McKinnon 2010; Hingley et al 2011; Reardon, Timmer and Berdegue 2008). While this centralisation of distribution saves money for retailers in terms of coordination and transaction costs, it usually increases transport costs and energy use due to extra movement of goods (Reardon, Timmer and Berdegue 2008; Harris et al 2015). If environmental and resource impacts were considered in distribution planning (instead of just cost reduction), centralisation could lead to certain resource efficiency benefits (Harris et al 2015).

Infrastructure required for distribution includes roads, railways, airports and ports for exports and imports. As shown in Table 1-4, rail, shipping and road transport have nearly equal shares of global freight transport, while aviation accounts for just 1% (due to much higher costs per unit of weight). While aviation is the most energy intense, road transport, with a similar rating, has a larger actual impact due to its far larger share of both global and domestic food distribution. It is therefore clear that the percentage of the energy use (and carbon footprint) for the transport of food products varies widely; from 50–70% for products transported hundreds of kilometres (kms) by road (e.g. fresh fruit), to a negligible share for products transported in bulk via the relatively less energy-intensive rail and shipping transport (FAO 2011a). Generally, though, the greenhouse gas emissions of primary agricultural production far exceed those of food transport, due to the various forms and extent of on-farm emissions such as carbon dioxide, nitrous oxide and methane from livestock (FAO 2011a).

Food aid plays an important role in meeting the basic food needs of populations in low-income countries or those facing disasters or conflict. The World Food Programme is probably the largest distributor of food aid; their website claims they now receive most ‘food aid’ as monetary donations and then purchase food closer to areas in need, which means most food is purchased from low- and middle-income countries (World Food Programme [WFP] 2015). On average, they distribute 2 million tonnes of food a year, and operate 5 000 trucks, 50 aircraft and 30 ships per day (WFP 2015). Large amounts of energy are required to transport food to these countries and then distribute it to those in need.

Consumption stage: Energy use in the consumption stage of the food system varies across countries and within countries. However, in their extreme examples of high- versus low-GDP countries, the FAO shows that this stage is by far the biggest consumer of energy (over 30% and 60% respectively of overall energy use in the food sector (2011b). Consumers in wealthy countries often use personal motorised transport to travel to food retail outlets, which has a significant energy and carbon-emission impact (FAO 2011a). However, these consumers have access to refrigeration for food storage and energy-efficient cooking appliances, while 2.7 billion people still rely on traditional biomass for cooking (IRENA 2015), which is far less efficient than electric or gas (FAO 2011a) and often associated with poor indoor air quality and health implications, as well as opportunity costs for people (mostly women and children) who spend large amounts of time collecting the biomass (UN-Water 2014). Energy is also required for food preparation within households. In poorer developing countries, a large proportion of household energy consumption is often allocated to cooking (UN-Water 2014).

Waste streams: The food system produces several waste streams from each stage of the value chain. Energy is required to deal with this waste – for example, the diesel required to transport waste to landfills. The FAO reports that one third of food produced globally is wasted each year (2011b); “in developing countries more than 40% of the food losses occur at post-harvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer levels” (FAO 2011b:5). Thus reducing food waste should be prioritised, especially in light of the limited resources available for the required increase in food production to feed the growing population (FAO 2011b). When food is wasted, up to 38% of the direct and embedded energy contained in food is also lost (FAO 2011b).

Water for food systems

Globally, agriculture is responsible for 70% of freshwater use (IAASTD 2009), due to irrigated agriculture drawing from groundwater and aquifers (UN-Water 2014), and this figure increases to about 90% in some countries (Hoff 2011). Note that these global figures do not include the freshwater used throughout the other stages. “As a rule of thumb, it takes on average about one litre of water to produce one calorie of food energy” (Hoff 2011:24).

Inputs and production stage: The mining and processing of fertilisers and agro-chemicals as agricultural inputs uses large amounts of water. The livestock sector, on its own, accounts for 8% of human water use, mostly due to irrigation of crops used as feed (FAO 2006). Water footprint analysis suggests that most of the water footprint of meat products is determined by the feed: the efficiency with which it is converted into animal protein, and its composition (Gerbens-Leenes, Mekonnen & Hoekstra 2011a). Industrial livestock production systems (i.e. concentrated animal feeding operations) use more concentrated feedstuffs than mixed systems and grazing systems, and so have much higher water footprints than the latter (Gerbens-Leenes, Mekonnen & Hoekstra 2011a).

The footprint varies depending on the animal production system: while poultry and pork have much higher feed efficiency than cattle, there tends to be high use of feed concentrates in pork (in industrial systems) and poultry production (in all systems) (Gerbens-Leenes, Mekonnen & Hoekstra 2011a). Significant variations across countries led Gerbens-Leenes, Mekonnen and Hoekstra (2011a) to conclude that there are major opportunities to improve water use efficiency by finding the best balance between low water-footprint feed and high feed-conversion efficiency.

Processing and storage stage: Examples of processing activities that require water are cooling, product washing, fluming water, processing equipment (starting, rinsing and cleaning), cleaning and disinfecting of facilities, water for boilers and fire extinguishers (Kirby, Bartram & Carr 2003). Water is also required for producing the plastics and other materials used to package food. While it is difficult to obtain precise figures for water use during this stage, it is far less than that used in primary production (Kirby, Bartram & Carr 2003; Gerbens-Leenes, Mekonnen & Hoekstra 2011a). Kirby, Bartram and Carr indicate that as much as 30% of the water used in processing could be reduced simply through behavioural and operational changes (2003).

Consumption stage: Again, water-use figures during the consumption stage are hard to find. However, given that about 783 million people still lack access to clean water, including water to prepare food, it is clear that improving access for this group will increase water demand (IRENA 2015).

Waste streams: When food is wasted, the water resources that were used to produce the food are also wasted. There are no large-scale estimates on the amounts of embedded water lost when food is wasted, but IRENA cites country-level studies that indicate that the amounts are significant (2015). For example, the Worldwide Fund for Nature in South Africa's report estimates that one-fifth of total water withdrawals in the country are lost based on estimated one third of food wasted (IRENA 2015).

Water footprints

Average water footprints like those in Table 1-5 hide the split between 'green' water, or the water provided by soils, and 'blue' water, the water provided by irrigation. There is significant variation across countries: on the whole water footprints are larger in less-developed countries, due to lower yields (Mekonnen & Hoekstra 2011a). Additionally, these water footprint calculations indicate that 'green' water is the most important component in

Table 1-5: Examples of water footprints for various crops and foods

CROP OR FOOD GROUP	AVERAGE WATER FOOTPRINT (M^3/TONNE)	EXAMPLE OF HIGH WATER FOOTPRINT (M^3/TONNE)	EXAMPLE OF LOW WATER FOOTPRINT (M^3/TONNE)
Cereals	1 644	Wheat = 1 827	Maize = 1 222
Sugar	200	Beet (no figure)	Cane sugar (no figure)
Vegetable oils	Not given	Olive oil = 24 700	Soybean oil = 4 200
Fruits	Not given	Grapes = 2 400	Watermelon = 235
Juices	Not given	Apple = 1 100	Tomato juice = 270
Coffee and tea	N/A	Coffee = 1 301 litres per cup	Black tea = 271 litres per cup
Alcohol	Not given	Wine = 870	Beer = 300

SOURCE: Adapted from Mekonnen and Hoekstra (2011a) less-developed countries, above that of 'blue' water (Mekonnen & Hoekstra 2011a). This has led to suggestions that large increases in yields of rain-fed agriculture (through increased green water-use efficiency) are possible without the need for increases in irrigation (although arid and semi-arid countries will always benefit strongly from irrigation) (Mekonnen & Hoekstra 2011a). "It is important to assess the spatiotemporal variability of blue water availability and how much blue water can sustainably be used in a certain catchment without adversely affecting the ecosystem" (Mekonnen & Hoekstra 2011a:1596).

Impacts of the food system on water

The food system has strong negative impacts on the water system (in terms of quality and availability) throughout the value chain. At the production stage, the *overuse* of fertilisers and agro-chemicals results in water contamination and pollution (IRENA 2015), as well as eutrophication of water bodies[1] (IAASTD 2009). About two-thirds of global irrigation water is drawn from groundwater and aquifers, which are usually recharged by an undisturbed hydrological cycle (FAO 2011a). Yet, due to over-pumping by farmers, often as a result of skewed incentives or lack of knowledge on efficient water use, these crucial water sources are suffering severe depletion rates in many regions (IAASTD 2009; UN-Water 2014). Modern agricultural practices have led to almost a quarter of all soils being degraded (Hoff 2011). Soil loss and degradation result in lowered land and water productivity, decreased groundwater recharge, lower soil water storage, and an increased need for fertilisers (Hoff 2011; UN-Water 2014). The livestock sector contributes the most to water pollution (FAO 2006). Intensive livestock production systems usually discard manure as waste, which can end up polluting water, as opposed to using it as an input for growing animal feed, as found in mixed and pasture-based systems. Concentrated animal feeding operations can negatively affect water quality in countries that allow use of prophylactic antibiotics, as these can remain in the manure. In addition, the fertilisers and agro-chemicals applied to feed crops, as well as sedimentation erosion, both affect water quality (FAO 2006; Gerbens-Leenes, Mekonnen & Hoekstra 2011a; IRENA 2015). Expansion of agriculture on new lands, including wetlands and forests, can also negatively affect water availability and quality as the ecosystem and its functions, such as flood prevention, are destroyed. This expansion also destroys habitats for various fauna and flora and contributes to climate change (IAASTD 2009).

At the processing stage, various waste streams from the processing of both food and its packaging can cause pollution of water (Gerbens-Leenes, Mekonnen & Hoekstra 2011a).

Drivers in the global food system

Economic growth

As economies grow, so does the demand for food; as people become wealthier, they consume more calories, usually through a change in diet (Foresight 2011). But this increased food demand eventually levels off, as has been the case in high-income countries over the past 40 years (Foresight 2011). The World Bank predicts that developing country economies will, on average, grow by 6% a year in the medium term (Rodriguez et al. 2013) and food demand will increase as incomes increase and the population grows (Foresight 2011). Hoff (2011) notes that the resource use of the growing middle class in Africa and Asia (the middle-class has tripled in size between 1990 and 2005) is rapidly approaching similar levels to those of more developed countries. The Foresight report (2011) says it is still unclear, though, at what levels these developing countries' resource use will stabilise: the slightly lower per capita use of countries like the United Kingdom, or the much higher levels of North America.

Per capita food production has increased from 2 280 to 2 800 kilocalories (kcal) a day over the past 50 years; however, the benefits of this have not been equally distributed and "additional resources must also be made available to meet the food and energy needs of the poorest" (Hoff 2011:7).

Shifting consumption patterns

Increased incomes are associated with increased meat consumption, along with that of processed food, fats, sugar and dairy, which all need more resources and energy to produce (Foresight 2011). Meat is one of the most resource-intensive with demand growing substantially in Brazil and China (and other parts of East and Southeast Asia). The demand for meat is predicted to increase by 50% by 2025 globally, which will in turn increase demand for grain by 42% (World Economic Forum [WEF] 2011). Not all meat products are as resource intense – chicken and pork, which are predicted to have the

1 Note that organic agriculture is not exempt from leaching nitrogen into water sources, but 35 to 65 percent less nitrogen leaches from organic farms, on average (Niggli 2015b).

highest growth in Asia, can be produced far more efficiently than cattle; however, "the global cattle population has [still] been predicted to increase by around 70%" (Foresight 2011:53) and the goat and sheep population by about 60% by 2050. Livestock and biofuel production are expected to increase more rapidly than crop production in the decade 2014-2025, and this means a shift from staple cereal production towards more coarse grains and oilseeds (OECD-FAO 2014). This additional production will come from regions with available land and water, and more amenable policy and regulatory environments, mostly in Asia and Latin America (OECD-FAO 2014).

In India and South Asia, despite strong economic growth, religion and culture prohibit meat consumption (Foresight 2011) and diets are vegetarian and fish-based. However, the increasing demand for fish protein will need to be met by aquaculture, rather than capture fisheries. Aquaculture already provides for over 50% of global demand for fish and seafood, but this will need to be increased as there is little capacity available in capture fisheries, even if well managed (Foresight 2011; OECD-FAO 2014). The FAO predicts that demand for fish will likely slow in the future as prices increase due to the high demand and the higher costs of aquaculture production (OECD-FAO 2014). Expanding aquaculture has major implications for other resources, such as freshwater in some cases and fertiliser and feed requirements (Foresight 2011).

Another key dietary transition is increasing consumption of processed foods: "three-fourths of [the value of] world food sales involve processed foods, for which the largest manufacturers hold over a third of the global market" (Stuckler & Nestle 2012:1). Stuckler and Nestle are in no doubt that these large food companies are driving the nutrition transition – the shift from simpler, traditional diets to highly processed foods[2] (2012). Eating habits have changed substantially as people now consume large amounts of calories via liquids, often in addition to a full meal and because they eat on the run, often unconsciously (Monteiro 2009).

Monteiro cites growing evidence that excessive consumption of calories is often related to unconscious cues received from our environment in the form of food accessibility, advertising and misleading statements about the health or nutritional benefits of certain foods, thereby negating the claims of a food industry threatened with censure by governments that obesity indicates a lack of individual 'self-control' (Monteiro 2009; Stuckler & Nestle 2012). But the obesity challenge is not confined to developed countries, or even to those with higher socio-economic status in developing countries (Popkin, Adair & Wen Ng 2012). Developing countries now face a 'double burden of disease': under-nutrition and its associated infectious disease and human development impacts, as well as over-nutrition and its non-communicable disease burden (WHO 2015).

Globalisation

Globalisation has been one of the most important factors shaping the food system in the past half century, and the Foresight Report (2011) predicts that better technology (in terms of further reducing transaction and logistics costs across vast distances) and economic growth mean that globalisation will likely increase in the future. Food trade, as a percentage of global trade, increased from 10% in 1970 to 15% in 2000 (Hoff 2011). Globalisation provides several distinct benefits. Countries and cities located in non-favourable agricultural climates, such as the Middle East, can easily import their food requirements (Hoff 2011), as can countries and cities facing crises, such as droughts (Godfray et al. 2010). However, there is a growing consensus that the liberalisation of food trade has not benefitted the small-scale farmers and rural poor in many countries (IAASTD 2009; United Nations Department of Economic and Social Affairs [UNDESA] 2011) and that many low-income countries are indeed dependent on their exports to higher-income countries to generate foreign exchange revenues (Foresight 2011). Globalisation also means that food price shocks can be transmitted to other countries more rapidly (Hoff 2011). The FAO notes that price increases in major traded food commodities do not have the same effect on all countries – the extent of the impact and time delay vary according to how reliant the country is on imports of these major commodity crops (and how important these foods are to the

2 Ultra-processed foods are defined by Monteiro as 'confections' of 'group 2 foods' (which are substances extracted from whole foods, like table sugar or flour or oils, and seldom eaten on their own). These are group 2 foods that have had salt or preservatives added, as well as flavourants and colourants: for example, soft drinks, sweets, bread, cookies, crisps, hot dog sausages, etc. They are designed to be "edible, palatable and habit-forming" (Monteiro 2009:730), and for use on-the-run. They have several unhealthy features: low levels of nutrients and fibre, high density of energy, high levels of potentially harmful substances like salt, simple carbohydrates and saturated fats (Monteiro 2009). Ultra-processed foods receive the most advertising spend because they "are very profitable. Their ingredients may cost the manufacturer a mere 5-10% of the product's retail price" (Monteiro 2009:731).

diet of its populace), the openness of their economy and the length of their value chains (OCED-FAO 2014). East African countries, for example, experience very direct transmission of global commodity price increases to local retail prices because they are dependent on imports and consumers rely heavily on primary commodities in their diets (OECD-FAO 2014). More generally, the globalisation of the food system accentuates societal teleconnections that link different countries across geographical space.

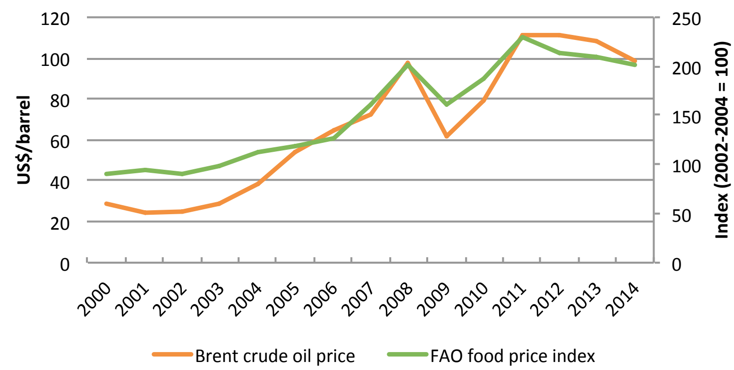
Globalised commodity markets and oil prices

Due to various traditional investment opportunities becoming less attractive, like the sub-prime mortgage sector in the United States, many more speculators started trading on commodities future exchanges in the late 2000s. Commodity market speculation increased nearly 20-fold between 2003 and 2008 (UNDESA 2011), exacerbating food price swings that were also being driven by growing demand and constrained supply.

One of the fundamental drivers of the rapid increase in food prices over this period was a sharp increase in the oil price. Although the exact nature of the relationship has been debated (Reboredo 2012; Gardebrook & Hernandez 2013), it is now more generally accepted that higher energy prices do lead to higher food prices (Alghalith 2010; Serra & Zilberman 2013; Koirala, Mishra, D'Antoni & Mehlhorn 2015), and increased energy price volatility also leads to higher food prices (Alghalith 2010; Serra & Zilberman 2013).

As can be seen in Figure 1-4, movements in international oil and food prices have been strongly correlated over the past 15 years. This is partially explained by the heavy reliance of food production on oil and natural gas-based nitrogen fertilisers, as discussed earlier (prices of natural gas, and therefore of fertilisers, tend to follow oil prices). Koirala et al. (2015) explain the transmission in terms of oil-based inputs becoming more expensive, resulting in farmers planting less acreage, and the subsequent reduced supply of crops leading to increased prices. Another reason that has been identified for the correlation is that oil price increases mean that biofuels become more economical to produce and sell and so demand for food crops increases (Koirala et al. 2015). Brown (2010) indicates that there has been a rapid growth in the conversion of certain food crops into liquid biofuels that substitute for oil, most notably the surge in ethanol production from corn in the United States since 2005.

Figure 1-6: International crude oil and food prices



SOURCE: **BP (2014) and FAO (2015a)**

Governance of the food system

International and national governance of the food system affects its activities and outcomes, such as food security (Foresight 2011). Countries that are major exporters can exert a lot of power. Brazil has recently emerged as a new "food superpower" (Foresight 2011:54), third only to the United Sates and the European Union in terms food export value. China is a net importer, although it is increasing its exports rapidly, while India is a net exporter, although its imports are rising as its population grows. Russia is expected to become more influential in the future, as it has large areas of under-utilised land suitable for agriculture (Foresight 2011).

Countries like China and India still practice somewhat protectionist food policies that focus on building huge food stocks; Foresight (2011) attributes this to a lingering fear around the famines their countries experienced earlier in the 20th century. This kind of export restriction and stockholding is seen as one of the contributing factors to the 2008 food price crisis (Foresight 2011; UNDESA 2011).

Farmer subsidies, import tariffs and other market interventions also influence the global food system and food security at this level (Foresight 2011). Although the World Trade Organization has ostensibly tried to reduce distortions to ensure 'free and fair trade', many developing countries have not benefitted from this, as evidenced by their vehement opposition to recent negotiations on the Agreement on Agriculture (UNDESA 2011). Much of their concern stems from the failure of the World Trade Organization or other international trade agreements to reduce the producer subsidies given by developed nations to their farmers, and to provide special protection for developing countries (both in terms of reduced import restrictions in their developed country trading partners and against dumping of cheaper produce by subsidised developed countries in their markets). How these issues play out will have a major influence on the future food system (Foresight 2011).

Another factor that is becoming increasingly important in international (and even national) food trade is the increasing level of quality requirements by importing nations and national retailers (Foresight 2011). Phytosanitary restrictions, health and safety laws, sustainability and other private standards also restrict the access of small farmers and poorer nations to certain, potentially lucrative, markets for their produce (Reardon et al. 2010; Foresight 2011).

Population growth

Population growth will be one of the major drivers of change across all systems, including food, for the next 40-odd years until population figures stabilise at between 8 and 10 billion by 2050 (Foresight 2011). This growth is projected to occur mainly in low-income countries; Africa's population is expected to double by 2050 (United Nations Population Division [UNPD] 2008). Foresight (2011) warns that population growth is affected by a complex set of factors, making population predictions uncertain and therefore food demand predictions difficult. Various models have been constructed to predict the amount by which agricultural output needs to increase in order to meet future demand; their results range from 50% more food by 2030, to 70% and even 100%. However, these figures have been contested as they are based on scenarios of the most likely food future, not the most desirable one (Godfray et al. 2010; Foresight 2011; Ronzon, Treyer, Dorin, Caron, Chemineua & Guyomard 2011; Tomlinson 2011; FAO 2012a).

Urbanisation

The global population is rapidly urbanising. Already more than 50% of people live in cities; 1 billion of these people live in slums and this figure is expected to increase to 2 billion by 2030 (Hoff 2011). Smaller cities in Asia and Africa are expected to grow substantially (UNPD 2007). Besides the additional pressure that will be placed on resources such as water and energy (Hoff 2011), more food will be needed. As food is traditionally grown far from cities, additional transport will be needed (Hoff 2011). Diets also shift when people urbanise and increase their incomes, change their lifestyle to a faster-paced urban one, and are exposed to advertising (Foresight 2011), which has implications for the type of food produced and consumed. In addition, given the estimated increase in slum populations, food insecurity is likely to increase as this sector of the population will not automatically increase its income and already spends a high proportion of its income on food.

Urbanisation thus presents many challenges, as well as the possibility that people may riot or protest at the time of food crisis. However, governments can promote initiatives on nutrition and groups of consumers can organise and push for better food system outcomes during times such as these (Foresight 2011). Also, there are major opportunities for cities to increase their resource use efficiency due to the concentration of economic and knowledge resources and lower per capita infrastructure costs (Hoff 2011).

Supermarketisation

This phenomenon fits into both urbanisation (driving the need for convenient one-stop shopping) and globalisation (driving the opening of markets to increased foreign direct investment and the arrival of international supermarket chains). It is now so powerful a force in the global food system as to warrant its own category. Reardon et al. (2010:1146) tell us that "the procurement practices of supermarkets and large processors are quickly reformulating the 'rules of the game' for farmers and processors." This is a major challenge, as supermarkets have quickly progressed from serving higher-income consumers in big cities to serving much poorer citizens even in the rural areas of many developing countries (Reardon et al. 2010). In other words, markets for food products are increasingly being limited to supermarkets (which consolidate their power by owning the processors and distribution channels too) (Reardon et al. 2010). In other words, supermarkets bring with them the transnational corporations that control large sections of the food chain and the resultant negative impacts on local farmers and producers and food prices (Stuckler & Nestle 2012).

Climate change

Changes in temperatures, precipitation levels and timing, and more extreme weather events will likely wreak havoc with crop and livestock production, water availability, fisheries and aquaculture outputs, and the ecosystem services on which agriculture depends (Foresight 2011). Although a few locations may benefit from more favourable climatic conditions for food production, many areas could face a dire future; for example, predictions are that yields from rain-fed agriculture in sub-Saharan Africa could fall by as much as 50% by 2020 (IPCC 2014).

Agriculture and the food system are also major contributors to climate change. Agriculture contributes through energy use, land-use change, methane emissions from livestock and irrigation practices in rice growing and nitrous oxide emissions from fertiliser used on soils (Hoff 2011). Land-use change seems to have slowed, but if current practices continue, it is predicted that more than 1 billion hectares of wild land will need to be converted to agricultural use to feed the global population by 2050 (Sachs 2010). Land-use change – particularly when forest is converted to agricultural use – is the largest contribution that the food system makes to climate change, followed by the production and application of nitrogen fertilisers and methane from livestock (Foresight 2011). This has led the Foresight team to strongly recommend that increased food production must come from intensified utilisation of current farmland as opposed to extensification.

Water scarcity

Growing demand for water will place major strain on agriculture (IRENA 2015). It is predicted that irrigation withdrawals need to increase by 11% by 2050 to meet growing food demand, but most of this demand will be in countries that are already water scarce and have multiple competing demands on their water resources from industry, domestic users, energy production etc. (IRENA 2015). While the concept of virtual water and increasing trade from water-rich countries to assist water-scarce countries make sense, there are many issues that limit this in practice (WEF 2011).

Research and technology

Major scientific advances have driven huge changes in the food system. The development of the Haber-Bosch process that allowed the fixing of atmospheric nitrogen is considered one of the most important inventions of the 20th century. In fact, using this process to produce agricultural fertilisers is often cited as the main enabler of the massive population explosion in the 20th century (Smil 1999).

Recent advances include the development of genetically modified crops that include features such as pest and herbicide resistance, leading to widespread hope in their potential (IAASTD 2009; Godfray et al. 2010; Foresight 2011). Reviews of the scientific literature seem to find positive benefits of the crops in terms of reducing pesticide use, increasing yields and raising farm income (Klumper and Qaim 2014; Brookes and Barfoot 2015). However, the use of genetically modified crops is still widely resisted due to concerns such as the lack of long-term tests on human health and impacts on natural biodiversity (Lotz et al 2014). Lotz et al (2014) found in their review that the benefits depend largely on the underlying societal, environmental and economic factors present in the area under study. They concluded that the use of genetically modified crops may still have negative impacts under certain conditions, and may perpetuate many of the inequalities and negative externalities of industrialised food systems (environmental, as well as social and economic inequalities) (Lotz et al 2014).

Degradation of biodiversity and ecosystem services resource base

Degradation is both caused by, and a driver of, changes in agriculture. Over 60% of the ecosystems on which humanity depends for essential services have been degraded severely (MEA 2005). This will ultimately have negative impacts on agriculture, which rests on a foundation of ecosystem services and resources. Certain agricultural practices also cause soil degradation (e.g. salinisation of soils through poor irrigation practices), which means that more land is required for agriculture (or expensive and long-term soil restoration projects) (IAASTD 2009).

Currently, the food system relies heavily on a very small number of crop varieties and domestic animals for consumption (Khoury, Bjorkman, Dempewolf, Ramirez-Villegas, Guarino, Rieseberg & Struik 2014). This reduction in agricultural biodiversity may be a risk; pests or diseases could potentially result in massive crop losses, dietary diversity is limited and the ability to find crops and livestock that can adapt to climate change are also reduced (Khoury et al. 2014).

Geopolitics: competition for land

As seen in the food price crisis of 2008, countries cannot always rely on trade to ensure their food security (WEF 2011) as other countries sometimes institute trade restrictions and export bans. Many countries are now turning to leasing or buying land from "poorer nations that have fertile, well-watered land" (WEF 2011:12).

> *Foreign direct investment (FDI) has become a major driver of change in many developing countries. For example, more than 200 million hectares, or between 2 and 20% of agricultural land in sub-Saharan countries, have been sold or leased over the past few years, or are currently being negotiated over, to help meet the rapidly growing demand for food, feed and other bioresources in particular from China, India and some Arab countries.*
> (Hoff 2011:8)

While the investment in these countries is welcome, there are concerns over negative impacts on local producers, as well as access to water and land, and lands rights issues more generally (Hoff 2011). There may be increased tensions around water access in these areas if local users are not adequately considered when these deals are made (WEF 2011). There is also the risk that these deals between particular countries will undermine the role of various multilateral organisations charged with protecting water and environmental resources (WEF 2011). These geopolitical drivers are another example of societal teleconnections, whereby the decisions regarding land use and investment in certain countries or regions can have ripple effects in other parts of the world.

1.1.3 Water system

Water is an essential ingredient for all life on Earth. As the WEF (2011:3) succinctly puts it, water "is a commodity in its own right with no substitute and no alternative, but it is also a crucial connector between humans, our environment and all aspects of our economic system." In particular, water is a basic requirement for all biomass growth and therefore for all ecosystem services, and the livelihoods and economic systems that depend on these (Hoff 2011). Agriculture captures the lion's share (70%) of total global freshwater withdrawals, while industrial – including energy – (20%) and domestic (10%) consumers account for much smaller shares (UN-Water 2014). In many of the world's least-developed countries, 90% of water may be used for agricultural purposes.

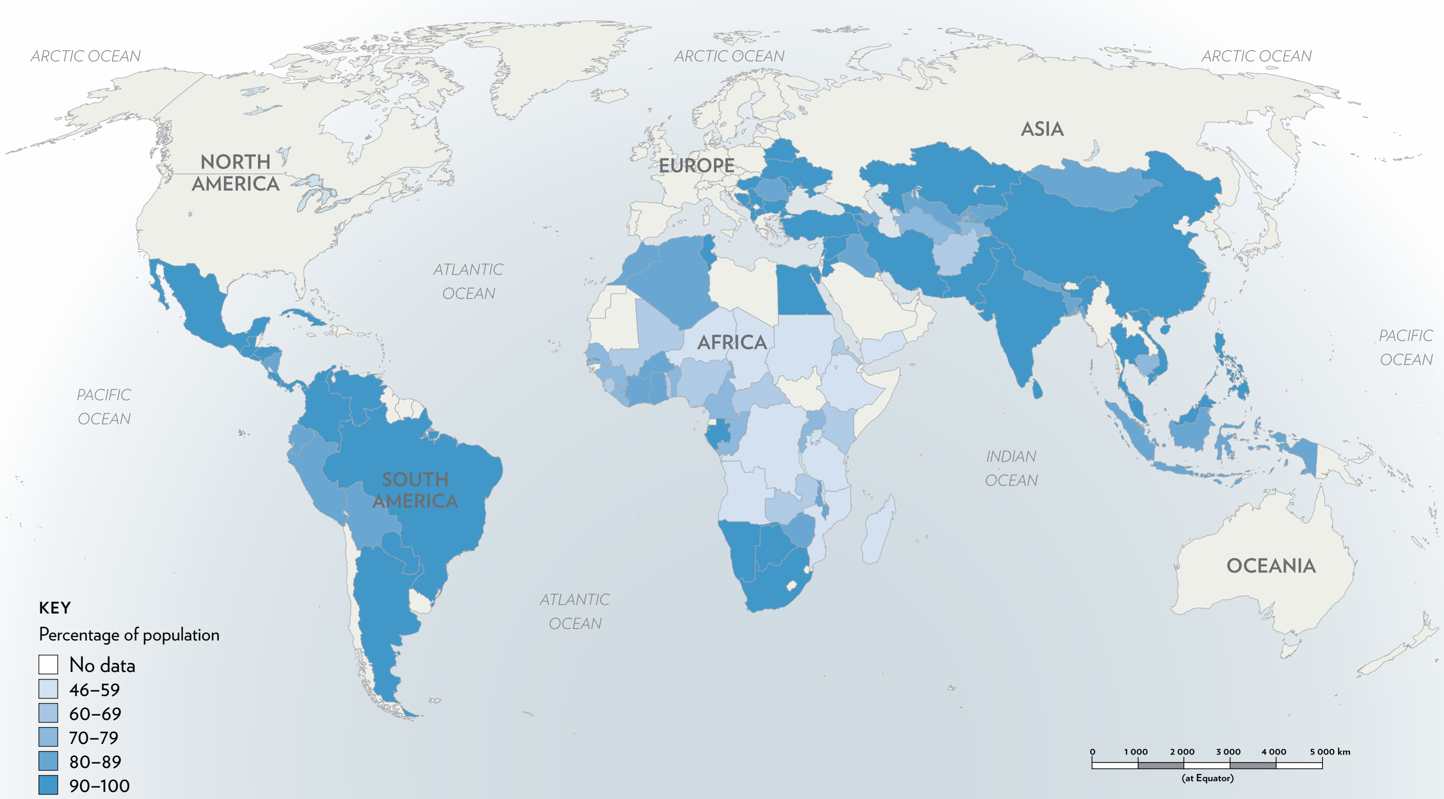
Global and regional geophysical processes including climate, hydrological cycles and geology govern supplies of fresh water. However, humans have a substantial impact on water systems through land-use practices, infrastructure built to capture and distribute water, and anthropogenic climate change. The three types of water available to humans are defined in Table 1-6.

Table 1-6: Types of water

GREEN WATER	Water in soil that emanates directly from rainfall, and which is available to plants and supporting natural and agricultural ecosystems; managed mainly through agricultural and land-use practices.
BLUE WATER	Water in lakes, rivers or aquifers that is available for irrigation, municipal uses (water supply and sanitation), industry and other uses; managed mainly through water infrastructure.
GREY WATER	Wastewater from households, which is reused for other purposes; managed mainly through water infrastructure.

SOURCE: Hoff (2011:16-17); IRENA (2015:37)

Figure 1-7: Access to safe drinking-water in selected developing countries, 2012 or latest



SOURCE: Based on data from FAO (2015b)

The water system lifecycle consists of primary abstraction (including pumping out of lakes and rivers, and desalination), storage (e.g. in dams and reservoirs), conveyance (transport of raw water to end users like agriculture or power stations, or to treatment facilities), processing (water treatment and purification), distribution (through pipeline networks to consumers), consumption (for example, by agriculture, industry and residential users), and waste-water treatment.

The United Nations' *World Water Development Report* distinguishes between management of water resources and services:

> *Water resources management is about managing the water cycle, in which water flows as a natural resource through the environment (i.e. rivers, lakes, estuaries and other water bodies, soils and aquifers), in terms of quantity and quality. Water services management is about developing and managing infrastructure to capture, treat as necessary, transport and deliver water to the end user, and to capture the waste streams via reticulation for treatment and safe onwards discharge or reuse.* (UN-Water 2014: 17)

From an economic point of view, fresh water systems only operate on regional, national and local scales as there is no global market for water as such. However, 'virtual water' – that is, water embedded in other products such as crops and manufactured goods that consume water in the production process – is effectively a globally traded commodity (Mekonnen & Hoekstra 2011a, b). Food is responsible for 88% of virtual water trade: 76% for food crops and 12% for animal products (the other 12% is related to industrial products) (IRENA 2015). Certain countries are disadvantaged in the rainfall or groundwater they receive, so it makes sense for them to preserve their scarce resources and import virtual water from countries that have a comparative advantage in water; "the global water saving related to trade in agricultural products in the period 1996-2005 was 369 billion m^3 per year" (IRENA 2015:37). This figure could be even larger, but water conservation just one factor determining food-trade decisions (IRENA 2015): in fact, three of the top ten food exporters are water scarce, while three of the top ten food importers are water rich (WEF 2011). Nevertheless, this concept of virtual water does not have an explicit price or cost dimension and is mainly a theoretical construct without real economic influence (UN-Water 2014).

Linkages and dependencies

The main water-related nexus linkages (not already discussed earlier) concern the reliance of water systems on energy, and the implications of poor water quality for energy and food security.

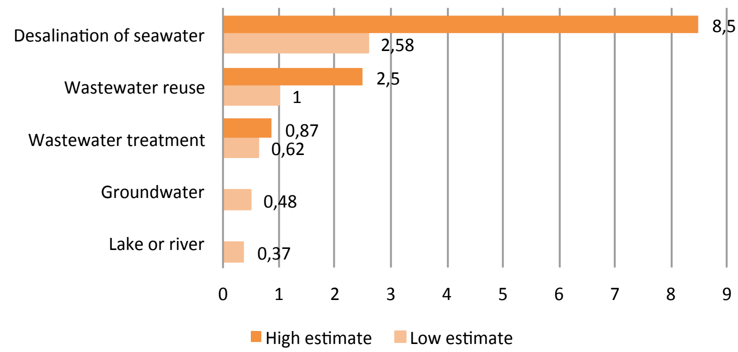
Energy for water systems

Water systems depend heavily on energy at many stages along the water supply/use chain (Rodriguez et al. 2013), but primarily to provide water services as opposed to managing water resources (UN-Water 2014). In the extraction stage, energy (typically in the form of electricity or diesel) is needed to pump water from lakes, rivers and underground aquifers. Factors such as distance, elevation change, pipe diameter and friction determine the amount of energy required (UN-Water 2014). Extracting groundwater, for example, is typically more energy-intensive than extracting surface water (Hoff 2011). Processes such as desalination of seawater are highly energy-intensive and are mostly done in water-scarce and energy-rich regions, notably the Middle East and North Africa.

A trade-off in energy requirements is often faced between surface water and groundwater, in that the former generally needs less water for pumping, but more for treatment as it is more susceptible to pollution, and vice versa (UN-Water 2014). Conveyance of raw water often requires energy for pumps. Further energy is required for water treatment and purification. These energy requirements are highly variable, depending on the quality of the input water, the type of treatment technique, and the use to which the water will be put. Drinking water requires the most extensive treatment, while water for irrigation may require little or no treatment. Distribution of water through pipeline systems to consumers depends on reliable supplies of energy, usually in the form of electricity. Energy is required indirectly for the construction, operation and maintenance of water-related infrastructure, including dams and reservoirs for water storage, pipelines and pump stations for distribution, and water (and wastewater) treatment plants. At the consumption stage of the water supply-use chain, substantial quantities of energy are utilised to heat water for industrial, commercial and domestic applications. Finally, energy is required for the collection, treatment and discharge of wastewater (Water in the West 2013). The reclamation of wastewater for re-use is particularly energy intensive (Hoff 2011).

The intensity of linkages between water and energy varies on a regional, national or sub-national basis, and is influenced by factors such as water-resource availability and accessibility, and the energy-supply mix and demand patterns (IRENA 2015). The energy intensity of water provision can vary greatly owing to differences in water source (e.g. surface freshwater or groundwater), water quality (e.g. fresh or saline) and the efficiency of water delivery systems (see Figure 1-5). According to Webber (2008 in Hoff 2011:22), "energy intensities per m^3 of clean water produced vary by about a factor of 10 between different sources, e.g. about 0.37 kWh from locally produced surface water, 0.66–0.87 kWh from reclaimed wastewater and 2.6–4.36 kWh from desalinated seawater."

Figure 1-8: Energy (kWh) required to provide 1 m^3 of potable water



SOURCE: Based on UN-Water (2014, fig. 2.2)

NOTE: Estimates do not include the distance water is transported or water efficiency levels.

Impacts of degraded water on energy and food systems

Poor water quality can have a negative effect on energy and food systems. Water that has been polluted by upstream or downstream production or consumption processes can be detrimental to the quality of agricultural and food products. Poor quality water can also impair the operation of certain types of thermal power plants (Rodriguez et al. 2013). Often the ultimate source of the pollution is other economic sectors (e.g. energy, agriculture or industry), although lack of adequate water service infrastructure may be (partly) to blame.

Drivers in the global water system

Many of the fundamental global drivers at play in energy and food systems also affect water systems, namely social, economic, geopolitical, environmental and technological factors.

Economic drivers

In general, economic growth and development leads to rising demand for water for all kinds of uses, including agriculture, mining, manufacturing and household consumption. According to UN-Water (2014), global water withdrawals are projected to grow by 55% by 2050. Demand for water for agriculture is projected to grow by 45% between 2010 and 2030 in the absence of efficiency improvements (WEF 2011). Some of this new demand encompasses catering to the rising demand for dairy and meat products, which are much more water intensive to produce than grains and vegetables.

Globalisation, in the sense of increasing international trade in physical goods, is driving an increase in global flows of virtual water. Such trade can result in substantial water savings by concentrating water-intensive production in water-rich countries. It has been estimated that trade in agricultural products resulted in global water savings of 369 billion m^3 per year between 1996 and 2005 (Mekonnen & Hoekstra 2011b). However, by 2030 some 2.5 billion people living in the Middle East and North Africa and South Asia regions will be facing water scarcity, and it is not clear that the international trading system can handle a large increase in demand for agricultural trade (which is also energy intensive) (WEF 2011).

Social drivers

The United Nations has declared water a basic human right, but estimates that 768 million people do not have access to an improved source of water and that up to half the world's population may not have their right to water adequately satisfied (UN-Water 2014). Furthermore, some 2.5 billion people lack access to improved sanitation. This places the need to address water insecurity and unequal access as a social driver in the global water system. The pressing need to meet this current social deficit will be intensified by future population growth, almost all of which is projected to occur in developing countries where water needs are already inadequately met. Growing populations demand increasing quantities of water for drinking and sanitation, as well as for food, energy and other water-demanding goods and services (UN-Water 2014). In addition, the rapid pace of urbanisation in the developing world is likely to lead to increasingly water-intense lifestyles, and often implies that water has to be transported longer distances to reach consumers.

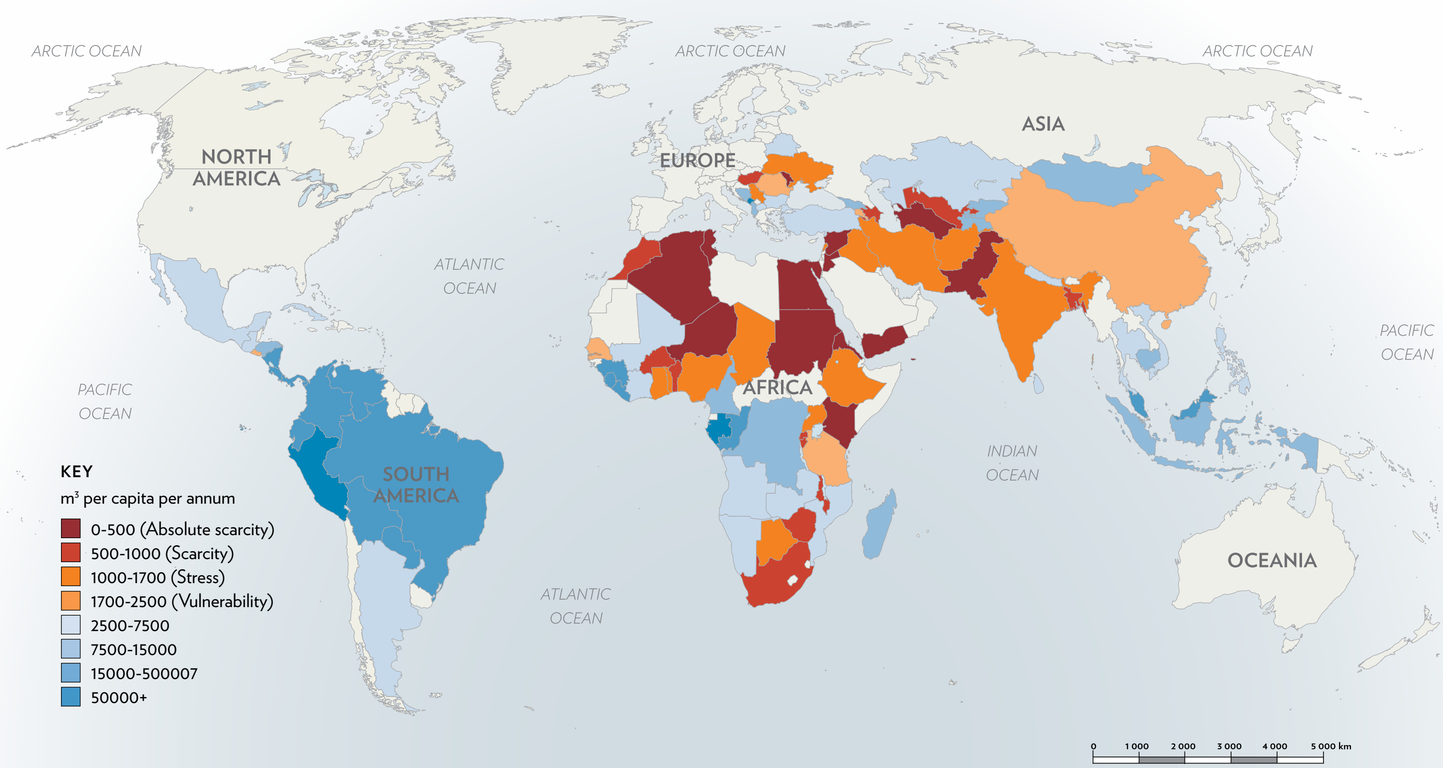
Environmental drivers

Environmental drivers include growing water scarcity and degradation of water resources. According to the World Bank (2013:1), "about 2.8 billion people live in areas of high water stress and 1.2 billion live in areas of physical scarcity." A number of countries are experiencing different degrees of water scarcity, stress or vulnerability (see Figure 1-9). In some areas, notably the Middle East and North Africa region, China and India, rising demand and limited supplies have resulted in the bursting of regional 'water bubbles' (WEF 2011). With groundwater abstraction growing by 1-2% globally, groundwater levels are dropping markedly in various parts of the world due to over-extraction (World Water Assessment Programme [WWAP] 2012). It has been estimated that a fifth of the world's aquifers are being over-used, some critically so – for example in India and China (World Bank 2013; UN-Water 2014). The depletion of readily accessible freshwater resources is anticipated to lead to increasing use of energy-intensive technologies, including groundwater pumps and desalination (World Bank 2013).

In addition, degradation of water resources and supporting ecosystems is compromising water quality. This arises from pollution from a wide range of human activities, including energy and food production, as well as land-use changes that disturb ecosystems. Across the world, deterioration of aquatic ecosystems and wetlands is eroding the water-purification capacity of ecosystems and reducing nature's flood-control mechanisms (UN-Water 2014). It has been estimated that as much as 90% of water consumed in developing countries is not collected or treated before being released into the environment (WWAP 2012).

Climate change is likely to be an increasingly important driver for water systems, encompassing a great deal of uncertainty as historical patterns in hydrological cycles may not hold in the future. Climate change is associated with more erratic rainfall patterns and an increasing frequency of droughts and floods (IPCC 2014). The melting of glaciers, which act as stores of fresh water and feed many important river systems, is also a major

Figure 1-9: Total renewable water resources, 2013



NOTE: Categories based on UN-Water definitions

SOURCE: Based on data from World Bank (2015b)

issue of concern (WEF 2011). Furthermore, "higher temperatures and an increase in the rate of evaporation may affect water supplies directly and potentially increase the water demand for agriculture and energy" (UN-Water 2014:22). The interaction of climate change and growth in populations and economies "will result in a heightened reliance on energy-intensive water supply options, such as water transport or desalination plants to supplement urban water supply" (Rodriguez et al. 2013:3).

Geopolitical drivers

Geopolitical issues are increasingly important in a water-constrained world (WEF 2011). There is potential for conflict over access to water to meet water, energy and food security needs where rivers or lakes cross country borders. For example, a decision to build a dam for water storage and/or hydropower generation may negatively affect water access and security downstream in neighbouring countries. A prime example is Ethiopia's Grand Renaissance Dam on the Nile River, which has drawn strong opposition from Egypt (IRENA 2015). Land grabs can intensify within-country competition for water because the crops grown on foreign-leased land contain virtual water (IRENA 2015). In fact, several of the countries that have been acquiring land in other nations are not short of land themselves, but rather of water, suggesting what is taking place is in effect 'water grabs' (WEF 2011).

Technological drivers

Technology improvements that raise water efficiency and productivity levels can reduce the burden on scarce water resources. However, a version of the 'rebound effect' noted in the context of energy may also be at work in the water domain: income savings from increased water resource efficiency may be spent on water-demanding goods and services, so that the aggregate demand for water does not decline (UN-Water 2014). Appropriate water-pricing regimes are necessary to avoid this situation, while giving due attention to equity and access considerations. Technology is an unpredictable driver as it can result in rapid and unanticipated changes (UN-Water 2014). A prime example is the advent of hydraulic fracturing, and the massive strain it can place on water resources.

1.1.4 Summary of global nexus linkages and drivers

Fossil fuels continue to dominate the global energy mix, with oil being of singular importance as the transport fuel of choice. The energy system requires substantial water inputs at various stages of the energy production and consumption chain, including primary extraction, processing/transformation, power generation, and indirectly in the construction and maintenance of energy infrastructure. Water use varies greatly by energy type, with biofuels being the most water intensive. Biofuels derived from food crops make only a very small contribution to global energy supplies (about 1.5% of total liquid fuels), but can have a large impact on international food prices. Energy production and consumption (especially of fossil fuels) can have a variety of negative impacts on both underground and surface water quality.

The globalised food system, which is dominated by large-scale industrialised commercial agriculture, food manufacturing and extensive trade and distribution of food products across national and international territories, is highly energy intensive all along the value chain and accounts for up to 30% of the world's total energy use. Mechanised industrial agriculture is responsible for a large share of energy consumption, but it is the processing and distribution stage that uses the most – up to 70% of the total. In terms of water dependencies of the food system, the production stage is the heaviest user, responsible for 70% of the world's freshwater use, up to 90% in some countries. The huge increase in agricultural yields and food supplies over the past century – which have sustained a rapidly growing world population – are largely attributable to the growing use of fossil fuels to power machinery and produce synthetic fertilisers and pesticides, and to pump water for irrigation. Furthermore, the food system has negative impacts on water availability and quality: over pumping of water for irrigation has led to groundwater depletion, while pollution from various stages of the food value-chain degrades water quality.

Water is a critical resource for all ecosystems and human societies, but some 2.8 billion people live in areas of high water stress. Water systems depend heavily on energy at many stages along the water supply/use chain, including abstraction and conveyance (pumping), desalination, treatment and purification, wastewater management, and construction of water infrastructure. On the other hand, poor water quality can negatively impact on food production and certain types of energy generation. At a global level, growing water scarcity and degradation is increasingly recognised as a major threat to human development. Climate change is expected to dramatically exacerbate these challenges over the longer term.

As the summary in Table 1-7 shows, there are several systemic drivers operating at a global level that affect all components of the nexus. On the demand side, these include: economic growth, increasing affluence and associated changes in lifestyles and consumption patterns; population growth and changing demographic profiles; urbanisation, which tends to go hand-in-hand with rising resource intensity; and globalisation. Common supply side drivers include resource depletion and increasing scarcity (e.g. of fossil fuels, arable land and fresh water supplies) and environmental degradation (including pollution). Climate change is both the result of processes in the energy-food-water nexus (e.g. fossil fuel combustion, land use changes and methane releases from dams) and a cause of instability and insecurity in some parts of energy, food and water systems – most notably water supplies and crop yields.

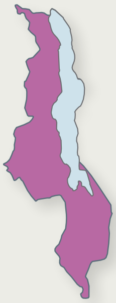
These demand and supply pressures are manifesting in volatile prices of internationally traded energy and food commodities, and these price swings are amplified by a financial sector prone to speculation and boom-and-bust cycles. Furthermore, the prices of energy and food commodities have been linked together through biofuel markets and because of the critical role play ed by energy inputs in the food supply chain. Thus food and energy security – both critically affected by international prices – are inextricably linked together. Another result of resource pressures is mounting geopolitical tensions – and fortunately in some cases cooperation – over access to water, land, food and energy. Technological developments are to some extent helping to alleviate the pressures on scarce resources by improving efficiencies, although such gains are counteracted by the rebound effect.

The confluence of these major global drivers – economic growth, population expansion, urbanisation, geopolitics, technological development and climate change – implies that the future could look very different to the past. New pressures and challenges will arise within the nexus that will need to be carefully managed on international, national and local scales. Ways to respond to these challenges and to fundamentally change energy, food and water systems to become more resilient and sustainable are considered in Part 3.

Table 1-7: **Key global drivers in the energy-food-water nexus**

DRIVERS	ENERGY SYSTEM	FOOD SYSTEM	WATER SYSTEM
ECONOMIC	■ Economic growth: rising energy demand ■ Oil price volatility and shocks ■ Oil market speculation	■ Economic growth driving food demand ■ Food price shocks ■ Globalisation of food system ■ Financial speculation in food commodity markets ■ Energy price fluctuations ■ Supermarketisation	■ Economic growth leading to growing water demand
SOCIAL	■ Inequality of access to energy ■ Energy poverty ■ Population growth ■ Urbanisation ■ Changing tastes (energy-intensive goods and services)	■ Population growth ■ Urbanisation ■ Inequality of access ■ Hunger and malnutrition ■ Poverty ■ Changing diets ■ Food protests and social instability	■ Inequality of access to water ■ Water insecurity ■ Population growth ■ Urbanisation
GEOPOLITICAL	■ Energy resource conflicts ■ Regional power pools ■ Strategic energy trade deals	■ Foreign direct investment in agriculture ■ Land grabs ■ Food export bans ■ International agricultural trade practices	■ Cross-border water conflicts ■ Virtual water trade and 'water grabs'
ENVIRONMENTAL	■ Conventional fossil fuel depletion ■ Expansion of unconventional fossil fuels production ■ Carbon emission caps or carbon taxes ■ Pollution concerns	■ Climate change impacts (e.g. temperature and rainfall) on crop yields ■ Soil erosion and land degradation ■ Depletion of rock phosphate reserves	■ Global climate change impacts on rainfall, runoff, evaporation ■ Water pollution (e.g. from agriculture, industry, mining) ■ Aquatic ecosystem degradation
TECHNOLOGICAL	■ Energy efficiency ■ New energy production & storage technologies ■ Rebound effect	■ Crop and livestock breeding ■ Genetically modified organisms ■ New chemical inputs	■ Water efficiency ■ New water technologies (e.g. desalination) ■ Rebound effect

Link to Global Risks



1.2 Agrarian Typology Case Study:

Malawi

Malawi is a small, landlocked country in East Africa with about 17 million inhabitants. As Malawi's economy is essentially based on producing crops and maintaining farmland and much of the country's total production stems from the agricultural sector, Malawi serves as an example of a dominant agrarian socio-ecological system.

WIKIMEDIA COMMONS

Collecting water, Ethiopia

WIKIMEDIA COMMONS: SWATHI SRIDHARAN (ICRISAT):

Cooking on a wood fire in Karonga District, Malawi

The following key nexus characteristics demonstrate aspects of this regime:

- The World Bank classifies Malawi as a low-income country with a per capita GDP (in purchasing power parity terms) of US$780 in 2013 (World Bank 2015a).
- Over 53% of the population lives in poverty based on the US$1 per day poverty line (CIA 2015a).
- Malawi's population is predominantly rural, with only 15% living in urban areas (NSO 2012).
- More than 77% of households depended on agriculture for their livelihood in 2013 (AQUASTAT 2015a). Farming takes place on fragmented small parcels of customary land (Gamula, Hui & Peng 2013) and the agricultural sector is the main source of economic growth and exports, representing about 37% of gross domestic product and 82.5% of foreign exchange earnings (AfDB 2013).
- Malawi is heavily reliant on biomass energy, with 90% of the population using wood or charcoal as a primary source of energy (Gamula et al. 2013). Only 8% of the population is connected to the electricity grid, with huge disparities between urban (25%) and rural areas (1%) (Renewable Energy and Energy Efficiency Partnership [REEEP] 2012).
- Water infrastructure is generally poorly developed, especially in the rural areas, and modern irrigation systems are underdeveloped. Most agriculture is rain-fed.
- The overreliance on singular sources of food (maize) and energy (biomass) both make the country more vulnerable to climate change (droughts and flooding), while aggravating its effects, as the pressure on woodlands has led to deforestation in several parts of the country (Kumambala & Ervine 2009).
- Malawi's economy is not completely agrarian, although manufacturing and service sectors are still very limited in extent. There is also a small, but important commercial farming sector that produces mainly for the export market. Given the country's lack of fossil-fuel resources and underdeveloped industrial sector, it relies heavily on imports for some key inputs – notably oil, coal and fertilisers – as well as manufactured consumer goods; it is completely reliant on imported petroleum fuels (Robinson & Wakeford 2013). Furthermore, due to low agricultural productivity levels, Malawi remained classified as a low-income food-deficit country by the FAO in 2014. Because dependence on imports (as well as foreign aid) is a typical challenge faced by many low-income countries, these are also addressed in the following discussion. The analysis of this case study is structured according to the interlinkages and drivers in the energy, food and water systems, respectively.

1.2.1 Energy system

Malawi's energy mix is dominated by biomass, with firewood, crop residues, charcoal and animal dung contributing about 88.5% of total primary energy supply (Gamula 2013) and catering for almost 99% of cooking needs (WHO 2005). Of this biomass energy, 59% is used in its primary form as firewood and residues, while the remaining 41% is converted into charcoal (Kambewa & Chiwaula 2010).

The balance of the total primary energy supply is provided by petroleum, which contributes 6.4% to the energy mix, with electricity contributing 2.8% and coal 2.4% (Gamula 2013 based on 2008 data). Malawi currently does not use any gas in its energy mix. The country's total primary energy supply amounted to 134.0 petajoules (PJ) in 2009 (IRENA 2012a).

Malawi suffers from a severe energy deficit, meaning that many productive sectors cannot fully perform due to energy insufficiencies and disruptions. Due to the gap between the country's energy production and its energy consumption, Malawi imports energy in the form of oil and coal. It imports 97% of all refined petroleum products, including gasoline and jet fuel via Tanzania, Mozambique and South Africa (Government of Malawi [GoM] 2009; REEEP 2012). The remaining 3% is locally produced ethanol, which is blended with petrol. The country's petroleum consumption was estimated at 13 000 bpd in 2013 (EIA 2015b), with fuel imports representing 12% of total imports (World Trade Organization [WTO] 2012). At a household level, paraffin is the predominant form of oil-based energy used (National Statistical Office [NSO] 2012).

Possible oil and gas discoveries beneath Lake Malawi would substantially alter the country's energy profile. Companies currently exploring for oil and gas in Malawi hope to replicate the large discoveries made in Uganda, also located within the Rift Valley system (SacOil 2015). The Malawian government has divided the area for oil exploration into six blocks and awarded six exclusive prospecting licenses. To date no findings on the possible oil and gas deposits have been made public and an extensive strategic environmental assessment is being carried out before presentation to the Ministry (Mining in Malawi, 2015).

Malawi's electrical sector is still underdeveloped. Despite its rich water resources (Kumambala & Ervine 2009), Malawi only generates 286 megawatts (MW) from hydropower (Lapukeni 2013), which falls short of the peak demand of 334MW (GoM 2011b) and only meets 2.6% of the country's estimated energy needs (REEEP 2012). The country's untapped hydropower potential is estimated at 2 gigawatts (GW) (Lapukeni 2013).

Since the 1970s Malawi has been attempting to transition to using bioenergy to mitigate the foreign exchange consequences of increasing oil consumption in the country. Biofuels currently contribute 3% to liquid fuel consumption (Gamula et al. 2013). According to government statistics (Table 1-8), in 2008 the household sector accounted for 83% of energy consumption, industry 12%, transport 4% and services 1%.

Table 1-8: Malawi's national energy demand per sector by fuel type (terrajoule/year) in 2008

	BIOMASS	PETROLEUM	ELECTRICITY	COAL	TOTAL
Household	125 574	672	1 798	5	130 049
Industry	10 004	3 130	2 010	3 481	18 625
Transport	270	5 640	35	15	5 960
Service	452	558	477	174	1 661
Total	**138 300**	**10 000**	**4 320**	**3 625**	**156 295**

SOURCE: Government of Malawi (2009:18).

Linkages and dependencies

Water for energy

Almost all of Malawi's electrical power is generated by hydropower. Five of the six hydropower plants are located on the Shire River, with only one small hydropower plant on Wovwe River (Kumambala & Ervine 2009). The capacity for each is illustrated in Table 1-9.

Table 1-9: Malawi's installed hydropower capacity

PLANT	RIVER	MW
Nkula A	Shire	24
Nkula B	Shire	100
Tedzani I&II	Shire	40
Tadzani III	Shire	52.7
Kapichira	Shire	64.8
Wovwe	Wovwe	4.5
Total		**286**

Source: Electricity Supply Commission of Malawi (in Kumambala & Ervine 2009:539)

The energy sector is thus highly vulnerable to changes in hydrology. The Shire River system is bolstered by outflows from Lake Malawi, which is mainly influenced by precipitation and evaporation, making it vulnerable to droughts. Between 1915 and 1935, the flow into the Shire River dried up completely (Wood & Moriniere 2013).

Water is also used to grow sugar cane and Jatropha for biofuel production. The local, privately-owned ethanol-producing company ETHCO Ltd. uses sugarcane molasses as feedstock from the neighbouring Dwangwa sugar factory, which uses irrigation water from Lake Malawi to ensure permanent production (Johnson & Silveira 2014). While Jatropha has strong drought-tolerance properties and planting is promoted for erosion control and improved water infiltration (Henning 2004), it can under favourable soil moisture conditions absorb large amounts of water to produce high yields. This calls for caution in identifying areas suitable for potential plantations, which could have significant impacts on water availability, especially in semi-arid or arid regions (Rao et al. 2012).

Food for energy

Reliance on imported liquid fuels renders Malawi vulnerable to shortages in oil supply, which has led the country to develop bioethanol production based on sugar crops since the 1970s. ETHCO Ltd. has produced between 10 and 20 million litres of fuel-grade ethanol a year since 1982 (Johnson & Silveira 2014). Besides the feedstock sourced from the neighbouring Dwangwa sugar factory, it also sources sugar molasses (as much as 40% of its inputs) from the Sucoma sugar factory several hundred kilometres away to ensure a regular supply. It expanded operations in 2004 and opened a new distillery in alignment with the government's drive to find alternatives to oil imports and facilitate the expansion of the national ethanol market (Johnson & Silveira 2014). In 2009 the Malawi Energy Regulatory Agency set a compulsory 10% ethanol – 90% petrol blending ratio (Malawi Energy Regulatory Agency [MERA] 2010), which has since been increased to a 20% ethanol – 80% petrol ratio (Ethanol Company of Malawi [ETHCO] 2015).

Bioenergy Resources Limited, a biofuel energy company, contracts Jatropha production out to small-scale farmers (Dyer, Stringer & Dougill 2012). The company estimates that by 2020 farmers will have grown 15 million trees that will produce 20 million litres of straight vegetable oil a year (Centre for Agricultural Research and Development [CARD] 2012). The oil will be blended in an 8% oil – 92% diesel ratio and 20% oil – 80% paraffin ratio (Bioenergy Resources Limited [BERL] 2015). Jatropha is not an edible crop and the company aims to avoid the food-fuel dilemma by ensuring that the trees are planted on the boundaries of maize fields.

Malawi has also experimented with converting the stillage waste (vinasse) from ethanol production into biogas through anaerobic digestion. A plant for this was funded in the 1990s, but lack of technological knowledge led to the project closing down. However, this technology is reportedly being re-explored though the Carbon Development Mechanism in Malawi and elsewhere (Johnson & Silveira 2014), which is funded by the United Nation's Framework Convention on Climate Change Adaptation Fund.

Impacts of energy on water and food

The exploitation of biomass energy in Malawi through the harvesting of wood contributes (along with agriculture) to soil erosion and consequently siltation, which results in lost hydro-electricity generation, increased costs of treating drinking water and the loss of ecosystem resilience pertaining to flood-prevention functions (Kambewa & Chiwaula 2010). Siltation also negatively affects the functioning of treadle pumps and canal-based irrigation systems (Yaron, Mangani, Mlava, Kambewa, Makungwa, Mtethiwa, Munthali, Mgoola & Kazemba 2011). The estimated annual cost of the effects of soil erosion on hydropower capacity is US$10 million a year, roughly equivalent to 1.9% of Malawi's GDP (Yaron et al. 2011).

Concerns have also been raised about the possible effect that exploration for oil reserves will have on the quality of Lake Malawi's water and fish stocks (Kainja 2012). The United Nations Educational, Scientific and Cultural Organization (UNESCO) has raised concerns as the lake provides a livelihood to more than 50 000 fishers and, indirectly, to a further 350 000-odd people involved in the value chain (Kainja 2012). The potential discovery and exploitation of fossil fuels therefore presents both opportunities and risks to a country that is currently largely dependent on biomass energy and subsistence agriculture and fishing activities. Biodiversity conservation is important, as Lake Malawi is home to about 800 fish species, more than any other lake in the world (UNEP 2004).

Uranium prospecting also has consequences for water quality. Uranium prospection in Malawi was initiated in the early 1990s on the Kayelekera site and Paladin was granted a 15-year mining license in 2007 (Paladin Energy 2015). Operations were discontinued in 2014 as the uranium price was deemed too low, but the intention is to reopen the mine when the price incentives are right and adequate power is supplied by ESCOM (Paladin Energy 2015). The Kayelekera site is operated as an open-pit mine and is located on a tributary river that flows into Lake Malawi, thus directly threatening air and water resources (Mudd & Smith 2007). Recent analyses conducted from water sampled in the Champhanji creek, which flows from the open-pit mine to the Sere River, showed high levels of uranium concentration. Further downstream the samples revealed concentrations of 42.8 μg U/L, above the WHO recommendation for drinking water of 30 μg U/L (Chareyron 2015).

A common criticism of biofuel production is that agricultural resources (land, water, labour and fertiliser) will be diverted from food to energy production. However, bio-ethanol in Malawi is produced from waste from the sugar industry so it does not complete for these resources with food production. And Jatropha is a commercial crop that requires high levels of technical and management skills and it takes 30 years to mature to optimal yield – it is therefore unlikely that small-scale farmers will shift from food crop production to Jatropha, given the size of their fields and the length of time to recoup on the investment (Nalivata & Mapemba 2012). In addition, maize is a crop of great cultural significance in Malawi and farmers are unlikely to surrender this practice (Dyer et al. 2012). Jatropha cultivation remains limited in Malawi and the potential yield of the crop – on marginal land – is still largely theoretical (Wiyo & Banda 2012).

Drivers in Malawi's energy system

Economic drivers

Economic growth and development is a major driver of energy demand. Malawi's GDP growth in 2013 was estimated at 5% and projected to increase to 6.2% in 2015 (African Development Bank [AfdB] 2014). However, it is affected by levels of foreign aid. Malawi's growing reliance on oil and food imports make it vulnerable to significant price fluctuations (Gamula et al. 2013; Robinson & Wakeford 2013).

There is a growing demand for electricity and supply is constrained by the lack of infrastructure and the poor state of existing infrastructure. Excess demand for electricity was about 347MW in 2013; this was projected to increase to 598MW in 2015, 874MW in 2025 and 1193MW in 2025 (Lapukeni 2013), indicating a growing trend in demand outstripping supply. The growth in demand originates with the mining sector, agricultural sector for irrigation, services and manufacturing sectors, as well as domestic demand (Lapukeni 2013). There has been a lack of investment in generation, transmission and distribution infrastructure (Lapukeni 2013) and poor maintenance of ageing infrastructure has resulted in losses ranging between 18% and 22% of generated electricity (Gamula et al. 2013). Vandalism is also a contributory factor. Malawi's electricity investment plan aims to bridge the gap between demand and supply by 2016 by promoting the use of renewable energy sources; improving the management of energy generation, transmission, distribution and supply; expanding urban and rural electrification networks; increasing liquid fuel stock-holding and distribution capacity; promoting public-private partnerships in energy generation and distribution; and improving the regulatory environment (GoM: 2011:78). However, it is most likely that the country will rely on biomass for the foreseeable future. Government's pre-feasibility study for a planned pipeline from Beira in Mozambique to Nsanje indicates that it would improve the supply of petroleum products to the country (GoM 2011b), but it would require considerable investment for implementation (Chinaumlungu 2014).

Social drivers

Population growth, urbanisation trends and unequal access to energy are the main social drivers. Malawi's population – estimated at just over 17 million in 2014 with an annual growth rate of 3.3% (CIA 2015) – is expected to double by 2033 (UNFPA 2015). People are moving from the rural areas to the cities at a rate of 4.2% a year (CIA 2015); however, only about 15% of the population are currently urbanised (NSO 2012). Only 8% of citizens are currently connected to the electricity grid – with huge disparities between urban residents (25% connected) and rural areas (only 1% connected) (REEEP 2012; Gamula et al. 2013).

Geopolitical drivers

Malawi's landlocked geography constrains potential economic activity in the country. Transport of goods accounts for about 14% of the total product cost, compared to a global average of 6% (United Nations Conference on Trade and Development [UNCTAD] 2011). Transportation unit costs in the country are 6 US cents per tonne/kilometre versus 3 US cents per tonne/kilometre for South Africa (Millennium Challenge Corporation 2011 in AfDB 2013).

Malawi has also been embroiled in a long geopolitical dispute with its neighbour Tanzania over the demarcation of their border traversing the lake. The decades-old contention was resurrected in 2012 when Malawi awarded exploration licenses for the possible exploitation of oil and gas reserves in Lake Malawi (Lalbahadur 2012). It is likely that the dispute will intensify should the reserves prove viable.

Environmental drivers

Resource depletion and environmental degradation are prime drivers. The reliance on biomass to meet energy needs and the extensification of agriculture have resulted in very high deforestation rates of 2.4% a year (FAO 2001); this is the highest in southern Africa. Between 1991 and 2008, about 669 000 hectares of woodland was converted to farmland. The contraction of the woodlands' standing stock means that there is decreasing amounts of biomass available for harvesting. The total consumption of biomass in 2008 was estimated at about 9 million tonnes of wood equivalent (Gamula et al. 2013). In addition, irregular rainfall constrains the capacity of the energy sector as hydropower generation is dependent on Lake Malawi's hydrological cycles and outflows into the Shire River.

Although Malawi is a net carbon emitter, its contribution to global greenhouse gases is minimal and being categorised as a less-developed country, Malawi will not be constrained by future global agreements on carbon dioxide emissions.

Technological drivers

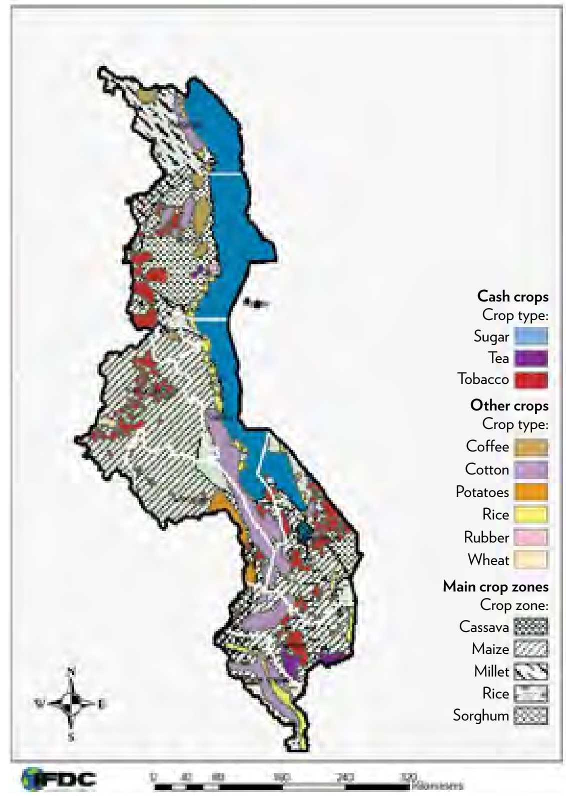
Technology is another important driver in the energy sector and Malawi has made significant technological progress in the field of bioenergy, emerging as a regional leader in this sector (Johnson & Silveira 2014). It has, for instance, experimented with different blends, modified vehicle engines and tested flex fuel. Some innovations include the use of a modern molecular sieve at ETHCO Ltd.'s new distillery to prevent chemical contact with the ethanol resulting in a purer product for fuel blending.

1.2.2 Food system

Nearly 33% of land in Malawi is cultivated – 3 885 million hectares (AQUASTAT 2015a) – and most cultivation is undertaken by the small-scale farming sector. This group contributes about 86% of Malawi's agricultural output and occupies approximately 80% of cultivated land (Europa 2012 as cited in Robinson & Wakeford 2013). Malawi's commercial crops are tobacco, tea, sugarcane and cotton, which account for about 75% of total exports for the country, with tobacco alone contributing about 52% (Gamula et al. 2013).

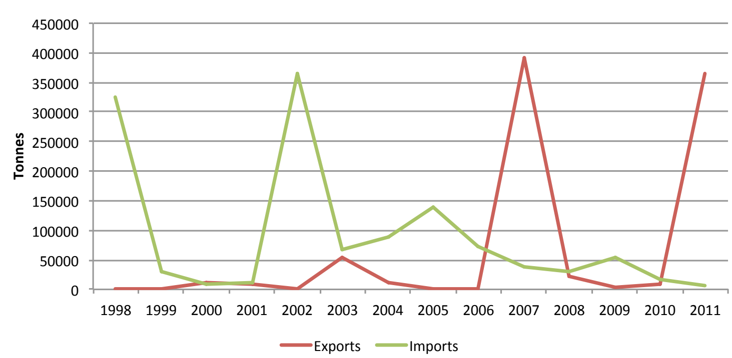
Besides two years of surplus production (2006/7 and 2010/11), Malawi has had to import grains over the past decade (see Figure 1-11). Malawi's average maize yield for the period 2009-2013 was 2.2 tonnes per hectare (t/ha), which compared favourably with similar average yields for Eastern Africa (1.7 t/ha) and Africa as a whole (2.0 t/ha) but was considerably lower than yields in Southern Africa (4.0 t/ha) and the world (5.2 t/ha) (FAO, 2015c). The population experiences fluctuating levels of food security; an estimated 23% of the population were undernourished between 2010 and 2012 (FAOSTAT 2015d). Between 2003 and 2011 14.4% of Malawi's imports were agricultural products (WTO 2013), with wheat being among the top import items. Frequently in times of food shortages, the country relies on emergency food-aid shipments (Attwell 2013).

Figure 1-10: Crop distribution and zones in Malawi



SOURCE: FAO (2015b)

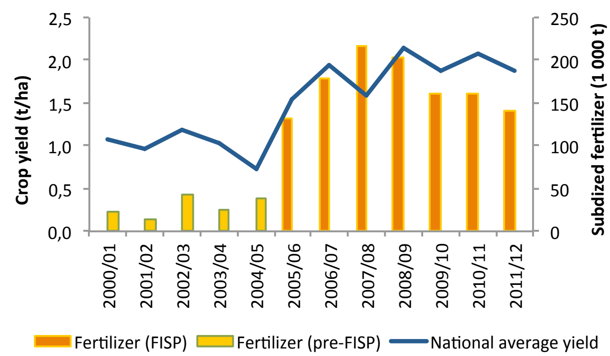
Figure 1-11: Imports and exports of maize in Malawi between 1998 and 2011



SOURCE: FAOSTAT (2015e)

Malawian households spend most of their money on food; an average of 54.1% in 2011 (NSO 2012). About 97% of rural households, increasing to 99% in the southern region, grow the country's staple food crop, maize (SOAS 2008). Maize represented more than half of the population's calorific intake per capita per day in 2011 (FAOSTAT 2015c). Access to maize is the prime indicator of national food security in Malawi (GoM 2011a). If maize supply is below the minimum food requirement the nation is deemed to be food insecure even if total food production exceeds the minimum requirement. Therefore food insecurity is strongly related to localised maize yields (Robinson & Wakeford 2013), which leads to regional differences in food prices. As a result, livelihoods and the food security of most Malawians are affected by frequent and high inter- and intra-seasonal volatility of maize prices. Only 10% of Malawian maize producers are net sellers of maize, while 60% are net buyers (SOAS 2008).

Figure 1-12: Maize yields and subsidised fertiliser in Malawi from 2000/01 to 2011/12



SOURCE: Pauw & Thurlow (2014)

Linkages and dependencies

Energy for food

Close to 90% of the population uses firewood for cooking needs, 8% use charcoal, 1% use paraffin, 1% use other means such as crop residues and just 2% use electricity (urban households) (Gamula et al. 2013). Small-scale farmers in Malawi traditionally use non-mechanised farming methods and so the primary energy used for food production is solar energy captured by crops – this is typical of agrarian socio-ecological regimes (GoM 2011a). However, some commercial farmers do rely on oil for production and transport of products; 94% of the general transport sector's needs are met by petroleum (Robinson & Wakeford 2013). The sector is generally not reliant on energy for irrigation because 98% of the country's agriculture is rain-fed. However, the commercial sector and farmers who use mechanical pumps are very reliant on fuel. Fuel shortages such as those in 2010 and 2011 curtailed the growth of irrigated crops, forcing farmers to cut down trees to sell as firewood as an alternative form of livelihood (Sukali 2011).

The food system is also indirectly dependent on the energy system through the energy 'embedded' in fertilisers. A true agrarian system makes use of natural fertilisers such as crop residues. However, synthetic fertilisers use, derived mainly from natural gas, has been increasing in Malawi.

The government-run Fertilizer Subsidy Programme (FISP) was introduced in 2005 and the near doubling of the average crop yield (see Figure 1-12) is credited to the sharp increase in fertiliser use. According to the Malawian government, the programme has resulted in maize production increasing from 1.2 million tonnes in 2004/05 to 3.4 million metric tonnes in 2009/10 (GoM 2011a).

Using imported fertilisers also increases the sector's dependence on transport fuels and vulnerability to volatile international prices. When the oil price increases, farm-gate fertiliser prices in Malawi are reported to be double or more than double international fertiliser prices (Futures Agricultures 2008).

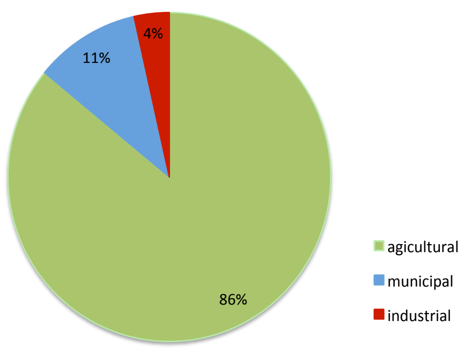
In contrast, the use of petroleum fuels for transporting produce to agricultural markets is negligible in the subsistence and small-scale farming sector and is primarily restricted to the commercial export sector.

A still marginal aspect of the energy/food nexus in Malawi is the use of waste from biofuel production as an agricultural input. Stillage waste (vinasse) from ethanol distilleries is used as an agricultural input in the form of fertilizer (Johnson & Silveira 2014) and Bioenergy Resources Limited is producing seedcake and biofertiliser from the by-products of the pressing process of Jatropha nuts (BERL 2015), but the amounts involved are very small.

Water for food

The agricultural sector accounts for about 86% of water withdrawal in Malawi, but in the form of green water (AQUASTAT 2015a) – this is one of the key features of largely agrarian socio-ecological regimes (see Figure 1-13). The balance of withdrawal comprises municipal consumption (10.5%) and industrial use (3.5%) (AQUASTAT 2015a). In 2012, just 74 000 hectares of land were under irrigation (FAOSTAT 2015f) out of the estimated 200 000 to 500 000 hectares of irrigable land (Wood & Morniere 2013). Scaling up irrigation would require more intensive use of blue water.

Figure 1-13: Sectoral water withdrawal in Malawi in 2005



SOURCE: AQUASTAT (2015a)

There is little food processing undertaken in Malawi so it is assumed that not much water consumption is used at that stage. Malawi's manufacturing sector has been earmarked as a key driver of energy consumption (Lapukeni 2013) and it can thus be assumed that the sector's water needs will also increase, although there is no existing data to quantify this need. Finally, food preparation requires safe drinking water, access to which is discussed in the water section.

Impact of the food system on water and energy

The expansion of agricultural land due to population pressure and low productivity has resulted in deforestation and soil erosion in many river catchment areas, including those previously protected. While the negative effects of the agrarian regime (largely subsistence-type agriculture) are generally limited compared to those of more industrialised farming systems, increasing use of fertilisers and other agro-chemicals poses a threat to water quality through leaching into river systems and lakes (GoM 2011c). Eutrophication in the Shire River has caused the exponential growth of aquatic plants, which, combined with eroded soils, compromises water intakes to the country's main hydropower plant (Liabunya 2004). Mhamgo and Dick (2011) warn that the fertilizer subsidy programme might potentially reduce wood-fuel resources as woodlands are converted to agricultural land, although currently this appears to be only a problem closer to urban areas.

Data pertaining to the pressure of irrigation on water resources is lacking. As most of the country's irrigation schemes are located near Lake Malawi, the lake's water levels could decrease, affecting water flow in connected rivers and make it difficult to maintain sufficient levels for hydro-energy production (Nielsen, Schünemann, McNulty, Zeller, Nkonya, Kato, Meyer, Zhu, Anderson, Forthcoming).

Drivers in Malawi's food system

Economic drivers

There are four key economic drivers in Malawi's food system. The first is the increasing dependency on imported fertilisers to meet the agricultural sector's input requirements. The average growth in fertiliser use was 6% a year from 1984/85 to 2004/05 (SOAS 2008), and fertiliser use grew much more rapidly under the subsidy programme between 2005 and 2007 (see Figure 1-12 above).

The second driver is period food prices spikes, resulting at times by sharp rises in international food prices (e.g. 2007-2008) and at other times by local droughts (Attwell 2013), lack of the financial resources to purchase food imports, or devaluations of Malawi's currency. For example, following the International Monetary Fund's requested devaluation of the Kwacha in 2012, prices of some basic items increased by as much as 50% (Robinson & Wakeford 2013).

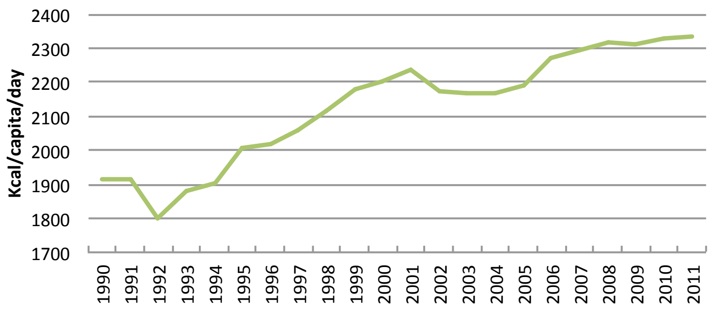
The third driver is the financial and resource constraints to expanding the agricultural network. The public irrigation sector is battling to meet the demand for infrastructure expansion and has been severely constrained by heavy operation and maintenance costs. The priority areas of health services and education compete for public resources, leaving the irrigation sector inadequately resourced (Wood & Morniere 2013).

The fourth economic driver is Malawi's dependency on donor aid. Malawi's aid per capita at US$68.6 is much higher than other countries in Africa (US$42.1) and southern Africa specifically (US$44.5) (AfdB 2013), which makes Malawi highly vulnerable to the precariousness of its relationship with the donor community. Donors have suspended direct budget support to the government on several occasions, including in 2002, 2012 (Attwell 2013) and in January 2015 over the 'cashgate' scandal (Nkhoma 2015). Multilateral agencies, however, continued their funding for specific objectives (Nkhoma 2015).

Social drivers

The primary social driver is the need to ensure food security for a growing population. The national domestic food supply in Malawi dropped below the threshold of 2 200kcal per capita a day between 2002 and 2005, but has since then steadily increased to reach 2 334kcal / per capita a day as illustrated in Figure 1-14. However, these national figures mask regional and rural/urban disparities. In 2008, the mean rural capita per day consumption of the poor rural population was 1 746 kcal, and 43.7% of the children aged between six months and five years were stunted (SOAS 2008).

Figure 1-14: Per capita food supply in Malawi, 1990-2011



SOURCE: FAOSTAT (2015f)

Despite the improvement in calorie consumption, only 57% of the population were classified as food secure in 2011 (NSO 2012). The balance was classified as being marginally food secure (2%) and experiencing low food security (8%) and very low food security (33%) (NSO 2012).

Malawians spend most of their income on food purchases (especially for maize) and the population is very vulnerable to food price fluctuations. Retail maize prices in southern Malawi doubled between July 2011 and July 2012 and were up to 40% more than in other parts of the country (FEWS NET 2012). The depreciation of the local currency has driven up the costs of imported fuel, agricultural inputs, transport and food (Robinson & Wakeford 2013).

Geopolitical drivers

Malawi's main geopolitical weakness with regard to food security is its periodic dependence on food aid from international donors. In the past few years, the flow of international aid has been interrupted as a result of political events in Malawi. Another factor is the land-locked status of the country, which increases the transport costs for imported food.

Environmental drivers

The agricultural sector drives environmental degradation because clearing land for cultivation leads to soil erosion and aggravates siltation of water bodies. Malawi loses soil at an estimated average of 20 tonnes a hectare a year, which contributes to reducing crop yields by more than 4% a year (Yaron et al. 2011). It is also highly vulnerable to climate change-induced shocks, such as dry spells and flooding during the cropping season, and outbreaks of crop and livestock disease. The increase in temperature was confirmed over the period 1997 to 2011 and Malawi experienced six very wet and five very dry summers over the same period, an abnormal pattern for the country (Wood & Morniere 2013). Uncertainty about the onset of the rainy season makes decisions on planting times difficult for farmers.

The recent flooding (January 2015) in southern Malawi has submerged 35 000 hectares of cropland, swept away livestock and displaced some 174 000 people (FAOSTAT 2015a), with the southern part of the country being most affected (Office for the Coordination of Humanitarian Affairs [OCHA] 2015). These floods have interrupted the agricultural cycle, thus threatening the already vulnerable food security of people in the area (FAOSTAT 2015a). Long-term climate projections over the 2020–2040 period indicate that the rainy season will likely start later and that temperatures will increase between 1.75°C and 2.5 °C (Wood & Morniere 2013).

1.2.3 Water system

Despite its large lake, Malawi is considered a water-stressed country (AQUASTAT 2015a). Most of the water available in Malawi is surface water, with precipitation contributing 90% to the total available (Wood & Moriniere 2013). Sustainably available groundwater resources are estimated to make up 2% of the nationally available total water resource (Atkins International Ltd and Wellfield Consulting Services 2011 in Wood & Moriniere 2013). Both surface and groundwater resources depend on rainfall inputs and support important wetlands along the shores of Lake Malawi and Lake Chilwa (GoM 2011c).

Linkages and dependencies

Energy for water

Most agricultural production in Malawi is rainfed and so does not rely on energy inputs. There are also about 62 000 hectares under manual, traditional irrigation techniques (Wood & Morniere 2013). However, large-scale commercial farms do require energy for irrigation. Irrigation schemes are reliant on surface water. The Green Belt Initiative is a key energy demand driver with a minimum projected requirement of 130MW (Lapukeni 2013). The effect of this demand on water and energy security may be substantial and a comprehensive analysis of macro- and micro-level nexus effects is needed (Nielsen et al. Forthcoming). Energy is also required for water and wastewater treatment, but these uses are under-researched in Malawi.

Drivers in Malawi's water system

Economic drivers

Economic growth and development generally increase the demand for water. The Green Belt Initiative, intended to maximise agricultural gains and drive economic development by using under-utilised land, represents a key driver of energy demand for the provision of irrigation water (Lapukeni 2013). The leasing or selling of land to foreign interests for commercial farmers in the hope of boosting foreign exchange earnings (Chinsinga, Chasukwa & Pashane Zuka 2013) will also increase the demand for irrigation.

Social drivers

Population growth and insufficient and unequal access to water are social drivers. The increased numbers of informal settlements, combined with lack of sanitation infrastructure, lack of sewage treatment facilities and deforestation are all social factors that aggravate pressure on and pollution of Malawi's water supply (UNEP 2004). Per capita water availability is rapidly declining due to the country's expanding population, especially in its urban and peri-urban areas (World Bank 2011). Various sources predict significant population growth over the next decade (up to 49.5 million people by 2050, according to a 2007 World Bank estimate). This growth, exacerbated by poverty, decaying infrastructure and urbanisation trends, will put increasing pressure on already over-subscribed water resources and services.

Some 20% of Malawians (2.9 million people) do not have access to improved water supply and 44% (6.5 million) do not have access to improved sanitation (WHO/UNICEF 2010). Despite these challenges, Malawi has achieved the Millennium Development Goal for access to drinking water, with 95% of the urban population and 77% of the rural population having access to drinking water (the goal is 75%) (WHO/UNICEF 2010). However, water access remains erratic, with reports of Blantyre residents relying on untreated well water for washing and cooking (World Bulletin 2014). Blantyre's water demand is 96 000 m^3 a day, but it only receives 78 000 m^3, hence the continued dry spells in certain neighbourhoods.

Geopolitical drivers

As mentioned earlier, the occurrence of geopolitical issues will be on the rise in a water-constrained world (WEF 2011). Malawi does not share major river systems with its neighbours, but the country has been at loggerheads with Tanzania regarding the disputed border of Lake Malawi (Lalbahadur 2012). According to the Tanzanian Government, the border should run through the middle of the Lake (Mining in Malawi 2014). However, this issue mainly concerns rights for mineral prospecting and fishing, rather than water resources.

Environmental drivers

Environmental drivers include freshwater scarcity (discussed above), degradation of water resources and climate change. Many factors result in water pollution. Malawians source the bulk of wood from natural forests, which leads to the destruction of 50 000 to 75 000 hectares of forest each year (REEEP 2012). The degradation of the forest cover affects water run-off into the lake and increases sedimentation. Also, as mentioned previously, the overall quality of surface and ground water in Malawi is fast degrading, with agro-chemical run-off, high faecal concentrations from direct pollution or untreated municipal waste and industrial and hazardous waste all contributing to water pollution (GoM 2011c). The eutrophication of Lake Malawi is a serious problem and nutrient and sediment loading from rivers into the lake is estimated to have increased by 50% over the past few decades (UNEP 2004).

Climate change is likely to be an increasingly important driver for water systems, and it also creates a great deal of uncertainty for farmers practising rain-fed agriculture. The aforementioned disruptions in seasonal patterns, characterised by erratic rains, extended dry periods, flash floods and increased evaporation, are already affecting water availability in Malawi. The disrupted rainfall patterns reduce the availability of surface water and higher reported temperatures over the last decade have contributed to increasing evaporation rates from lakes Malawi and Chilwa (Wood & Morniere 2013). While total annual average water demand is estimated at approximately 2 900 megalitre (Ml)/day (2010), this value increases to 3 900Ml/day during an average dry season, an increase of approximately 35% (Wood & Moriniere 2013).

1.2.4 Summary and conclusion: agrarian typology

Given the predominance of its largely subsistence agricultural sector, especially in terms of providing livelihoods for the majority of the population, Malawi constitutes a useful example of a country that is still functioning mainly within an agrarian socio-ecological regime. As Malawi's extremely low per capita income suggests, the agrarian regime has enormous limitations. At the heart of this is the country's overwhelming reliance on traditional biomass energy resources and the extremely limited electricity network. The extensive use of fuel wood in turn has negative impacts on soil and water resources through deforestation and soil erosion. Food security is tenuous for most of the population, partly because of the low productivity of traditional agriculture, which provides barely enough for many households' own consumption, let alone a marketable surplus to generate income and alleviate poverty. Food security is also jeopardised by the direct dependence for much of agricultural production on rainfall and the lack of irrigation infrastructure. Climate change already appears to be having an impact on Malawi's rainfall patterns, which are becoming more erratic. These issues illustrate how the nexus manifests in a predominantly rural context.

In an effort to transcend the limitations of the agrarian regime, Malawi's government has in recent years introduced a significant fertiliser subsidy programme in order to boost farm yields. The programme aims to both improve food security and boost foreign exchange reserves through increased agricultural exports. While this programme appears to have raised yields (in particular of maize), the increasing dependence on imported fertilisers presents the country with new challenges and risks. These include both exposure to teleconnections such as global fertiliser price shocks and exchange rate weakness, as well as the detrimental effects of excess fertiliser use on water resources – which in turn can affect energy production (for instance, by stimulating plant growth that reduces water flows to the country's main hydropower facility). The main system drivers in Malawi are summarised in Table 1-10.

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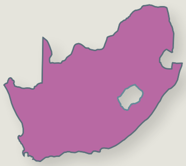
Wood collection, Malawi

Table 1-10: Key nexus drivers in Malawi

DRIVERS	ENERGY	FOOD	WATER
ECONOMIC	■ Economic growth and energy infrastructure development depend on foreign aid ■ Financial constraints to expand and maintain energy grid ■ Increasing reliance on fossil fuel imports ■ Energy demand increasingly exceeding supply	■ Increasing dependency on imported fertiliser ■ Financial and resource constraints to expand the agricultural network ■ High dependency on donor aid to meet nutrition needs ■ Depreciation of currency drives up costs of imported fuel, agricultural inputs & transport, resulting in high rate of food price inflation	■ Economic growth and development lead to rising demand for water ■ Green Belt Initiative is a key driver of energy demand for the provision of irrigation water
SOCIAL	■ Demographic growth and high urbanisation rate put pressure on electricity grid and compound disparities in energy access	■ High degree of food insecurity with regional and rural/urban disparities	■ Demographic growth and insufficient and unequal access to water ■ Declining per capita water availability
GEOPOLITICAL	■ Landlocked geography inflates transport costs ■ Exploration for oil and gas reserves under Lake Malawi has resurrected old border tensions with Tanzania	■ Lack of access to the coastline increases transport costs of imported food	■ Dispute with Tanzania regarding the border of Lake Malawi may have consequences in a future water-constrained future
ENVIRONMENTAL	■ Pressure on woodlands to meet energy demand, resulting in deforestation ■ Water and soil contamination by uranium waste leaching ■ Possible threat of pollution from oil extraction in Lake Malawi ■ Irregular rainfall constrains the power sector	■ Deforestation a key driver of environmental degradation, as the clearing of land for cultivation leads to soil erosion and siltation of water bodies ■ Agricultural production affected by abnormal climatic events, the occurrence of which is on the increase (droughts and flooding) ■ Greater uncertainty on the onset of the rainy season affects crop systems	■ High level of pollution in water-ways with agro-chemical run-off, high faecal concentrations from direct pollution or untreated municipal wastes ■ Deforestation-induced nutrient and sediment loading ■ Erratic rains, extended dry periods, flash floods and increased evaporation
TECHNOLOGICAL	■ Malawi is emerging as a regional leader, with demonstrated innovative expertise in the field of bio-energy		

Link to Malawi Risks



1.3 Industrial Typology Case Study:

South Africa

As mentioned in the introduction, the industrial socio-ecological regime consists of complex economic systems and infrastructures that are powered mainly by fossil fuels. Within a developing country context, South Africa serves as a useful example of relatively sophisticated industrialised systems that nonetheless exhibit a high degree of vulnerability, especially when viewed from the energy-food-water nexus perspective.

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Arnot coal-fired power station, Middelburg, South Africa

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Harvesting grain, Limpopo, South Africa

The following key nexus features illustrate the dominant industrial regime in South Africa:

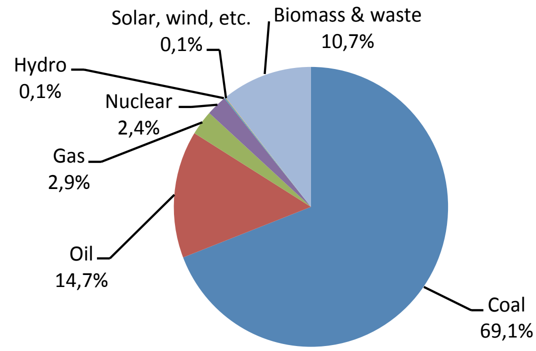
- South Africa is classified by the World Bank as an upper-middle income country, with a per capita GDP (in purchasing power parity terms) of US$12 867 in 2013 (World Bank 2015b).
- Slightly more than half of the total population of 54 million live in urban areas.
- About 95% of agricultural output originates from industrialised commercial farming that relies heavily on external inputs derived from fossil fuels. Less than 5% of employed people work in the agriculture sector.
- Fossil fuels contribute to 87% of the primary energy mix, 98% of transport fuels and about 90% of electricity generation.
- Most households and industry get their water from municipal water systems with infrastructure for abstraction, treatment, distribution and wastewater treatment.

This case study is analysed according to the interlinkages and drivers in the energy, food and water systems, respectively.

1.3.1 Energy system

The composition of South Africa's total primary energy supply is shown in Figure 1-15. Coal is the mainstay of the economy, providing 69% of primary energy. The next most important source of energy is oil (15%), followed by biomass and waste (10.7%). Gas and nuclear power contribute less than 3% each, while modern renewables (hydro, solar and wind) make a negligible contribution (0.2%) to primary energy. Coal's relative share has declined somewhat from 76% in 2001 as imports of crude oil and refined petroleum fuels have increased. Some 90% of electricity is generated from coal, which is also used as feedstock for coal-to-liquid fuel production that meets about a quarter of total liquid fuel demand. Total final energy consumption comprises the following energy carriers: petroleum fuels (34%), coal (24%), electricity (24%), biofuels and waste (16%), and natural gas (2%). The largest energy demand sector is industry (35%) followed by transport (23%), the residential sector (23%), commerce and public services (6%), agriculture (3%), non-energy use (7%) and non-specified (3%) (IEA 2015). The transport sector is almost entirely (98%) dependent on petroleum fuels such as diesel, petrol and jet fuel; and this sector accounts for about three-quarters of total petroleum product consumption.

Figure 1-15: Shares of total primary energy supply by energy type in South Africa (%), 2012



SOURCE: IEA (2015)

Although South Africa is a net energy exporter thanks to its considerable coal exports (6th largest in the world), the nation nevertheless relies on imports to meet some key energy needs. Most significantly, South Africa relies on imports to meet about 71% of its oil demand, the remainder of which is met by domestically produced coal-to-liquid (26%) and gas-to-liquid (3%) fuels (EIA 2014). Oil imports are sourced mainly from OPEC, with nearly 90% supplied by Saudi Arabia, Angola and Nigeria in 2013 (EIA 2014). As of 2012, three-quarters of South Africa's gas consumption was met by imports from Mozambique (EIA 2014). Eskom, the state-owned electricity utility, imports about 5% of the country's power from neighbouring countries. Although nuclear power is produced locally in Africa's only two nuclear reactors, the enriched uranium is imported, as South Africa no longer has enrichment capacity following its voluntary nuclear disarmament in the early 1990s.

Linkages and dependencies

Water for energy

Water is needed at various stages of the energy production, processing, transformation, consumption and use cycle in South Africa. Although the energy sector accounts for only 2% of abstracted water consumption (von Bormann & Gulati 2014), the sector is nevertheless critically dependent on reliable water supplies.

At the energy extraction and production stage, water is consumed for coal and uranium mining, including transport of coal in slurry pipelines and dust suppression. However, Gulati (2014:13) reports from stakeholder meetings that "the large coal-mining companies are treating and reusing water." Water is then needed for processing of fossil fuels: washing coal to prepare it for use in power stations and industry, crude oil refining, and liquefaction of coal and gas to produce synthetic liquid fuels. Embedded water is also contained in various manufactured chemicals that are used for energy extraction and treatment (Gulati 2014). Should exploration and production of shale gas proceed in the Karoo Basin, this will require large amounts of water for drilling, well completion and hydraulic fracturing in one of the most arid and water-stressed regions of the country.

Different quantities of water are required for various types of electricity generation (see Table 1-11). Hydropower is most obviously dependent on water, and water losses occur as a result of evaporation from dams and reservoirs. However, since hydropower contributes less than 2% of South Africa's power generation capacity, the water footprint of this technology is relatively small. Of greater significance is the extensive water requirement for coal-fired electricity generation, which includes scrubbing and cooling in Eskom's 13 coal-fired power stations. According to Eskom, its wet-cooled coal-fired power stations accounted for nearly four-fifths of national generation capacity and 98% of the utility's water requirements in 2010 (Eskom 2011 in Gulati 2014). Some of these power stations are located in water-scarce areas and thus rely on interbasin water transfers. According to projections contained in the *Integrated Resource Plan for Electricity 2010*, 65% of electricity will still be generated in coal-fired power stations in 2030 (Department of Energy [DoE] 2011). Efforts to mitigate climate change by introducing carbon capture and storage could raise the water intensity of power stations by between 46 and 90%, according to the type of plant technology used (von Bormann & Gulati 2014). Furthermore, installing flue-gas desulphurisation at coal power plants could also significantly increase water demands (Gulati 2014). Eskom's twin nuclear reactors at Koeberg near Cape Town also require water, although seawater is used for cooling purposes. South Africa's nascent renewable electricity sector currently requires negligible amounts of water for washing solar PV panels, although these requirements are set to grow as use of this energy type expands. The deployment of concentrated solar plants is projected to grow significantly, and these plants require significant quantities of water for cooling.

Although a biofuels industry has yet to take off in South Africa, it is being promoted by various government policies (see below). A study conducted by Jewitt, Wen, Kunz and van Rooyen (2009) assessed the likely water requirements of a range of biofuel feedstocks, and found that in aggregate under rain-fed conditions, biofuel production would not likely place additional demands on national water resources, with the possible exception of sugarcane and sorghum. However, local water demands could be significant. Furthermore, Brent (2014:16) argues that biofuels are likely to be irrigated, in which case "the impact of biofuel production on water resources could be significant if there is competition with irrigated food crop production."

Table 1-11: Water consumption by various electricity generation technologies in South Africa

TECHNOLOGY TYPE	WATER USE (L/KWH)
Wet-cooled coal (existing)	1.15–2.30
Wet-cooled coal (future)[a]	2.12–2.80
Dry-cooled coal (existing)	0.11
Dry-cooled coal (future)[b]	0.36
Nuclear	0.055
Open cycle gas turbine	0.01
Combined cycle gas turbine	0.25
Solar photovoltaic (PV)	0.01
Concentrated solar power (dry-cooled)	0.34
Wind	0

SOURCE: **Eskom (2011) in Gulati (2014)**

NOTES: **(a) Committed and uncommitted future capacity (b) Includes flue-gas desulphurisation technology**

Food for energy

Although the sugar industry has been using bagasse waste to generate electricity for many years, the direct use of food products for bioenergy production is very limited, mainly because the biofuel industry is at a nascent stage in South Africa (see section 3.3.1 for a discussion of biofuel policy development). However, as of early 2015, a number of bioethanol and biodiesel projects were in various stages of development, with a combined capacity of over 1 billion litres a year (representing about 4% of annual road fuel consumption) (Brent 2014). Therefore, the dependence of the energy system on the agriculture/food system is set to increase in the coming years. In addition, biodiesel is produced from recycled vegetable oil for the transport market by at least 200 small-scale operators (Brent

2014). This does not impact negatively on the food system; by contrast, it represents an efficient re-use of a waste product from the food industry – albeit on a small scale.

Impacts of energy on water and food

The energy production-transformation-use cycle can have significant negative impacts on water quality, and consequently on agriculture and food production (which relies on high-quality water inputs). In the South African context, the main threats are posed by coal mining, coal use in power stations, and possible shale gas development.

Coal mining – especially of the surface variety – has a significant impact on land and vegetation, with knock-on effects on nearby water catchments and resources (Gulati 2014). Of particular concern is acid mine drainage, which has major adverse effects on surface water and groundwater resources in South Africa's mining heartland, by raising acidity levels and concentrations of heavy metals (World Wildlife Fund [WWF]-SA 2011 in Gulati 2014:15). Unfortunately, much of the country's best coal reserves overlap geographically with the most productive agricultural land as well as important water catchments, which implies that coal mining (and electricity generation because most of the coal-fired power stations are located in the same area) comes into direct conflict with food production and preserving water quality (von Bormann & Gulati 2014). For example, coal mining in the Olifants River catchment has polluted rivers to such an extent that the area's coal-fired power stations cannot use the water unless it is treated first at great cost (Groenewald 2012 in IRENA 2015:35).

Power generation also results in large volumes of solid and liquid waste that can pollute water resources (Gulati 2014). The worst culprit is pollution from coal combustion, which includes ash and sulphur dioxide. Similarly, oil refining can negatively affect water quality because of the chemicals used and sometimes released.

The possible exploration and production of shale gas in the Karoo Basin could pose a major threat to scarce water resources in the region. Hydraulic fracturing for shale gas could potentially contaminate underground aquifers and would result in significant quantities of produced water containing toxic fracking chemicals, saline water and radioactive material, which has to be treated and disposed of (de Wit 2011; Fig & Scholvin 2015).

Drivers in South Africa's energy system

Economic drivers

Economic growth is expected to stimulate greater demand for energy in South Africa. According to the Department of Energy's *Draft 2012 Integrated Energy Planning Report*, future energy demand is expected to grow by an average annual rate of 2%, and will therefore double from 2010 levels by 2050 (DoE 2012). The *Integrated Resource Plan for Electricity* projects that electricity demand will grow at a faster rate than this and double by 2030 (DoE 2010). However, Eskom's actual power generation has been constrained in recent years due to the historical lack of investment in new plant, and an increase in unplanned outages and maintenance requirements for the existing fleet. After growing steadily for two decades, electricity supply has stagnated since mid-2007 (StatsSA 2014a). Eskom has been forced to institute demand management schemes and to request large industrial users to cut demand when capacity is unable to meet peak demand. In late 2014, Eskom reintroduced regular load shedding across the country for the first time since 2008 as the grid was under severe strain. In addition, average electricity tariffs have more than doubled since 2008 and are set to increase by above-inflation rates over the next few years, which will dampen demand for electricity. Despite these tariff increases, Eskom faces a severe financing constraint (Crowley 2014), which is contributing to the uncertain outlook for power supplies.

The other major economic driver in the South African energy system is petroleum fuel prices, which are determined by international oil prices and the rand exchange rate. Petrol prices have a substantial impact on the demand for petrol, although diesel demand is tied mainly to GDP and has limited responsiveness to price changes (Wakeford, 2012).

Social drivers

The main social driver in the energy system is the need to extend modern energy services to those currently without access. For example, some 17% of the population still lack access to electricity (World Bank 2015b). Another major social issue, unemployment, appears to be the major factor driving the government's biofuels policy – which is seen as a means to create jobs in economically marginalised rural areas. In recent years, the country's unemployment rate has hovered around 25% according to the 'narrow definition' and 37% by the 'broad definition' (StatsSA 2014b).

Environmental drivers

Given the overwhelming reliance of South Africa's energy system on finite fossil fuels, resource depletion is an important consideration for future energy security. There is considerable uncertainty and debate over the extent of South Africa's remaining coal reserves, with estimates ranging between 67Gts from a yet-to-be-released report from the Council for Geosciences (Ryan 2014) to as low as 15Gt by an independent researcher (Rutledge 2011). There is greater agreement about the fact that the mature, more easily accessible fields in the Central Basin in Mpumalanga are in an advanced stage of depletion, and one expert anticipates that production from this area will peak and decline within the coming decade (Eberhard 2011). Most of the remaining underdeveloped resources are in the more remote, geologically challenging and water-constrained Waterberg field (Hartnady 2010), which means that costs of coal production and transport will likely be significantly higher.

South Africa's crude oil reserves stood at a meagre 15 million barrels as of 2014 (EIA 2014), and are likely to be fully depleted within a few years in the absence of new oil field discoveries. Similarly, the country's only currently producing natural gas fields, which lie offshore south of the country, are rapidly depleting and may be exhausted within the next few years, especially as work on a new field being developed by national oil company PetroSA has yielded disappointing results (Mathews & Vecchiatto 2014). The only other established domestic natural gas reserves are contained in the Ibhubesi field located off South Africa's west coast, which has "proved and probable" reserves of 540 billion cubic feet (bcf) (Mantshantsha 2013). The companies that are developing this field recently signed an agreement with Eskom to supply gas to the utility's Ankerlig open-cycle gas turbine near Cape Town for a 20-year period. The government, Eskom and PetroSA are investigating possibilities for importing liquefied natural gas for various uses, including industry, power generation and feedstock for PetroSA's gas-to-liquids plant.

The flip-side of the fossil fuel depletion issue is that of pollution and emissions. Mainly due to the heavily reliance on coal, the carbon intensity of the economy is very high by international standards.[3] On an absolute basis, South Africa is ranked as the 14th largest carbon dioxide emitter in the world and the leading emitter in Africa (EIA 2014). The government's National Climate Change Response Policy (Republic of South Africa 2011) outlines its commitment to a 'peak, plateau and decline' trajectory for emissions, which envisages a peak in greenhouse gas emissions being reached between 2020 and 2025 and an absolute decline after 2035. This implies a commitment to finding less carbon-intensive substitutes for coal. Furthermore, the National Treasury is planning to implement a carbon tax in a phased approach, which could have a major effect on the structure of the energy system over the longer term.

Technological drivers

Technological innovation is an important factor in the South African energy system, although new technologies are mostly imported from abroad. The main driver in recent years has been improvements in the efficiency of wind and solar (PV and thermal) power technologies, with associated cost reductions. A number of international and local companies have begun building renewable energy installations under the Department of Energy's Renewable Energy Independent Power Producers Procurement Programme (REIPPPP). A total renewable capacity of 3 913MW was commissioned under the first three phases of the REIPPPP, with a further 1 121MW accepted in a fourth bid round in April 2015 (Cloete 2015). The *Integrated Resource Plan for Electricity* plans for 42% of new electricity generation capacity to come from renewables in the period leading up to 2030 (DoE 2011).

1.3.2 Food system

South Africa's agricultural economy is made up of two parts: an industrialised commercial sector and a largely rural subsistence or smallholder sector (Government Communication and Information System [GCIS] 2012). Commercial farmers account for at least 95% of the total marketed agricultural produce (FAO 2005) and are the focus of this case study since the vast majority operate within an industrial metabolic regime. The commercial agriculture sector produces a wide range of commodities, including field crops (grains such as maize, wheat and sorghum; sugar; oil seeds; and cotton), horticultural produce (fruits and vegetables), and livestock products (meat and dairy products). Maize occupies about half of all the land under crops, is the most significant food crop by volume of output, and is the staple food of the majority of South Africans (Department of Agriculture, Forestry & Fisheries [DAFF] 2014b). Agricultural production is geographically determined by favourable growing

3 In 2012 South Africa's carbon dioxide emissions from the combustion of energy amounted to 7.2 tons per capita and 1.22kg per US$ of GDP in 2005 dollars, compared to world averages of 4.51 and 0.58, respectively (IEA 2015).

conditions, including soil types, rainfall and temperatures. Most agricultural production takes place in the wetter eastern half of the country, although the south-western Cape is an important source of fruit, wine and wheat.

South Africa is self-sufficient in most agricultural products (GCIS 2012) and usually produces a surplus of maize (DAFF 2014a), except in drought years. Nonetheless, the country depends on imports for several important agricultural commodities, such as rice, wheat, poultry and vegetable oils (DAFF 2014b). The primary agricultural export products are wine, a large variety of fruits and fruit juices, maize, sugar and wool (DAFF 2014a). On balance, South Africa is a net food exporter in value terms in most years. The country's extensive agricultural trade means that it is firmly embedded within the global food system and therefore subject to that system's dynamics.

Although the agriculture sector contributes less than 3% to GDP, the broader agro-industrial sector – which takes into account forward and backward linkages including food processing and manufacturing – accounts for about 12% of GDP and nearly 20% of manufacturing employment (GCIS 2012; von Bormann & Gulati 2014).

The food retail industry in South Africa is highly commercialised and concentrated. According to von Bormann and Gulati (2014:10), "a mere 3% of farms yield 99% of the country's food, which is then distributed largely by the four retail chains (Pick n Pay, Shoprite, Spar and Woolworths), which together control 55% of the food retail industry." About a fifth of the population is considered food insecure, indicating that at the household level, food security is largely related to income poverty (and a lack of access to productive land and other agricultural inputs) rather than to the capacity of the country as a whole to meet its food needs through domestic production and trade.

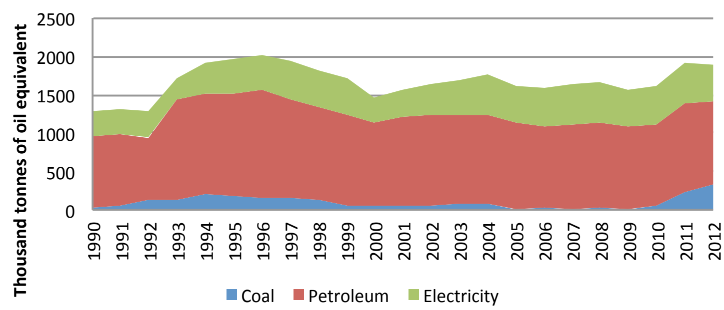
Linkages and dependencies

Just as at the global level, the food system in South Africa is critically reliant on energy and water inputs – even if these inputs do not comprise a major portion of retail food prices (Mason-Jones Notten & Rambaran 2014).

Energy for food

The food system in South Africa is highly dependent on fossil fuel energy at every stage of the value chain, including primary production on farms, refrigeration, processing in factories, wholesale and retail distribution, consumption and even waste disposal. The agriculture sector in South Africa accounts for 2.7% of total final energy consumption, 4.4% of petroleum fuel consumption, and 2.8% of electricity demand (IEA 2015). This is roughly commensurate with agriculture's share of GDP (2.4% in 2013). The agriculture sector derives just over two-thirds of its energy from petroleum fuels, about 30% from electricity and 3% from coal (IEA 2015) – see Figure 1-16.

Figure 1-16: Energy consumption in South Africa's agriculture sector, 1990-2012



SOURCE: IEA (2015)

At the production stage, liquid petroleum fuels – especially diesel – are used to power farm vehicles and machinery such as tractors, planters and harvesters. Electricity, and to some extent diesel, is also used to power irrigation systems and other farm machinery. The relative capital intensity of commercial agriculture has increased considerably over the past several decades, as farmers have progressively replaced human labour with machinery and materials, including fuel and fertilisers (Liebenberg & Pardey 2012). The level of farm employment fell from 1.67 million in the 1960s to under 900 000 in the 2000s (Liebenberg & Pardey 2012). Industrialised agriculture consumes significant quantities of natural gas (or gasified coal) and oil embodied in fertilisers and pesticides, respectively. The application of fertilisers per hectare of major field crops planted has been on a slightly increasing trend since the late 1980s (Fertilizer Society of South Africa [FSSA] 2014). Organic fertilisers (derived from manures) comprise only 3% to 4% of total fertiliser consumption (FAO 2005). Fertilisers are mostly delivered to farms by road (FAO 2005), which further entrenches dependence on oil. In some parts of the country, beekeepers transport their bee colonies by truck to farms to offer pollination services, sometimes travelling hundreds of kilometres (Bega 2011).

After production, agricultural output has to be transported from farms to industrial centres for processing and packaging. Farms in South Africa are widely dispersed and the predominant mode of freight transport to urban centres is by road in diesel-fuelled trucks, although a limited amount of farm produce is carried by (diesel or electric) trains.

The storage of some agricultural produce (e.g. milk and certain fruit) and processed food requires significant inputs of electricity for refrigeration. The quantity of goods in the cold chain has been growing steadily over time, pushing up the demand for energy (Wakeford & Swilling 2014).

The next stage in the food chain is the processing of raw agricultural commodities into food products in factories, which involves energy in the form of electricity and coal for process heat. Furthermore, food packaging materials – especially plastics – can be energy intensive (e.g. derived from petrochemicals). However, from a life cycle perspective the energy contained in packaging needs to be balanced against the potential energy lost through spoilage if food is not adequately packaged.

From factories (and ports in the case of imported food products), processed and packaged food products are transported to distribution centres and then to retail outlets – mainly the four dominant supermarket chain stores, but also local 'spaza shops' found in South Africa's townships. Retail shops use electricity for lighting, air-conditioning and refrigeration. Most urban consumers depend on motorised transport – whether private or public – and hence energy, to access shops to purchase their food.

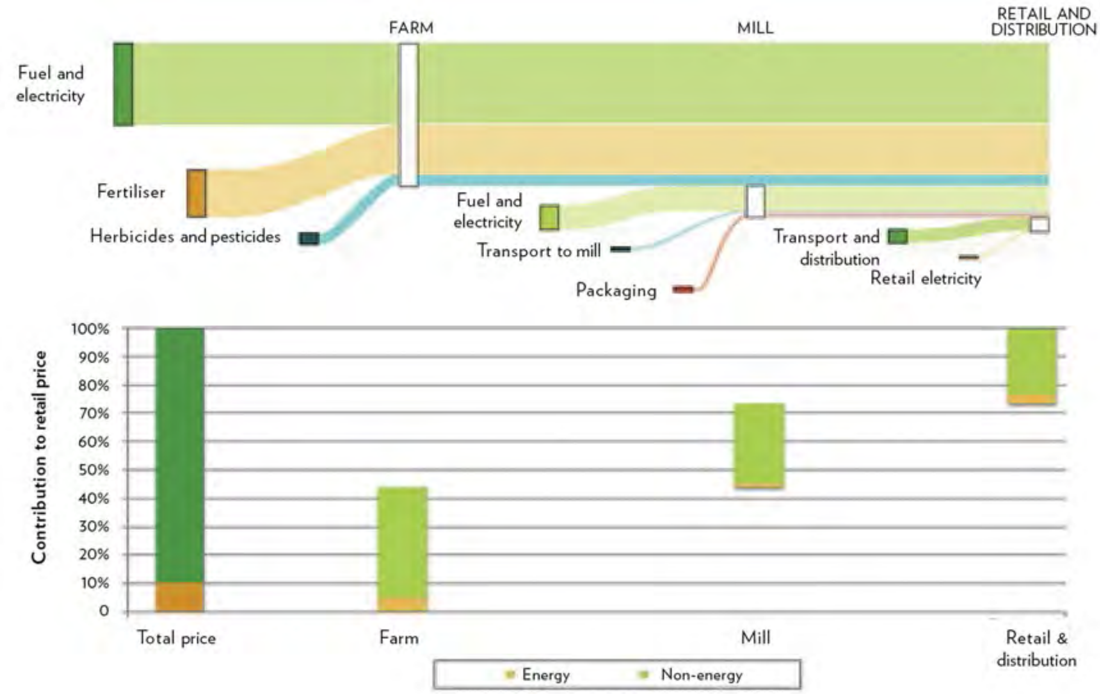
At the consumption stage, further energy – electricity, LPG, paraffin or wood, depending mostly on income status – is then required for food preparation within households (and also restaurants). Some 79% of households used electricity for cooking in 2013, 3.2% used gas, 6.8% relied on paraffin, while 10.5% used wood (StatsSA 2014c). While energy for cooking comprises a relatively small share of total household energy demand and overall expenditure in higher income brackets, among poorer households cooking can be the dominant use of energy and total energy expenditures can comprise over 20% of household income (StatsSA 2014c). It has been estimated that reliance on paraffin for cooking maize meal can add approximately 20% to the cost of the maize meal itself (Mason-Jones et al. 2014).

The final stage of the food value chain is waste disposal. Food waste is a significant source of municipal waste in South Africa, which gets trucked from households (and commercial retailers and restaurants) to landfills – again requiring petroleum fuels. Nearly one-third of food is wasted along the food supply chain each year with a cost of about 1 billion South African Rand (ZAR) (approximately US$83 million) (von Bormann & Gulati 2014).

Energy intensity figures for food production in South Africa are not readily available. However, in the United States, where the agriculture sector is also heavily mechanised and reliant on fossil fuels, it has been estimated that 10 calories of fossil energy inputs are required to produce one calorie of food (Pfeiffer 2006). The extensive application of fossil fuels in South African agriculture seems to have underpinned the substitution of capital for labour and boosted field crop yields over the long term, rendering the agriculture sector increasingly energy intensive (Wakeford & Swilling 2014).

Based on an in-depth life cycle analysis of the energy requirements for six common food products, Mason-Jones et al. (2014:3) found "a general tendency for energy use to be concentrated at earlier stages of the value chain, particularly before the farm gate." On the other hand, "an analysis of price development across the value chain for the different case study foods found that price contributions to final retail price tended to be more equally spread across the value chain or weighted towards the latter stages of the value chain." This reflects the highly concentrated nature of the food retail industry, and the pricing power of the retail chains. Nevertheless, it is important to note that energy inputs vary considerably among different food types, and sometimes for the same food type, depending on factors such as growing conditions and distance to markets (Mason-Jones et al. 2014). Figure 1-17 illustrates the life-cycle energy inputs, and their contribution to the final retail price, for the maize value chain. Although most of the energy inputs occur on the farm (upper panel) the farmer receives less than half of the retail price of maize (lower panel). Although energy is an important component of the retail price of maize, it is not a dominant contributor. The contribution of local energy costs to retail prices can be moderated in the case of those food items that can be imported instead (Mason-Jones et al. 2014).

Figure 1-17: Life-cycle energy use and contribution to retail price in South Africa's maize value-chain

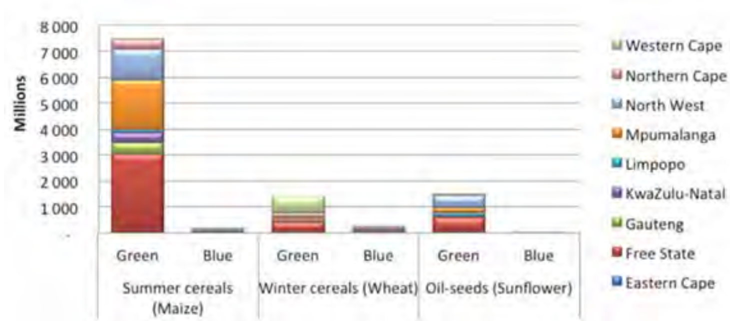


SOURCE: Mason-Jones et al. (2014:15, fig. 12)

Water for food

Food production is clearly critically dependent on water inputs – primarily at the primary production stage, but also to a lesser extent in the food processing stage (Baleta & Pegram 2014). Rain-fed crops are dependent on reliable rainfall (green water), while irrigated crops use blue water. Just 12% of South Africa's land is suitable for cultivating rain-fed crops. Overall, just 1.5% of the country's land area is under irrigation, but this contributes 30% of crop volumes (von Bormann & Gulati 2014). Virtually all (90%) horticultural production and 12% of land planted to wheat are irrigated. The agriculture sector accounts for 60% of freshwater withdrawals in South Africa (Baleta & Pegram 2014). The bulk of water inputs are for field crop production and horticulture, although fresh water is also required for aquaculture and stock watering. Water requirements – in terms of both quantity and quality – vary greatly by agricultural commodity (Baleta & Pegram 2014). For example, producing a litre of milk consumes about 1 000 litres of water before it exits the farm gate, while a loaf of wheat bread embodies about 1 600 litres of water, of which 70% is green water, 19% is blue water and 11% is grey water (Baleta & Pegram 2014). Figure 1-18 displays the water footprint of major field crops in South Africa.

Figure 1-18: Water footprint of South Africa's field crops (m^3/per annum)



SOURCE: Baleta and Pegram (2014:17, fig. 18)

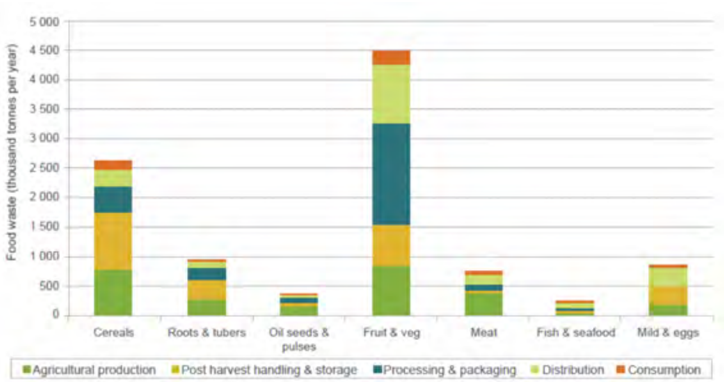
Impact of the food system on water and energy

The food system has two kinds of effect on water and energy systems. Firstly, producing and processing food and disposing of food waste can pollute water resources. Extensive use of antibiotics and chemical fertilisers and pesticides, together with excessive irrigation, can contaminate surrounding water catchments such as lakes and rivers (e.g. resulting in eutrophication) and even pollute underground water resources (von

Bormann & Gulati 2014). Food manufacturing (which uses various chemicals) and improperly handled food waste can also pollute water resources.

Secondly, the food system has an indirect impact on energy and water systems through the embodied energy and water that are lost in food waste. Food waste incorporates both food losses during the production, post-harvest and processing stages (which results from inefficiencies in the supply chain such as inadequate infrastructure, logistics and market access), as well as food wastage at the consumption stage (arising from inefficient management at the retail stage and from wasteful consumer habits) (Notten, Bole-Rentel & Rambaran 2014). Estimates suggest that about a third of food is wasted along the supply chain in South Africa each year, representing approximately 210 kilograms (kg) per person each year (Nahman & De Lange 2013 in Notten et al. 2014). Figure 1-19 provides estimates of food waste for seven commodity categories, and shows that most of the wastage happens in the earlier stages of the food value-chain. Food waste contains about one-fifth of South Africa's annual water withdrawals (Notten et al. 2014).

Figure 1-19: Estimated food waste by food commodity group in South Africa



SOURCE: Notten et al. (2014:13, fig. 3)

Drivers in the food system

The major factors at play in South Africa's food system and affecting food security are demand drivers, international energy and commodity prices, and land and water resource scarcity. However, several other social, environmental, institutional and technological forces are also relevant.

Economic drivers

As incomes rise with economic growth, there is expected to be growing demand for food and shifts in food consumption patterns, for example, towards more protein-based diets. This will increase demand for energy and water inputs, since "the only feasible way to grow the agricultural sector is through irrigation" (von Bormann & Gulati 2014:21-22).

Global energy prices – especially oil prices – are major drivers of food prices in South Africa, as in most of the world. This is partly because the prices of oil and agricultural commodities such as grains (e.g. maize, wheat, rice and soya beans) are linked in global financial markets, with fluctuations in oil prices often driving movements in the latter, which in turn determine agricultural commodity prices in South Africa (Brent 2014; von Bormann & Gulati 2014). The transmission of global energy prices also takes place more directly through farm input costs, including diesel fuel and fertiliser costs. South Africa switched from being a net exporter to a net importer of fertilisers in the 1990s as a result of the abolishment of fertiliser subsidies and tariff protection after 1994 (FAO 2005). Domestic fertiliser prices are influenced heavily by international fertiliser (and energy) prices, the ZAR exchange rate and freight costs (FAO 2005).

Figure 1-20 shows that the prices of several key farming inputs that are linked to energy prices increased dramatically between 2006 and 2013. The cost of fuel as a percentage of gross income rose from a low of 4.3% in 1987 to a high of 9.8% in 2008, driven mainly by the rising international price of crude oil. Total input costs rose from an average of 33% of gross income in the 1970s to 55% in the 2000s (DAFF 2014a). Farmers have also experienced steep increases in electricity tariffs since 2008, and the National Energy Regulator has already approved tariff increases of at least 8% a year until 2018. Mason-Jones et al. (2014:3) note that "the effect of an energy price increase on food prices – and thereby on food security – is highly dependent on where energy is used, what share of cost it represents, what proportion of retail price it commands and whether this price can be passed on to the buyer." They further state that "in at least some cases, the energy price impact on the direct energy costs of food preparation could be at least as significant as the indirect costs passed on through the food price" (Mason-Jones et al. 2014:16).

Social drivers

The major immediate social driver is the need to improve the food security of South African households. Currently, about 20% of households are regarded as food insecure, as they experience difficulty in accessing adequate food to meet nutritional needs (Baleta & Pegram 2014). Food insecurity is mainly a function of affordability and hence mostly affects lower-income groups, with over 40% of the poorest fifth of households being food insecure (Mason-Jones et al. 2014). Food insecurity has knock-on effect, as "analysts have linked the social unrest in South Africa's informal settlements, the mining sector and among farm workers during recent years to the rise in global food prices" (von Bormann & Gulati 2014:8).

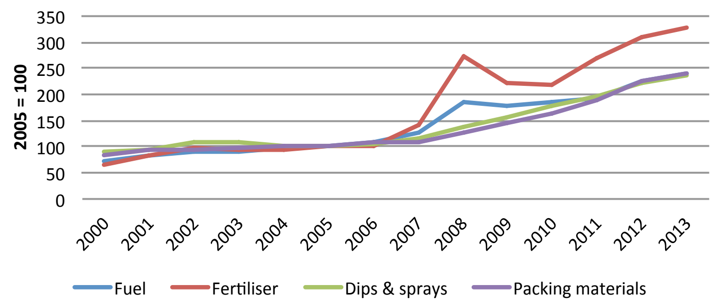
In the longer term, the two main social drivers that will impact on the food system are population growth and urbanisation. South Africa's population is projected to grow from 54 million in 2014 to 58.1 million by 2030 and 63.4 million by 2050 (UN 2013). This will raise the aggregate demand for food. Increasing urbanisation is expected to result in changes in dietary patterns (e.g. consumption of more meat and dairy products), and also implies that food has to travel further from farm to fork.

Another important social-demographic trend, which could negatively affect food security in years to come, is the declining number of farmers and farm workers – which implies an attrition of farming skills. According to the Department of Agriculture, agricultural employment levels declined between 2006 and 2013 from over 1 million to 740 000, while the number of skilled agricultural workers declined from 432 000 to 67 000 (DAFF 2014a). The decline of farming employment and skills has partly been driven by the consolidation of commercial farms and the mechanisation of farming (Liebenberg & Pardey 2012). The average age of commercial farmers in South Africa has been trending upwards and was recently estimated as 62 years, which has potentially serious implications for future farm productivity (Business Report 2015).

Environmental drivers

The most significant environmental drivers affecting the food system are land and water scarcity. Of South Africa's total agricultural land area of 122 million hectares, about 100 million hectares is classified as farmland (DAFF 2014a) – but most of this (84 million hectares) is suitable for grazing only.

Figure 1-20: Price indices of agricultural inputs in South Africa, 2000–2013



SOURCE: DAFF (2014a)

Approximately 16.7 million hectares (13%) receives sufficient rainfall to be potentially arable, although only about a fifth of this arable land is of high quality (GCIS 2012). Some of this arable land is being lost through conversion to industrial, residential and mining uses (Laker 2005).

Compounding the scarcity of arable land, South Africa is generally endowed with poor quality soils, which are mostly shallow and sandy, and low in organic content and essential minerals (FAO 2005; Laker 2005). Moreover, soils are being degraded by water and wind erosion, soil compaction and crusting, acidification (partly the result of coal mining), nutrient leaching, pollution (mainly from mines and industry) and intensive use of chemical fertilisers and pesticides (FAO 2005; Laker 2005; GCIS 2012).

The South African government has identified water scarcity as a major limiting factor for agriculture (GCIS 2012). Large areas of the country, especially the western half, are arid to begin with (with average rainfall less than 500 millimetres (mm) and, moreover, prone to drought (O'Farrell et al. 2009).

Climate change is expected to exacerbate the water scarcity situation, with more erratic rainfall patterns in the eastern half of the country, a general drying in the west, and an increase in the prevalence of droughts overall (O'Farrell et al. 2009). In addition, higher average temperatures, enhanced evaporation and reduced soil moisture content may reduce the yields of certain crops – notably maize (Walker & Schulze 2008). Climate change can also lead to an increase in the prevalence of plant diseases, pest and weeds, as well as altered growing seasons (von Bormann & Gulati 2014).

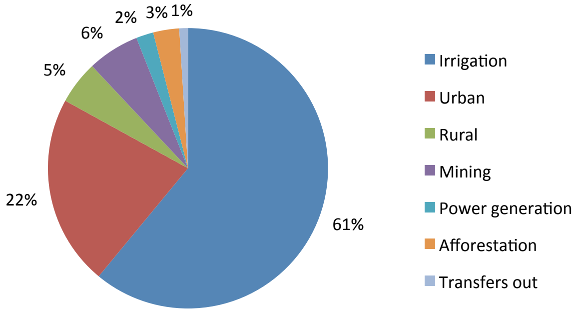
Technological drivers

As noted earlier, a major trend in South Africa's agriculture sector in recent years – and still continuing – has been increasing mechanisation and shedding of labour, which generally increases reliance on energy inputs. However, there has also been a trend towards adopting conservation agriculture practices, including reduced tillage, notably in the maize-producing areas. It has been estimated that a third of South Africa's cultivable area has been subject to reduced tillage farming practices (Du Toit 2007). This trend has helped to curtail growth in the use of liquid fuels on farms. Although organic farming is on the rise, it is off a very low base and there are only about 250 organic farms occupying about 45 000 hectares of certified land in South Africa (GCIS 2012).

1.3.3 Water system

Water plays an especially critical role in the nexus in South Africa because it is widely regarded as the limiting resource for food production and energy generation (Goga & Pegram 2014). With an average rainfall of 450mm, South Africa is a semi-arid and water-scarce country, and is ranked as the 30th driest country in the world with only 1 000m³ of water per person (von Bormann 2014). South Africa is a net importer of water, relying on transfers from large dams in landlocked Lesotho. The country has a sophisticated network of water-transfer and storage schemes to deliver water from catchment areas to consumers in the agricultural, industrial, energy and residential sectors. It boasts the highest level of artificial water storage per person on the continent, but has limited exploitable aquifers, with groundwater contributing only 13% of water supply (Baleta & Pegram 2014). Declining water quality is also a huge challenge, as discussed below. The demand for water by consumption sector in South Africa is depicted in Figure 1-21. Irrigation for agriculture accounts for by far the largest share (61%) of blue water demand, followed by urban consumption (which includes residential, industrial and commercial uses). The mining sector consumes 6% of water, while power generation accounts for only 2% of water demand. Green water (rainfall) supplies about ten times as much water as blue water (irrigation) for crop production and animal products (von Bormann & Gulati 2014).

Figure 1-21: Water demand in South Africa by sector



SOURCE: **Based on data from Goga and Pegram (2014)**

Linkages and dependencies

Energy for water

Energy inputs are needed at all stages of the water supply-consumption cycle, including abstraction, treatment, distribution to consumers, and waste-water reticulation and treatment. First, energy (usually in the form of electricity, but also in some cases diesel) is required for pumping water from aquifers and to transport water across watersheds. Irrigation systems are particularly energy-hungry, although as mentioned in the section 1.3.2, only a small fraction of South Africa's arable land is currently irrigated. Energy is also used to deliver water from rivers and reservoirs to urban areas and rural towns. Further energy is then needed for the treatment of water (purifying it for human consumption) and its distribution to industrial, commercial and residential users through municipal supply systems. At the consumption stage, considerable amounts of energy are required to heat water for domestic and industrial purposes. It has been estimated that about 40% of household electricity consumption in South Africa is devoted to water heating (Gouws & le Roux 2012). Finally, wastewater needs to be treated, again with energy inputs – including energy embodied in manufactured chemicals (Gulati 2014).

Several factors determine the quantity of energy used in the water value chain, "including the stage of the water supply chain, the technology deployed, the condition of assets and the quality of the water being treated" (Winter 2011 in Gulati 2014:17). Table 1-12 provides some range estimates of energy consumption for each stage of the water supply chain in South Africa.

Table 1-12: Energy consumption range for stages in the South African water supply chain (kWh/Ml)

PROCESS	MINIMUM	MAXIMUM
Abstraction	0	100
Distribution	0	350
Water treatment	150	650
Reticulation	0	350
Wastewater treatment	200	1 800

SOURCE: Winter (2011)

Impacts of water on energy and food

Deteriorating water quality can negatively affect both energy and food production. In the case of energy, poor water quality can affect the operation of thermal power stations and raise costs of energy generation by requiring expensive water treatment, for example as has occurred in the Olifants River catchment where extensive coal mining has polluted water resources (see above). As regards agricultural production, evidence suggests that some of South Africa's rivers are so polluted that they are unsuitable for irrigation purposes (Britz & Sigge 2012b in von Bormann 2014:9). For example, a combination of nutrient enrichment, salinity and microbial pollution in a key river system in the Western Cape province threatened that region's lucrative fruit exports to Europe in 2005 (Oberholster & Botha 2014).

Drivers in South Africa's water system

Economic development, population growth and urbanisation are expected to drive up water demand for industry, agriculture and household use in the coming decades. Much of the increase in water demand will emanate from the agriculture sector as it strives to meet increasing demands for food and more water-intensive food products (such as meat and dairy products). The *National Development Plan Vision 2030* calls for an expansion of irrigated land by 50% (von Bormann & Gulati 2014), while there is a dire need for improved access to potable water and perhaps water-borne sanitation in rural areas and urban information settlements.

However, it is unclear whether additional water resources will become available to meet these demands. South Africa is classed as a water-scarce country and there are large differences in the distribution of rainfall, both geographically and temporally (von Bormann 2014). Some 98% of water resources are already allocated (von Bormann & Gulati 2014), and many of the water management areas are experiencing water deficits (Baleta & Pegram 2014). Gauteng Province, the industrial heartland of the South African economy, depends on water imports from far-away rivers and from neighbouring Lesotho. The Department of Water projects a 1.7% deficit in the water supply by 2025 (von Bormann 2014).

The water scarcity issue is compounded by the extent of pollution and degradation of water resources. It has been estimated that 40% of the country's freshwater systems are in a critical state and 80% are under threat (von Bormann 2014). This is partly due to the lack of adequate investment in water-related infrastructure that is designed to ensure water quality. Climate change will further exacerbate the water stress situation, considering that droughts are the major climate-related risk in sub-Saharan Africa (von Bormann & Gulati 2014). These environmental factors are exacerbated by inadequate institutional responses, such as poor enforcement of the National Water Act (von Bormann & Gulati 2014).

1.3.4 Summary and conclusion: industrial typology

Given its relatively sophisticated industrial systems, South Africa provides a useful example of a largely industrial socio-ecological regime within a developing country context. The discussion of energy, food and water systems illustrated how all depend on complex infrastructures that are mostly underpinned by fossil fuel resources; it also demonstrated how inextricably linked these systems are. Table 1-13, which contains a summary of the system drivers, provides a snapshot of the major challenges South Africa faces in terms of addressing current inequality in access to food, energy and water, and meeting growing demand as the population grows and incomes rise with economic growth and development.

The main challenges for energy security are oil import dependence (and resulting vulnerability to global oil price fluctuations), the urgent need to expand electricity generation capacity with a more diversified (and lower carbon) primary energy mix, and rapidly rising electricity prices. Declining availability and rising cost of high-quality coal could be a significant factor in the coming years.

Food security is presently mainly an issue of affordability at the household level, as the country is able to meet its overall food requirements through domestic production and imports. However, the high level of dependence of food production on energy – especially petroleum fuels, but also electricity – exposes the food system to systemic shocks from energy price spikes or supply disruptions. Furthermore, industrial farming is degrading the nation's limited arable soils.

Despite the numerous challenges within the energy and food systems, their dependence on increasingly scarce and degraded water resources could be their biggest limiting factor in the medium to long term. Ironically, perhaps, it is the industrialised, fossil energy-intensive food and energy systems that pose the greatest threats to the water resources they depend on – particularly given the spatial overlap of key arable land, water and coal resources. This is the dilemma of the industrial regime, and it implies that difficult trade-offs will have to be faced in terms of the allocation of water among competing sectors. Thus far, the South African government is insufficiently integrating its planning and policy across the nexus. Ultimately, society will bear the burden through rising prices of energy, food and water.

Table 1-13: Key nexus drivers in South Africa

DRIVERS	ENERGY	FOOD	WATER
ECONOMIC	▪ Rising energy demand resulting from economic growth ▪ Liquid fuel price volatility (crude oil price and exchange rate) ▪ Rising electricity prices ▪ Financial constraints on energy infrastructure ▪ Falling renewable energy costs	▪ Rising incomes and urbanisation driving changes in dietary patterns ▪ Global commodity price volatility ▪ Volatile liqwuid fuel prices ▪ Rising input costs (fertilisers, pesticides, etc.) ▪ Rising electricity prices push up production & storage costs	▪ Economic growth driving increasing water demand in agriculture, industry and residential sectors
SOCIAL	▪ Population growth ▪ Urbanisation raises demand for electricity ▪ Need to expand access to modern energy sources ▪ Need to create jobs (e.g. from biofuels) to reduce unemployment	▪ Population growth ▪ Need to address food insecurity, hunger and malnutrition ▪ Urbanisation leads to shifts in diet and increased 'food miles' ▪ Attrition of farming skills	▪ Need to expand access to water services in informal settlements and rural areas ▪ Disputes and protests over water access/rights
ENVIRONMENTAL	▪ Fossil fuel depletion (or possible future discoveries) ▪ CO_2 emissions reduction targets ▪ Carbon tax ▪ Carbon capture raises water demand at power stations	▪ Limited arable land ▪ Soil erosion and land degradation ▪ Conversion of farmland to other uses ▪ Local climate change and extreme weather events ▪ Rising average temperatures affecting crop yields	▪ Declining water quality as a result of pollution ▪ 80% of water systems under threat ▪ Climate change affecting rainfall patterns, evaporation rate ▪ Droughts, floods
TECHNOLOGICAL	▪ New energy technologies ▪ Falling costs of renewables (e.g. solar & wind)	▪ Continuing mechanisation of farming ▪ Adoption of conservation agriculture practices, including reduced tillage	▪ Need for more water-efficient infrastructure

Link to SA Risks

1.4 Ecological Typology Case Study: Cuba

Cuba is an insular socialist state with more than 11 million people. Following the collapse of the Soviet Union, Soviet subsidies and preferential trading in energy and food supplies came to an abrupt halt (Suárez, Beatón, Faxas Escalona & Pérez Montero 2012) and Cuba entered a period called the 'Special Period in Peacetime'. The country's GDP declined by 35% between 1989 and 1993 and in the following 20 years the country was forced to become self-reliant in terms of food (Endres & Endres 2009) and energy production. As a result, Cuba experienced two major revolutions: of food (Altieri et al. 2012; Koont 2004) and energy production (Guevara-Stone 2008). As a result of these two 'revolutions' Cuba is used as a compelling example of an agroecological socio-economic regime within the energy-food-water nexus.[4]

Inner city garden. Cuba

Rooftop solar water heater, India

4 Some of the data presented in this case study should be interpreted with caution. Information about Cuba's energy-food-water nexus is scarce and most sources focus primarily on socio-economic changes in the country. It is difficult to find literature in English on the topic or on the state of contemporary Cuba, and much of the information originates from an autocratic system or is provided by local authors who display a bias towards the regime. Their work arguably lacks the critical rigour found in academic peer-reviewed publications.

The following key nexus features illustrate aspects of this regime:

- Cuba ranked 131st out of 230 countries with a GDP per capita (in purchasing power parity terms) of US$10 200 in 2010 (CIA 2015b).
- While Cuba does not rank well in material indexes, its Human Development Index rating was 0.815 in 2013 (44th in the world (United Nations Development Programme [UNDP] 2014)) and it was 12th out of 151 countries on the 2015 happiness index in 2015 (UNDP 2014).
- About 10.2% of the workforce is in the agricultural sector (FAOSTAT 2015g), which contributed 3.9% to GDP in 2014; industry contributed 22.3% and the tertiary sector 73.7% (CIA 2015b).
- A quarter of the population lives in rural areas (FAOSTAT 2015). Measures were put in place to curb a rural exodus and encourage the uptake of farming (Cherni & Hill 2009).
- About 3 million hectares of land are farmed using agroecological practices (Altieri et al. 2012).5
- Cuba has achieved major energy efficiencies, with its total energy consumption falling by 52% between 1990 and 2012 (based on FAOSTAT 2015j). The government has set the goal of producing 24% of its electricity from renewable sources by 2030 (EIA 2015c). Renewables have formed the backbone of decentralised energy systems ensuring greater energy security in the event of major weather events such as hurricanes (Piercy et al. 2010).
- Although not considered a water-stressed country, Cuba suffers from periodic water scarcity as a result of droughts.

Despite the impressive strides made towards achieving food and energy self-sufficiency, Cuba remains economically dependent on food and fuel imports, among other products. Fuel makes up an average of 35% and food 15% of total imports (IFAD 2015).

It is important to note that these import ratios are proportionally low when compared to other island nations, which are all traditionally reliant on imports (Sharma 2006), as are developing countries (Funes et al. 2009). However, this dependence does have geopolitical implications as Cuba sources most of its oil from Venezuela. Thus Cuba today is embedded in global energy and food systems, although not to the same degree as many other developing countries.

Cuba is often portrayed as an unparalleled example of agro-ecological practice and successful urban agriculture and put forward as a country with valuable lessons to offer regarding land and energy sector reform and policymaking aimed at enhancing resilience, food autonomy and human well-being. It must be noted that the entire country does not conform to such a model; it is still reliant on fossil fuels and aspects of its agricultural sector remain or are once again becoming industrial. This case study focuses on those sections of its energy and food systems that exhibit key ecological characteristics and how these manifest in the energy-food-water nexus.

1.4.1 Energy system

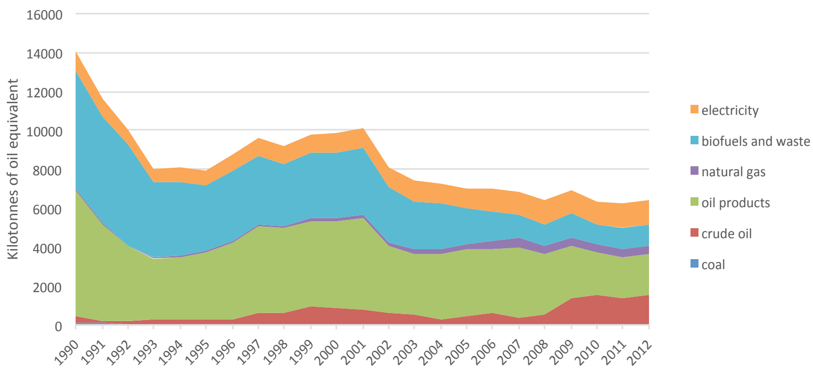
Cuba underwent a profound transformation following the collapse of the Soviet Union as it was compelled to cater much more extensively for its own energy needs. Figure 1-22 indicates the depression of the energy sector in the early 1990s, led by a sharp fall in oil-product consumption.[6] Since 1990 the energy mix has changed significantly with crude oil playing a greater part and biofuels and waste contracting by 81% (IEA 2015). Total energy consumption declined by 52% between 1990 and 2012. Cuba embarked on the Energy Sources Development Programme in 1993 to reduce reliance on energy imports and capitalise more on its domestic energy sources (Suárez et al. 2012).

Cuba produces 35% of its own oil and refines 82% of the petroleum it consumes (IEA 2015) in four refineries, which are all the property of the state-owned oil and natural gas company Cuba Petroleum (EIA 2015d). Between 1989 and 2003, total oil supply more than quintupled and stabilised at an average of 50 000 bpd over the past five years (EIA 2015c). However, the high sulphur content of locally produced oil damaged several oil-fired power stations resulting in a serious power crisis in 2004/05. It must be noted that the main active oil field in the Varadero zone is beginning to dry up (Statistical Yearbook of Cuba 2009). Cuba's oil consumption averaged 171 000 bpd in

5 Agroecological farming comprises "diversified agricultural systems that contribute to local and national food and livelihood security" resting on "ingenious systems and technologies of landscape, land, and water resource management and conservation" (Altieri et al. 2012:3).

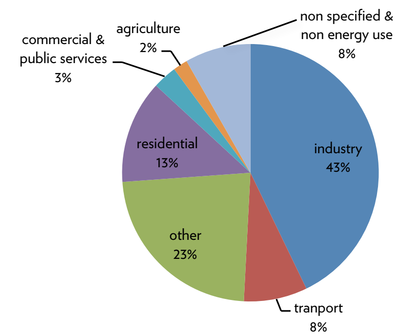
6 In the early 1990s Cuba's population continued to expand, although the rate of population growth declined slightly from 0.8% in 1991 to 0.5% in 1995. This deceleration trend continued until 2008, when the population began to shrink in absolute terms (based on data from World Bank, 2015b).

Figure 1-22: Total final energy consumption in Cuba, 1990–2012



SOURCE: IEA (2015)

Figure 1-23: Sectoral composition of Cuba's total final energy consumption in 2012



SOURCE: IEA (2015)

2014 (EIA 2015d). Cuba imports most of its oil from Venezuela, which provides crude oil at a heavily subsidised price under a 2005 energy agreement (Petroleum Economist 2014; EIA 2015c), under which Cuba supplies skilled people to work in Venezuela, including about 30 000 medical professionals as part payment (CIA 2015b).

As of January 2015, Cuba had 124 million barrels of proven crude oil reserves (EIA 2015c). In 2012, Cuba had high hopes that the country's suspected oil reserves in the North Cuba Basin (Gulf of Mexico) would alleviate its dependency on imports. The North Cuba Basin is indeed estimated to hold 4.6 billion barrels of recoverable crude oil, as well as 900 million barrels of natural gas liquids and 9.8 trillion cubic feet of natural gas (United States Geological Survey 2004). However, exploration has to date only uncovered wells with non-commercial reserves. The country's challenging geology and the high cost of drilling in the basin's deep waters make further exploration challenging (Petroleum Economist 2014). Exploration in Cuba has now shifted onshore, to areas along Cuba's northern coast and prospecting is ongoing (EIA 2015c).

In 2012 the total final energy consumption was 6 435 million tonnes oil equivalent, of which close to 23% came from crude oil and 33% from refined oil products. Electricity generation represented 19% of the total, followed by biomass (sugar cane bagasse and fuel wood) (17%) and natural gas (6%) (IEA 2015). Figure 1-23 indicates the sectoral disaggregation of Cuba's total final energy consumption in 2012.

As of 2011, total installed electrical capacity was 6 240MW (Liu, Masera & Esser 2013). Oil is used to produce the bulk of electricity (85%), gas contributes 11.3% and renewable sources 3.7% – biofuels (3%), hydropower (0.6%) and wind (0.1%) (IRENA 2012b). Some sources report the renewable contribution as much higher, particularly during sugar harvesting season (Community Solutions [CS] 2006). The country had 9 oil-fired power stations, 416 fuel-oil generators and 893 diesel generators in 2009 (SYC 2009). The residential sector uses 50% of generated electricity, industry 27% and commercial and public services 19%. Nearly 95% of households use electricity for energy, while 5% rely on solid fuels for cooking (IRENA 2012b). Electricity consumption averaged 1 348kWh per capita in 2009, compared to the world average of 2 728kWh per capita (IRENA 2012b).

Linkages and dependencies

Water for energy

The direct reliance of the energy sector on water is minimal, as hydropower accounts for only 0.6% of the country's electricity mix. Cuba's installed hydro capacity is 21.9MW (ONEI 2014a) with the potential to generate an estimated 848MW and a further 62MW from small-scale hydropower plants (UNIDO & ICSHP 2013). Although there is limited data about indirect uses of water such as cooling in power stations and water used in the processing/refining of oil and other feedstocks, it can be inferred from studies of other countries (e.g. Rodriguez et al. 2013) that these uses could be significant in Cuba as well.

As discussed below, some energy is generated from bagasse and bioethanol. There has not been quantified research conducted on the water requirements of sugarcane in Cuba; however, it can be assumed that sugarcane, known to be one of the world's thirstiest crops (WWF 2015), contributes significantly to the water intensity of the agricultural sector (see Table 1-2).

Food for energy

The agricultural sector in Cuba contributes modestly to energy production. Sugarcane bagasse (4 138 megatonne (Mt)), wood (1.2 million m^3), rice husks (16.5Mt) and waste from the coffee industry (0.5Mt) is used as feedstock for power generation (ONEI 2014a). Some sources note that most co-generation in the country is coupled with sugar production, particularly during the harvest season (CS 2006). However the share of sugar in cogeneration has decreased over the years; it is reported that in the 1970s sugar accounted for 18% of all electricity generated countrywide, a share that had dropped to 5% by 2003 (IAEA 2008). By 2009, Cuba had 54 bagasse-fired power plants generating only 3% of national electricity (SYC 2009). It produced just more than 20 million litres of sugarcane bio-ethanol for transport needs, of which it consumed about 18 million litres (Dufey & Stange 2010).

Impacts of energy on water and food

The success of the sugarcane sector, which stretches back to the arrival of the Conquistadores, has come at the expense of the country's forests, driving major deforestation during the 19th and early 20th centuries and causing major soil fertility loss and erosion (Gonzalez 2003). However, since most of the sugar is produced for food rather than fuel, and the energy component relies mainly on agricultural waste, biomass energy has a limited negative impact.

The energy sector can however affect food output via competition for land and water. Another notable negative impact of the energy sector on the water and food sectors pertains to the pollution risks associated with oil extraction. The last incident to be reported in the media was a 15 000 litre oil spill at the Sergio Soto Refinery in 2013, which contaminated local waters (Fuerte 2013). Cuba was mostly spared the fall-out of the massive oil spill triggered by the explosion in 2010 of the Deepwater Horizon oilrig operated by BP in the Gulf of Mexico (Lanier 2013). Although deep-sea oil exploration has been put on hold for now, Cuba's prospecting in the Straits of Florida in 2012 aroused concern, given the lack of Cuban technical expertise for deep-water drilling and the risk of an oil spill in the major conduit for the start of the Gulf Stream (Lanier 2013). An oil spill would have major repercussions for the country's fishing sector.

The Cuban government has limited the externality impacts of expanding energy access through small-scale renewable energy installations in rural areas. Small pulses of energy are captured in micro-hydro schemes in different locations to prevent major artificial fluctuations in water flow. It has also promoted the use of bio-digesters, particularly in places where farming activities threaten or potentially threaten riparian ecosystems; pig farms are a good example and biogas digesters capture and compost effluents (Olalde 2002 in Cherni and Hill 2009).

Drivers in Cuba's energy system

Economic drivers

Cuba's energy consumption has remained steadily aligned with the country's GDP growth (an average of 5.5%) over the past decade (Murillo 2009 in Suárez et al. 2012). The recent reforms initiated by Raúl Castro in 2008 and 2011 to modernise the economy and allow for the emergence of a private sector, have facilitated the emergence of a middle class in Cuba, which is an important new potential driver of energy consumption. According to recent research, if the informal sector is included, about 30% of Cubans classify as middle class (Feinberg 2013). The rise of middle classes in developing countries is historically associated with increased car purchases. Cuba had only 21 passenger cars per 1 000 inhabitants in 2008 (World Bank 2015b). Until 2011, only influential bureaucrats could own a car, but then the government lifted the ban on the ownership of cars manufactured after 1959 and in 2013 lifted the 50-year import ban on cars (Daily Mail 2012). So, although transportation currently accounts for a small portion of oil consumption, this figure could rise considerably as the middle class expands and purchases more cars.

Cuba's predicted tourism boom will also have repercussions for the energy sector. About 2.8 million foreign tourists visited the country in 2013 and following the United States administration's announcement in 2014 that travel restrictions to Cuba were lifted an estimated 1 million Americans are expected to visit the country in the first year and 3 million a year thereafter (Ward & Middleton 2014). This will have a significant impact on the built environment as developing hospitality and tourism infrastructure will increase energy needs.

A key economic driver threatening the security of the national energy supply pertains to the scarcity of hard currency, which undermines the running of day-to-day electrical operations. Also, the Cuban Government suffers from a lack of financial resources to undertake new investments, maintenance work, modernization, grid extensions, etc (IAEA 2008). Lack of finance also affects the scheduling of hydrocarbon imports, causing supply disruptions and 'brown outs' (IAEA 2008).

Hindrances to expanding renewable energy capacity include a lack of adequate data on the actual potential for renewables, a lack of local capability to manufacture energy equipment and spare parts, and insufficient financial support (Suárez et al. 2012).

Social drivers

The government has made solid progress in reaching its ambition of universal electrification. The electrification rate in rural areas is fairly high at 85% of households (Cherni & Hall 2009); the cost of extending the grid to the remaining households – mostly located in the remote mountain regions – was estimated to be prohibitively high, varying from US$12 500 to US$17 000 per km of grid extension (Berriz & Madruga 2000 in Cherni & Hall 2009).

Geopolitical drivers

As a result of the Cold War and the ongoing United States embargo, Cuba has been politically isolated and insular in nature. This has been a key driver for the focus on indigenous sources of energy. However, the country's challenging geology has thwarted oil exploration (Petroleum Economist 2014) and forced it to rely heavily on imported oil, notably from Venezuela under a special arrangement with that country.

Environmental drivers

Resource depletion and environmental degradation are key factors in the food-energy nexus. Cuba's finite oil and gas reserves are depleting and it is dependent on imported oil, supplies of which may be constrained in the future (see section 1.1.1). An important environmental factor to take into consideration is the high sulphur content of domestic crude oil, which presents adverse environmental effects.

The country's centralised energy infrastructure (designed largely by Soviet engineers) is vulnerable to the hurricanes that regularly batter the island and which could increase in frequency as a result of climate change. However, in response to the drastic decline in oil supply after 1989, the government has deployed decentralised energy systems to ensure greater energy security and continuity (Piercy et al. 2010).

Another important driver is whether Cuba will be expected to curb emissions in a carbon-constrained world. Interestingly, Cuba's first national communication reports a decrease in greenhouse gas emissions of close to 37% between 1990 and 1994. This was attributed to the fall in oil consumption, but also to an increase of greenhouse gas sequestration by land use and forestry practices, such as afforestation and agroecological farming (Republic of Cuba 2001). Cuba has not completed its second or third national communication but given its reliance on fossil fuels, Cuba is now a net emitter (IEA 2015). Some 52% of Cuba's ecological footprint is attributed to carbon emissions (WWF 2014).

Technological drivers

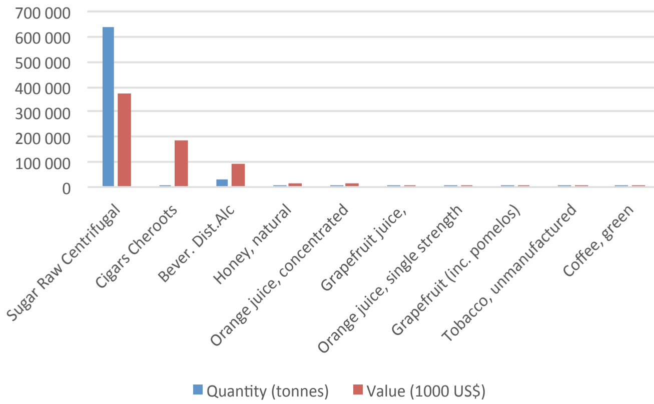
In line with its geopolitical constraints and political orientation, Cuba has since the 1990s focused on energy-related technological research and education to bring renewable energy to bear on its energy needs, and made significant progress in promoting renewable energy (Suárez et al. 2012). However, as mentioned previously, it would appear that in the recent years, the government has focused more on ensuring fossil-based energy independence (King 2012).

1.4.2 Food system

The need to grow food using much less oil sparked major changes in Cuba's agricultural system in the early 1990s. Farmers had to overcome the limitations on mechanised means to prepare the land and plant the crops as well as a sharp reduction in availability of synthetic chemical inputs (fertilisers and pesticides). The country entered a 'post-productivist' agricultural model, underpinned by the phasing out of mass-produced food, the emphasis on producing nutritious and quality food and the introduction of more sustainable methods of farming. This new paradigm also implied a shift in farming practices (from conventional to organic) and in land management, notably including the rise of urban agriculture (Piercy et al. 2010), as well as a major restructuring of the agricultural workforce. Today, non-governmental production units occupy about 74% of the agricultural land area (4,92 million hectares) and are responsible for about 78% of the total cultivated area (5,18 million hectares) (based on Suárez et al. 2012 & IFAD 2015).

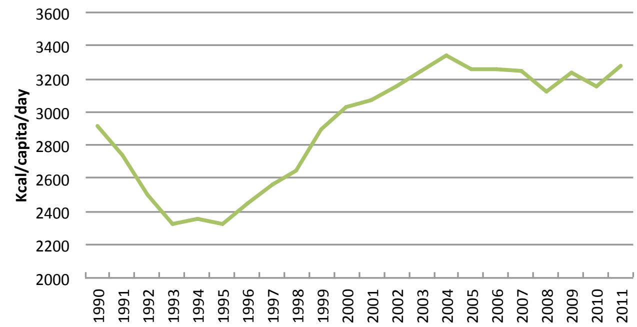
The set of incentives introduced by the government to bolster food production in the early 1990s resulted in substantial yield increases, especially in urban agriculture. By 2002, over 18 000

Figure 1-24: Cuba's top 10 food exports in 2011



SOURCE: **FAOSTAT 2015h**

Figure 1-25: Per capita food supply in Cuba, 1990–2011



SOURCE: **FAOSTAT 2015i**

hectares of land were under cultivation in urban or suburban areas (Koont 2004). By 2004, urban gardens produced most of the fruit and vegetable requirements of urban areas (60% in Havana) and in some areas surpluses were sold for wider consumption, with a third of all vegetables being produced for export (Wolfe 2004).

Farmers embraced agroecological practices, allowing them to make the best out of all types of terrains and soil structures. These practices included intercropping, crop rotation, deep mulching, the use of insect traps and medicinal plants, companion planting, production and use of organic fertilisers and pesticides, vermiculture and composting (Koont 2004; Piercy et al. 2010; Rosset et al. 2011; Altieri et al. 2012). According to Altieri et al. (2012), agroecological farming is practised on 3 million hectares of land, which represents about 83% of Cuba's total cultivated land area (estimated at 3.6 million hectares by AQUASTAT (2015b)).

This subsistence-oriented agroecological system has always co-existed with commercial crop production. As part of its efforts to generate the foreign currency needed to import foodstuffs not available in the country, the government has also focused on developing crops or products specifically for export – such as honey and shellfish in the early 2000s. Top export commodities include raw sugar (the highest earner at close to US$374 million in 2011), cigars, alcoholic beverages (rum), honey and citrus juices (FAOSTAT 2015h) (see Figure 1-24).

Cuba became a net agricultural importer between 2000 and 2004 (Valdés & Foster 2012) and has remained so since then. In 2011 wheat was the most important agricultural import both in value (US$323 000) and in quantity (805 975 tonnes), followed by maize (US$240 939 and just over 700 000 tonnes), dried milk, chicken meat, cake of soybeans and soybean oil (FAOSTAT 2015l).

Indicators of food security such as the average dietary supply adequacy, food supply or fat intake (FAOSTAT 2015i) follow the historical curves of Cuba's food security situation through the 'Special Period' when food production plummeted (Suárez et al. 2012) and its progressive recovery in the late 1990s (see Figure 1-25). During this period, the average daily calorific intake was seriously disrupted and fell to an average of 2 321 kcal/person/day in 1993 (FAOSTAT 2015i) with some sources reporting this to be as low as 1 863 in that year (Koont 2004). Fat supply per person per day collapsed from 85 grams (g) per person per day to 42.6g in 1996 (FAOSTAT 2015i). The prevalence of undernourishment for three-year old children peaked at 20.7% in 1996 (FAOSTAT 2015i).

The average dietary supply has improved substantially and the average calorie intake now stands at above the pre-'Special Period' level, with nationwide vegetable and fresh herb intakes reaching 469g a person a day, which is far above the FAO-recommended threshold of 300g per day (Koont 2004). This change in diet has resulted in health improvements: incidences of diabetes have decreased, as has heart disease, although obesity and diabetes have resurfaced in recent years (Franco, Bilal, Orduñez, Benet, Morejón, Caballero & Kennelly 2012). The latter are symptomatic of the 'westernisation' of Cuba's diet.

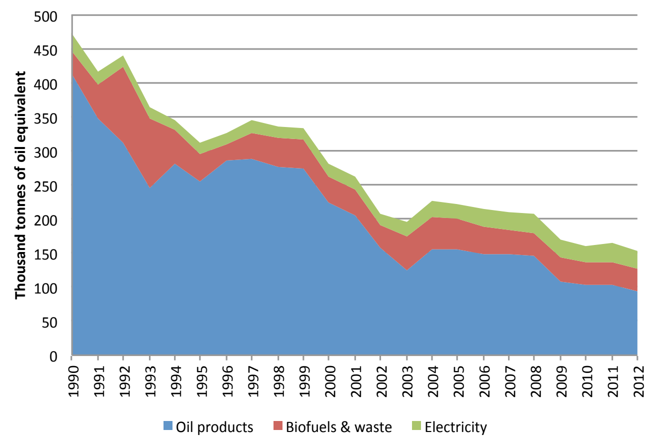
Despite all the evidence testifying to the agroecological features of the food dimension in the Cuban food-energy-water nexus, a duality in the way that Cuba produces food is noticeable. This has been referred to as Cuba's 'agricultural paradox' (Altieri & Funes-Monzote 2012). The first aspect of this paradox is that Cuba produces much of its own food, yet still relies heavily on food imports.[7] For instance, Cuba imports cereals for about two-third of its consumption (Altieri & Funes-Monzote 2012). However, Funes et al. (2009) report that 23 other countries in the central and South American region were also net food importers (in 2006) and that food import dependency is common among developing countries, and even more so for island nations, many of which are wholly dependent on imported cereals. Secondly, Cuba relies on the commercial production of certain cash crops to finance imports of some of its food requirements. These 'protected' areas for large-scale, industrial-style agricultural production represent less than 10% of the cultivated land, but they are increasing in scale (Altieri & Funes-Monzote 2012). A third dimension of this paradox is the co-existence of agroecological traditions with genetically engineered crops. In 2008 the first experimental fields were planted with genetically modified corn FR-Bt1. The area planted with genetically engineered maize by 2009 had reached 6 000 hectares, which is arguably perplexing in the light of the established network of widely available bio-insecticides and alternative methods for weed control (Altieri & Funes-Monzote 2012).

Linkages and dependencies

Energy for food

The energy consumed by Cuba's agricultural sector[8] followed a marked declining trend between 1990 and 2012, with a 68% reduction in overall energy use over the period (Figure 1-26). Use of oil products fell dramatically – by 40% – between 1990 and 1993 after Soviet-subsidised oil imports dried up. Nevertheless, the sector still depends significantly on fossil energy inputs on a proportionate basis (nearly 80% of the

Figure 1-26: Direct energy consumption in Cuba's agricultural and forestry sector, 1990–2012



SOURCE: IEA (2015)

sector's energy supply is met by oil products or oil-derived electricity). The consumption of petroleum fuels is mainly attributable to mechanisation and irrigation requirements for the commercial sector.[9] Cuba's irrigated export crops are the most electricity-intensive crops, notably the citrus (grapefruit and oranges) industry, of which Cuba is a world leader, the sugarcane sector, as well as other commercial crops such as soya and maize that Cuba is wanting to grow more intensively (Altieri & Funes-Monzote 2012).

In the early 1990s, three quarters of the Cuban population lived in urban areas. The urban population relied largely on food imports and as the embargo tightened they suffered most from food shortages (Piercy et al. 2010; Suárez et al. 2012).[10] This gave birth to the wide-spread adoption of agroecological farming methods and urban agriculture, which played a part in decoupling food production from synthetic inputs and reliance on fossil fuels for the transportation of food from the hinterland (or overseas) to urban areas. Farmers returned to animal traction to replace tractors they could no longer run on diesel (Pfeiffer 2006). By 2003, the Ministry of Agriculture used 50% less diesel fuel than it had in 1989 (Koont 2004) and the country as a whole used 72% less

7 The United States Clinton administration authorised agricultural exports to Cuba in 2000 (Alvarez 2004). Since then Cuba has reportedly purchased US$4.7 billion worth of US-produced food (Gollner 2014) on a cash basis. Between 2008 and 2010, Cuba imported roughly 25 to 30% of its food from the United States (Canadian Trade Commissioner Service 2013). These imports have been reported to have been politically instrumentalised to enlist support in the United States against the embargo, but have nonetheless undermined national production (Funes et al. 2009).

8 This refers to direct energy consumption (e.g. fuel and electricity), rather than the energy embodied in inputs such as fertilisers, pipes, etc.

9 Most of Cuba's irrigation schemes comprised hydraulically driven diesel-combustion systems that date back to the 1970s. These have progressively been replaced by more modern infrastructure (OPEC 2003), with a total switch from diesel to electricity for power irrigation systems in 2002 (IAEA 2008).

10 However the overall ratio of imported food over the 'Special Period' actually followed a declining trend, dropping from a ratio of 58% in 1990 to about 47% in 1997 (Alvarez 2004).

agricultural chemicals in 2007 than in 1988 (Rosset et al. 2011). The decrease in synthetic inputs was accompanied by an increase in the production of vegetables produced by small farmers, with an annual growth of 4.2% in per capita food production from 1996 to 2005 (Rosset et al. 2011). Table 1-14 shows that while the yields of general vegetables, beans, and roots and tubers initially fell after the oil crisis hit in 1989, these yields recovered strongly after the onset of the agro-ecological revolution (1996 to 2007), while chemical use for these crops declined significantly.

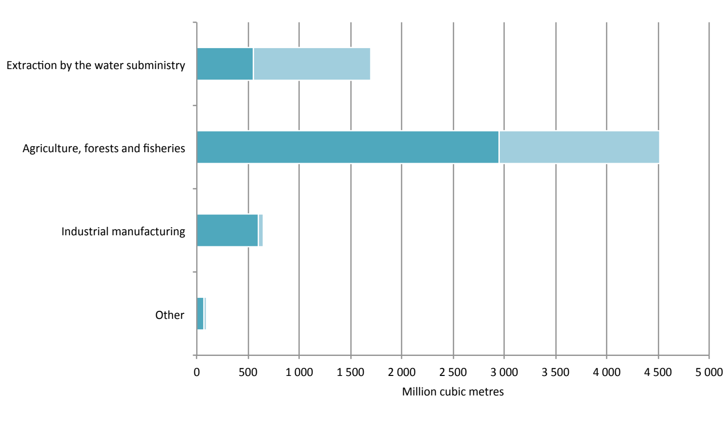
During this agroecological revolution, natural inputs for fertilisers and pest control were widely available to producers (Piercy et al. 2010). These are respectively referred to as bio-fertilisers – earthworms, compost, natural rock phosphate, animal manure and green manures, and the integration of grazing animals – and bio-pesticides – using microbes and natural enemies to combat pests (Pfeiffer 2006).

Table 1-14: Changes in crop production and agrochemical use in Cuba

FARMING METHODS	CROP	PERCENTAGE CHANGE IN PRODUCTION		PERCENTAGE CHANGE IN CHEMICAL USE
		1988 to 1994	1996 to 2007	1988 to 2007
Peasant crops	General vegetables	-65%	+145%	-72%
	Beans	-77%	+351%	-55%
	Roots and tubers	-42%	+141%	-85%

SOURCE: Rosset et al. 2011

Figure 1-27: Sectoral extraction of water in Cuba, 2013



SOURCE: Based on figures from ONEI 2014b

Another interesting aspect of the energy-for-food nexus pertains to Cuba's commercial fishing industry that shifted during the 'Special Period' from high-volume, low-value, pelagic stocks toward high-value, near-shore fishing, partly because of the shortage of fuel preventing off-shore fishing, but also because the sector had become dysfunctional (Adams & Alvarez 2001). In the late 1990s, investments in freshwater aquaculture followed a similar path to that of the other agricultural sectors with a focus on production at the family scale and the integration of aquaculture to animal husbandry (FAO 2015d).

Water for food

In 2013, 65% of water was extracted for the agricultural, forestry and fisheries sector, 24.4% for state-owned farms,[11] with the balance for other uses (ONEI 2014b) (see Figure 1-27). Cuba is estimated to have had 558 000 hectares of land under irrigation in 2012, although only 88% of this area was actually irrigated (AQUASTAT 2015b), representing 14% of the cultivated land area. However, the land earmarked for irrigated agriculture is set to increase, as the country has since 2009 opted to grow intercropped soya and maize under irrigation (Altieri & Funes-Monzote 2012).

Several factors make agroecological systems more water wise than industrial agricultural systems. Agroecological practices ensures that water run-off is minimised and soil evapotranspiration is prevented through: deep mulching (covering the ground with thick layers of biomass), canopy control through agroforestry; green manuring and optimising water usage by all tree and plant species. Also carbon levels and microbiological life is higher in organic soils, thus ensuring greater water absorption. Finally, polycultures have been demonstrated to result in greater yields than monocultures and to make a more efficient use of water resources (Altieri et al. 2012).

Inland aquaculture is extensively practiced in Cuba, and was developed in the many irrigation reservoirs across the country, as well as in artificially impounded water left after the passage of hurricane Flora on the eastern part of the country in 1963. Today, irrigation reservoirs, but also small dams and ponds, play a vital role not only in providing water to agricultural fields, but also as the basis of an intensive aquaculture focused the production of high-value fish species for export (FAO 2015d).

11 As for most statistical information in Cuba, a distinction is made between resource use by the government and the private sector.

There is little information on water requirements for food processing in Cuba. However, sugarcane processing is water intensive. Sucrose is extracted by diffusion into water and the later stages require the use of water-cooled condensers (Cheesman 2004).

Impact of food system on water and land resources

Cuban waterways are highly polluted – more than 250 of its rivers are severely contaminated (Diaz Blanco 2013). Poor sewage-treatment infrastructure appears to be the leading cause of this problem, but agricultural chemicals leaching into rivers also aggravate the issue (Diaz Blanco 2013).

The agricultural sector is primarily responsible for soil degradation in Cuba. Close to 60% of the surface of the country is affected by some form of erosion (2.5 million hectares), salinisation (1 million hectares), acidification (3.4 million hectares) and/or compaction (2.5 million hectares) (Suárez et al. 2012). All these phenomena, attributable to industrial farming and especially the sugar sector (King 2012) contribute to loss of arable land; the extent of arable land decreased by 3.7% between 2011 and 2012 alone (World Bank 2015b). Developments in agroecological practices have played a critical role in curbing such pressure on soils and on reducing over-cultivation of land, thus reducing stress on soils, and reducing the use of fertilisers and pesticides, thereby protecting watercourses from nutrient leaching and chemical contamination (Rosset et al. 2011). As agroecological agriculture makes use of waste sources (such as paper, cardboard and garden refuse), these farming practices have certainly contributed to alleviating waste-management issues in urban areas (Hiranandani 2009). The number of biogas digesters increased by 20% between 2008 and 2013 (ONEI 2014a). This technology plays a part not only in generating energy, but also in managing effluents from farming operations, as well as household grey and black water, preventing water contamination.

Drivers in Cuba's food system

Economic drivers

Cuba is experiencing negative population growth (-0.14% in 2014 (CIA 2015b)) and the GDP per capita is still relatively low with a power purchasing parity of 10 200 US$ (2010 estimate, CIA 2015b). Empirical evidence suggests that the average Cuban diet still mainly comprises rice, beans and vegetables and people can hardly afford the price of rare and overpriced meat (Gollner 2014). However, the government's efforts to increase earnings from food exports has supported the increase in the size of the middle class (Feinberg 2013), which will increase demand for food and drive a change in diet. In general, rising incomes lead to a shift in consumption away from cereals toward livestock products, fish and high-value crops (Molden, Frenken, Barker, de Fraiture, Mati, Svendsen, Sadoff & Finalyson 2007). The growing tourism sector is likely to also place pressure on the food system, notably meat production. The production of beef and buffalo meat remains at 1994 levels, with just under 67,000 tonnes of such meat produced in 2013 (FAOSTAT 2015m). Cattle numbers dropped from a peak of 6.8 million in 1968 to 3.8 million in 2005, and have increased marginally since then (FAOSTAT 2015k).

Social drivers

The social fabric of Cuban society also shapes the food system. The government enacted major land reforms in 1993 and introduced incentives for working in the agricultural sector. In urban agriculture in particular, the agricultural working sector is among the top earning professions, contributing to the revaluing of agriculture and related professions in Cuban society (Wright 2008). 'Re-peasantization' – meaning the re-emergence of a peasant class – also mitigated the rural/urban divide and rural exodus (Hiranandani 2009). Despite this, statistical analysis reveals that the labour force in agriculture has been steadily declining from 750 000 in 1999 to 540 000 in 2014, currently representing 10.2% of the economically active population (FAOSTAT 2015g).

Cuba has found the right social dynamic for a widespread adoption of agroecological practices, namely the "*Campesino – a – Campesino*" (CAC) (peasant-to-peasant) movement. Most of the small farmers – a cohort of about 100 000 families – who accomplished Cuba's agroecological revolution are members of the National Association of Small Farmers and the CAC. Through CAC, a farmer who has discovered a solution shares it with other farmers; this grew into a nation-wide movement in Cuba in the 2000s and resulted in 65% of the country's food being produced on only 25% of the land (Rosset et al. 2011).

Geopolitical drivers

The collapse of the Soviet Union led Cuba to experience drastic energy shortages, which were exacerbated by the United States trade embargo. These geopolitical factors have been the key driver of Cuba's ambition to become self-sufficient and more energy efficient in its food production. However, as mentioned earlier, Cuba still imports various foodstuffs and is also reliant on Venezuelan oil, which is to some extent used in agricultural production and food distribution.

Environmental drivers

The agricultural sector already suffers from droughts and irregular rainfall, and future climate change projections indicate that Cuba could experience substantial increases in temperatures, more variable rainfall, greater aridity and more frequent droughts. Sea level rise will also affect land-use patterns in general, including agriculture, with an estimated increase from 8cm to 44cm by 2050 and between 20 centimetres (cm) and 95cm by 2100 (Republic of Cuba 2001).

Cuba was hit by three hurricanes in 2005 alone, which greatly affected the economy of the country. The country's import dependency ratio was significantly exacerbated, as Cuba had to import 55% of its total food needs. According to research focusing on the impact of the 2005 hurricane Denis on Cuba's agricultural sector, about 3 000 tonnes of stored foods were ruined and the country's large citrus-producing area was severely damaged (Messina & Spreen 2005).

Agroecological farms are, however, found to be more resilient to hurricanes than conventional systems, as integrated polyculture systems gives increased protection to soils, thus preventing erosion and gully formation and fewer landslides during the devastating hurricane. Vegetative systems also rebound much faster in the aftermath of a hurricane (Rosset el al. 2011).

Technological drivers

Noticeable technological innovations have taken place in Cuba's agricultural sector, especially in urban agriculture, with food production taking various forms and expanding spatially (Piercy et al. 2010). The Crop Protection Institute is a pivotal institution that supports organic farming in the country, operating over 220 centres that provide beneficial insects and microorganisms as natural pest controls.

Hundreds of vermicomposting centres farm earthworms that turn organic waste into compost and thus enrich poor soils. In 2003, over a million tonnes of organic compost was produced (Koont 2004).

Lastly, Cuba has also invested in biotechnological research, an agricultural model that is at odds with the agroecological heritage of the food revolution. The Centre for Genetic Engineering and Biotechnology and a network of institutions across the country are focusing on research and development of genetically modified crops that are free from corporate control and the global intellectual property-rights regime. Cuban biotechnologists affirm that their biosafety system sets strict biological and environmental security norms (Altieri & Funes-Monzote 2012).

1.4.3 Water system

In 2010 Cuba had about 9 600 million m^3 of water stored in dams (Suárez et al. 2012). Up to 65% of Cuba's water supply comes from surface water and the balance from ground water.[12] Groundwater is predominantly used in the La Habana, Matanzas, Ciego de Avila, and Camaguey regions (Cueto & De Leon 2010). Many cities otherwise rely on rainfall water stored in the county's 240 reservoirs (Grogg 2012). Between 2010 and 2013, an average of 142 216 million m^3 of rainwater fell each year (ONEI 2014b). In 2007 total freshwater withdrawal was 11.59% of the total renewal water and the agricultural sector consumed 9.3% of this in 2010 (AQUASTAT 2015b).

According to a global mapping of physical and economic water scarcity, Cuba's water stress index[13] indicates there is "little or no water scarcity" in the country, with "abundant water resources relative to use (and) less than 25% of water from rivers withdrawn for human purposes" (Molden et al. 2007:63). However, the AQUASTAT water withdrawal indicators do not fully capture the sustainability dimension of water use. This national indicator masks regional disparities and possible water scarcity in some parts of the country (Frenken 2015 pers.com.). Water resources are deemed insufficient to meet the demand of all sectors (Suárez et al. 2012).

In 2007, total water demand was 7260 million m^3 a year, which is equivalent to 646 m^3/per capita per year[14] (Cueto & De Leon 2010). In 2012 national drinking water coverage was 93.4% (Suárez et al. 2012), but it was less than 80% for the regions of Holgín, Granma and Santiago de Cuba (ONEI 2014b).

12 According to national statistics the split in water withdrawal is 60% from surface water and 40% from underground water (ONEI 2014c).

13 "Water Stress (water withdrawal intensity) is the ratio of total water withdrawals to available water, taking environmental water requirements (EWR) into account. It is measured at the scale of the river basin and aggregated to the country and region" (UN-Water 2015)

14 Data on annual per capita consumption vary according to the sources. According to AQUASTAT (2015) annual per capita water consumption was 391m3 in the same year.

Linkages and dependencies

Energy for water

Water extraction, treatment and distribution depend on reliable power supplies, and were certainly disrupted when the country experienced its power crisis in 2004/05 with very frequent blackouts lasting up to 16 hours.

In the agricultural sector the highest energy requirements for water pertain to the conveyance of water through irrigation networks. Water extraction in the agricultural sector increased by an average of 9.7% a year between 2010 and 2013 (ONEI 2014b). Commercial agriculture is thus dependant on power, but since most of the country's food is produced through water and energy-efficient agroecological systems, this food supply source is relatively decoupled from 'mechanised' water. Cuba added 0.15% water to the country's freshwater supply through desalination in 2007 (AQUASTAT 2015b). This amount is marginal, but worth noting given the extensive energy requirements for water desalination.

Impacts of water on energy and food

The impacts of water on energy and food relate to the detrimental impacts of poor water quality on these sectors as well as the effect of water shortages. Cuba has over 250 highly polluted rivers, which severely affects the heath of people and the environment. The impact of this polluted water on food systems appears, however, to be poorly documented. Water shortages resulting from prolonged periods of droughts (like those experienced in 2004, 2005, 2012 and 2015) are accompanied by food shortages and food price hikes that people can ill afford (Grogg 2004).

Although 60% of the country's land is degraded in some way (Suárez et al. 2012), efforts to reclaim marginal, unused or degraded land for the purpose of agricultural production, especially in urban and peri-urban areas, have played a positive part in restoring the quality of soils. Healthier soils generally help to improve the quality of water and to retain moisture – although this aspect is not quantified by any specific research in Cuba.

Drivers in Cuba's water system

Economic drivers

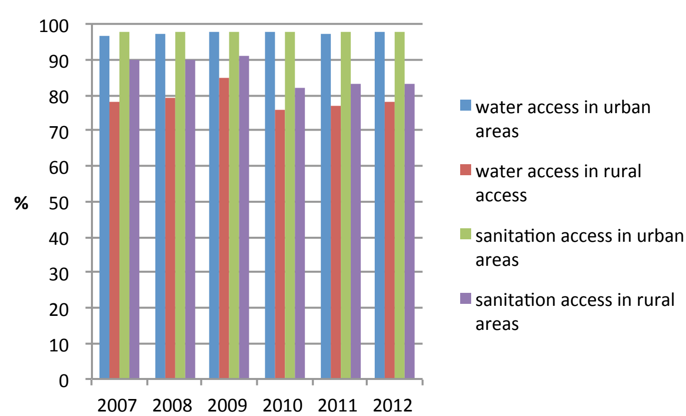
A major factor underlying increased water demand is increased food demand as a result of population growth and changes in diet as living standards improve. The amount of water needed to produce food depends on diets and how the food is produced (Molden et al. 2007). Most of the water withdrawn in Cuba is used by the agricultural sector for irrigation purposes, but the pressure of the sector on water resources is not documented.

Lack of adequate sanitation, mainly in some rural areas, compounded by the proximity of latrines to rivers, together with agricultural chemicals leaching into rivers and poor infrastructure development, are the main causes of the poor quality of water in Cuba's surface water bodies. Moreover, water supply points, notably in Havana, are located within low-lying zones subject to flooding, thus contaminating water supplies (Diaz Blanco 2013).

Social drivers

Demographic growth and insufficient and unequal access to water are important social drivers in the water system. Urbanisation is occurring at a relatively low rate (0.07% between 2010 and 2015), but demographic pressure in cities compounds the issue of water access (CIA 2015b). As of 2012, 98.4% of the urban population and 78.3% of the rural population had access to drinking water (ONEI 2014b), but access is not equal within cities as parts of Havana have access every day and other parts have running water every other day. Water authorities acknowledge that about half the water pumped nationwide does not reach its destination, due to leaks in the pipes (Grogg 2012).

Figure 1-28: Percentage of Cuba's population with access to drinking water and sanitation



SOURCE: Based on figures from ONEI (2014b)

Geopolitical drivers

Cuba's island status means that it is not exposed to any geopolitical risk regarding water.

Environmental drivers

Although not considered a water-stressed country, Cuba suffers from periodic water scarcity as a result of droughts. The country is vulnerable to variances in hydrology. For instance, Havana and Santiago de Cuba rely heavily on rain (Grogg 2012). In February 2012, in the middle of the dry season, the country's 240 reservoirs were on average down to 56.5% of their capacity and 10% were completely dry (Grogg 2012).

1.4.4 Summary and conclusion: ecological typology

Having experienced drastic energy shortages in the 1990s and found ways to fundamentally alter the way its society produces and consumes food and (to a lesser extent) energy, Cuba offers perhaps the best available illustration of a functional agroecological typology within the food-energy-water nexus. Cuba has successfully harnessed some of its agroecological potential thanks to the nation-wide embracing of the CAC peasantry movement (Rosset et al. 2011), backed by a number of effective policies and regulations.

This agricultural model has demonstrated its viability in terms of certain types of food production, with yields of numerous agricultural products outperforming those of the industrial model. Agroecological farming has also boosted energy efficiency and conservation, while reducing impacts on water resources. Thus far, however, agroecological farming has important limitations in terms of cereal, dairy and meat production.

A few additional caveats regarding this case study need mentioning. First, it has intentionally ignored the political and ideological dimensions underpinning the transformational change that Cuba underwent over the past 25 years. Second, research data discussing the food-water and energy-water dimensions of the nexus is scant, both with regards to the benefits attributable to the agroecological revolution, but also with regards to conventional agricultural practices. Third, there is evidence that Cuba's agricultural sector is becoming dualistic, with the emergence of an industrial/biotechnological facet, as testified by the expansion of maize and soya monocrops and the advent of genetically modified crops. Cuba has also demonstrably embarked on a path of increased fossil-fuel consumption, as it strives to find and produce more indigenous oil and venture capital projects in the sector increase. Fourth, although Cuba's ecological footprint remains well within its bio-capacity (WWF 2014), it has increased over the years – from 1.5 global hectares per capita in 2003 (WWF 2006) to just below 1.7 global hectares in 2014. This seems to indicate that Cuba's development is slowly (re-) coupling with resource consumption.

These aspects might raise questions about the 'eligibility' of Cuba as an illustrative agroecological case study, as the country embarks on a path that may lead to greater dependence on non-renewable resources and compromise the long-term viability of its soils, as illustrated by the case study of South Africa. Nevertheless, the historical evolution of agroecology in Cuba arguably provides a rich example of the possibilities of such a regime, and it appears as if its legacy is so deeply rooted in society that it will likely continue prospering alongside the (re-)emergence of conventional industrial farming practices.

Table 1-15: Key nexus drivers in Cuba

DRIVERS	ENERGY	FOOD	WATER
ECONOMIC	■ Emergence of a middle class will drive up energy demand and car ownership ■ High projections in tourism visitation will put more pressure on the grid ■ Drive to expand renewables limited by manufacturing and financing constraints	■ Emergence of a middle class will change consumption patterns towards livestock products, fish and high-value crops ■ Increase in the number of tourists and government's focus on increasing earnings from food exports will increase pressure on the food system	■ Population growth, seasonal influx of tourists and changes in diets will put increasing pressure on water system ■ Lack of reliable provision of water in some cities ■ Poor sanitation infrastructure development and maintenance resulting in pollution of rivers
SOCIAL	■ Higher and changing consumption patterns associated with the emergence of the Cuban middle class ■ Highly educated population - strong and broad skill base to expand the renewable energy sector ■ Strong awareness about energy supported by extensive educational programmes	■ 'Re-peasantization' of Cuba led to revaluing of agricultural sector with strong increments in food production and containment of rural exodus ■ "Campesino – a – Campesino" was a catalyst for the widespread adoption of agroecological practices	■ Fairly high access to drinking water and sanitation in urban areas with regional disparities and lower coverage in rural areas resulting in insufficient and unequal access to water
GEOPOLITICAL	■ Insularity exacerbated by United States trade embargo has driven energy independence, but limited domestic supplies lead to reliance on Venezuelan oil	■ Insularity and political and economic isolation was a driver to create self-sufficiency in food production, but insularity also a factor for high food import levels	
ENVIRONMENTAL	■ High vulnerability of the grid to hurricanes, mitigated however by the development of decentralised energy systems ■ 52% of environmental footprint attributable to greenhouse gas emissions, but Cuba unlikely to be constrained by future mitigation requirements	■ Vulnerable to tropical cyclones and hurricanes, severe droughts and irregular rainfall, which can lead to greater food imports ■ Sea-level-rise threatens current land-use patterns ■ Agroecological farms more resilient to hurricanes than the industrial farming sector	■ Water access provided mostly through reservoirs hence a high vulnerability to variances in hydrology as Cuba becomes more arid and drought prone ■ Poor sanitation infrastructure leads to chronic pollution of rivers, which will be aggravated by sea-level-rise
TECHNOLOGICAL	■ Strong expertise in renewable energy ■ Limited technical knowledge for deep-oil extraction raises environmental concerns about extraction of offshore reserves	■ Technological innovation in food production (agroecology and urban agriculture) ■ Investment in own patented biotechnology with the development of own genetically modified maize	

Link to Cuba Risks

1.5 Conclusions on Nexus Issues and Drivers

In an increasingly resource-constrained world, the interconnections between the systems vital for human survival – energy, food and water – are emerging as increasingly important as countries and sectors within countries have to make difficult trade-offs between the three. Part 1 examined this energy-food-water nexus by presenting an overview of the interconnections between the three systems at a global scale and identifying the principal global drivers affecting these systems, and then analysing three countries in different stages of development. The three case studies are depicted as illustrating three different socio-metabolic regimes – agrarian (Malawi), industrial (South Africa) and the emergent ecological regime (Cuba) – as this allows for consideration of the interactions between human societies and natural systems within integrated social-ecological systems (Fischer-Kowalski 1998; Fischer-Kowalski & Haberl 2007).

The global perspective is important given the increasing international integration of energy and food markets. While water is not (yet) a globally traded commodity, it is increasingly traded in its 'virtual' form, embedded in food – both raw and processed – and manufactured goods. Globalisation has brought both benefits and new threats to countries with vulnerable economies whose agricultural sectors, for example, are not resilient to international price shocks and volatile commodity markets. Food prices have risen markedly in recent years, and this is linked in part to higher oil prices; volatility of both food and energy prices has also increased dramatically compared to the 20 year period up till 2005. Despite a lot of 'noise' driven by speculation, the market price dynamics are to some extent signalling fundamental resource scarcity as increasing ecosystem degradation and energy, land and water resource limitations confront an expanding, urbanising and increasingly affluent world population. With the socio-demographic shifts, consumption patterns are becoming more energy intensive, placing further stress on a largely industrialised global food system that is highly reliant on fossil fuels for transport, mechanised farming, fertilisers and pesticides, antibiotics for livestock and electricity for irrigation pumps. The convergence of these challenges facing the global food system has been termed a 'perfect storm' (Godfray et al. 2010).

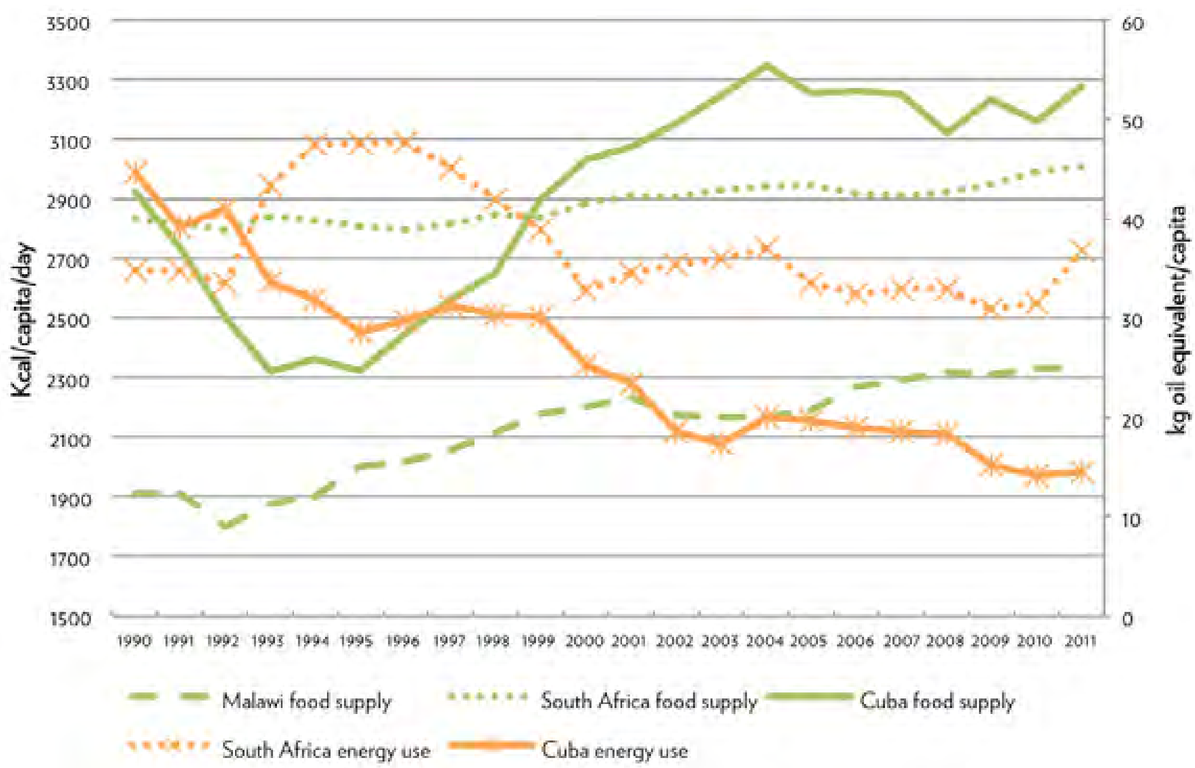
While the three case studies are not precise depictions of their assigned socio-metabolic regimes as they are also embedded in a globalised economy, they provide a more nuanced and detailed illustration of how the nexus dynamics play out in different contexts. They also provide some guidance as to the increasingly difficult trade-offs governments and societies will need to make over the coming decades as energy, food and water systems come under increasing pressure from national and global drivers.

The three countries rely primarily on different types or mixes of energy resources – traditional biomass (Malawi), fossil fuels (South Africa) and a strong drive towards using renewable energy in Cuba. Traditional biomass is limiting in the range and extent of economic activities it supports, and carries high costs for human health and the environment when used in inefficient cookstoves. Fossil fuels like coal and oil have underpinned industrialisation in South Africa as elsewhere, but a high price is also paid in terms of pollution impacts. The Cuban case shows how difficult and slow a transition away from fossil fuels can be.

The various farming styles in each country are also illustrative of different challenges facing their food systems. Malawi has a majority subsistence and small-scale farming sector characterised by low productivity, and nearly a quarter of the population is undernourished. In an effort to boost productivity, the government has resorted to an extensive fertiliser subsidy programme in recent years, which has helped to boost maize yields. South Africa's predominantly industrial farming regime provides adequate amounts of food nationally – but only for those that can afford it; about a fifth of the population is considered food insecure owing to widespread income poverty and a lack of access to productive land, inputs and farming knowledge. This industrial agriculture regime is also highly dependent on fossil fuel inputs and contributes greatly to soil degradation and water pollution. Cuba, with a mix of agroecological and industrial farming methods – has managed to increase not only the quantity of food available, but also the nutritional quality – while significantly decreasing the amount of energy used in the agriculture sector.

The food-energy nexus differences between Malawi, South Africa and Cuba are nicely illustrated in Figure 1-29, which shows the level of food supply (in kcal/capita/day) and energy consumption in the agriculture sector (in kgs of oil equivalent

Figure 1-29: Per capita energy use in agriculture and food supplies in Malawi, South Africa and Cuba



SOURCE: FAOSTAT (2015), IEA (2015)

per capita) in each country.[15] In Malawi, the per capita food supply is substantially lower than in the other two countries, but has been growing fairly steadily throughout the period 1992-2011 – partly, no doubt, as a result of increasing fertiliser use. In South Africa, food supply per person has grown very slowly, while energy use in agriculture has been relatively stable since 2000. Cuba's food supply in 1990 was very similar to that in South Africa, but plummeted in the early 1990s during that country's 'Special Period' as oil imports were drastically curtailed. Once the transition to agroecological farming got underway, however, per capita food supply recovered strongly from the mid-1990s, before stabilising around 2004 at a level considerably higher than that in South Africa. Meanwhile, the per capita level of energy use in Cuba's agriculture sector has followed a declining trend throughout the period, and by 2011 was just 40% of the level in South Africa. These data clearly demonstrate that Cuba has found a much more energy-efficient way of meeting its citizens' dietary requirements compared to South Africa.

Another difference between the case studies is the way that the nexus plays out spatially: the rural/urban differences alluded to earlier are illustrated in the predominant issues that arise in the three countries. The Malawi case study deals to a large extent with rural nexus issues (e.g. land use, climate change and ecosystem degradation), partly because the country's population is still predominantly rural, and also because the regime is agrarian and the economy undeveloped. By contrast, South Africa, with a majority urban population and a more advanced economy, illustrates issues most relevant to cities (e.g. infrastructures, consumption, waste and pollution). Cuba provides an interesting perspective because the government intentionally introduced policies that affected the rural/urban aspect of the nexus, for example energy and agricultural policies that encouraged people to stay in (or return to) rural areas to engage in labour-intensive agro-ecological farming. In so doing, the Cuban authorities were able to alleviate rural-urban migration pressures as rural livelihoods improved, thus reducing demands on urban infrastructure and peri-urban supply chains.

15 Data on energy consumption in agriculture are not available for Malawi.

There are also notable differences in the susceptibility of the three case study countries to societal teleconnections – arising from climate change and from their embeddedness in the global trading system (especially global energy and food value chains). Malawi's subsistence farmers, who form the majority of the population, are affected more by local climatic conditions (e.g. rainfall patterns and temperatures) than by global food system perturbations, except to the extent that they increasingly rely on synthetic fertilisers whose prices (albeit subsidised by the government) are determined in global markets. Similarly, the vast majority of Malawi's energy is derived from domestic biomass sources, which means that only the small minority who use imported petroleum fuels are exposed to international oil price fluctuations. South Africa's economy, by contrast, is highly integrated with the global economy and the country relies heavily on oil imports, making global oil prices a major driver in the nexus by affecting both energy and food security. Food security in South Africa is likewise affected by international food prices; even though the country produces much of its own food, local prices for key commodities such as maize are determined by import or export parity pricing. Other key drivers, such as growing water scarcity and rising electricity tariffs, have local origins. Cuba has been partially shielded from global teleconnections because of its political and economic isolation following the collapse of the Soviet Union, which forced it to meet more of its own energy and food needs. In recent years, much of Cuba's oil has been imported from Venezuela at subsidised prices, thus partially protecting Cuba from the impact of oil price spikes in 2007-08 and 2011-14. However, as documented earlier, Cuba does depend considerably on imports of key food products such as grains and meat, which exposes consumers to the vagaries of international prices and global drivers in the food system.

Regardless of the sometimes stark differences between the three countries, they all exemplify the extensive linkages and interconnections within the nexus. Moreover, many of the same basic drivers influence their energy, food and water systems. These include economic growth plus growing and urbanising populations with rising expectations and demands for energy services, food, and consumer goods – which all require water and energy resource inputs and infrastructure. Unfortunately, the material growth that many believe will solve the social ills of unemployment, entrenched poverty and social inequities, carries negative externalities – especially when based on fossil fuels. These include worsening pollution, degradation of ecosystems and increased strain on both renewable and non-renewable resources. In the longer term, all of these detrimental effects will in turn feed back into deteriorating human health, less access for the poor to the resources they depend on for livelihoods, and increasing prices of food, water and energy. Thus, ultimately, every country faces trade-offs as it strives to improve energy, food and water security: for instance, using land and water to grow food crops or biofuels; using water for power generation or agriculture; and prioritising financial investments in energy or water infrastructure.

The short case study of Vidarbha in India (see Appendix 1.1) demonstrates some of the challenges and trade-offs involved in navigating a transition from an agrarian to an industrial socioecological regime. An industrial system generally produces greater yields (of food and other goods), but is also more energy and water hungry – and has a greater negative impact on the environment. In a rapidly industrialising economy such as India's, the energy and resource demands of burgeoning urban populations can trump the water requirements of rural farmers and threaten their food security and livelihoods.

The brief case study of sub-Saharan Africa's two largest oil exporting countries (see Appendix 1.2) shows that even energy-rich nations can struggle with food, energy and water security. In Angola in particular, the large revenues derived from crude oil exports support a high degree of reliance on imported foodstuffs for the wealthy minority, while much of the population languishes in poverty using traditional biomass fuels and struggling to eke out a living from subsistence agriculture. Nigeria has been more successful in recent years in diversifying its economy, and yet decades of oil pollution continue to wreak havoc on the environment and local communities. Both countries are struggling to shrug off the resource curse and deal effectively with nexus challenges.

The next part of the report draws on the foregoing global and national-level analysis to highlight the various risks and vulnerabilities faced by developing countries in terms of ensuring food, energy and water security for their populations.

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Water distribution during drought

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Flooding in Mozambique

Link to Contents

part 2.

NEXUS RISKS AND VULNERABILITIES FACED BY DEVELOPING COUNTRIES

Key Messages

- The major catalytic risks to nexus security are: (1) extreme weather events including droughts and floods; (2) oil price shocks; (3); food price shocks; (4) geopolitical tensions; and (5) financial speculation in commodity markets.
- Nexus impacts and vulnerabilities do not result only from local causes; they can come about due to 'societal teleconnections', i.e. long-distance relationships such as the embeddedness of individual countries within integrated international trade and financial systems.
- Nexus linkages and feedback loops create a web of interconnecting – and reinforcing – risks and impacts. One likely end result of these threats to food, energy and water security is heightened social instability within countries and regions.
- The risks and vulnerabilities faced by rural dwellers can differ considerably from those encountered by their urban counterparts.
- Agriculture plays a dominant role in most low-income country (LIC) economies. The high levels of dependence on traditional biomass energy means that LICs are vulnerable to deforestation, energy poverty (especially a lack of access to electricity) and low-productivity agriculture.
- Lower-middle-income countries (LMICs) are at varying stages of transition from the biomass-based agrarian regime to a fossil fuel-based industrial regime, and there is a great deal of variability in the nexus indicators across this diverse group of countries.
- Most upper-middle-income countries (UMICs) are performing quite well in terms of basic energy, food and water security access and availability/consumption, with the exception of several southern African nations that have high levels of income inequality and poverty. The level of dependence on fossil fuels – and thus exposure to oil price shocks – is very high in most UMICs.
- There is a high degree of variability in the values of many of the indicators across countries, even within each of the three income categories. Key indicators of availability of and access to energy, food and water are quite strongly related to the level of income per capita and inversely related to the poverty rate. Beyond these access indicators, however, many of the nexus risks and vulnerabilities are spread widely and unevenly across countries depending on local context.

2.

NEXUS RISKS AND VULNERABILITIES FACED BY DEVELOPING COUNTRIES

This second part of the report addresses the following research question:

> *What are the main risks and vulnerabilities faced by different types of developing countries with regard to the energy-food-water nexus?*

To address this question, Part 2 involves two types of risk and vulnerability assessment. Section 2.1 presents a qualitative analysis of risks made on the basis of the nexus issues, linkages and drivers identified in Part 1. This assessment is performed firstly at a global level to identify general risks facing most, if not all, developing countries, and secondly for each of the three case studies to provide a greater degree of nuance and specificity for different country typologies. The box below shows the analytical structure for the risk assessment. The risks to energy security, food security and water security, respectively, are identified that emanate from within each system itself, as well as from that system's dependence on the other two systems. This is done to highlight the ways that risks and vulnerabilities arise from nexus interdependencies and drivers, rather than in isolated systems. Section 2.2 complements the qualitative risk assessment by presenting and analysing a range of key quantitative national-level indicators of energy, food and water security for a sample of 96 developing countries.

Analytical Structure for Qualitative Risk Assessment

The following structure is used within each major section (Global, Malawi, South Africa, Cuba):

ENERGY SECURITY RISKS AND VULNERABILITIES

- Energy-specific risks
- Water-related risks
- Food-related risks

FOOD SECURITY RISKS AND VULNERABILITIES

- Food-specific risks
- Energy-related risks
- Water-related risks

WATER SECURITY RISKS AND VULNERABILITIES

- Water-specific risks
- Energy-related risks
- Food-related risks

2.1 Qualitative Assessment of Risks and Vulnerabilities in the Energy-Food-Water Nexus

2.1.1 Global nexus risks and vulnerabilities

Energy, food and water security each face risks and vulnerabilities on the global level emanating from internal drivers within the relevant system itself (as identified in section 1.1.1), as well as from the linkages and dependencies on the other two systems. The following sections delineate these risks for energy, food and water according to the source of the risk. A summary table is presented at the end of the section. The risks and accompanying impacts may be realised at regional, national and local scales.

Global energy security risks and vulnerabilities

Energy-specific risks

Oil price shocks are the most significant global-scale risk within the energy system because the global oil market is so tightly integrated and is subject to so many forces (Wakeford & de

Wit 2013). Geopolitical events in oil-producing countries and regions, notably the Middle East and North Africa, continue to present the greatest short-term risk in terms of sudden oil price spikes. Previous geopolitical shocks in the Middle East resulted in the oil price doubling (1990), trebling (1979) or quadrupling (1974). Longer-term supply-side risks arise from depletion of conventional oil resources and rising costs of production. While in the past demand-side drivers have also contributed to steep increases in oil prices, such as China's spectacular economic boom between 2003 and 2008, a positive demand shock to oil prices seems highly unlikely in the short- to medium-term due to persistent economic weaknesses and financial fragility in the world's major economies. In the longer term, however, it is conceivable that India and (parts of) Africa could also undergo rapid economic expansion that will drive up global oil demand.

While the global coal market is arguably less susceptible to supply shocks than the oil market, regional gas networks (and to a lesser extent, global liquefied natural gas flows) are vulnerable to geopolitical and resource-related supply disruptions and price spikes. Geopolitical complications can inhibit the development of regional energy systems (such as the long delays to implementing the Grand Inga Power project on the Congo River that are partly a result of ongoing internal and cross-border conflict in the region). In addition, ageing and poorly maintained energy infrastructure and a lack of new investment in energy production remains a key risk in many countries (IEA 2014). Another major risk to the current energy configuration is climate change; if the countries of the world negotiate a binding agreement to limit carbon emissions, it will have major ramifications for sources of energy supply and could constrain the amount of energy available during a period of transition to renewable energy technologies.

Water-related risks

The energy system is subject to several risks arising from its various dependencies on water. A key supply-side risk is increasing water scarcity in certain parts of the world – often driven or exacerbated by climate change (IPCC 2014). The International Energy Agency, for example, has warned that water shortages could limit the capacity of existing energy infrastructure and suppress proposed new projects, as well as raising operational costs (IEA 2012). Security of electricity supply can be compromised when there are power outages at hydroelectricity plants due to erratic river-flow volumes, or insufficient water available for cooling thermal power plants, including nuclear reactors. Rising water temperatures (resulting from global climate change) also pose a threat to thermal power stations due to the reliance on water for cooling (Rodriguez et al. 2013). More broadly, the energy sector faces growing competition from other sectors for water supplies, such as agriculture, industry and residential consumers. The intersection of rising demand and constraints on supply increases the risk of rising water prices, which can, in turn, push up costs of energy production. Alternatively, authorities may impose restrictions on the water supplies available for energy in order to protect other users, including farmers (IRENA 2015:31). Nearly half of the 125 countries surveyed by the United Nations in 2012 stated that risks of water constraints for energy were a high priority (UNEP 2012).

Food-related risks

The risks posed to energy security related to a direct dependence on food sources are relatively small at a global level because modern bioenergy contributes a small percentage (about 4%) of primary energy supply. Nevertheless, with the expansion of use of bioenergy these risks are of growing significance, especially in particular regions and countries that rely heavily on bioenergy. More than 60 countries have set biofuel targets or mandates (Lane 2014). The risk of reliance on bioenergy feedstock is compounded by the comparatively low energy return on investment ratios – that is, the energy output divided by the energy used in the production process – for most biofuels compared to other energy sources (Lambert et al. 2012). This generally implies higher energy prices for biofuels than other sources, which could threaten the affordability aspect of energy security. Bioenergy prices could also rise because of competition between food and fuel.

More broadly, as discussed in detail in Part 1 (section 1.1.2), global food systems consume large amounts of energy at all stages of the food supply and use chain. This means that projected growth in global demand for food will place increasing demands on the energy sector. An important example of this could be expanded demand for energy for irrigation to boost agricultural yields. In addition, limitations on land and water availability pose risks for continued or expanded reliance on bioenergy sources, as do the projected impacts of climate change on production of feedstock crops like maize (FAO 2011).

Global food security risks and vulnerabilities

Food-specific risks

The major threat to food security on a global scale is the risk of food price increases, which can threaten the affordability of food for millions of people, especially the poor in developing countries. Food price shocks may arise from demand- and/or supply-side factors. On the demand side, a growing world population and rising incomes, which result in shifting dietary patterns that are more resource intensive (e.g. increased consumption of meat), are increasingly putting pressure on global food security. On the supply side, availability of arable land is constrained, as much of the high-quality land is already under production. Furthermore, climate change poses a significant threat to global food supplies and prices, both because yields of certain crops (e.g. maize) are sensitive to changes in average temperatures, and because of vulnerabilities to extreme weather events (Bailey, Benton, Challinor, Elliot, Gustafson, Hiller, Jones, Jahn, Kent, Lewis, Meacham, Rivington, Robson, Tiffin & Weubles 2015). The risk of food price spikes is compounded by the fact that many food commodities are traded on securities exchanges, rendering their prices vulnerable to speculative forces and fluctuations. Food price shocks can be quickly transmitted across the world due to the high degree of globalisation in the food system (Bailey et al. 2015).

Energy-related risks

Rising energy costs generally translate into higher food prices, partly because energy is an important input in food production, and also because biofuels have linked oil and food markets. The 500% increase in fertiliser prices between 2005 and 2008 was partly a result of the steep oil price increases at that time (Foresight 2011). In low-GDP countries that rely heavily on imported fossil fuels, total energy-related costs as a percentage of the final purchase price of food may be significant (usually linked to higher transport costs) (FAO 2011a). Because these same countries have large populations of poor citizens, high and variable food prices have negative food security impacts, as food makes up a large share of their household budgets (FAO 2011a). "Future high and volatile fossil fuel prices, global energy scarcities and the need to reduce GHG [greenhouse gas] emissions are the key reasons why the global food sector needs to become more 'energy-smart'" (FAO 2011a:18).

Energy supply constraints can compromise the physical availability of food; for example, if oil supply restrictions result in lower food-production volumes and problems with food delivery. If energy access is limited, it will have knock-on effects throughout the food system: from limiting irrigation for large-scale agriculture to increased food wastage when food cannot be processed, refrigerated or stored appropriately (IRENA 2015).

Increasing competition for the biomass waste products from the various stages of the food system may mean that farmers, food processors, retailers and so on do not take advantage of the opportunity to reduce their energy reliance by using this waste to produce their own energy (FAO 2011a). Also, the opportunity to return the nutrients present in this biomass waste to the soil would be lost, which is particularly problematic for agroecological and organic production methods (FAO 2011a).

Water-related risks

Some predictions suggest that global water demand from agriculture could increase by 30% by 2030 (Foresight 2011), but that water scarcity might threaten increased food production. Because food production is so water intensive, water-system drivers (see section 1.1.3) can have major impacts on food security by lowering crop yields or rendering them more variable. Foresight (2011) predicts that water-supply issues are likely to be the first of the many coming crises; intense competition from other uses will be a major factor, as will depletion of aquifers and the impacts of climate change (reduced precipitation, extreme weather events, etc.). Water scarcity issues could mean a reduction in grain yields of 30% ([WEF 2011) and disruptions or limitations of water supply that are specific to certain areas will result in disruptions to global food trade (IRENA 2015). Reduced water quality will thus affect food production and processing (IRENA 2015). Again, the drivers and feedback loops are complex: climate change mitigation and adaptation measures could have negative impacts on other systems, for example, "intensified irrigation or additional water desalination, are often energy intensive. Thus climate policies can impact on water, energy and food security, and adaptation action can in fact be maladaptive" (Hoff 2011:8). Poorly managed land deals can result in water-rich countries losing access to their own water as it is 'exported' as virtual water embedded in agricultural products (IRENA 2015).

The complexity of the global food system means that changes that are made to deal with one issue could end up causing several more problems. For example, over-exploiting groundwater means that the shallower aquifers that are easier (less energy-intensive) to exploit will run dry, and more energy will be required to withdraw water from deeper aquifers, thereby increasing reliance on energy and affecting food prices (UN-Water 2014). Another example is food waste: efforts to reduce food waste in developing countries might push up the energy requirements of the sector, for example, by increasing use of refrigeration facilities (FAO 2011a). The food system's continued contribution to climate change will negatively affect crop yields and food prices.

Global water security risks and vulnerabilities

Water-specific risks

The major overall risk is of demand outstripping available water resources in certain areas, resulting from a combination of growing demand (driven by the forces discussed above) and constraints on supplies. For example, these forces can result in 'basin closure', namely the full allocation of water resources within a river basin (Falkenmark et al. 2008 in Hoff 2011:11). The United Nations has estimated that almost 50% of the world's population will reside in areas of high water stress by 2030, with knock-on impacts on energy and food security (WWAP 2012). According to the World Economic Forum (2011:9), "the world could face a 40% shortfall between water demand and available freshwater supply by 2030." Second, there is potential for 'beggar-thy-neighbour' actions arising from geopolitical conflict over water access and use, with potentially significant implications for economic and political stability on a regional basis (WEF 2011). Third, many developing nations – especially low-income countries – face severe financial constraints regarding infrastructure development, including for water abstraction, treatment and distribution. In a 2011 survey by UN-Water, nearly 50% of all nations reported financial constraints as an important inhibitor of water resource management (UNEP 2012). Fourth, climate change can result in unexpected disruptions to surface runoff, stream flows and water supplies as higher temperatures accelerate evaporation and precipitation, rain patterns intensify and shift, glaciers melt and the frequency of extreme weather events increases (Hoff 2011; Rodriguez et al. 2013; IRENA 2015). Fifth, not only the quantity, but also the quality of available water is at risk of degradation from economic activities. Declining water quality has negative impacts on human health and ecosystems, and constrains economic activities (World Bank 2013). Finally, in some regions – notably sub-Saharan Africa – there is insufficient data and knowledge about water resources (including basin-level storage), which is required to assess the impacts of development policies, climate change and land-use changes (Brent 2014).

Energy-related risks

Given the numerous ways in which the water supply-chain depends on energy, any disruption to energy supplies (particularly electricity, but in many developing countries also diesel fuel) can pose significant threats to water security. Furthermore, costs of providing water can be raised substantially if energy prices rise, thereby undermining water security. This is especially so in the case of desalination, but also in countries where water has to be pumped from deep underground or transported long distances over land. The demands placed on water by the energy sector can lead to competition with demand from other sectors, such as residential consumers, industry and food producers. This competition can be exacerbated by efforts to mitigate climate change, for example through the construction of new hydroelectric plants, increased production of biofuels, or carbon sequestration (Hoff 2011:32). Indeed, the water demands of projected increases in biofuel production poses a significant demand-side risk to water security (UN-Water 2014).

Another major energy-related risk to water security is the threat of contamination or degradation of both surface and underground freshwater resources from energy-related processes, including extraction and processing of fossil fuels, uranium, and rare earth metals that are used in renewable energy technologies (see section 1.1.1). A spatial mismatch between energy and water systems can introduce further complications to this component of the nexus and increase vulnerabilities (UN-Water 2014). This is because water infrastructure systems (aside from large dams and inter-basin pipeline or canal systems) typically operate on local (city or community) scales, while energy infrastructure systems (such as electricity grids and pipelines) often extend over a whole country.

Food-related risks

The food system poses several risks to the water sector, and these are of particular concern given that agriculture consumes the largest share (70%) of freshwater resources globally (IRENA 2015). The first is that the food system will demand an increasing amount of water as food demand rises. This demand-competition can be especially acute in the case of countries that are trying to meet national food security goals, such as Saudi Arabia, where subsidised energy and inappropriate water pricing have led to rapid depletion of underground water resources. It can also result from foreign direct investments in land (e.g. foreign leasing of agricultural land), which can place additional strain on local water resources and the communities that rely on them (FAO 2010 in IRENA 2015; World Bank 2010). Second, contamination of water resources could stem from over-use of chemical fertilisers and pesticides in agricultural production, resulting in eutrophication of rivers and lakes, and toxic pollution of water, respectively. Food processing can also lead to the discharge of toxic chemicals into water supplies. At the very end of the food chain, inadequate treatment of food waste and human waste (sewage) can pollute water resources, posing serious risks to human health. Third, the conversion of forests and wetlands into farmland can disrupt local water cycles and ecosystem-service functions that are critical to the provision of reliable, clean water supplies.

Table 2-1: Summary of global nexus risks and vulnerabilities

ARISING FROM: / RISKS TO:	ENERGY SYSTEM DRIVERS AND LINKAGES	FOOD SYSTEM DRIVERS AND LINKAGES	WATER SYSTEM DRIVERS AND LINKAGES
ENERGY SECURITY	▪ Energy (oil) price shocks, arising from: – Geopolitical disruptions to energy supply (e.g. oil, gas or electricity). – Depletion of conventional fossil fuel resources, especially oil. – Rising costs to produce oil and gas. – Financial market commodity speculation. – Ageing infrastructure and lack of investment in new capacity. – Rapid demand growth in emerging markets. ▪ Climate mitigation could impose restrictions on fossil fuel combustion.	▪ Dependence on bioenergy sources derived from food crops raises energy access and affordability risks. ▪ Low net energy yield of many bioenergy sources, implying higher energy prices. ▪ Increasing demand for energy from food systems to meet growing global food demand. ▪ Limits on land and water availability for growing bioenergy. ▪ Climate change impacts on biofuel production.	▪ Water scarcity and impaired quality could constrain energy supplies, including hydropower and thermal power. ▪ Increasing demand for energy from water systems, and growing competition for water supplies with other sectors. ▪ Rising water temperatures threaten thermal power stations. ▪ Possible increases in water prices due to water scarcity and demand growth would raise energy production costs. ▪ Possible stricter regulations on water use for energy.
FOOD SECURITY	▪ Energy price shocks can raise food prices. ▪ Energy supply disruptions can negatively affect food production, storage and distribution, and increase food waste. ▪ Increasing competition for biomass waste. ▪ Biofuels may threaten food security via competition for land and water.	▪ Rising food demand driven by growing population and rising incomes. ▪ Constraints on arable land; eroding soils. ▪ Global warming can affect crop yields. ▪ Food prices are subject to financial speculation and price shocks are transmitted globally.	▪ Water scarcity and impaired quality could constrain food production and processing. ▪ Competition from other water uses could drive up water prices for agriculture. ▪ Droughts and floods driven by climate change can impair food production.
WATER SECURITY	▪ Energy supply shocks can disturb water extraction, treatment and distribution. ▪ Increasing demand for water from energy systems, possibly exacerbated by climate mitigation (e.g. expansion of biofuels). ▪ Threat of rising energy costs feeding through to water prices. ▪ Pollution of water resources from energy extraction and processing. ▪ Spatial mismatch between energy and water systems.	▪ Increasing demand for water from food systems and to meet food security goals. ▪ Water demand competition arising from foreign leasing of land for agriculture. ▪ Degradation of water resources from agriculture (e.g. fertilisers and pesticides) and food processing. ▪ Disruption of water-related ecosystem services from conversion of wetlands & forests to farmland.	▪ Population and economic growth place additional strain on water supplies. ▪ Geopolitical conflict over access to transboundary water resources. ▪ Financial constraints on water infrastructure development. ▪ Impacts of climate change (e.g. changing rainfall patterns, more frequent droughts and floods, melting glaciers, etc.). ▪ Degradation of water quality from economic activities.

Link to Generic Policies

2.1.2 Risks and vulnerabilities in the agrarian typology

Risks and vulnerabilities in Malawi's energy system

Energy-specific risks

Most of Malawi's current demand for energy is met from indigenous and renewable resources (Kambewa & Chiwaula 2010), with an energy self-sufficiency ratio of 89% (IRENA 2012a). However, this comes at the expense of Malawi's woodlands, which raises questions about the sustainability of this heavy reliance on biomass. In addition, the transportation sector's high dependency on oil imports makes Malawi's energy system vulnerable to oil price shocks. Shortages in oil supply have a significant and immediate impact on Malawi's economy as fuel reserves may last for only a few days (Chimwala 2012a). The lack of adequate foreign exchange reserves and the weakness of Malawi's currency poses a major threat to liquid fuel security. The government-sponsored ethanol programme is susceptible to periodic collapses of the oil price (e.g. 1986, the late 1990s and 2009), since the price of ethanol has always been pegged slightly lower than the cost of imported gasoline in order to create an incentive for oil companies and fuel distributors (Government of Malawi [GoM] 2009).

Food-related risks

The dependence of the ethanol industry on sugar feedstock in Malawi poses a certain degree of risk related to energy security. ETHCO Ltd, the country's first ethanol plant, initially faced difficulties in sourcing reliable supplies of feedstock (molasses). ETHCO is a separately owned entity to the adjacent Dwangwa sugar factory, resulting in the need for price negotiations, which creates uncertainty (Johnson & Silveira 2014). However, this risk was mitigated when ETHCO started sourcing molasses from another sugar plant, although this plant is several hundred kilometres away and the transportation of this feedstock depends on diesel-powered trucks.

Water-related risks

Malawi's energy system is subject to several risks arising from its various dependencies on water. First, environmental degradation is affecting hydropower generation through siltation and aquatic weed invasion (Lapukeni 2013). Second, droughts can result in water levels lowering in Lake Malawi and a diminished flow of the Shire River, which threatens electrical power production; power has regularly been rationed at the end of dry seasons (Wood & Moriniere 2013). This pressure is likely to be aggravated by the rising demand for electrical power resulting from the country's electrification targets (GoM 2011b), combined with increasing constraints on supply (compounded by the demand for irrigation water withdrawn from Lake Malawi).

Risks and vulnerabilities in Malawi's food system

Food-specific risks

Risks internal to Malawi's food system generally pertain to low productivity, a growing dependence on imported fertiliser, difficulties in transportation and post-harvest losses, which are estimated at 40% of production ([IFAD 2015). More than 90% of the rural population comprises smallholder farmers with customary land tenure. Most of them practice subsistence farming and the productivity of most crops has not significantly improved over the past 40 years (Wood & Moriniere 2013). Low productivity is attributable to declining soil fertility, lack of input and credit access, low access to markets as well as the small size of landholdings (IFAD 2015). The average size of landholdings is reported to have fallen from an average of 1.5 hectares (ha) in 1968 to around 0.8ha since 2010 (Wood & Moriniere 2013). The low productivity, combined with population growth and seasonal dependence on rainfall, is fuelling expansion of Malawi's agricultural land area to the detriment of woodlands (Kumambala & Ervine 2009) and aggravating the siltation of water bodies.

When asked why they experienced food insecurity, most of the food-insecure population noted the causes as a lack of farm inputs (41%), followed by natural factors such as erratic rainfall, droughts and floods (26%), and the high food prices (14%) (National Statistical Office 2012). The government's fertiliser subsidy programme, targeted mainly at maize production, is an attempt to mitigate the risk of food security arising from low productivity. While benefits in terms of yields have already occurred and are expected to continue in the medium term, concerns have been raised about the long-term negative environmental impacts of fertiliser subsidies. The continuous use of high levels of nitrogen fertilisers has been demonstrated to cause soil acidification (Bekunda et al. 1997) and land degradation (Marenya & Barrett 2009). Holden and Lunduka (2012) highlight the risk of fertiliser subsidies encouraging use of synthetic fertilisers and thereby crowding out the use of organic manures and cultivation of crops other than maize. This results in the unsustainable monocropping of maize, leading to soil degradation, nutrient mining, a decline in soil organic matter and increase in pest and disease accumulation – all factors that can ultimately result in falling maize yields and undermine food security in the country in the long term.

Energy-related risks

Since the mainstay of Malawi's agricultural output is produced by smallholder farmers who do not rely on mechanised farming methods, the direct exposure to the adverse effects of oil price shocks is limited (Robinson & Wakeford 2013). However, under the government's fertiliser subsidy programme, Malawi is becoming increasingly reliant on imported fertilisers in a bid to increase agricultural productivity. This exposes the food sector to rising fertiliser prices, which are closely correlated with international oil prices (partly due to expensive transport costs given Malawi's landlocked status). Farm gate fertiliser prices in Malawi have been reported to be more than double international prices (Futures Agricultures 2008). The spike in fertiliser prices in 2008 (related to the spike in oil prices) had a major impact on farmers' and on the country's ability to purchase fertiliser; the average fertiliser amount received per farmer declined from around 85kgs in 2006/07 to 60kgs a farmer by 2012/13 (Dorward et al. 2013). Increasing fertiliser prices cast doubt on whether the Ministry of Agriculture and Food Security's subsidy programme is affordable; on average, 50% of its budget is allocated to the programme (GoM 2011a).

Development of biofuel energy could potentially pose a risk to food security if it is scaled up considerably. The major biofuel crop is likely to be sugarcane, which may require irritation water and could compete with food production for water and land resources. However in the case of Jatropha, several studies established that the crop could be and was grown in a way (notably boundary planting) that reduced its competition with food crops for land (Centre for Agricultural Research and Development 2012).

Water-related risks

Since 98% of the country's agriculture is rainfed (Sukali 2011), the major water-related risk to food security stems from the impact of climate change on rainfall patterns. Reliance on increasingly erratic rainfall is affecting food production as the onset of the season (occurrence of rain) is becoming increasingly unpredictable. Malawi has experienced severe droughts in the past, notably in 1948/49 and 1991/92 (Robinson & Wakeford 2013). Growth in demand for water from other sectors (such as industry and power) in the future could pose risks to water security given the limited extent of blue water infrastructure.

Risks and vulnerabilities in Malawi's water system

Water-specific risks

The major overall risk is that demand outstrips available water resources in certain areas, notably the urban areas due to a combination of growing demand (driven by the forces discussed in section 1.2) and supply constraints. Malawi is increasingly a water-scarce country: it is estimated that less than 1 000 cubic metres (m^3) of rain-fed freshwater resources are available per capita a year (Wood & Moriniere 2013). Disruptions in seasonal patterns, characterised by erratic rains, extended dry periods and increased evaporation are already having a proven effect on water availability. Long-term predictions indicate that surface water availability will increase in the wet season and decrease in the dry season by 2035 (GoM 2011c).

Water scarcity will lead to increasing competition between users, including municipalities, hydropower plants and small- and large-scale irrigation users. Competition and tension among different geographic areas will also increase as currently water extraction functions on a 'first come, first served' basis; users that are situated upstream of the Shire River will increasingly withdraw at the expense of downstream users who will have less water availability (Wood & Moriniere 2013).

Malawi, like most low-income countries, faces financial constraints and has a high dependence on donor funding for water abstraction, treatment and distribution infrastructure development. Any suspension of direct donor support, such as that experienced in early 2015, seriously impedes infrastructure development. It is not only the quantity, but also the quality of water that is at risk because of increasing levels of nitrification, sedimentation, faecal and other residues in surface and ground water (GoM 2011c).

Energy-related risks

The main energy-related risks pertain to the expansion of the hydro-electrical infrastructure and water contamination. Additional small-hydro schemes are in the pipeline (Lapukeni 2013), but these will have a far lesser impact on hydrological cycles than large hydro-schemes. Increasing demand for water from energy systems, possibly exacerbated by the expansion of biofuels (notably sugarcane for ethanol) in a drive to mitigate dependence on oil importation and increase foreign currency earnings (Chinsinga et al. 2013) puts significant pressure on water resources. Within the nexus context, Malawi has experienced one of the major energy-related risks to water security – the threat of water contamination from uranium leaching (see section 1.2.1).

Food-related risks

Increasing demand for water will emanate from the food system as food demand rises. The Malawian government's commitment to expand irrigation, as reflected by the Green Belt Initiative, will put more pressure on water resources. A change in farming practices is expected due to increasing shifts in rainfall patterns. Smallholder farmers traditionally reliant on rainfed agriculture will likely resort to *ad hoc* small-scale irrigation, diverting and further reducing the water available for large-scale irrigation systems, hydropower plants, and municipal use (Wood & Moriniere 2013).

Mhango and Dick (2011) studied the predicted effects of fertiliser subsidies on Malawi ecosystem services based on Millennium Ecosystem Assessment definitions and found that the subsidy's contribution to improving food security was offset by several negative impacts on ecosystems services that could compromise water quality.

Table 2-2: Summary of risks and vulnerabilities in Malawi's energy, food and water systems

ARISING FROM: / RISKS TO:	ENERGY SYSTEM DRIVERS AND LINKAGES	FOOD SYSTEM DRIVERS AND LINKAGES	WATER SYSTEM DRIVERS AND LINKAGES
ENERGY SECURITY	▪ Deforestation as a result of over-harvesting of biomass for energy. ▪ 100% oil import dependency. ▪ High cost of oil and transport sector dependence on oil. ▪ Foreign exchange constraints and currency weakness. ▪ Ageing infrastructure leading to breakdowns and blackouts.	▪ Dependence of bioethanol production on reliable sugar feedstock production levels.	▪ Rising temperatures and drought episodes increase evaporation and limit river water flow thereby threatening hydro-power station capacity. ▪ Increasing siltation of water bodies raises cost of energy generation. ▪ Possible increase in water prices due to water scarcity and demand growth.
FOOD SECURITY	▪ Limited overall dependence on energy as the sector mostly relies on traditional, non-oil dependant farming practices. ▪ Growing dependence on subsidised fertiliser inputs, and exposure to link between fertiliser costs and oil prices.	▪ Heavy reliance on staple crop (maize). ▪ Limited productivity (limited access to credit, input, markets, transportation; weather dependence; nutrient depletion). ▪ Limited access to organic fertilisers. ▪ Large post-harvest losses, estimated to be 40% of production. ▪ Excessive synthetic fertiliser application and maize mono-cropping undermine soil structures and long-term food security.	▪ Impact of climate change on rainfall patterns, given that agriculture is almost entirely rainfed. ▪ Limited blue water dependence as agriculture is mostly rainfed. ▪ Water withdrawal from Lake Malawi for commercial irrigation competes with other sectors (e.g. power generation).
WATER SECURITY	▪ Disruptions to energy supplies can disturb water extraction, treatment and distribution. ▪ Increasing demand for water from energy systems, possibly exacerbated by the expansion of biofuels (notably sugarcane for ethanol) in a drive to mitigate dependence on oil imports. ▪ Future threat of water resource pollution from oil extraction and current pollution of water from leaching of uranium waste.	▪ Increasing demand for water from expansion of irrigation. ▪ Increasing risk of illegal small-scale irrigation connections that might constrain water availability for large-scale irrigation. ▪ Degradation of water resources from high input agriculture, especially fertilisers. ▪ Disruption of water-related ecosystem services and run-off from conversion of catchment areas and forests to farmland.	▪ Uncertain impacts of climate change (e.g. changing rainfall patterns, more frequent and intense droughts and floods). ▪ Population and economic growth put strain on water supplies and infrastructure. ▪ Dependence on foreign aid to maintain, upgrade and expand water infrastructure. ▪ Increasing competition among different users.

Link to Malawi Policies

2.1.3 Risks and vulnerabilities in the industrial typology

Risks and vulnerabilities in South Africa's energy system

Energy-specific risks

South Africa's energy security vulnerabilities relate firstly to its dependence on oil imports to meet 70% of liquid fuel demand. This exposes the energy system to international oil price and supply shocks, which together with exchange rate weakness can result in volatile and often high liquid fuel prices. On the domestic front, a key threat to liquid fuel energy security is the depletion of existing gas reserves, which is already constraining gas-to-liquid fuel production. In the longer term, depletion of higher quality coal reserves presents a major risk, particularly to the power sector, which is 90% dependent on coal.

The second major vulnerability is inadequate electricity-generation capacity, which has resulted in regular load shedding and power outages. The national electricity utility faces massive infrastructure maintenance backlogs and funding gaps for new energy infrastructure. As a result of these factors, consumers have been facing steeply rising electricity tariffs for the past several years, which undermines the affordability of electricity for poorer households in particular. Third, the very high carbon intensity of South Africa's energy system represents a significant vulnerability as the government has committed to reducing carbon emissions after 2030.

Food-related risks

Biofuel production based on use of food crops is currently minimal in South Africa, and thus the energy security risk of dependence on food stocks is currently negligible. However, this risk is set to increase as the country has recently embarked on a programme to boost biofuel development. But perceived or actual competition between food and biofuel production in the longer term could hinder the expansion of biofuels, given constraints on arable land and water supplies. Furthermore, a lack of transparency surrounding the land that government policy documents have termed 'new, additional or currently underutilised' and earmarked for biofuel production creates uncertainty for stakeholders and retards investment in the sector (Brent 2014).

Possibly of greater significance is that growth in demand for energy from the food system – including transport costs and the need for electricity to power irrigation systems – will place additional strain on energy security. An additional risk is the loss of energy that is embodied in food and subsequently wasted at various stages of the food value chain (von Bormann & Gulati 2014).

Water-related risks

Given South Africa's arid status, water scarcity may be a limiting factor for expanded energy production, including thermal and hydro-electricity generation as well as shale gas development (von Bormann & Gulati 2014). Biofuel feedstock production is also susceptible to water scarcity (and constraints on arable land). Furthermore, declining water quality (ironically attributable in part to coal mining) threatens the operation of some thermal powerstations and pushes up energy production costs. Climate change poses threats such as rising temperature of water that is needed for cooling in thermal power stations, while an increasing frequency and severity of droughts may diminish hydropower generation. Finally, energy can be wasted as a result of ageing and poorly maintained water infrastructure, inefficient pump stations, obsolete water treatment processes, water leaks and inefficient use of water (Gulati 2014a).

Risks and vulnerabilities in South Africa's food system

Food-specific risks

South Africa is reasonably food secure at the national level as it is a net food exporter in value terms (Wakeford & Swilling 2014). However, the reliance on imports for some key agricultural commodities (rice, wheat, sugar and poultry) and processed foods presents a risk since the country is exposed to volatile international food prices via import and export parity pricing, and exchange rate weakness and volatility. Furthermore, this aggregate national food security does not guarantee food security at the household level. Food insecurity currently affects about 20% of South Africa's population, and social unrest has been linked to rising global and local food prices (von Bormann & Gulati 2014). As already indicated, waste along the food value-chain undermines the attainment of food security (Notten et al. 2014).

The limited extent of arable land and the generally poor quality of the country's soils presents a further vulnerability in the food system. In addition, some farm land has fallen into disuse as a result of failed land-redistribution programmes, while arable land is continually lost on urban fringes and to mining development (von Bormann & Gulati 2014). The agriculture sector is also experiencing an ongoing attrition of farming skills, with a high and rising average age of farmers and major farm employment losses (Liebenberg & Pardey 2012).

Energy-related risks

The commercial agriculture sector – as well as the broader food system – has become increasingly dependent on fossil fuels (in the form of petroleum products and coal-fired electricity) over the past several decades (Wakeford & Swilling 2014). This has made the food system increasingly vulnerable to rising energy prices and potential energy-supply disruptions. Rising liquid fuel and electricity prices push up farm input costs (such as costs of fertilisers, irrigation, the operation of machinery and tractors, and cold storage), and farmers may not be able to pass all of these costs on to consumers as the retail sector, which is highly concentrated, dominates price setting (Wakeford & Swilling 2014). Diesel fuel shortages could have serious negative consequences for agricultural production if occurring during critical planting or harvesting periods, and would pose a major threat to food security through interrupting the distribution of food products. Power outages interrupt irrigation and can cause increased food wastage by interrupting refrigeration processes. Rising energy prices also raise the cost of energy used for cooking food (Mason-Jones et al. 2014). Higher-income households in South Africa use electricity or liquid petroleum gas for cooking, whereas many poorer households use paraffin (especially in urban areas) or wood (mainly in rural areas).

Although, as mentioned above, biofuels are at a nascent stage of development in South Africa, they nonetheless could pose a risk in terms of competing with food production for scarce land and water resources – particularly if farmers face prices that incentivise switching from food to biofuel crops and the government does not take steps to limit biofuel production. However, Brent (2014) argues that there are complementarities between bioenergy and food production, which, if managed carefully, could yield sustainable social upliftment and rural development in an African and South African context. An important issue is the distinction between large-scale commercial production of biofuels (e.g. crop-based ethanol or biodiesel) versus small-scale bioenergy development that is twinned with food production.

Water-related risks

The primary risk to food security from the water system is growing water scarcity: there is a significant risk that the ambitious national socioeconomic development goals for boosting agricultural production by expanding irrigation will not be realised due to water shortages. Although South Africa cannot really afford to export virtual water, food trade data reveal that South Africa is a net exporter of blue water and that the quantities involved are increasing (Dabrowski 2014). Proper water-resource management will require more cost-reflective water pricing, which could significantly push up water costs for farmers and hence affect food prices.

Second, deteriorating water quality (resulting from various forms of pollution) poses a major threat to food quality and agricultural exports. Third, the lack of coordination between planning in the food and water sectors (Goga & Pegram 2014) presents an institutional risk. Fourth, climate change is expected to bring greater uncertainty and variability to rainfall patterns and result in an increased frequency of droughts and floods, which will negatively affect food security (Baleta & Pegram 2014). Finally, water constraints and rising costs could make smallholder farming less viable and undermine efforts to boost rural development and poverty alleviation (von Bormann & Gulati 2014).

Risks and vulnerabilities in South Africa's water system

Water-specific risks

As already mentioned, increasing water scarcity is a major threat in South Africa, an already arid country. This is likely to be compounded by climate change (which creates uncertainty and may result in more droughts, floods and enhanced evaporation) and may necessitate more energy-intensive water supply solutions, including recycling, desalination and inter-basin transfers. Declining water quality (e.g. resulting from mining, agriculture, industrial effluence and municipal wastewater) is also a major and growing problem, and is exacerbated by poor water infrastructure and a lack of associated management capacity and skills (von Bormann 2014). Deteriorating water quality also implies a need for more energy-intensive water-treatment processes. Growing demand for water in the face of these threats is likely to result in the cost of water-service provision rising.

Energy-related risks

Water security faces four main risks related to its relationship with energy. First, erratic or constrained electricity supplies can negatively affect various stages of the water cycle and reduce the availability of water to consumers (Winter 2011. It does this through the interruption of abstraction and distribution of water reliant on electric pumps; the impairment of water-treatment processes, resulting in compromised water quality; and the stoppage of wastewater and sewage-treatment processes, with possible risk of damage to equipment and pollution. Farmers, water utilities and consumers may need to fall back on expensive diesel generators and portable water-storage tanks. Indeed, rolling power outages in South Africa in 2007–2008 and again in 2015 disrupted water supplies to some localities and put greater financial strain on the municipalities that had to resort to back-up power generation (Winter 2011). Second, rising electricity and diesel costs will increase the costs of providing water services. Third, growing demand for water from the energy sector (including biofuels, possible shale gas development and new thermal power plants) will increase the competition for scarce water resources among different demand sectors. Eskom, the state power utility, is guaranteed a supply of water as a strategic water consumer under the National Water Act (IRENA 2015). Fourth, energy processes are a major source of water pollution, notably coal mining and combustion, which produce acid mine drainage and acid rain, respectively.

Food-related risks

Water security is at risk from the food system via the pollution of water from agricultural production (e.g. extensive use of fertilisers and pesticides and resulting eutrophication), food processing and food waste (Oberholster & Botha 2014). Furthermore, growing demand for water for irrigation will place increasing strain on an already stressed water system. This is compounded by the loss of water embodied in wasted food.

Table 2-3: Summary of risks and vulnerabilities in South Africa's energy, food and water systems

ARISING FROM: / RISKS TO:	ENERGY SYSTEM DRIVERS AND LINKAGES	FOOD SYSTEM DRIVERS AND LINKAGES	WATER SYSTEM DRIVERS AND LINKAGES
ENERGY SECURITY	▪ Dependence on oil imports implies exposure to oil price and supply shocks. ▪ Depletion of domestic gas and coal reserves. ▪ Power generation capacity constraints and funding gaps, resulting in rising tariffs. ▪ Very high carbon intensity.	▪ Minimal but growing risk of biofuel dependence on food crops. ▪ Competition between food and fuel might limit biofuel development. ▪ Growing energy demand from food sector. ▪ Embodied energy lost through food waste.	▪ Water scarcity may limit expansion of energy production. ▪ Declining water quality and climate change threaten operation of thermal and hydro powerstations. ▪ Energy wasted through inefficiencies in the water supply chain.
FOOD SECURITY	▪ High level of dependence on fossil fuel-based inputs at all stages of food chain. ▪ Vulnerability to oil and electricity price increases. ▪ Diesel shortages and power outages can be highly detrimental to the food system. ▪ Biofuels could compete with food for scarce land and water resources.	▪ Reliance on imports for some key agricultural commodities (rice, wheat, sugar and poultry) and processed foods. ▪ Household food insecurity and vulnerability to rising prices. ▪ Loss of limited arable land and attrition of farming skills.	▪ Water scarcity could thwart plans to expand agriculture by increased irrigation. ▪ Net exports of virtual water are increasing. ▪ Cost-reflective water pricing could push up food prices. ▪ Deteriorating water quality threatens food quality. ▪ Threat posed by climate change to rainfall and hence food production.
WATER SECURITY	▪ Erratic or constrained electricity supplies can negatively affect various stages of the water cycle. ▪ Rising electricity and diesel costs will raise the costs of providing water services. ▪ Growing demand for water from the energy sector will increase competition for water resources. ▪ Energy processes are a major source of water pollution.	▪ Pollution resulting from agricultural production (e.g. eutrophication, pesticides), food processing and food waste. ▪ Additional water demand for irrigation. ▪ Embodied water lost through food waste.	▪ Growing water scarcity, exacerbated by climate change. ▪ Declining water quality resulting from pollution and inadequate infrastructure and management. ▪ Risk of rising costs of water service provision.

Link to SA Policies

2.1.4 Risks and vulnerabilities in the ecological typology

Risks and vulnerabilities in Cuba's energy system

Energy-specific risks

While Cuba's energy sector is now significantly more stable than it was during the country's energy crisis in the early 1990s, the high level of dependence on imported energy (principally oil) carries very high economic costs as well as posing energy security risks, in the event of international oil price spikes or supply disruptions. This situation is common to many small island states (Wakeford & de Wit 2013).

As the country progressively diversified its economic reliance away from Russia, its former patron state, it established increasingly strong trade ties with Venezuela. Cuba and Venuzuela signed 49 economic agreements in 2005, notably including one regarding oil; Venezuela sends about 90 000 barrels a day of crude oil and derivatives to Cuba (Suarez et al. 2012). The country would likely fall into a new energy crisis should this support be reduced or terminated (Suarez et al. 2012). The recent warming of diplomatic relations between Cuba and the United States may affect the geopolitical situation if it leads to greater normalisation of trading relationships between these two countries.

Since the 2006 'energy revolution' the Cuban government has attempted to diversify the country's energy mix to include a greater share of renewables, and it plans to generate 24% of its electricity needs from renewable sources by 2030 (Energy Information Administration [EIA] 2015a). However, some analysts argue that over the past decade, Cuba has embarked on a path towards possible increased fossil-fuel consumption as venture capital projects in oil exploration have increased (King 2012). It therefore appears that Cuba is seeking greater energy independence as opposed to reducing its reliance on fossil fuels.

Food-related risks

Cuba produces ethanol from sugarcane and uses sugarcane bagasse residues in the country's co-generation power plants, which are an important part of the energy mix, especially during the harvest season. King (2012) contends that the marked fall in sugar production is putting the country's energy sector in peril as it leads to an increase in oil imports.

Water-related risks

The energy sector is only marginally reliant on water with hydropower representing just 0.1% of the total primary energy supply. There is a dearth of research into the indirect uses of water, such as cooling powerstations and processing/refining oil, along with the associated contamination risks.

Risks and vulnerabilities in Cuba's food system

Food-specific risks

Cuba is self-sufficient in many food items, particularly fruits and vegetables. The major risk is that the country still needs to import a sizeable portion of its food requirements, especially grains and meat products. Cuba's average cereal import dependency ratio was 76% for the period 2009 to 2011, while the ratio of the value of food imports to total merchandise exports was 35% (World Bank, 2015). Reliance on imports of meat and vegetable oils is particularly high (Saurez et al. 2012).

The country is also heavily reliant on imported fertilisers. Between 2002 and 2012, Cuba imported on average 62% of its nitrogen, 85% of its phosphate and 88% of its potash fertilisers (data sourced from FAOSTAT 2015d). Oil price dynamics affect the price and availability of these synthetic inputs. The introduction of genetically modified maize in Cuba could also put the strong agroecological system in peril, with the risk of contaminating – through cross-pollination – heirloom crop varieties, which constituted the backbone of Cuba's agroecological food revolution.

Energy-related risks

The 'peak oil' period that Cuba has traversed and the subsequent changes made to its agricultural system helped the country reduce its dependence on imported inputs in times of economic crisis (Rosset et al. 2011). One can assume that most of the food grown in Cuba is still produced organically as asserted by Piercy et al. (2010), therefore implying that the country's energy-related risks to the food system are fairly well mitigated. However, the recent drive to grow genetically modified crops, notably maize and possibly soya, may jeopardize the low-energy footprint of the agricultural sector because this form of agriculture typically requires higher levels of mechanisation as it is intrinsically geared towards cultivation on larger tracks of land (Altieri & Funes-Monzote 2012). This would further expose the country to oil dependency.

Water-related risks

There is a lack of documentation on the food sector's vulnerability to water-related risks in Cuba. However, it can be argued that the increase in land areas planted to mono-crops will increase pressure on water demand. The productivity rate of soya bean cultivation increases by 40% when irrigated and the recent expansion of soya fields was to be accompanied by the installation of 544 centre-pivot irrigation systems in 2014 (Altieri & Funes-Monzote 2012).

Risks and vulnerabilities in Cuba's water system

Water-specific risks

As in many countries, the primary risk is posed by growing demand relative to available water resources, especially as agricultural and domestic demand increase. Prolonged dry periods, water overexploitation, pollution, saline intrusion, deficit of the forest cover and low levels of reusing and recycling all compromise water availability (Suarez et al. 2012). There is a significant risk of water shortages resulting from prolonged periods of drought that are expected to be more frequent with global warming (RoC 2011). Sea-level rise is another factor that may compound water issues in the country, which is already suffering from inadequate sanitation due to its low-lying infrastructure.

Energy-related risks

Prolonged electricity blackouts lead to water shortages, with knock-on effects in terms of food shortages and food price hikes (Grogg 2012). Another major energy-related risk to water security is energy-related processes such as oil and gas extraction and processing contaminating surface and underground freshwater resources.

Food-related risks

The pollution of rivers is reportedly causing serious illnesses and even death (Diaz Blanco 2013). Although this aspect is not documented, it is probable that degrading water quality will affect the quality of food, especially food grown with polluted irrigation water. Another substantial risk posed is the heavy and increasing demand that the food sector might exert on the water sector in response to the country's drive to improve food security, particularly through increased irrigation. As mentioned earlier, the expansion of commercial (and genetically modified) agriculture has led to an increase in the area under irrigation (Altieri & Funes-Monzote 2012).

Table 2-4: Summary of risks and vulnerabilities in Cuba's energy, food and water systems

ARISING FROM: / RISKS TO:	ENERGY SYSTEM DRIVERS AND LINKAGES	FOOD SYSTEM DRIVERS AND LINKAGES	WATER SYSTEM DRIVERS AND LINKAGES
ENERGY SECURITY	■ Measures to expand renewable energies mitigate risks of energy import reliance, but continued reliance on imported oil presents energy security risks, compounded by geopolitical risk associated with sourcing subsidised oil from Venezuela. ■ Thawing of relationship with the United States may help to mitigate energy supply risks by expanding trade opportunities.	■ Decrease in sugarcane production could compromise Cuba's energy diversification plan by limiting availability of bagasse for co-generation. ■ Foreseeable increase in energy demand for agricultural production with the rise of industrial mono-cropping (maize and soya).	■ Marginal reliance of the energy system on water, except for sugarcane production.
FOOD SECURITY	■ Much food production relies on non-mechanised agro-ecological processes and limited inputs – hence limited energy-related risks for food production. ■ But large-scale industrial agriculture is on the rise, with heavy reliance on the importation of synthetic fertilisers, the prices of which are linked to oil prices.	■ Self-sufficiency in many fruits and vegetables. ■ Reliance on food imports for specific foodstuffs, notably cereals, meat products and vegetable oils. ■ Growing reliance on importation of synthetic fertilisers. ■ Introduction of genetically modified organisms may compromise legacy of agroecological revolution.	■ Limited blue water dependence as agroecological practices are intrinsically water efficient. ■ Foreseeable increase in water requirements for agricultural production with the return of industrial farming and irrigation.
WATER SECURITY	■ Disruptions to electricity supplies can disturb water extraction, treatment and distribution. ■ Threat of contamination of both surface and underground freshwater resources from energy-related processes, notably extraction and processing of oil and gas.	■ Pollution of rivers affects the quality of food, especially food grown with polluted run-off irrigation water. ■ Heavy and increasing demand exerted by the agricultural sector on the water sector in response to the country's drive to improve food security; the expansion of commercial (and genetically modified) agriculture implies an increase in the area under irrigation.	■ Growing demand for water puts pressure on available supply and infrastructure. ■ Water availability compromised by prolonged dry periods, water overexploitation, pollution, saline intrusion, lost forest cover and lack of reuse and recycling. ■ Sea-level rise a direct threat to water and sanitation infrastructure in coastal areas.

Link to Cuba Policies

2.2 Quantitative Indicators of Vulnerability in the Energy-Food-Water Nexus

Objectives

The primary objective of this section is to identify and quantify the major vulnerabilities in developing countries in terms of energy, food and water security. The cross-country comparisons will enable individual nations to assess their relative standing among their peers and identify particular weaknesses and strengths, which can then assist development of appropriate policies and prioritisation of mitigation responses. The analysis will also highlight any patterns in the indicators and identify countries that do not conform to such patterns (i.e. outliers).

A secondary objective is to identify any relationships (or lack thereof) between different indicators based on a sample of developing countries. For example, do the same countries generally suffer from food, energy and water insecurity, or is there no general association across the three areas? It might be expected, for instance, that countries with meagre water resources will generally struggle to produce enough food (although they may be able to import food if they have oil or other minerals to export). However, energy and water security indicators may not correlate closely, as endowments of (fossil fuel) energy resources are in some instances very different to those of water resources, notably in the Middle East and North Africa region. Indeed, it will be shown that many of the water indicators are uncorrelated with the food and energy indicators. The data also show the extent to which energy-food-water insecurities are related to income and poverty levels. This is the case where poorer countries generally have less capacity to build the infrastructure required to provide energy and water services, and have less sophisticated agricultural systems producing lower yields.

Methodology

In order to meet the above objectives, this section presents and analyses several key national indicators of energy, food and water security for a wide range of developing countries. For ease of interpretation, the data are represented in selected charts in the following subsections, while Appendix 2.4 contains the full data tables.

The sample of countries (drawn in the first instance from the World Development Indicators (WDI) database) was limited by two factors. First, individual countries were excluded if there were insufficient data available across the range of selected indicators. Second, the sample excludes Small Island Developing States (SIDS), both because they have special characteristics that set them apart from other countries (e.g. their generally small size, both in terms of population and land area), and because many of them lacked data for a number of key indicators. The one exception is Cuba, which although being part of the SIDS grouping is included as it was selected as one of the case studies in Part 1 (it is also a fairly large country compared to most SIDS). Lists of the included and excluded countries are provided in Appendices 2.1 and 2.2, respectively.

To make the data depiction and analysis more tractable, the sample of developing countries has been grouped into three categories based on incomes. Ideally, the categorisation would have followed the socioecological system typology developed in Part 1, namely agrarian, industrial, and ecological types. However, in practice it is difficult to define these categories quantitatively and also to apply the typology unequivocably at a national level (since individual countries might contain elements from more than one typology, such as traditional and modern agriculture). One way to distinguish between agrarian and industrial countries would be on the basis of the percentage of energy derived from traditional biomass (for example, using a threshold of 50%); another could be to use the percentage of the population employed in agriculture as a proxy. However, there are probably no countries that as yet typify the ecological typology (where the majority of energy should be derived from renewable sources and agriculture systems should be largely organic).

This study uses a more practicable categorisation based on the World Bank's income groups, namely low-income countries (LICs), lower-middle-income countries (LMICs), and upper-middle-income countries (UMICs). As will be seen, there is a reasonably close (inverse) association between income level and the degree of reliance on traditional energy and (mostly subsistence) agriculture. This grouping facilitates the comparison (using charts) of countries at a similar stage of development. The countries are ordered on the charts from lowest to highest gross national income (GNI) per capita, and thus the charts give a sense of the relationship (if any) between income per capita and specific security/vulnerability indicators. Bar charts are used to display two indicators at a time in order to save space, although the intention is not to examine relationships between indicators in these charts. Scatterplots and correlation analysis are used to determine whether any meaningful relationships exist between particular pairs of energy, food and water security indicators, and to identify patterns and outliers. It must be emphasized, however, that the data represent snapshots of the various indicators, some of which may vary over time. Hence, the particular relationships found in this dataset may not hold in other time periods in the case of indicators that tend to be volatile from year to year. Nevertheless, many of the indicators tend to change slowly over time.

In section 2.2.4, the average values of the indicators across the three income groups are compared, in order to highlight the main similarities and differences between the groups. Section 2.2.5 uses scatterplots and correlation analysis to investigate the extent to which there are relationships between various pairs of indicators across the full sample of 96 developing countries. Section 2.2.6 examines the relationships among indicators within multivariate regression analysis. Finally, in section 2.2.7 several key indicators are presented on spider diagrams for a selection of DFID priority countries (for which sufficient data are available), in order to highlight specific areas of vulnerability and to compare and contrast patterns across the selected countries.

Data

Country-level data on indicators that specifically address the interconnections in the energy-food-water nexus are, unfortunately, very scarce.[16] This reflects the complexity of the nexus linkages, such as the multiple stages within the energy production-use cycle that consume water, and vice versa; and the various ways and forms in which energy enters the food system. Agencies such as the IEA, FAO and UN-Water typically do not collect national data on nexus variables (e.g. the amount of water consumed for electricity generation, or the amount of energy used by the water sector). We attempted to construct a cross-country indicator of energy use in agriculture (relative to the value of agricultural production), drawing from the IEA's national energy balances. However, the figures for energy consumption in agriculture vary dramatically across countries and bear little relationship to the relative sizes of the agriculture sectors (in terms of their contributions to GDP); therefore, these data are not presented.

As a result, this section presents a range of indicators relating to energy, food and water security, which are of ultimate interest for policymakers. The set of indicators included in the analysis are listed in Table 2-5 according to five categories cutting across the energy, food and water domains: characterisation of the type of metabolism/economy; availability and use of the resource; access to the resource/service; various indicators of vulnerability; and a measure of productivity. A more complete description of the indicators including their units of measurement, and along with the respective data sources, is provided in Appendix 2.3.

Three main sources of publicly available data were drawn upon: the World Bank's WDI for general socioeconomic indicators and energy indicators; the FAO's FAOSTAT database for food security indicators; and the FAO's AQUASTAT database for water-related indicators. In general, data from the most recent available year or time period were selected, although in cases where there were too many missing observations for the latest year, an earlier year was chosen. In the case of some indicators, data for certain countries were not available for the selected year, in which case earlier observations were used (if available).[17]

Some important general notes about the interpretation of the various indicators should be borne in mind when considering the charts that follow:

- ***Availability*** of energy, food and water in terms of the average per capita level of consumption or supply are important indicators of security, and at least in the case of energy and food hint at issues of affordability. However, they only tell part of the story as averages can mask extensive inequalities in consumption levels within a country.
- ***Access*** to electricity, adequate nourishment and safe drinking water are vital indicators of energy, food and water

16 See, for example, UN-Water (2014: 44) and IRENA (2015: 95). In general, nationally aggregated data are more readily available for energy than for water, partly because energy consumption data (by fuel type) are derived from international energy trade statistics, while there is no comparable global market for water (UN-Water, 2014).

17 Missing data was a problem for a number of countries, especially among LICs. Some nexus-related indicators had to be omitted altogether owing to the sparseness of the data; for example, (i) the percentage of irrigated land area equipped with power irrigated systems (sourced from FAOSTAT), which would have given some indication of the extent to which countries depend on energy for irrigation of crops: (ii) the ratio of fertiliser consumption to fertiliser production (from WDI), which would indicate a country's vulnerability to fertiliser price increases.

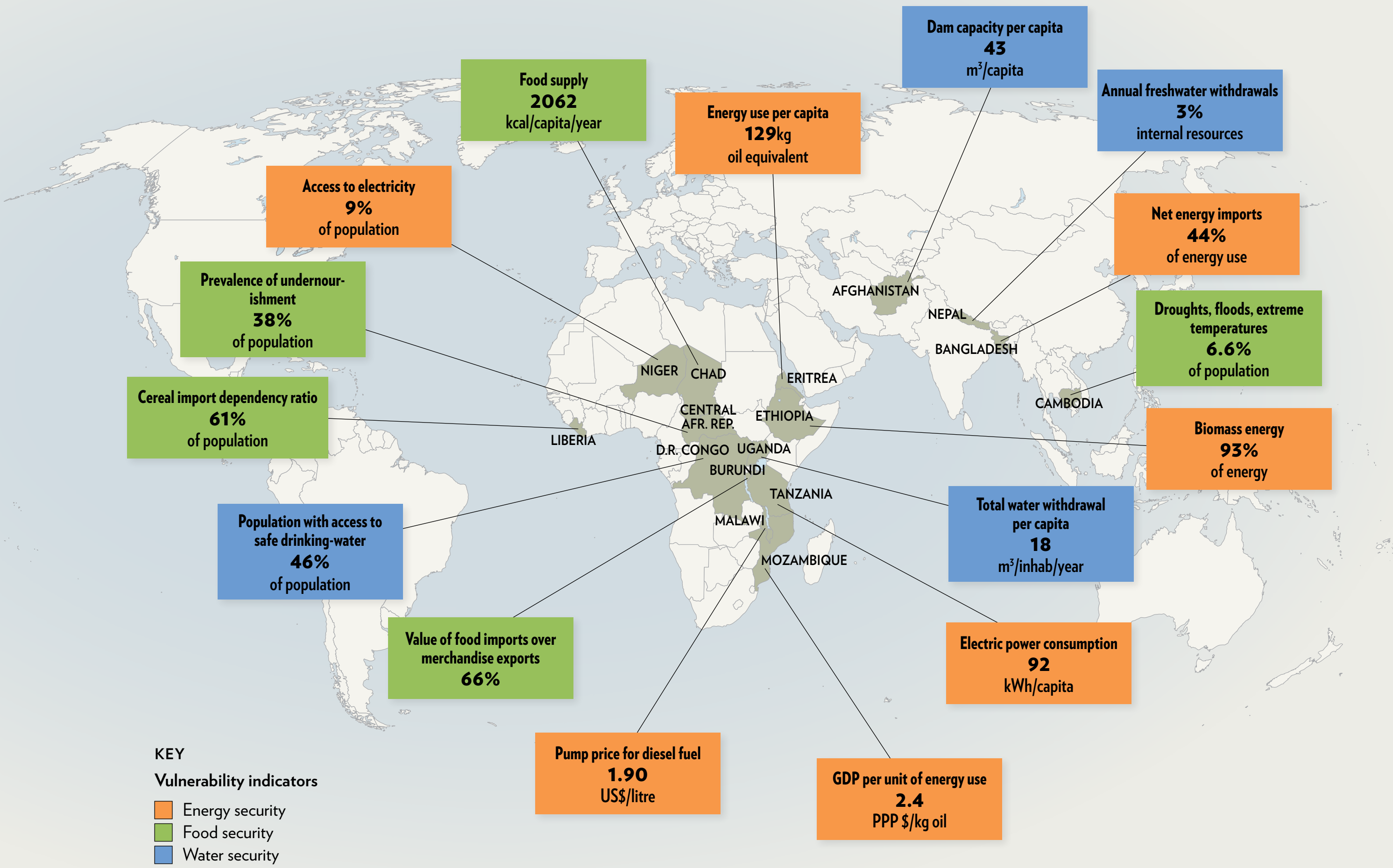
Table 2-5: Categorisation of energy, food and water security indicators

INDICATOR TYPE	ENERGY	FOOD	WATER
Characterisation of metabolism/economy	Reliance on biomass versus modern energy sources (% of total energy supply)	Agriculture's share of GDP and employment (%)	Agriculture's share of water use versus domestic and industry (%)
Availability and use	Energy consumption per capita (kg/year) Electricity consumption per capita (kilowatt hours (kWh)/year)	Food supply per capita (kilo calories (kcal)/year)	Water withdrawal per capita (m^3/year)
Access	Access to electricity (% of population)	Adequately nourished (% of population)	Access to safe drinking water (% of population)
Vulnerabilities	Net energy imports (% of energy use) Price of diesel fuel (US$/litre)	Cereal import dependency ratio (%) Value of food imports over total merchandise exports (%) Agricultural irrigated land (% of agricultural land) Agricultural machinery (tractors per 100 square kilometres (km^2) of arable land) Fertiliser consumption (kg/ha of arable land)	Annual freshwater withdrawals (% of internal resources) Droughts, floods, extreme temperatures (% of population affected, average for 1990–2009)
Productivity	Energy productivity (GDP per kg of oil equivalent)	Cereal yield (kg/ha) Value of food production (International $/person)	Water productivity (GDP per m^3 of total freshwater withdrawal)

security, respectively, and because they are expressed in percentages of the population, provide an indication of equality/inequality. Access depends on both resource availability and infrastructure (such as electricity grids and water reticulation).

- ***Vulnerability*** to international energy price shocks or supply disruptions can be gauged by the extent of dependence on energy imports, and to some extent also by the degree to which countries rely on fossil fuels (the prices of which are generally determined in international markets). Similarly, the cereal import dependence ratio and the extent of dependence on food imports are important indicators of vulnerability to global food price shocks or supply disruptions (e.g. resulting from extreme weather events). The closest indicator for water vulnerability is the extent to which annual withdrawals are met by internal resources. Diesel prices can indicate logistical vulnerabilities in fuel supply (e.g. land-locked nations with limited transport infrastructure), but can be distorted by fuel subsidies (in which case the vulnerability to oil price spikes lies primarily in the government budget). Extensive reliance on energy-intensive agricultural inputs such as irrigation, tractors and fertilisers can raise yields and thus boost food security, but at the same time increase exposure to energy price increases, thus representing a nexus vulnerability.
- Countries that have relatively high levels of energy/water/food ***productivity*** are generally in a better position to make effective economic use of scarce resources. Conversely, however, disruptions to the availability of energy or water can have a substantial impact on the GDP of high-productivity countries. Energy and water productivities depend significantly on the structure of the economy in question. While we do not have a comparable measure of food productivity as the resource base is complex (land, soils, water, fertilisers and energy are all important inputs), two proxies are provided (cereal yield per ha of arable land and the value of food production per person). Cereals are particularly important in providing for minimum dietary requirements, whereas the value of food production does not necessarily correlate with domestic food security as it could be determined mostly by agricultural export products.

2.2.1 Low-income countries



Selected vulnerability indicators for low-income countries (Gross National Income per capita less than US$1 045 in 2014).

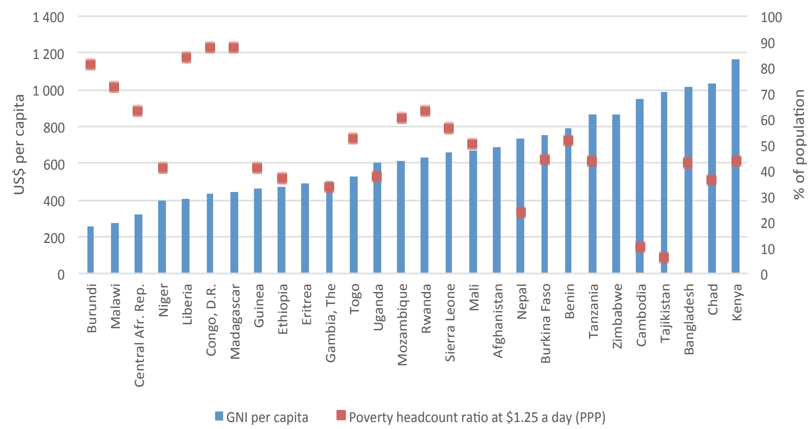
Figure 2.1 shows the income per capita and headcount poverty ratio (at US$1.25 per day) for the selected group of 28 LICs. As expected, poverty rates tend to be highest (in several cases over 70%) in the countries with the lowest GNI per capita, although there are exceptions, such as Niger with a comparatively low poverty rate of 41%. Tajikistan and Cambodia[18] have the lowest poverty rates, 6% and 10% respectively, while Kenya's poverty rate is stubbornly high (43%) despite having the highest GNI per capita in the group.

Another distinguishing feature of LICs is the large role played by the agriculture sector in most of their economies. Agriculture's contribution to GDP averages 32% and is more than 20% for all but three countries: Bangladesh, Eritrea and Zimbabwe (whose agriculture sector collapsed after 2000). Agriculture accounts for 65% of total employment on average, and for over 42% in all countries. Most of these countries are essentially agrarian, with little industrialisation having taken place.

Within this group, energy consumption per capita is not, somewhat surprisingly, tied to the level of per capita income, with the lowest levels of energy consumption per capita being recorded in The Gambia, Eritrea and Bangladesh. Zimbabwe is the one outlier with significantly higher energy consumption, a result of its relatively good electricity infrastructure including the Kariba hydropower plant. Energy productivity (measured by GDP per unit of energy use) varies considerably, and is highest in Bangladesh (that uses mostly fossil fuels, which are high-quality energy sources) and Eritrea.

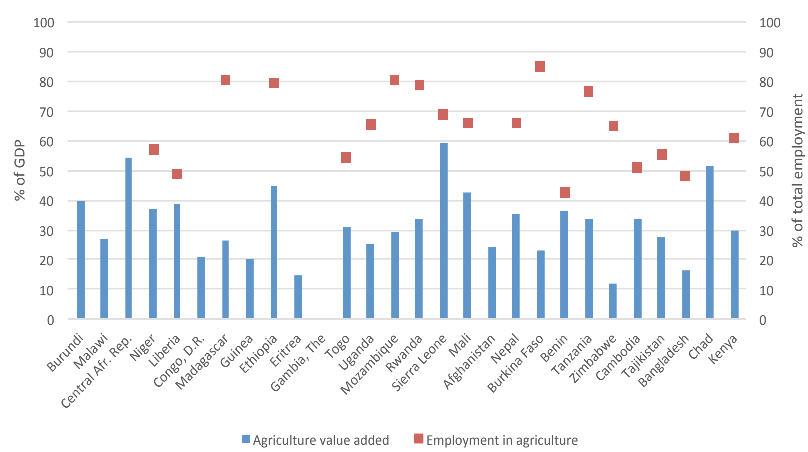
In almost all LICs, biomass accounts for the bulk of primary energy supply. One exception is Tajikistan, which has substantial hydropower capacity and imports natural gas from Russia. Another exception is Bangladesh, where fossil fuels (mainly domestically produced natural gas) account for 72% of primary energy supply, while biomass supplies 28%. Afghanistan derives 68% of its energy from fossil fuels and 27% from biomass. In several countries, the reliance on biomass for primary energy supply is more than 80%

Figure 2-1: Per capita income and poverty rate in LICs



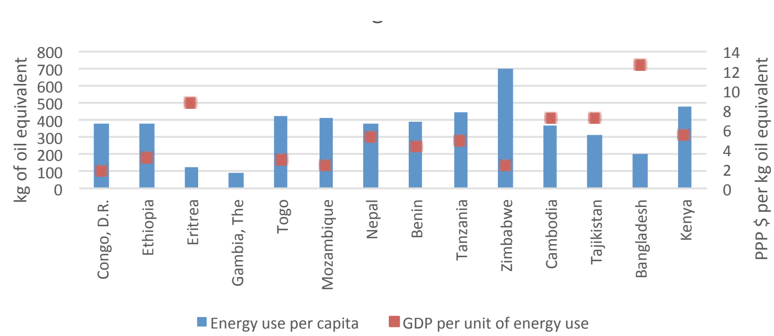
SOURCE: World Bank (2015b)

Figure 2-2: Contribution of agriculture sector in LICs



SOURCE: World Bank (2015b)

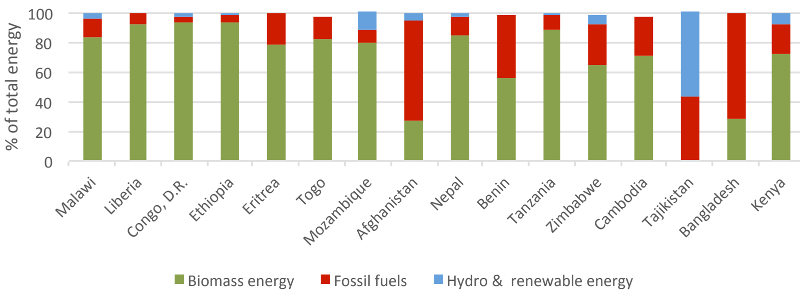
Figure 2-3: Energy consumption and productivity in LICs, 2011



SOURCE: World Bank (2015b)

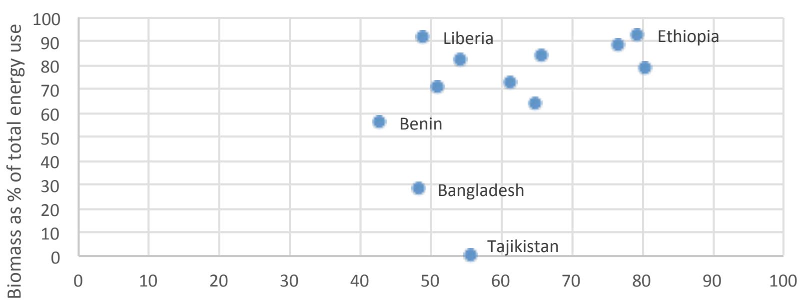
18 Cambodia's poverty rate more than halved between 2004 and 2011, thanks mainly to higher rice prices and increased rice production (World Bank, 2014).

Figure 2-4: Shares of primary energy supply by major fuel type in LICs, 2011



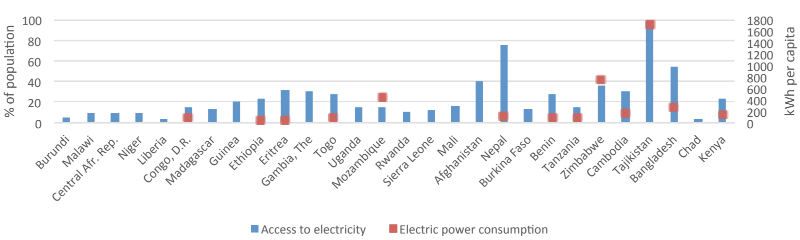
SOURCE: World Bank (2015b)

Figure 2-5: Reliance on biomass energy and agricultural employment in LICs



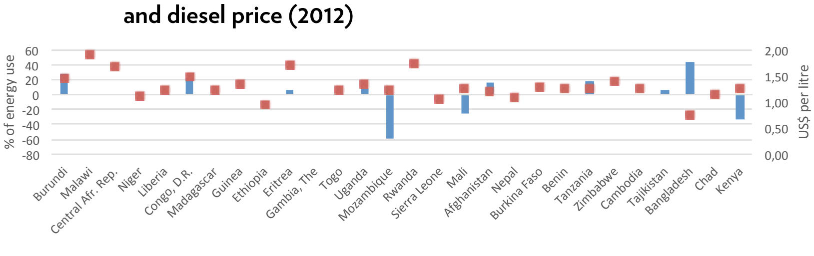
SOURCE: World Bank (2015b)

Figure 2-6: Access to electricity and electric power consumption in LICs



SOURCE: World Bank (2015b)

Figure 2-7: Energy vulnerabilities in LICs: net energy imports (2011) and diesel price (2012)



SOURCE: World Bank (2015b)

(Democratic Republic of Congo, Liberia, Ethiopia, Nepal, Tanzania and Togo). In general, the poorest countries tend to have the greatest reliance on traditional biomass fuels, as they lack electricity infrastructure and for the most part lack fossil fuel reserves.

The relationship between the share of biomass in total energy use and the share of employment in agriculture in shown in Figure 2-5. Apart from the two outliers discussed above (Tajikistan and Bangladesh), there appears to be a positive relationship between these two indicators (note that only 12 of the 28 countries in the LIC group have data for both indicators), and all are clustered in the top right quadrant of the figure.

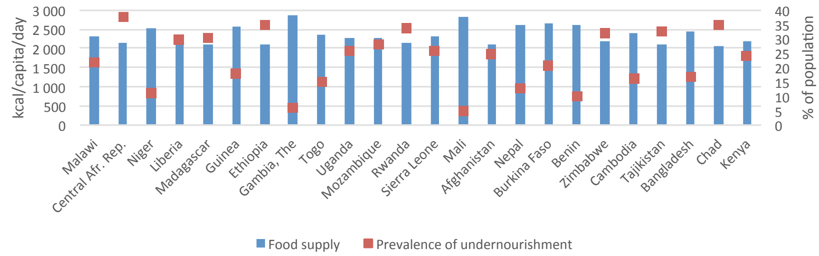
Access to electricity is very limited – below 30% of the population – in most LICs and especially those located in sub-Saharan Africa. The exceptions are the Asian nations of Bangladesh (55%), Nepal (75%) and Tajikistan (100%). The latter two countries have considerable hydropower capacity, while Bangladesh relies mainly on its domestic gas to generate electricity. Electric power consumption per person follows a similar pattern of very low usage (except in Tajikistan). Broadening electricity access is one of the greatest development challenges facing poor countries, especially those in Africa.

Two important measures of energy vulnerability are net energy imports (as a percentage of energy consumption) and the price of diesel fuel (which is critical for road freight transport in most countries). Most LICs are net energy importers, with the exception of Mozambique (which is a growing exporter of coal) and Chad (an oil exporter, for which data on net energy imports is unavailable). Mali and Kenya refine and export more oil than they consume. Bangladesh relies on imports for nearly half of its energy use. Diesel prices vary from a low of US$0.76/litre in Bangladesh (where it is subsidised) to over US$1.70/litre in Eritrea and land-locked Rwanda and Malawi. The latter countries are highly vulnerable to further oil price increases, while fuel subsidies can present a major economic burden and distort incentives.

In 2011 the per capita food supply (in kcal per day) ranged between 2 062 and 2 849 (averaging 2352), with the lowest levels recorded in Afghanistan, Chad, Ethiopia, Madagascar and Tajikistan. The low level of food supply in Tajikistan is initially surprising given the relatively low level of poverty (6%), but may be explained by the fact that over 90% of the country is covered by mountains and cotton is the dominant agricultural commodity, rather than food products. The best performers in the group were Mali and The Gambia. Access to food is a major problem for many LICs, with more than 20% of the population experiencing undernourishment in most of these countries, with an average rate of 23%. The prevalence of undernourishment varies greatly (from a low of 5% in Mali to a high of 38% in Central African Republic), and does not appear to have any association with income level. Also surprising is that the correlation between poverty and undernourishment is very low (0.23). It seems likely that the (generally low) productivity of agriculture in largely subsistence farming regimes is a major cause of undernourishment. Figure 2-9 indicates that there is a fairly close inverse relationship between food supply per capita and undernourishment, as one would expect.

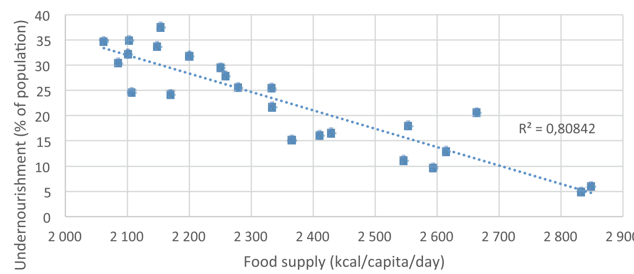
Countries' vulnerability to international food price increases depends on the extent to which they rely on food imports. The cereal import dependency ratio is high in several countries, including Liberia (61%), The Gambia (44%), Tajikistan (44%) and Zimbabwe (49%). Only Cambodia is a net cereal exporter, but marginally so. The ratio of the value of food imports to total merchandise exports is over 20% in 21 out of the 28 LICs, indicating a high degree of vulnerability to international food price increases. Three outliers were omitted from the chart: Afghanistan (258%), Eritrea (572%) and The Gambia (181%). Cambodia (6%) and Chad (4%) have the lowest vulnerability according to this indicator, in the latter case probably because merchandise exports (the denominator of this indicataor) are large as a result of significant oil exports.

Figure 2-8: Food availability (2011) and access (2013) in LICs



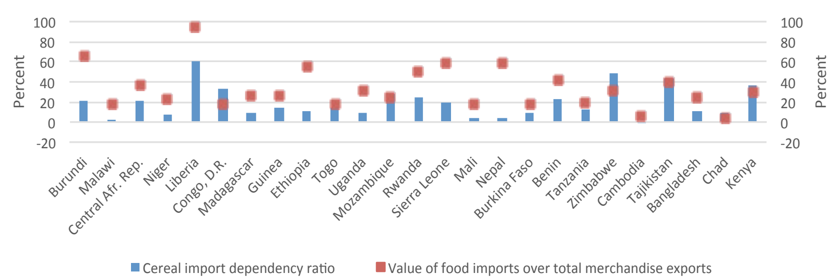
SOURCE: World Bank (2015b) and FAO (2015a)

Figure 2-9: Comparison of food supply and undernourishment in LICs



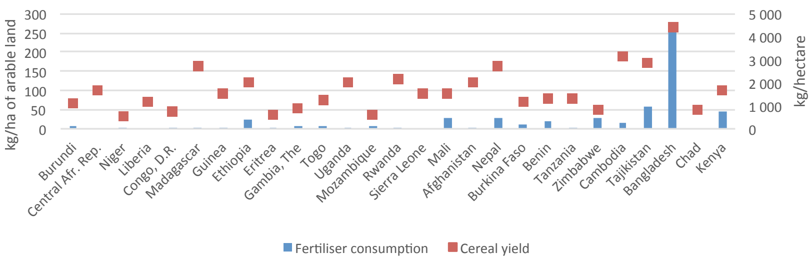
SOURCE: FAO (2015a) and World Bank (2015b)

Figure 2-10: Food import vulnerability in LICs, average for 2009–2011



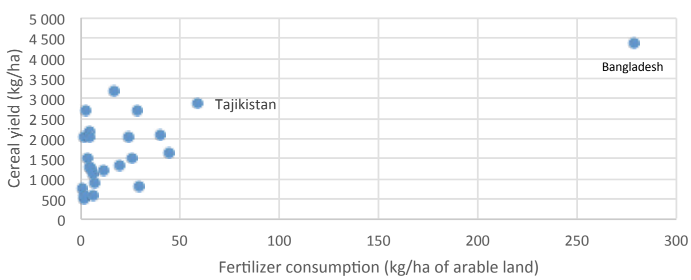
SOURCE: FAO (2015a)

Figure 2-11: Fertiliser use and cereal yields in LICs, 2012



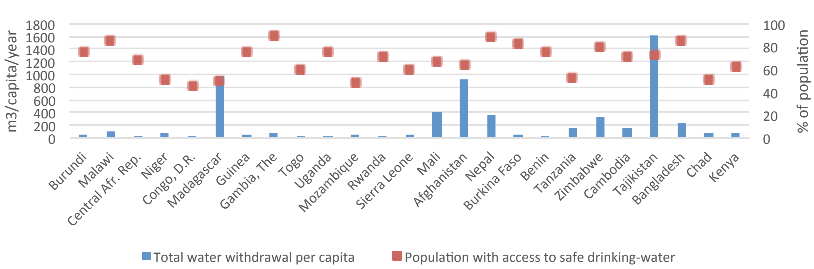
SOURCE: World Bank (2015b)

Figure 2-12: Fertiliser use and cereal yields in LICs



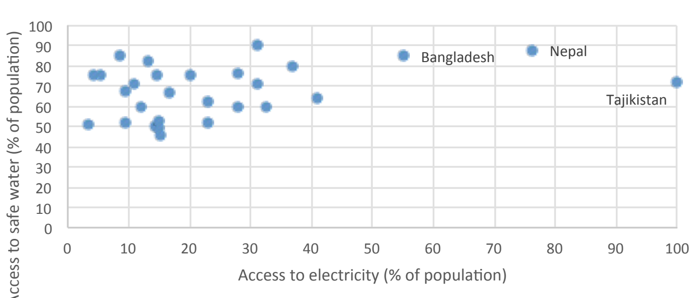
SOURCE: World Bank (2015b)

Figure 2-13: Water withdrawal per capita and access to safe drinking-water in LICs



SOURCE: FAO (2015b)

Figure 2-14: Relationship between access to safe water and electricity in LICs



SOURCE: FAO (2015b) and World Bank (2015b)

Use of fertilisers is minimal in most LICs, where much of the farming is subsistence in nature with minimal inputs. The notable exception is Bangladesh, which reportedly used 279kg of fertiliser per hectare of arable land in 2012. Cereal yields vary greatly, with the highest value again recorded in Bangladesh.

Figure 2-12 shows that there is no particular pattern in the relationship between fertiliser use and cereal yields in this group of LICs, especially if the major outliers (Bangladesh and Tajikistan) are discounted. Other factors like rainfall and soil quality are no doubt important determinants of crop yields.

Water withdrawal per capita is at very low levels in most LICs, apart from Afghanistan (which has low rainfall and thus relies heavily on abstracted water), Madagascar and Tajikistan (a mountainous country with significant hydropower capacity). The percentage of the population with access to safe drinking water varies from 46% in the Democratic Republic of Congo to 90% in The Gambia. There is no particular association between either indicator and income level (the countries are ranked according to income level on the horizontal axis). Access to water is also not strongly (negatively) correlated with poverty (-0.24), as one would expect. As with electricity, basic household water security is a major challenge for most of these countries, especially those in sub-Saharan Africa.

The scatter diagram in Figure 2-14 reveals no particular association between rates of access to safe drinking-water and electricity amongst LICs, even if one disregards the three outliers that have significantly higher rates of electrification (Bangladesh, Nepal and Tajikistan). The low rates of electricity access among the remaining countries is the most notable feature of this chart, and is partially explained by low levels of economic development and income per capita.

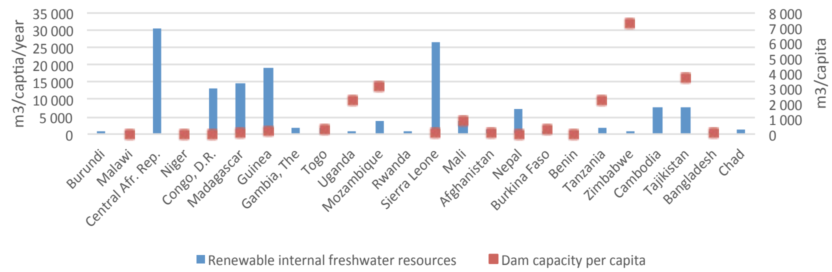
The availability of renewable freshwater resources on a per capita basis varies enormously, and is highest amongst several West and Central African countries (including Central African Republic, D.R. Congo, Guinea and Sierra Leone). Dam capacity is generally low, as expected in poor countries with low levels of water infrastructure development, with some notable exceptions such as Zimbabwe (benefitting from the massive Kariba Dam on the Zambezi River), Mozambique (with the Cahora Basa dam on the Zambezi) and Tajikistan. Those countries without much dam capacity are especially vulnerable to droughts and climatic instability.

Countries with high levels of water withdrawals relative to their internal resources (such as Afghanistan, Bangladesh, Niger and Zimbabwe) are particularly vulnerable to climate change and droughts. Water productivity is low in many LICs, probably reflecting the lack of high-value industries (such as manufacturing and services) that typically generate substantial value added (GDP) per unit of water use. Agriculture, the dominant sector in many of these LICs, typically uses large volumes of water but yield relatively low-value products.

Indeed, agriculture accounts for the largest share of freshwater withdrawals for most of this group. Exceptions include the Central African Republic, the Democratic Republic of the Congo and several West African nations, where domestic use reportedly dominates (presumably because agriculture is sustained by very high rainfall levels). Industry generally accounts for a very small share of water use, which is understandable given the very limited industrialisation of these countries' economies. The major challenge facing LICs is how to sustainably increase water availability to the entire population as well as to the agriculture and industry sectors as they grow and develop.

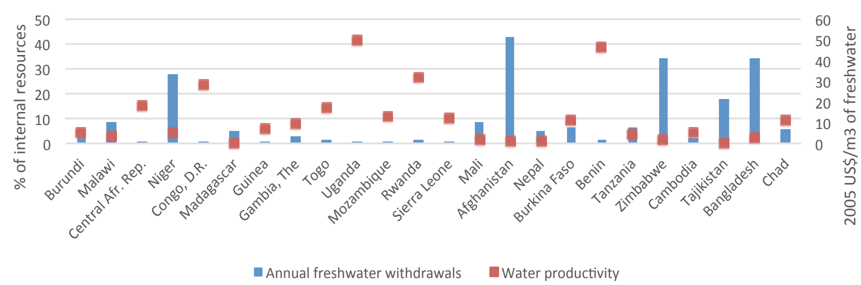
In 11 of the 28 LICs, more than 2% of the population was affected by droughts, floods or extreme temperatures between 1990 and 2009. When compared to the data for LMICs and UMICs (see subsequent sections), the figure below reinforces the oft-quoted claim that the world's poorest countries are often those at greatest risk from climate change. East Africa contains several countries that have been affected by extreme weather events, but in general there is a high degree of variability in this vulnerability indicator.

Figure 2-15: Renewable freshwater resources (2013) and dam capacity (2010 or latest) in LICs



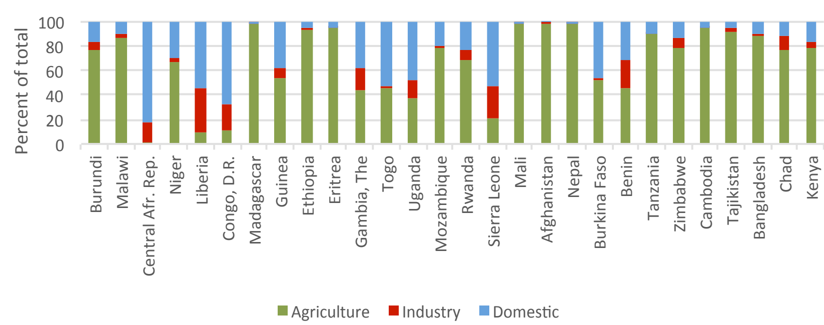
SOURCE: World Bank (2015b) and FAO (2015b)

Figure 2-16: Water withdrawals as a % of internal resources and water productivity in LICs



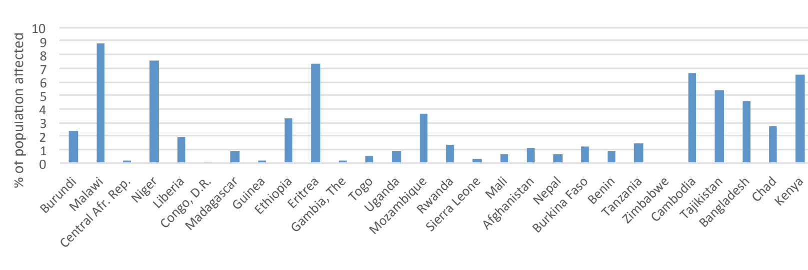
SOURCE: World Bank (2015b)

Figure 2-17: Annual freshwater withdrawals by sector in LICs, 2013



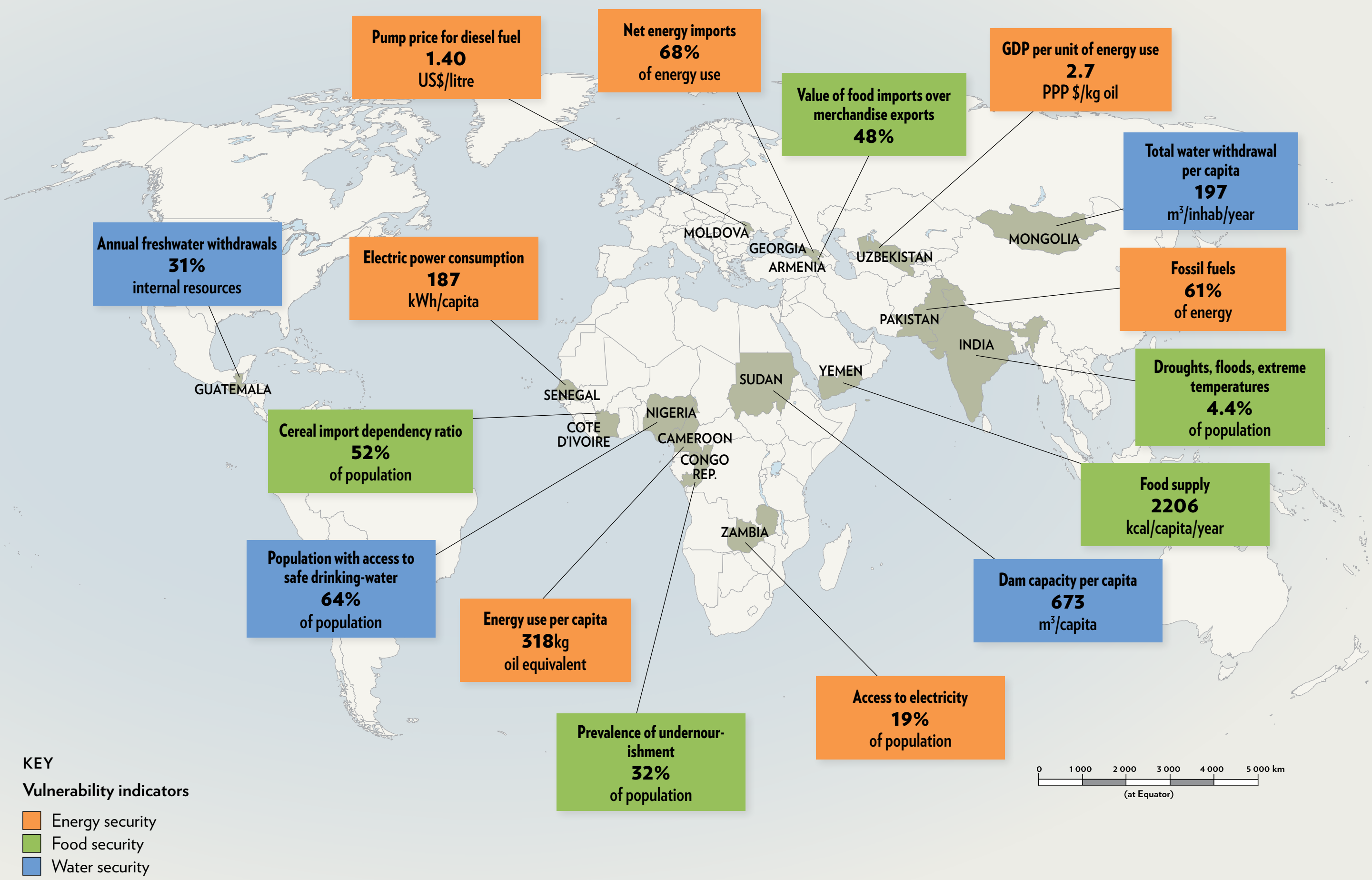
SOURCE: World Bank (2015b)

Figure 2-18: Percentage of population in LICs affected by extreme weather, average 1990–2009



SOURCE: World Bank (2015b)

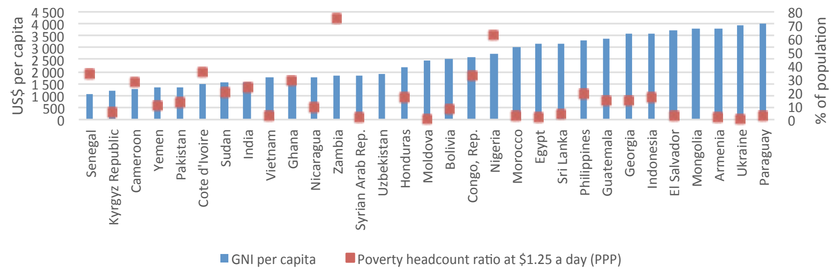
2.2.2 Lower-middle-income countries



Selected vulnerability indicators for lower-middle-income countries (Gross National Income per capita between US$1 045 and US$4 125 in 2014).

In the sample of 31 LMICs, GNI per capita ranges from US$1 050 in Senegal to US$4 010 in Paraguay. The poverty headcount ratio is 35% or less in all but two countries, namely Nigeria (62%) and Zambia (74%), which have not been very successful in spreading the major sources of national income (derived from oil and copper exports, respectively) to the general populace. Quite a number of the LMICs have achieved very low poverty rates, especially the relatively wealthier nations but also in Vietnam, Syrian Arab Republic and Moldova.

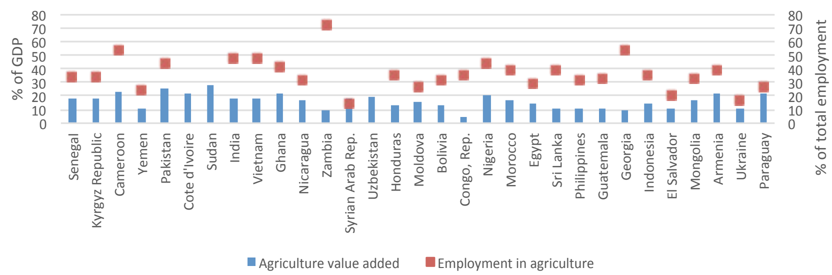
Figure 2-19: Per capita income and poverty rate in LMICs



SOURCE: World Bank (2015b)

Agriculture makes a substantial contribution to many of these economies, and accounts on average for 16% of GDP and 36% of employment. Zambia is an outlier in terms of agricultural employment (72%), even though the sector contributes just 10% to GDP – clearly showing the large extent of subsistence farming in the country. Most LMICs are evidently somewhere along a transition pathway from agrarian to industrial regimes, with between 25% and 50% of employed people deriving an income from agriculture. The Syrian Arab Republic and Ukraine are the only LMICs with less than 20% of workers in the agriculture sector. By comparison, the average share of agricultural employment in LICs is 65%.

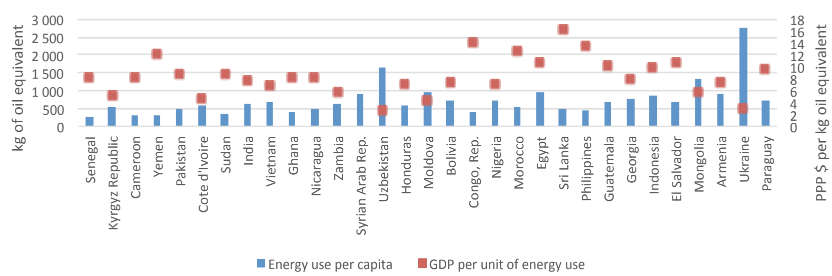
Figure 2-20: Contribution of agriculture sector in LMICs



SOURCE: World Bank (2015b)

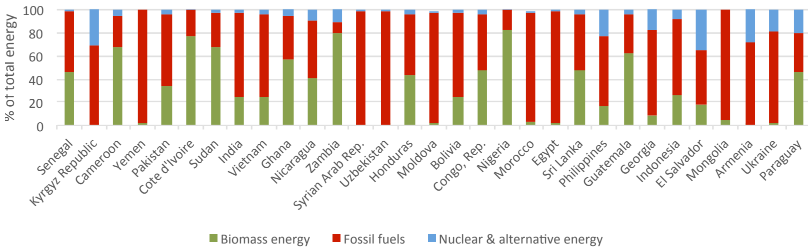
Energy use per capita ranges mostly between 300 and 1 000kg of oil equivalent, although the two former Soviet Republics of Uzbekistan and Ukraine are notable outliers (1 628kg and 2 766kg respectively). There is only a moderate association between energy use per capita and income level in this group (correlation 0.46); energy use is also determined by countries' available energy resources and energy infrastructure. Energy productivity is not correlated with incomes (0.22). In Uzbekistan and Ukraine, very high levels of energy consumption do not align with GDP levels, resulting in comparatively low energy productivity.

Figure 2-21: Energy consumption and productivity in LMICs, 2011



SOURCE: World Bank (2015b)

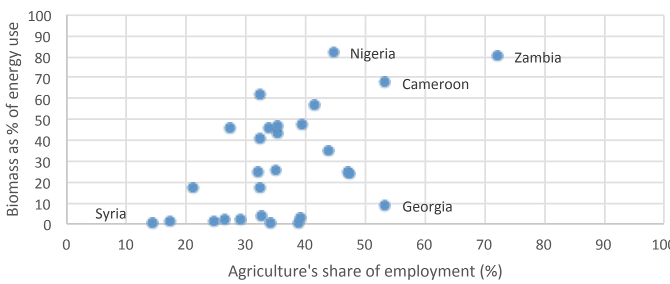
Figure 2-22: Shares of primary energy supply by major fuel type in LMICs, 2011



SOURCE: World Bank (2015b)

The composition of energy by fuel type varies greatly among LMICs. Several countries (including Cameroon, Cote d'Ivoire, Ghana, Guatemala, Nigeria, Sudan and Zambia,) rely on biomass for more than half of their energy supply (agriculture plays a large role in most of these countries). These countries are susceptible to deforestation and associated environmental problems. Fossil fuels comprise the largest share of energy for most in this group, and for more than 90% in several of these countries (Egypt, Moldova, Mongolia, Morocco, Syrian Arab Republic, Uzbekistan, Yemen). A high degree of reliance on fossil fuels implies a vulnerability to oil (and associated gas and coal) price shocks, except in the case of fossil-fuel exporters that subsidise domestic prices.

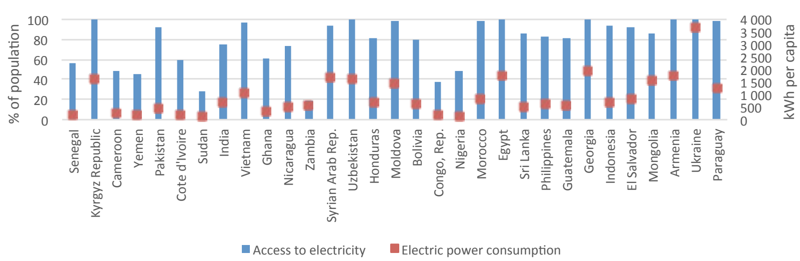
Figure 2-23: Reliance on biomass energy and agricultural employment in LMICs



SOURCE: World Bank (2015b)

The comparison of reliance on biomass energy and agriculture's share of employment reveals a generally different pattern from the LICs, in that the distribution is mainly clustered around 20-50% employment in agriculture and less than 50% of energy derived from biomass. The values of these indicators for Zambia, Cameroon and Nigeria are more typical of LICs; these countries' per capita incomes are probably skewed upwards by mineral exports (copper in the case of Zambia and oil in the latter two countries).

Figure 2-24: Electricity access (2010) and consumption (2011 or latest) in LMICs



SOURCE: World Bank (2015b)

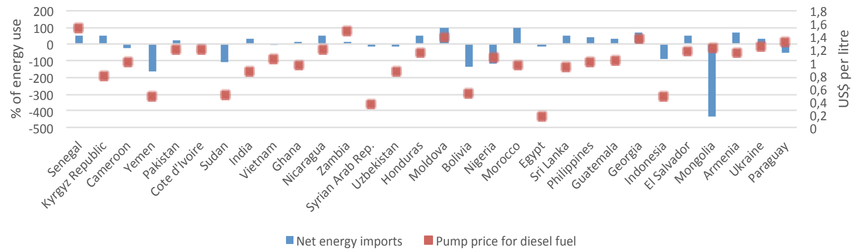
Electricity access is highly variable across LMICs, ranging from 19% in Zambia to 100% in Kyrgyz Republic (which makes use of its mountainous terrain and abundant water supplies to generate hydropower in excess of domestic requirements). Levels of electricity consumption are generally quite low (between 1 000 and 2 000kWh/capita), with the notable exception of Ukraine (3 662kWh/capita), whose heavy industrial sector and residential sector both consume large quantities of energy derived from coal, gas (imported from Russia) and nuclear power. Both electricity access and consumption are moderately correlated with income per capita (0.46 and 0.49, respectively). Electricity access is inversely related to poverty (-0.79). The chart demonstrates that household energy security, in terms of access to sufficient quantities of modern energy, is still a major challenge for many countries in this group.

The LMIC group includes several countries that are significant net energy exporters (Bolivia, Indonesia, Nigeria, Paraguay, Sudan and Yemen),[19] but also some nations that rely heavily on energy imports (Georgia, Kyrgyz Republic, Moldova, Morocco and Senegal). Diesel prices are highly variable, partly due to substantial subsidies in several oil-producing countries such as Bolivia, Egypt, Indonesia, Sudan, Syria and Yemen. Egypt and Indonesia, however, are net oil importers and high oil prices put severe strain on government budgets. Senegal and Zambia are among the countries where diesel has a relatively high cost, in the latter case partly because of Zambia's landlocked status and underdeveloped transport infrastructure.

Daily food supply ranges from 1 907kcal in Zambia to 3 557kcal in Egypt, with an average of 2 633kcal, and this does not appear to correlate much with income level. These levels of calorie intake indicate a lack of nutritional food security in many countries, which is further supported by undernourishment affecting more than 10% of the population in all but eight in this group. Zambia (48% undernourished) is once again an outlier; in fact in many respects its indicators are more like that of lower-income countries, with the exception of its per capita income level.

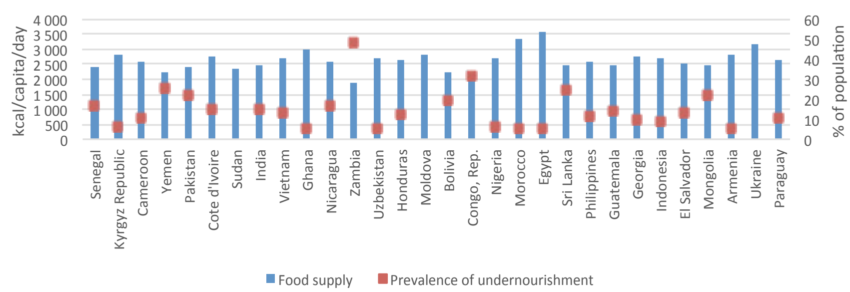
Figure 2-27 reveals a clear negative relationship – with an exponential curve – between food supply and undernourishment. Zambia is a clear outlier for the LMIC group, but is not far from a projected curvilinear trend. Egypt and Morocco lie on the opposite end of the scale, with relatively high levels of food supply and minimal undernourishment. In Egypt, the government subsidises bread prices.

Figure 2-25: Energy vulnerabilities in LMICs: net energy imports (2011) and diesel price (2012)



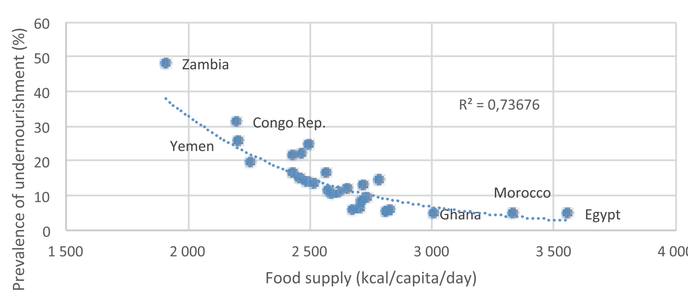
SOURCE: World Bank (2015b)

Figure 2-26: Food availability (2011) and access (2013) in LMICs



SOURCE: FAO (2015a) and World Bank (2015b)

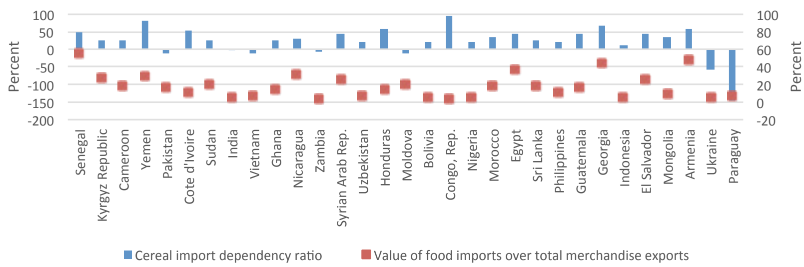
Figure 2-27: Food supply and undernourishment in LMICs



SOURCE: FAO (2015a) and World Bank (2015b)

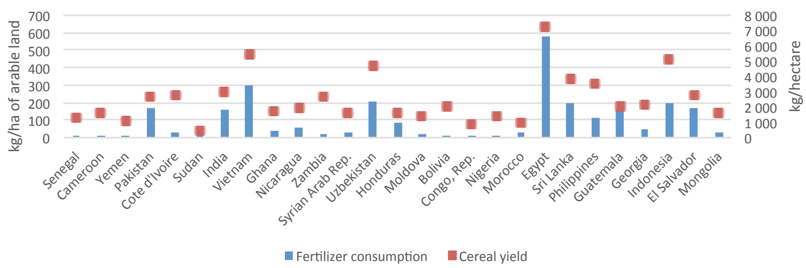
19 Mongolia (not shown) is an outlier, with net energy exports (coal) amounting to 435% of energy use.

Figure 2-28: Food import vulnerability in LMICs, average for 2009-2011



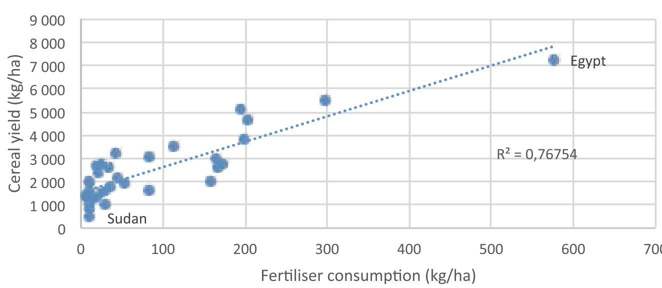
SOURCE: FAO (2015a)

Figure 2-29: Fertiliser consumption and cereal yields in LMICs



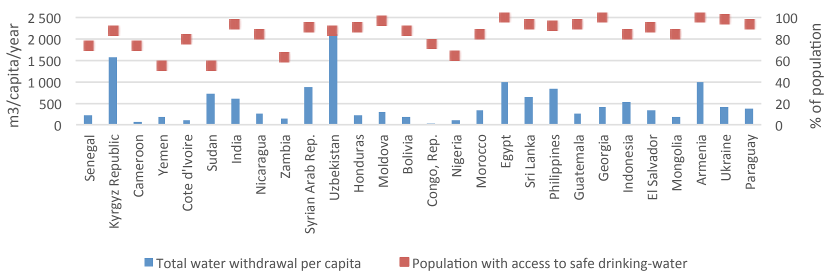
SOURCE: World Bank (2015b)

Figure 2-30: Fertiliser use and cereal yields in LMICs



SOURCE: World Bank (2015b)

Figure 2-31: Water withdrawal per capita and access to safe drinking-water in LMICs



SOURCE: FAO (2015b)

Most LMICs are net cereal importers (aside from India, Moldova, Pakistan, Paraguay, Ukraine and Vietnam), leaving them at risk of events that push up grain prices, such as oil price spikes and extreme weather events in major grain producing countries. Several of the group members (such as Armenia, Egypt, Georgia, Senegal and Yemen) are vulnerable to food price increases, as the value of their food imports is more than 20% of their merchandise exports. Egypt in particular suffered greatly from the food price spikes in 2007-2008 and 2011; the latter may have contributed to the political ructions experienced in that year (Biello, 2011).

Fertiliser consumption on a per capita basis is minimal in about half of the group, but extremely high in Egypt and fairly high in grain exporting countries like India, Pakistan, Uzbekistan and Vietnam. In this group, cereal yields vary greatly.

Figure 2-30 shows more clearly that cereal yields tend to be higher in countries that make extensive use of fertilisers, although there is considerable variability around the trend. Countries that rely heavily on fertilisers to boost grain yields (e.g. Egypt, Pakistan and Vietnam) are vulnerable to international fertiliser price increases, which may result from energy price hikes. Interestingly, Egypt's neighbour Sudan is at the opposite end of the scale, with very low levels of fertiliser use and cereal yield.

Water security in terms of availability and access are shown in the chart below. Water withdrawal per person varies enormously, although it stands at less than 500m3/capita/year in most countries; the level does not appear to be related to income per capita, but is probably determined by rainfall and water resource availability. The rate of access to safe drinking water, a critical indicator of water security, is over 80% in all but seven of the countries (Cameroon, Nigeria, Republic of Congo, Senegal, Sudan, Yemen and Zambia). In the case of water access, national income per head does appear to play a positive role in general.

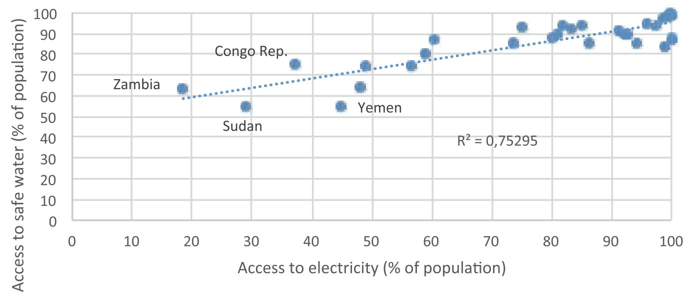
There is a strong positive relationship between access to electricity and access to safe drinking-water in LMICs (Figure 2-32). Both indicators reflect the extent to which countries have overcome poverty and built the infrastructure required to provide access to basic services.

When it comes to renewable internal freshwater resources, there are a few outliers and a high degree of variability among this group. A few countries have very substantial dam capacity per capita (Egypt, Ghana, Nicaragua, Paraguay and Zambia), but for most the volume is small, indicating vulnerability if rainfall or river flows are erratic.

The countries that are most vulnerable in terms of the amount of their annual water withdrawals relative to available internal resources include Egypt (with a ratio of 3 974%, not shown), Pakistan, Syria, Sudan, Uzbekistan and Yemen, for which the ratio is more than 100%. Water productivity is highly variable, with the highest figures all recorded in West African nations (Cameroon, Congo Republic [not shown as the outlying value is 190], Cote d'Ivoire, Ghana and Nigeria) situated in the equatorial zone. Aside from Cote d'Ivoire, these countries are notable oil exporters; the oil industry creates substantial economic value with low water requirements relative to many other industries. Several countries that rely heavily on water for irrigation of major crop production have low water productivity (such as India, Pakistan, Sudan and Vietnam).

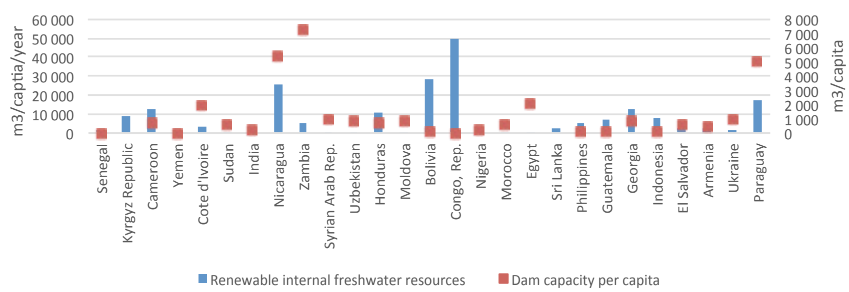
Agriculture accounts for most water use in many of the LMICs, with Moldova and Ukraine (where industry dominates) and Republic of Congo and Cote d'Ivoire (where the domestic sector consumes the largest share) being the exceptions.

Figure 2-32: Access to electricity and safe water in LMICs



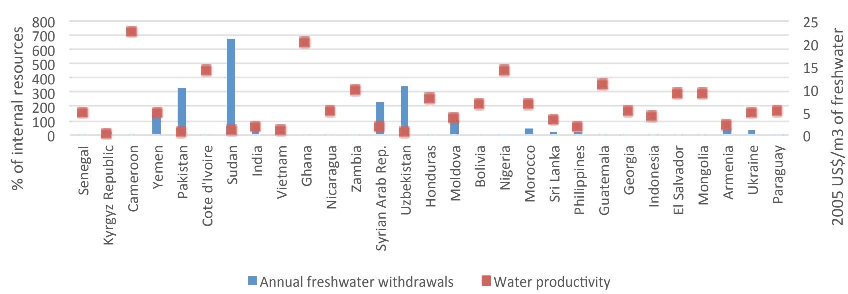
SOURCE: FAO (2015b)

Figure 2-33: Renewable freshwater resources (2013) and dam capacity (2010 or latest) in LMICs



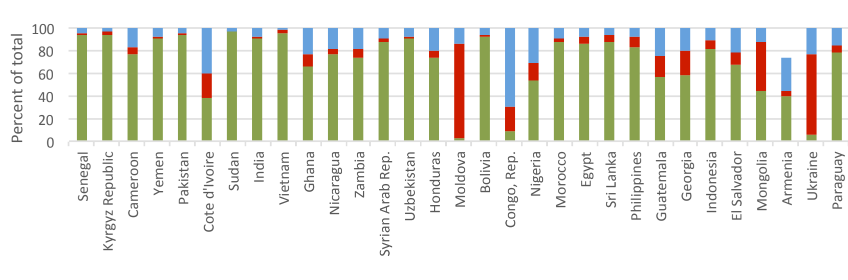
SOURCE: FAO (2015b) and World Bank (2015b)

Figure 2-34: Water withdrawals as a % of internal resources and water productivity in LMICs



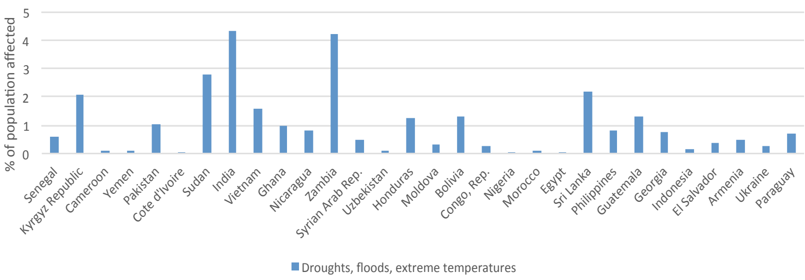
SOURCE: World Bank (2015b)

Figure 2-35: Annual freshwater withdrawals by sector in LMICs, 2013



SOURCE: World Bank (2015b)

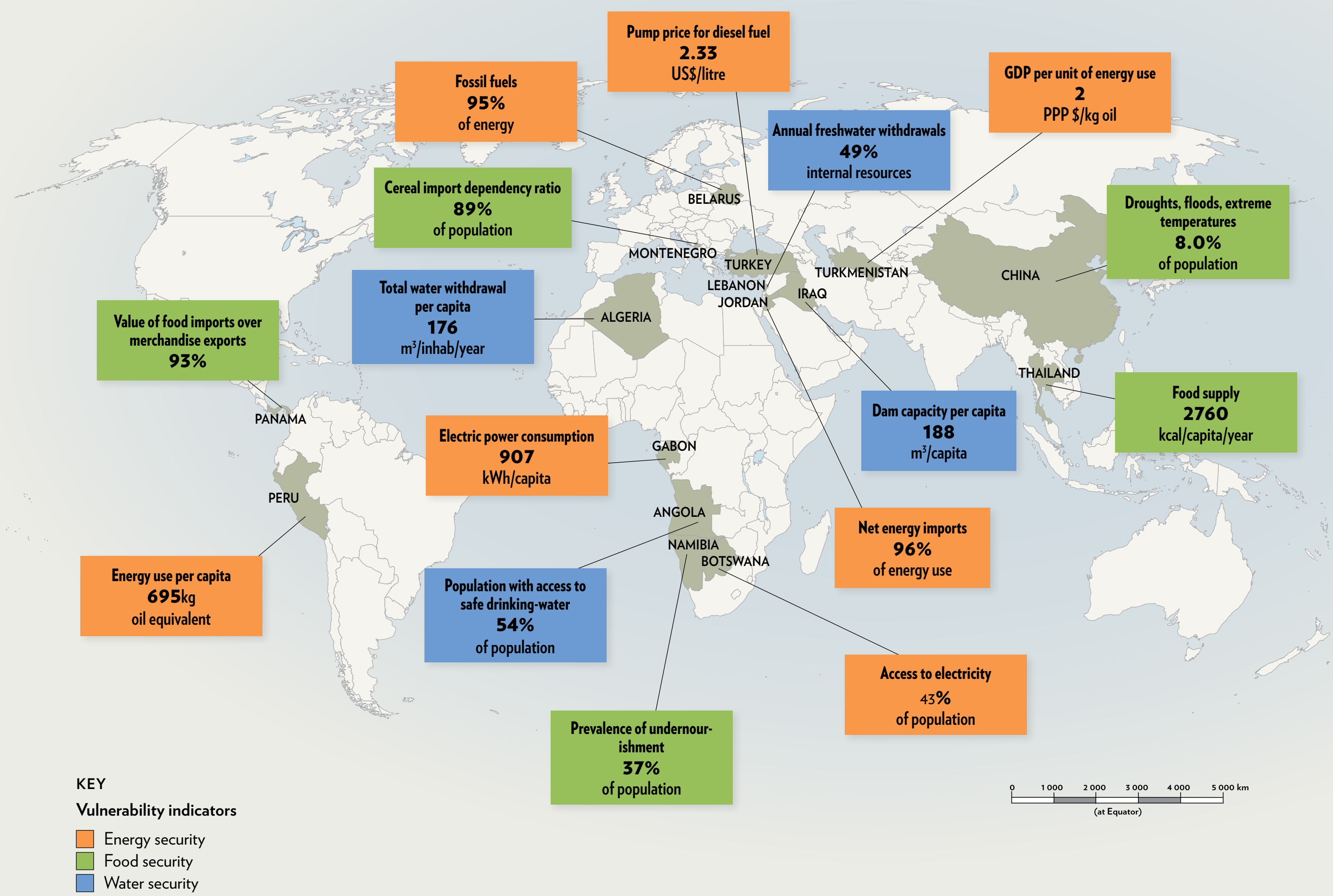
Figure 2-36: Percentage of population in LMICS affected by extreme weather, average 1990-2009



SOURCE: **World Bank (2015b)**

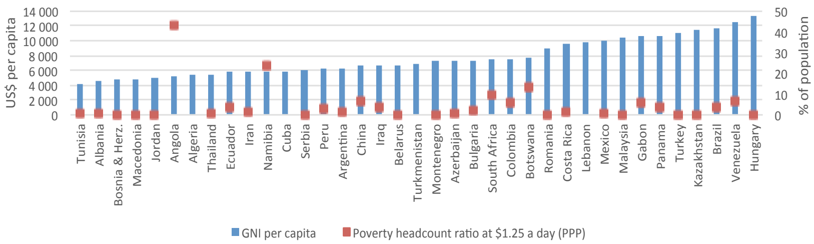
The figure alongside shows the extent to which people living in these countries were affected by extreme weather events between 1990 and 2009. India, Kyrgyz Republic, Sri Lanka, Sudan and Zambia were the worst affected, with more than 2% of the population experiencing droughts, floods or extreme temperatures.

2.2.3 Upper-middle-income countries



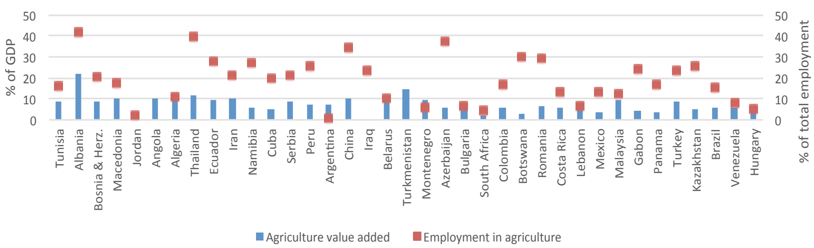
Selected vulnerability indicators for upper-middle-income countries (Gross National Income per capita between US$4 126 and and US$12 736 in 2014).

Figure 2-37: Per capita income and poverty rate in UMICs



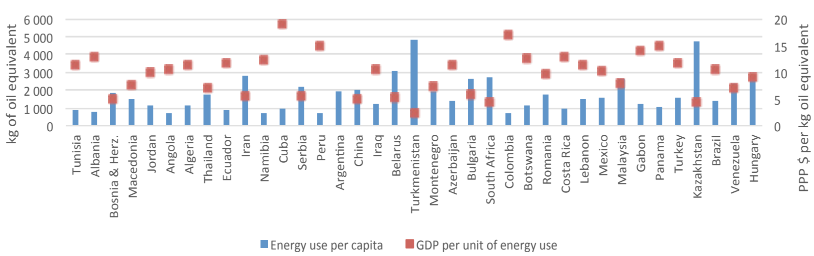
SOURCE: World Bank (2015b)

Figure 2-38: Contribution of agriculture sector in UMICs



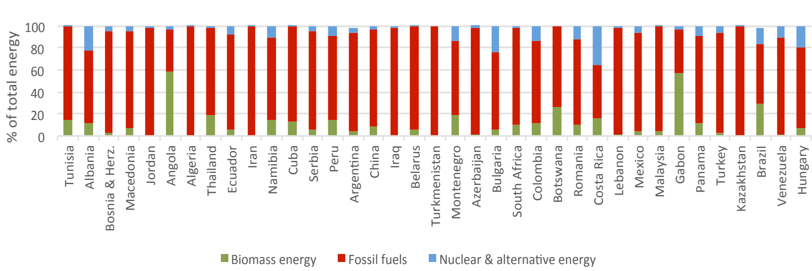
SOURCE: World Bank (2015b)

Figure 2-39: Energy consumption and productivity in UMICs, 2011



SOURCE: World Bank (2015b)

Figure 2-40: Shares of primary energy supply by major fuel type in UMICs, 2011



SOURCE: World Bank (2015b)

In our sample of 37 UMICs, GNI per capita varies from US$4 200 in Tunisia to US$13 260 in Hungary. Poverty rates (at the US$1.25/day level) are very low (less than 7%) in most countries in this group, with the exception of several southern African countries, namely Angola (43%), Botswana (13%), Namibia (24%) and South Africa (9%) – all countries with very high levels of income inequality.

The agriculture sector plays a relatively minor economic role in most UMICs, accounting for less than 15% of GDP in all but Albania and Turkmenistan. However, agriculture accounts for more than 20% of total employment in sixteen of these countries (reaching 42% in Albania, 40% in Thailand and 38% in Azerbaijan). In general, countries with higher income levels have diversified their economies away from agriculture to a greater extent (the countries to the right of the graph, with higher per capita incomes, generally have proportionately smaller agriculture sectors as a percentage of GDP).

Energy use per person varies considerably, from as low as 673kg oil equivalent per person in Angola to 4 839kg in Turkmenistan and 4 717kg in Kazakhstan. There is no general rule apparent whereby average energy consumption levels are high in countries with large energy resources. On the contrary, Angola (Africa's second largest oil exporter), Algeria (a major oil and gas exporter) and Ecuador (an oil exporter) all have low per capita energy consumption. Energy productivity (GDP per unit of energy use) is also highly variable, with Cuba, Colombia and Peru recording the highest levels and Turkmenistan, Kazakhstan, Belarus and China, the lowest.

UMICs are overwhelmingly dependent on fossil fuels as the major source of energy. Two notable exceptions are Angola and Gabon, which, despite their substantial oil reserves and production, each rely on biomass for 58% of domestic energy consumption. This is largely due to inequality in access to modern energy and the extensive poverty in these countries. Brazil derives a comparatively large share of energy from biomass (29%), but this includes a massive bioethanol industry, which is considered a modern rather than a traditional energy source.

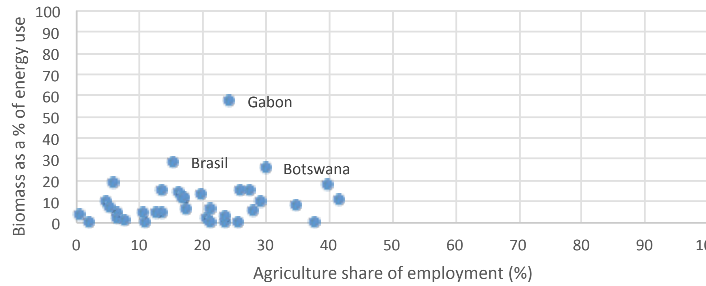
The scatterplot of biomass usage and agriculture's share of employment for UMICs shows a very different pattern to that of LICs (see Figure 2-5). With the exception of Gabon,[20] the UMICs are all clustered in the lower left quadrant, whereas almost all LICs are in the upper right quadrant of the respective chart. As can be expected, LMICs (Figure 2-23) fall largely in between the other groups.

Most countries in this group have achieved near-universal access to electricity. However, access rates remain low in Angola (35%), Botswana (43%) and Namibia (44%), three countries with highly unequal income distributions and extensive poverty. Actual per capita electricity consumption differs markedly across the group, from 248kWh per person in Angola to 5 747kWh per person in Montenegro. Electricity access and consumption are not as highly correlated (0.38) as one might expect. Actual power consumption depends not only on access, but also on electricity prices, the amount of generating capacity, and the energy-intensity of the country's industries, amongst other factors.

In terms of dependence on energy imports, the most vulnerable countries in this group are Jordan (96%), Lebanon (97%), Namibia (79%) and Panama (80%). However, UMICs include several major energy exporters, including Angola, Algeria, Azerbaijan, Colombia, Gabon, Iraq, Turkmenistan and Venezuela. Diesel prices are very low in several oil-producing states (such as Algeria, Ecuador, Iran and Venezuela) that subsidise fuel prices, and are highest in several eastern European countries (which tend to impose substantial fuel taxes).

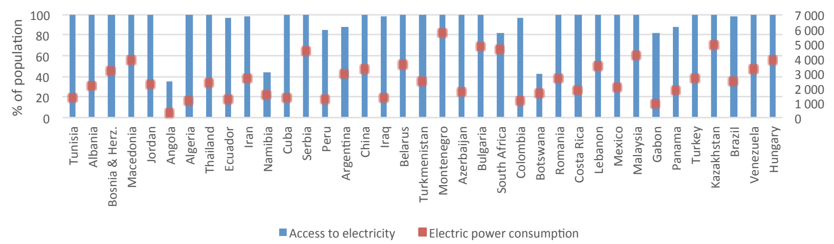
The average food supply is over 2 500 kcal/capita/day in most UMICs, indicating a reasonably good level of food availability. However, several southern African countries are lagging behind. Undernourishment affects around 5% of the population in most countries, with some notable outliers such as Angola (18%), Botswana (27%), Iraq (24%) and Namibia (37%).

Figure 2-41: Reliance on biomass and agriculture's share of employment in UMICs



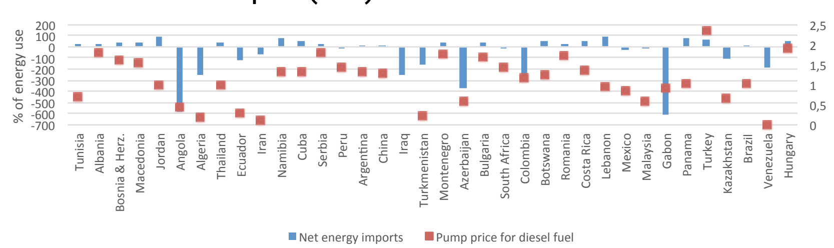
SOURCE: World Bank (2015b)

Figure 2-42: Electricity access (2010) and consumption (2011 or latest) in UMICs



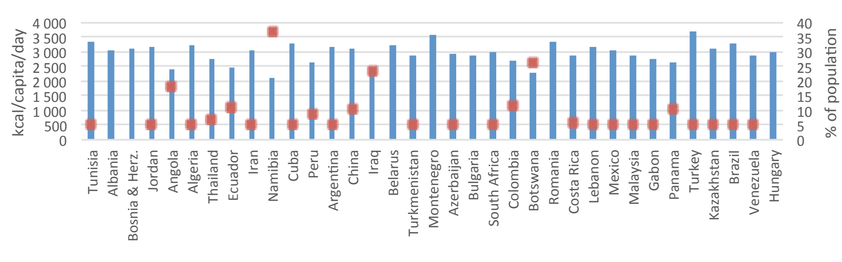
SOURCE: World Bank (2015b)

Figure 2-43: Energy vulnerabilities in UMICs: net energy imports (2011) and diesel price (2012)



SOURCE: World Bank (2015b)

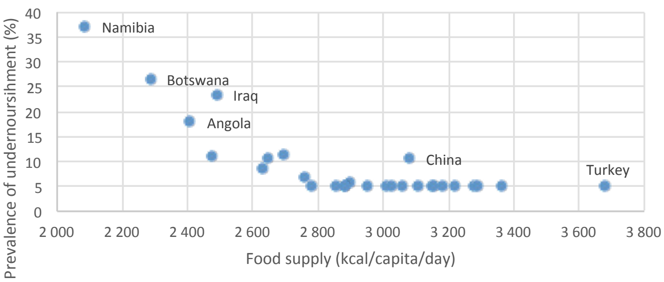
Figure 2-44: Food supply (2011) and access (2013) in UMICs



SOURCE: FAO (2015a) and World Bank (2015b)

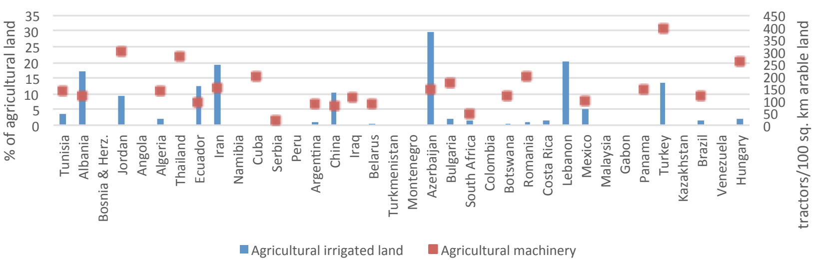
20 Angola (with 58% biomass usage) is not shown because data for employment in agriculture is not available.

Figure 2-45: Relationship between food supply and undernourishment in UMICs



SOURCE: FAO (2015a) and World Bank (2015b)

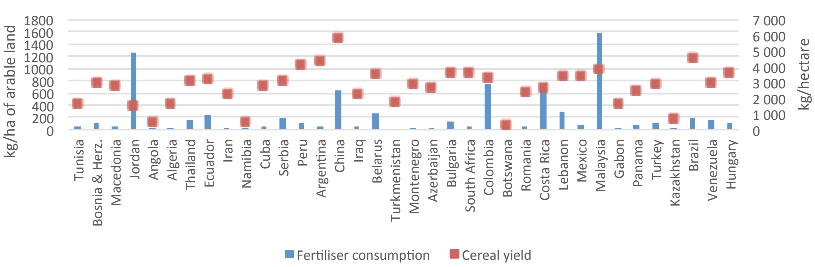
Figure 2-46: Agricultural irrigation and machinery in use in UMICs



SOURCE: World Bank (2015b)

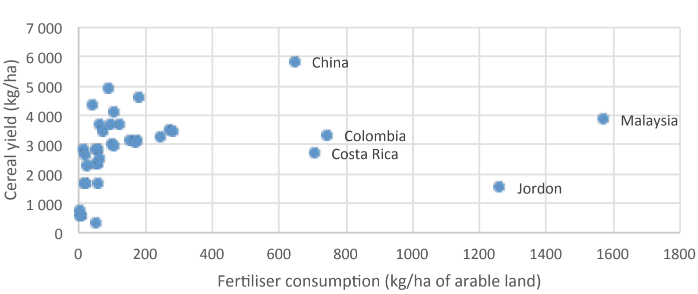
NOTE: Irrigation data is for 2012 or latest; tractors in use is the latest data from 2005-2008.

Figure 2-47: Fertiliser consumption and cereal yields in UMICs



SOURCE: World Bank (2015b)

Figure 2-48: Comparison of fertiliser use and cereal yields in UMICs



SOURCE: World Bank (2015b)

Figure 2-45 shows a fairly close negative relationship between per capita food supply and the prevalence of undernourishment: as food supply rises, undernourishment falls until a threshold of about 2800 kcal/capita/day. This is a similar pattern to that found for LMICs (Figure 2-27).

There is extraordinary variability in both the percentage of agricultural land that is irrigated and the use of tractors per km^2 of arable land. Drier countries such as Azerbaijan, Iran, Lebanon and Turkey rely heavily on irrigation (and hence the energy used to power it, usually electricity).

Fertiliser consumption is relatively low in most UMICs, but a few countries are highly dependent (China, Colombia, Costa Rica, Jordan and Malaysia). Countries with the highest cereal yields per hectare include major producers such as Argentina, Brazil and China, as well as Bulgaria, Hungary and Serbia. Botswana and Namibia are both extremely arid countries and hence it is not surprising their cereal yields are very low, but Angola is evidently performing far below its potential, partly as a legacy of the decades-long civil war that ended in 2002.

The scatter diagram (Figure 2-48) shows that there is no evident correlation between fertiliser consumption and cereal yield, as one might expect. This could be because other country-specific determinants of crop yields such as climate, rainfall, extent of irrigation and soil quality are more important. China has had the most success in converting extensive use of fertilisers into high cereal yields. Malaysia produces several non-cereal crops such as palm oil, rubber and bananas, so extensive fertiliser use for these crops would help to explain its outlier status.

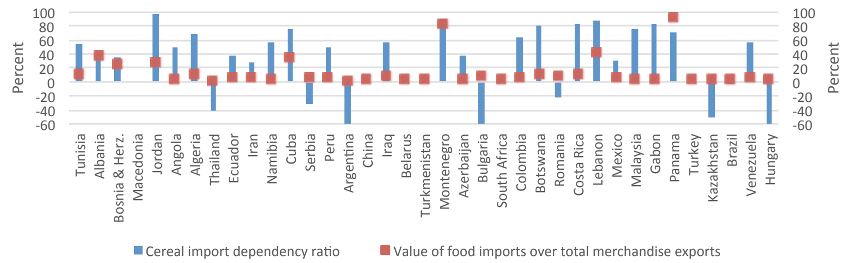
A number of countries are highly dependent on cereal imports for over 50% of their consumption, but there seven that are significant net cereal exporters.[21] The value of food imports over total merchandise exports is modest in most countries, with some major outliers like Cuba, Lebanon, Montenegro and Panama. These countries are therefore more vulnerable to global food price shocks.

Water withdrawal is under 500m3 per capita in most countries in this group, although it is very high in two arid Middle Eastern countries (Iran and Iraq) as well as Thailand (an intensive rice cultivator), Azerbaijan and Kazakhstan (the latter is a major wheat producer). Most have achieved fairly high rates of access to safe drinking water (above 85%), although Angola is struggling to achieve water security with just 54% enjoying access to safe water.

Comparing access to electricity and safe drinking-water, it is clear that the vast majority of UMICs have attained high rates of access in both areas. The major exceptions are once again the Southern African countries (Angola, Botswana and Namibia) where poverty is still a major problem.

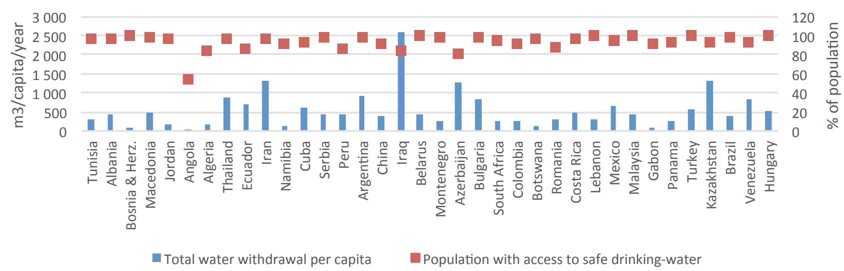
The extent of renewable freshwater resources and dam capacity per capita are both characterised by low levels for most UMICs and much higher levels for a few outliers. The South American nations of Brazil, Columbia, Ecuador, Peru and Venezuela clearly all benefit from high rainfall in the Amazon basin, while Gabon in Africa also experiences equatorial rainfall. Argentina, Brazil, China and Kazakhstan have all invested heavily in dams. Several arid countries (such as Botswana, Iran, Jordan, Lebanon and Namibia) are highly vulnerable to water shortages as they score low on both indicators.

Figure 2-49: Food import vulnerability in UMICs, average for 2009–2011



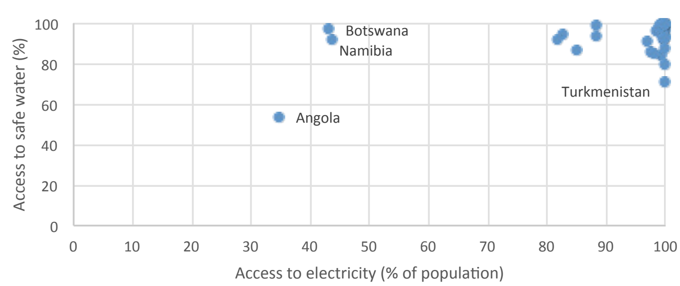
SOURCE: FAO (2015a)

Figure 2-50: Water withdrawal per capita and access to safe drinking-water in UMICs



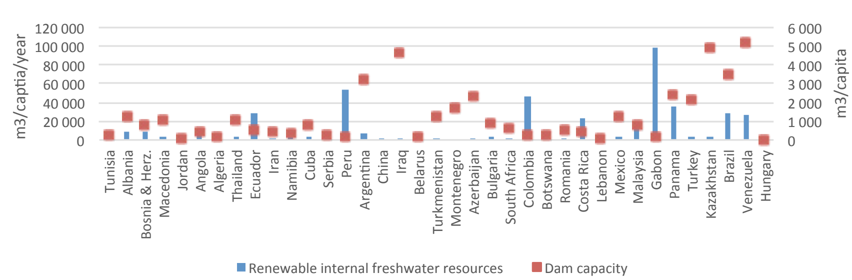
SOURCE: FAO (2015b)

Figure 2-51: Access to electricity and safe water in UMICs



SOURCE: FAO (2015b) and World Bank (2015b)

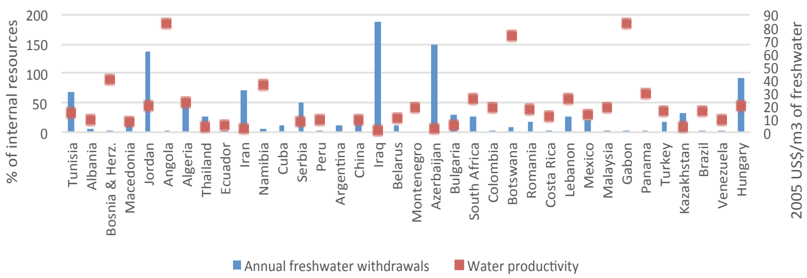
Figure 2-52: Renewable freshwater resources (2013) and dam capacity (2010 or latest) in UMICs



SOURCE: FAO (2015b) and World Bank (2015b)

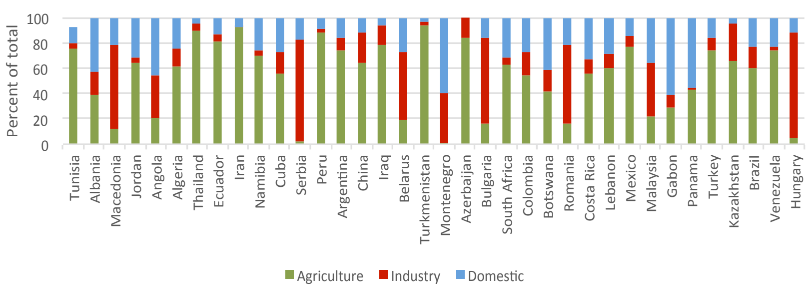
21 The following observations for cereal import dependency are truncated on the chart to make it readable: Argentina -169; Bulgeria -92; Hungary -81.

Figure 2-53: Water withdrawals as a % of internal resources and water productivity in UMICs



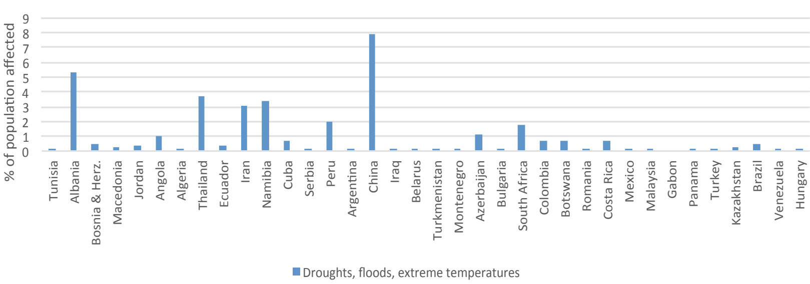
SOURCE: World Bank (2015b)

Figure 2-54: Annual freshwater withdrawals by sector in UMICs, 2013



SOURCE: World Bank (2015b)

Figure 2-55: Percentage of population in UMICs affected by extreme weather, average 1990-2009



SOURCE: World Bank (2015b)

The countries exploiting their water resources most intensively – and hence more vulnerable to climatic variations – include several arid nations (Azerbaijan, Iraq, Iran, Jordan and Tunisia).[22] Water productivity is highest in several African countries – perhaps because they have meagre water resources (Botswana and Namibia) or because the oil sector dominates the economy and does not use much water (Angola and Gabon).

The allocation of water among agriculture, industry and domestic uses is highly variable across countries in this group. Industry dominates in several Eastern European countries (Belarus, Hungary, Macedonia and Serbia), while services account for the largest share of water use in Albania, Angola, Gabon, Montenegro and Panama. There is no correlation between agriculture's share of water use and its percentage contribution to GDP in this sample.

On average, more than 2% of the population in five UMICs was affected by droughts, floods and extreme temperatures between 1990 and 2009, namely Albania, China, Iran, Thailand and Namibia.

22 Turkmenistan's renewable freshwater resources of 1989 m^3/capita/year are not shown in order to make the other observations visible.

2.2.4 Comparison of indicator averages for country groups

Table 2-6 presents average values of the energy-food-water nexus indicators across three country categories (low-income, lower-middle-income and upper-middle-income). As expected, the poverty rate is much higher on average in LICs (50%) than among LMICs (17%) and UMICs (4%). Agriculture contributes on average about a third of GDP in the poorest category of countries, but only half of this (16%) in LMICs and half again (8%) in UMICs. The situation is similar in respect of the percentage of the population employed in agriculture: on average, nearly two-thirds of people in LICs are employed in agriculture, one-third in LMICs and 19% in UMICs. These averages show that LICs on the whole fall mainly within the agrarian regime, while LMICs are in the process of transitioning and UMICs are even further down the road of economic diversification and development, with agriculture playing a minor role on average. Of course, as noted in previous sections, there are exceptions to these averages.

Energy security indicators

Several energy security indicators follow the pattern of income levels (at least on average for the three groups), including energy use per person, the percentage reliance on fossil fuels for energy supply, access to electricity, and electric power consumption per capita. Interestingly, energy productivity (measured by GDP per unit of energy use) rises with income level, with the average for UMICs double that for LICs. This reflects both the inefficiency of biomass as an energy source (used mainly in LICs for household cooking) and the low economic productivity of agriculture compared to industry and services powered by electricity and fossil fuels. LICs on average are marginal net energy importers, while the other two groupings are on average significant net energy exporters – the summary statistics being strongly influenced by several major oil-exporting countries. It is noteworthy that poorer countries on average face significantly higher prices for diesel, especially compared to LMICs; this is partly because the LIC group does not include any significant oil-exporting countries (which tend to subsidise domestic petroleum prices).

Food security indicators

Average food security status is also positively associated with income level. The average food supply per capita is 25% higher in UMICs than among low-income countries, while the percentage of the population with adequate nourishment also rises with income level. The average use of tractors and fertilisers increases dramatically with income level, reflecting a shift from minimal input traditional (largely subsistence) farming in LICs to fossil fuel-powered industrial agriculture in many LMICs and UMICs. The percentage of agricultural land under irrigation is, somewhat counter-intuitively, smaller in UMICs than in the other two categories. Cereal yields and the average value of food production per person also rise with income level, possibly reflecting the greater use of modern productive inputs. The cereal import dependency ratio rises slightly with income level (possibly because wealthier countries can afford to import more grains and there is less subsistence agriculture), although the average value of food imports relative to total merchandise exports is much higher in LICs (66%) than in LMICs (18%) and UMICs (14%). On average, people in LICs happen to have been affected by droughts, floods and extreme temperatures to a greater extent than those in the wealthier developing countries, which compounds their food security vulnerabilities. Their low income levels constrain their ability to cope with such natural disasters.

Water security indicators

As with energy and food, water security indicators tend to improve with income level. Water withdrawal per capita is more than three times higher on average in UMICs than in LICs, while access to safe drinking water is considerably higher (93% compared to 68%). Renewable internal freshwater resources are notably larger on average in UMICs than in the other two categories. Dam capacity does not differ markedly between LMICs and UMICs, which is somewhat surprising as richer countries should be able to afford to construct more dams. Average dam capacity per capita is notably lower in LICs, as expected. Water productivity (measured by GDP per cubic metre of water use) is substantially higher in UMICs, which probably reflects the fact that industry and services generally use less water per unit of economic value than agriculture, which, as noted earlier, plays a greater role in poorer economies. Indeed, the share of water withdrawal used in agriculture is considerably smaller in UMICs (54%) than in LICs (67%) and LMICs (70%). On average, UMICs allocate a much larger share of water resources to industry than the other income groups.

Table 2-6: Average values of indicators across country categories

Indicator	Units	LICs	LMICs	UMICs
SOCIOECONOMIC				
Poverty headcount ratio at US$1.25 a day (PPP)	% of population	50	17	4
Agriculture value added	% of GDP	32	16	8
Employment in agriculture	% of total employment	65	36	19
ENERGY SECURITY				
Energy use per capita	kg oil equivalent	364	738	1 753
GDP per unit of energy use	PPP $/kg oil	5	8	10
Biomass energy	% of energy	68	31	11
Fossil fuels	% of energy	25	61	82
Nuclear and alternative energy	% of energy	6	9	7
Access to electricity	% of population	25	78	93
Electric power consumption	kWh/capita	314	925	2 611
Net energy imports	% of energy use	3	-42	-55
Pump price for diesel fuel	US$/litre	1.30	0.99	1.09
FOOD SECURITY				
Food supply	kcal/capita/year	2 352	2 633	2 951
Prevalence of adequate nourishment	% of population	77	85	91
Agricultural irrigated land	% of agric. land	12	12	7
Agricultural machinery	tractors/sq km	1	112	199
Fertiliser consumption	kg/ha arable land	26	92	214
Cereal yield	kg/ha	1664	2497	2801
Average value of food production	I$/capita	155	255	352
Cereal import dependency ratio	%	21	23	26
Value of food imports over total exports	%	66	18	14
Droughts, floods, extreme temperatures	% of population	3	1	1
WATER SECURITY				
Total water withdrawal per capita	m^3/inhab/year	219	514	689
Population with access to safe drinking-water	% of population	68	85	93
Renewable internal freshwater resources	m^3/capita	7 090	7 362	12 087
Dam capacity per capita	m^3/capita	951	1 265	1 215
Annual freshwater withdrawals	% internal resources	9	192	86
Water productivity	2005 US$ GDP per m^3	11	12	20
Annual freshwater withdrawals, agriculture	% of total withdrawal	67	70	54
Annual freshwater withdrawals, domestic	% of total withdrawal	25	16	24
Annual freshwater withdrawals, industry	% of total withdrawal	8	13	23

Source: Calculated from data drawn from FAO (2015a), FAO (2015b) and World Bank (2015b)

2.2.5 Cross-indicator comparisons

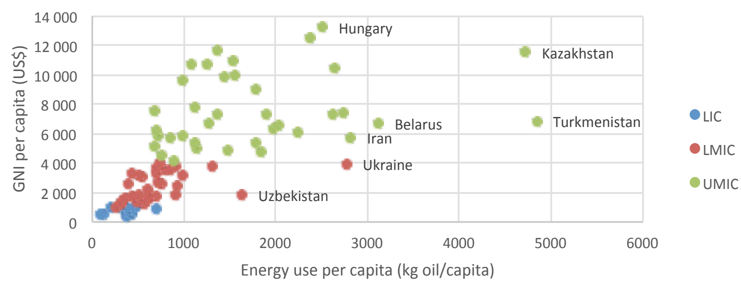
The following comparisons between the various indicators of energy, food and water security are made on the basis of bivariate correlations and scatter diagrams for the full sample of 96 countries[23] and apply to a cross-country level; the relationships found (or lack of relationships) may not hold within individual nations. A correlation matrix is provided in Appendix 2.5, and correlation coefficients are provided in the text in parentheses.

Energy security indicators

Several energy indicators are moderately or strongly correlated with income per capita: energy use per capita (0.65), access to electricity (0.65) and electric power consumption (0.69). As shown in Figure 2-56, however, there is a wide spread of energy consumption levels amongst relatively wealthier countries (mainly UMICs). The main outliers that have high levels of energy consumption in relation to their income levels are former members of the Soviet Union, which typically have energy intensive economies. Energy consumption per capita is also very strongly related to electric power consumption (0.81) and moderately correlated with access to electricity (0.52).

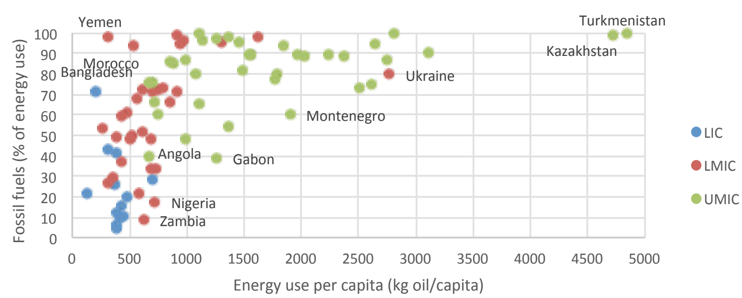
As expected, energy use per capita is negatively related to dependence on biomass energy (correlation coefficient = -0.53) and positively correlated with the share of fossil fuels in the energy mix (0.57). The latter relationship is also depicted in Figure 2-57, which reveals a moderate logarithmic relationship between fossil fuel use and energy consumption. The major outliers in this figure are Kazakhstan and Turkmenistan, which have very high levels of energy consumption thanks to their abundant supplies of oil and gas, respectively. Very few countries achieve a high level of per capita energy consumption without relying heavily on fossil fuels (the major exception is Montenegro, where fossil fuels comprise 60% of the energy mix and energy use is 1900 kg/capita). However, a high proportion of fossil fuels in the energy mix does not guarantee a high level of energy consumption: there are quite a number of countries where fossil fuels comprise more than 70% of energy use, but where energy consumption is less than 1000 kg/capita (Yemen and Morocco are the extremes in this regard, as shown in the figure). Zambia and Nigeria are two LMICs that more closely

Figure 2-56: Relationship between income and energy use per capita



SOURCE: World Bank (2015b)

Figure 2-57: Relationship between fossil fuel use and energy use per capita

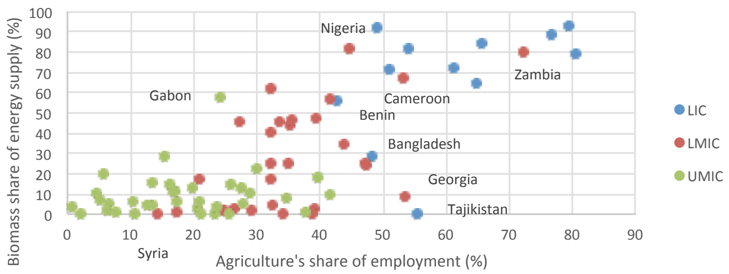


Source: World Bank (2015b)

23 Some of the indicators having missing observations for certain countries; correlation coefficients are calculated using pairwise samples, i.e. using all available data points – but the samples differ slightly when data are missing.

resemble the pattern of LICs. Similarly, Angola's energy profile is closer to that of LMICs than its fellow UMICs. Ukraine is an outlier among the LMICs due to its high level of energy consumption per capita. Bangladesh is a LIC outlier as a result of its comparatively heavy reliance on fossil fuels.

Figure 2-58: Relationship between biomass dependence and agriculture's share of employment

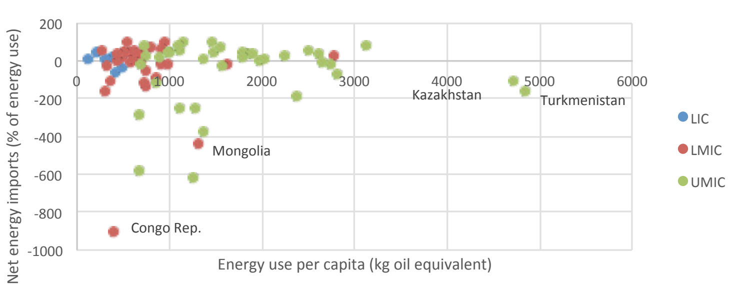


SOURCE: World Bank (2015b)

Reliance on biomass energy is strongly and positively correlated with the level of poverty (0.80), as well as agriculture's share of GDP (0.61) and agriculture's share of employment (0.73). Fossil fuels as a percentage of energy use is strongly associated with access to electricity (0.76), since both of these are modern sources of energy whose use typically increases as countries develop and grow richer. As one would expect, access to electricity has a very marked inverse relationship (-0.89) with the extent of poverty; it is also negatively associated with agriculture's share of GDP (-0.70) and employment (-0.77). Figure 2-58 illustrates the generally positive link between biomass energy use and agriculture's share of employment: most countries with more than half of their workforce employed in agriculture are also heavily reliant on biomass energy. There are, however, some outliers such as Tajikistan (0% biomass, 56% agricultural employment) and Georgia (9%, 53%). Tajikistan derives nearly two thirds of its energy from hydropower, and the rest from fossil fuels. Zambia falls amongst LICs on the graph, belying its LMIC status. Nigeria and Cameroon also fit more closely with LICs in terms of their reliance on biomass and agricultural employment.

These data confirm that there are essentially two energy-economy regimes: (1) the agrarian regime characterised by a high reliance on biomass energy, low access to electricity, and dominance of the agriculture sector in GDP and employment; and (2) the industrial regime powered by fossil fuels and electricity, where the agriculture sector plays a relatively minor role.

Figure 2-59: Relationship between net energy imports and energy use per capita



SOURCE: World Bank (2015b)

In this sample of countries, per capita income, energy usage per capita, and the extent of reliance on fossil fuels are unrelated to whether countries are net energy importers or exporters.[24] There are evidently a number of net energy importers that are able to sustain substantial levels of (especially fossil fuel) energy consumption by exporting other goods and services. Conversely, some major energy exporters have not managed to convert their energy wealth into high levels of domestic energy

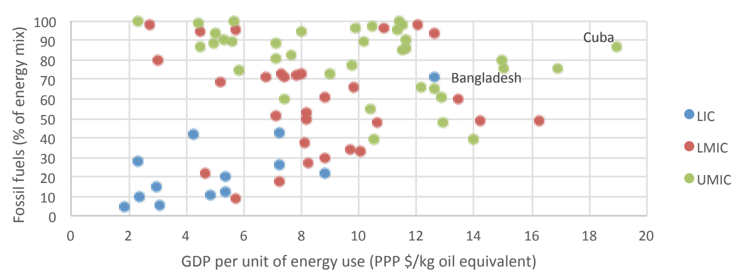
24 The bivariate correlation coefficients are all less than 0.15 in absolute value.

use. The eight countries with the largest net energy exports to energy consumption ratios (Algeria, Angola, Azerbaijan, Colombia, Congo Republic, Gabon, Iraq and Mongolia) all have relatively low per capita energy use (under 1500 kg oil per capita – see Figure 2-59). Two countries (Kazakhstan and Turkmenistan) have moderate levels of net energy exports but very high levels of energy consumption.

There is some correlation (0.36) between the level of the diesel price and the extent to which countries rely on energy imports, but not as much as might be expected (on the basis that diesel prices are likely to be lower in oil-exporting countries); this could possibly be due to the provision of significant diesel subsidies in some net energy-importing countries. The price of diesel is uncorrelated with income per capita (-0.08). The main factors determining variation in diesel prices across countries are likely to be transport costs (e.g. prices are generally higher in landlocked countries such as Malawi and Burundi) and subsidies.

Energy productivity (GDP per unit of energy consumption) is not strongly associated with whether a country relies mostly on biomass (-0.26) or fossil fuels (0.26) (see Figure 2-60). Energy productivity is also very weakly related to income per capita (0.33). Economic structure is probably the major determinant of energy productivity, with high-tech goods and high-end services adding more GDP per unit of energy than agriculture and heavy industry. This could explain why energy productivity is on the low side for almost all LICs (the exception is Bangladesh, which has specialised in light manufacturing industries such as clothing). Cuba achieved the highest energy productivity in the sample, possibly because of the sweeping energy efficiency measures the country has introduced in the past two decades (see section 3.4.1).

Figure 2-60: Relationship between energy productivity and fossil fuel use

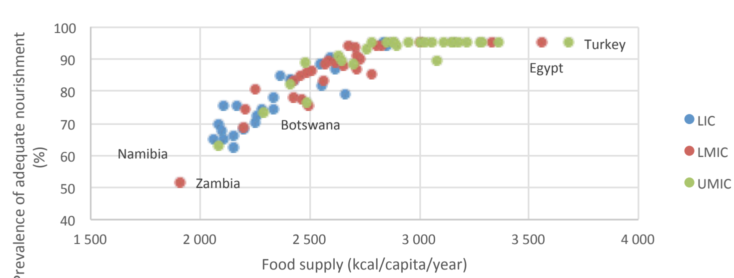


SOURCE: World Bank (2015b)

Food security indicators

The level of food supply per capita is very strongly related to the prevalence of adequate nourishment (0.86), and moderately correlated with the use of tractors (0.56), cereal yields (0.47) and the average value of food production per person (0.54) – all in line with expectations. However, per capita food supply is weakly related to fertiliser consumption per hectare (0.24) and essentially uncorrelated with cereal import dependency (-0.07) and the ratio of food imports to total exports (-0.16). Figure 2-61 shows that the prevalence of adequate nourishment tends to rise as food supply per capita rises until a food supply

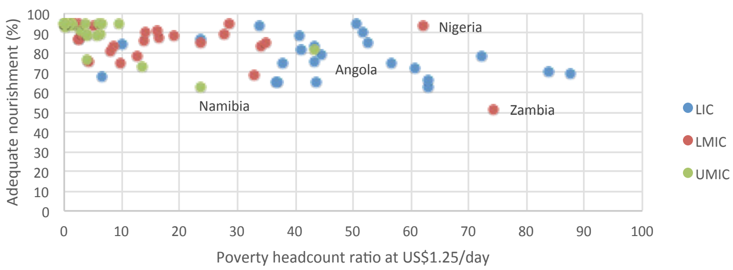
Figure 2-61: Relationship between food supply and prevalence of adequate nourishment



SOURCE: World Bank (2015b)

level of around 2800 kcal/capita/day, which appears to be the level required for almost the entire population of a country to be adequately nourished. Zambia is a notable outlier, while Namibia and Botswana underperform relative to their UMIC peers. Egypt has achieved a high level of food supply, owing in part to extensive bread subsidies.

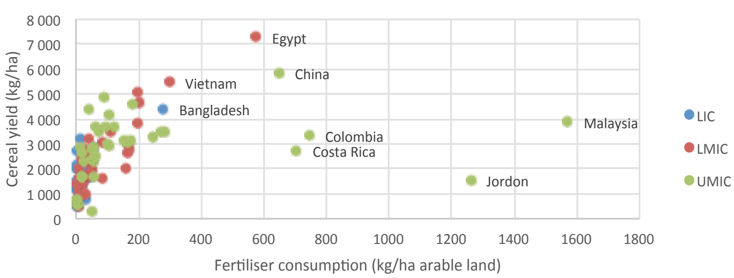
Figure 2-62: Relationship between poverty and prevalence of adequate nourishment



SOURCE: FAO (2015a) and World Bank (2015b)

The prevalence of adequate nourishment appears to be related most closely to the level of income (0.51) and (inversely) to the extent of poverty (-0.59), as depicted in Figure 2-62, as opposed to the use of inputs such as irrigation, tractors and fertilisers (correlation coefficients of -0.04, 0.2 and 0.28, respectively). Prevalence of adequate nourishment is moderately correlated (0.5) with the average value of food production per capita, which indicates that access to food may be unequal in some countries producing significant quantities of high-value food. Namibia and Angola stand out for their high rates of poverty and low nourishment levels compared to other UMICs. Nigeria and Zambia are outliers within the LIMIC group, although only the latter has a significant undernourishment problem.

Figure 2-63: Relationship between fertiliser consumption and cereal yield



SOURCE: World Bank (2015b)

Cereal yields are moderately correlated with fertiliser consumption (0.47). Figure 2-63 shows that there are several outliers that have very high fertiliser use and greatly varying cereal yields. For example, while Egypt and China recorded high yields, Malaysia and Jordan used very large amounts of fertilisers without achieving particularly high yields (Malaysia produces tropical crops such as palm oil and rubber in addition to rice). Bangladesh is an outlier among the LIC group, both in terms of fertiliser use and cereal (mainly rice) yields. Cereal yields are essentially unrelated to the use of tractors (0.18) and the percentage of agricultural land that is irrigated (0.16). Clearly, there are other factors determining cereal yields, such as climate, rainfall and soil quality.

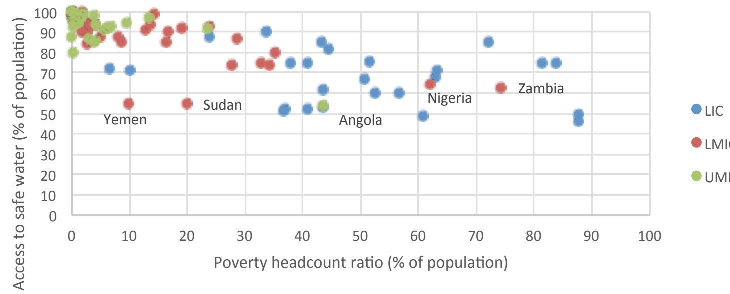
Contrary to expectations, there is a negligible association between two food vulnerability indicators: the cereal import dependency ratio and the ratio of food imports to total merchandise exports (0.16). Neither of these vulnerability indicators has any significant correlation with the extent of irrigation, tractor usage or fertiliser consumption.

Water security indicators

Somewhat surprisingly, water withdrawal per capita is uncorrelated with per capita income (0.21), renewable internal freshwater resources (-0.15) and dam capacity per capita (0.14), although there is a moderate relationship with annual freshwater withdrawals as a percentage of internal resources (0.46). Also surprising is the lack of association between water consumption per capita and access to safe drinking-water (0.12); the latter is, however, related to income per head (0.60) and inversely related to poverty (-0.74) – see Figure 2-64. This figure shows that Angola, Nigeria and Zambia are once again outliers relative to their income groups. Access to water is also compromised in Sudan and Yemen, two conflict-ridden countries. At a cross-country level, access to safe drinking-water is unrelated to the availability of renewable freshwater resources (0.06) or dam capacity (0.04), suggesting that downstream water distribution infrastructure is a key factor in ensuring water access.

Water productivity is inversely related to agriculture's share of water use (-0.42), probably owing to terms of trade and retail prices favouring manufactured (industrial) goods over agricultural commodities.

Figure 2-64: Relationship between access to safe water and poverty



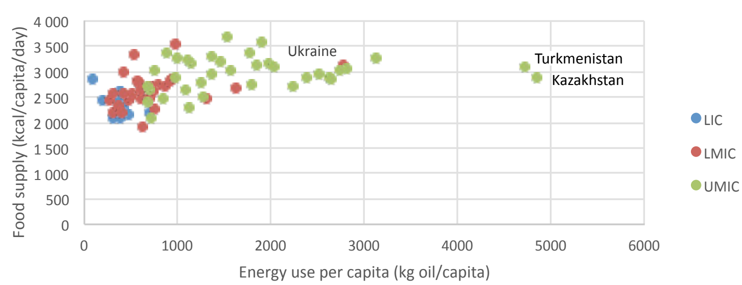
SOURCE: FAO (2015b) and World Bank (2015b)

Correlations across energy-food-water sectors

Cross-sectoral correlations provide an extra layer of insight into countries' energy-food-water security status and vulnerabilities. In particular, they show whether or not countries that are vulnerable in one sector (e.g. food security) are also vulnerable in others (e.g. energy and water security).

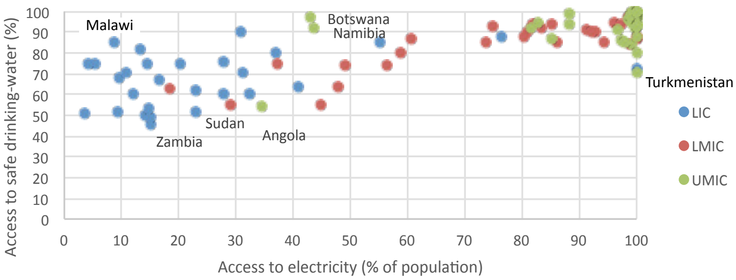
There is a moderate relationship between energy consumption and food supply per person (0.49), but this is reduced somewhat by the presence of two outliers, namely Turkmenistan and Kazakhstan (see Figure 2-65). There is also a moderate association between energy consumption and water withdrawal per capita (0.51). These positive relationships can be expected on the basis that these energy, food and water indicators are all connected to a country's level of development and income per capita. However, there is almost no correlation between per capita food supply and water withdrawal – perhaps partly because the water supply measure does not strictly reflect water consumption by individuals, but rather national usage averaged over the population size. Also, food supply may be determined largely by the extent of imports in some countries, rather than domestic food production (implying that water availability is less relevant to food supply).

Figure 2-65: Availability of energy and food in developing countries



SOURCE: FAO (2015a) and World Bank (2015b)

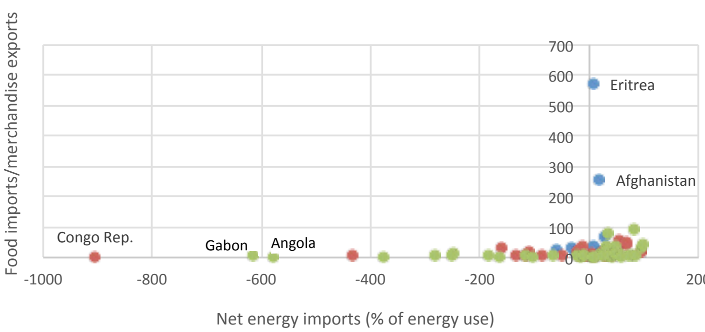
Figure 2-66: Relationship between access to electricity and safe drinking water



SOURCE: FAO (2015a) and World Bank (2015b)

Access to food, energy (in the form of electricity) and water are all correlated with one another to some extent. This is especially so in the case of access to electricity and safe drinking water (0.80), as can be seen in Figure 2-66. Nevertheless, there are several countries that have achieved rates of water access over 70% while recording electricity access rates of less than 20% (top left of the chart), namely Burkina Faso, Burundi, Liberia, Malawi and Uganda. Conversely, Tajikistan and Turkmenistan both have 100% electricity access but only 72% and 71% of these countries' populations have access to safe water, respectively. The correlation between access to electricity and prevalence of adequate nourishment is 0.67, while that between access to safe water and adequate nourishment is 0.59. All three variables are influenced by the level of per capita income and are negatively related to poverty rates (see the correlation matrix in Appendix 2.5).

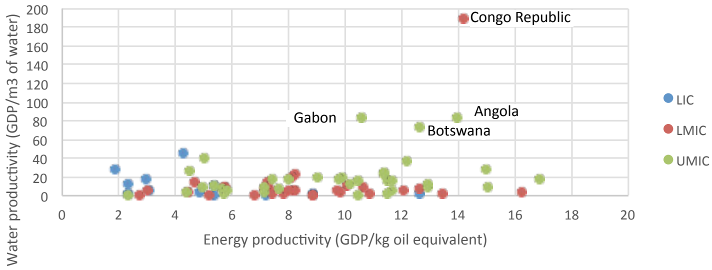
Figure 2-67: Comparison of net energy imports and food import dependency ratio



SOURCE: FAO (2015a) and World Bank (2015b)

In the case of vulnerability indicators, however, there is very little or no association across energy-food-water systems. More specifically, the pairwise correlation coefficients between the price of diesel or net energy imports (as a percentage of total energy use), cereal import dependency and food import dependency, and freshwater withdrawal (as a percentage of internal resources) are all less than 0.27 in absolute value. This is probably a good thing for developing countries in general, as it implies that the various types of vulnerabilities do not in general reinforce each other. Figure 2-67 illustrates this lack of association by plotting the ratio of food imports to total merchandise exports against net energy imports; even disregarding the few outliers, no pattern is evident.

Figure 2-68: Comparison of water and energy productivity



SOURCE: World Bank (2015b)

There is also no particular association between energy, food and water productivity across the sampled countries (all three pairwise correlation coefficients are less than 0.30). For example, Figure 2-68 plots the energy and water productivity measures. Interestingly, the countries with the outlying water productivities are significant oil or diamond exporters (Angola, Botswana, Congo Republic and Gabon) with undeveloped agriculture sectors (which account for the largest share of water use in most countries).

2.2.6 Multivariate analysis of indicators

The following multivariate linear regression models explore the statistical relationships among a number of the nexus indicators already analysed above. In particular, certain key indicators of energy, food and water access are regressed on a number of possible explanatory variables, in order to test which of these variables best explain the variation in these key indicators. The results should be treated with caution for a several reasons, such as: (1) some variables have missing observations, which reduces the sample size; (2) no additional explanatory variables beyond those available in the indicator dataset were included, which might result in specification bias; (3) the models have not been adjusted for factors such as heteroscedasticity and outliers; (4) multicollinearity is likely to be an issue in some of the models, i.e. correlation among the independent variables. The objective was not so much to develop robust models for explaining the dependent variables, but rather to explore the relationships among a given set of variables within a multivariate framework, in order to augment the bivariate correlation analysis.

Energy consumption is regressed on income, poverty, diesel price, net energy imports, the fossil fuel share of the energy mix, access to electricity, and agriculture's share of employment (Table 2-7). Per capita income is the most significant variable explaining variations in energy consumption, while the share of fossil fuels in the energy mix is also a significant factor as theoretically expected. Access to electricity is strongly and positively related with fossil fuel use (which is expected because many countries generate much of their electricity from coal, gas or oil) and does not add additional explanatory power for energy consumption; both variables tend to increase with economic development. The price of diesel and the ratio of net energy imports to energy consumption are statistically insignificant alone and in combination with other explanatory variables. Poverty and agriculture's share of employment are individually significant in explaining variations in energy consumption, but may be regarded as (somewhat weak) proxies for income, and are insignificant if income is included in the regression.

Table 2-7: Regression results for energy use per capita

Dependent Variable: ENERGYUSE_PC
Method: Least Squares
Sample (adjusted): 14 96
Included observations: 62 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-841.4342	916.9527	-0.917642	0.3629
INCOME	0.142289	0.032805	4.337369	0.0001
POVERTY	13.63661	11.65251	1.170272	0.2470
FOSSIL_FUELS	12.54161	5.354940	2.342064	0.0229
DIESEL_PRICE	52.17452	210.5296	0.247825	0.8052
ELEC_ACCESS	4.801767	7.163476	0.670312	0.5055
ENERGY_IMPORTS	0.343742	0.575636	0.597152	0.5529
AGRI_EMPT	-4.269285	8.052893	-0.530156	0.5982

R-squared	0.536213	Mean dependent var	1211.389
Adjusted R-squared	0.476093	S.D. dependent var	892.0654
S.E. of regression	645.6898	Akaike info criterion	15.89843
Sum squared resid	22513426	Schwarz criterion	16.17290
Log likelihood	-484.8513	Hannan-Quinn criter.	16.00619
F-statistic	8.918973	Durbin-Watson stat	2.509569
Prob(F-statistic)	0.000000		

Table 2-8: Regression results for electricity access

Dependent Variable: ELEC_ACCESS
Method: Least Squares
Sample (adjusted): 6 96
Included observations: 73 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	75.92224	7.496108	10.12822	0.0000
POVERTY	-0.954973	0.130566	-7.314080	0.0000
FOSSIL_FUELS	0.204732	0.090115	2.271890	0.0262
INCOME	0.000666	0.000582	1.143765	0.2567

R-squared	0.766291	Mean dependent var	77.58219
Adjusted R-squared	0.756130	S.D. dependent var	28.55222
S.E. of regression	14.10000	Akaike info criterion	8.183462
Sum squared resid	13717.88	Schwarz criterion	8.308967
Log likelihood	-294.6964	Hannan-Quinn criter.	8.233478
F-statistic	75.41314	Durbin-Watson stat	2.054121
Prob(F-statistic)	0.000000		

Table 2-9: Regression results for food supply per capita

Dependent Variable: FOOD_SUPPLY
Method: Least Squares
Sample (adjusted): 9 96
Included observations: 68 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2331.115	181.4553	12.84678	0.0000
INCOME	0.033221	0.012693	2.617155	0.0111
POVERTY	-4.319491	3.002524	-1.438620	0.1553
FOSSIL_FUELS	2.375502	1.945842	1.220809	0.2268
WATER_RESOURCES	-0.004296	0.002311	-1.859024	0.0678
CEREAL_YIELD	0.065084	0.026943	2.415672	0.0187

R-squared	0.503297	Mean dependent var	2720.456
Adjusted R-squared	0.463240	S.D. dependent var	378.6945
S.E. of regression	277.4463	Akaike info criterion	14.17323
Sum squared resid	4772541.	Schwarz criterion	14.36907
Log likelihood	-475.8898	Hannan-Quinn criter.	14.25083
F-statistic	12.56461	Durbin-Watson stat	2.107642
Prob(F-statistic)	0.000000		

Access to electricity is regressed on income, poverty and the fossil fuel share of the energy mix (Table 2-8). Poverty is the dominant variable explaining variations in access to electricity. Income is only significant if poverty is omitted, but has weaker explanatory power. The fossil fuel share of the energy mix is statistically significant and therefore adds explanatory power in a model with poverty as a regressor.

Food supply per capita is regressed on the following variables: income, poverty, cereal yield, fossil fuel share of the energy mix, and renewable internal freshwater resources (Table 2-9). The regression results show that income per capita and cereal yield are the two significant variables for explaining variations in food supply per capita, which conforms to expectations (food supply per person depends on affordability and availability of local produce). Although poverty is individually significant, it does not add explanatory power beyond the two variables just mentioned. The same is true of the fossil fuel share of the energy mix. Renewable internal freshwater resources are not individually statistically significant, and despite being borderline significant in the multivariate model, the sign of the coefficient is negative, which is contrary to expectations (i.e. that increased water availability would be associated with greater food production). Still, more than half of the variation in food supply is left unexplained, indicating that better (or more) data and more variables are required.

Access to safe drinking-water is regressed on income, poverty, dam capacity, renewable water resources, water withdrawal per capita and access to electricity (Table 2-10). Somewhat surprisingly, only access to electricity is statistically significant in this regression. (Water withdrawals per capita is borderline significant, but has the wrong sign.) However, electricity access is hard to justify as an explanatory variable for water access; rather, both variables are likely to depend on other factors (such as a country's historical investment in infrastructure, which is largely related to national income and level of development). Indeed, when electricity access is dropped from the model, then income and poverty become significant explanatory variables. The other three variables, dealing with water resources, remain statistically insignificant.

Water withdrawal per capita is regressed on income per capita, poverty rate, dam capacity per capita, renewable water resources per capita, access to safe water and energy consumption per capita (Table 2-11). The only variables that are statistically significant are poverty (with a negative sign, as expected) and dam capacity (with a positive coefficient as expected, since dams provide the infrastructure for storing water that can then be withdrawn and used for various purposes). Renewable freshwater resources is borderline significant, but has the wrong sign as one expects it to be positively related to water withdrawals. However, poverty is hard to justify as a causal variable, except to the extent that it serves as a proxy for lack of economic development and extent of water infrastructure. In any event, the explanatory power of the model is low, possibly indicating that other relevant variables could be missing. In addition, the dependent variable (water withdrawal per capita) has one extreme outlier (Turkmenistan), as does the explanatory variable renewable freshwater resources (Gabon); however, removal of these outliers did not materially alter the regression results.

Table 2-10: Regression results for access to safe water

Dependent Variable: WATER_ACCESS
Method: Least Squares
Date: 11/10/15 Time: 13:23
Sample (adjusted): 2 96
Included observations: 77 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	61.86926	6.720320	9.206297	0.0000
INCOME	0.000556	0.000407	1.367699	0.1758
POVERTY	-0.058703	0.098043	-0.598751	0.5513
DAM_CAPACITY	-0.000351	0.000670	-0.523562	0.6022
WATER_RESOURCES	-2.47E-05	6.85E-05	-0.360895	0.7193
WATER_PERCAP	-0.005782	0.002857	-2.023498	0.0468
ELEC_ACCESS	0.344290	0.074104	4.646012	0.0000

R-squared	0.700483	Mean dependent var	83.75325
Adjusted R-squared	0.674810	S.D. dependent var	15.75065
S.E. of regression	8.981877	Akaike info criterion	7.314803
Sum squared resid	5647.188	Schwarz criterion	7.527876
Log likelihood	-274.6199	Hannan-Quinn criter.	7.400030
F-statistic	27.28492	Durbin-Watson stat	2.226050
Prob(F-statistic)	0.000000		

Table 2-11: Regression results for water withdrawals per capita

Dependent Variable: WATER_PERCAP
Method: Least Squares
Sample (adjusted): 6 96
Included observations: 68 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1133.310	478.3704	2.369106	0.0210
WATER_RESOURCES	-0.005621	0.003265	-1.721645	0.0902
DAM_CAPACITY	0.076570	0.027929	2.741561	0.0080
WATER_ACCESS	-6.097115	5.156652	-1.182379	0.2416
INCOME	-0.006458	0.022484	-0.287243	0.7749
POVERTY	-13.82740	3.805888	-3.633160	0.0006
ENERGYUSE_PC	0.057932	0.081770	0.708473	0.4814

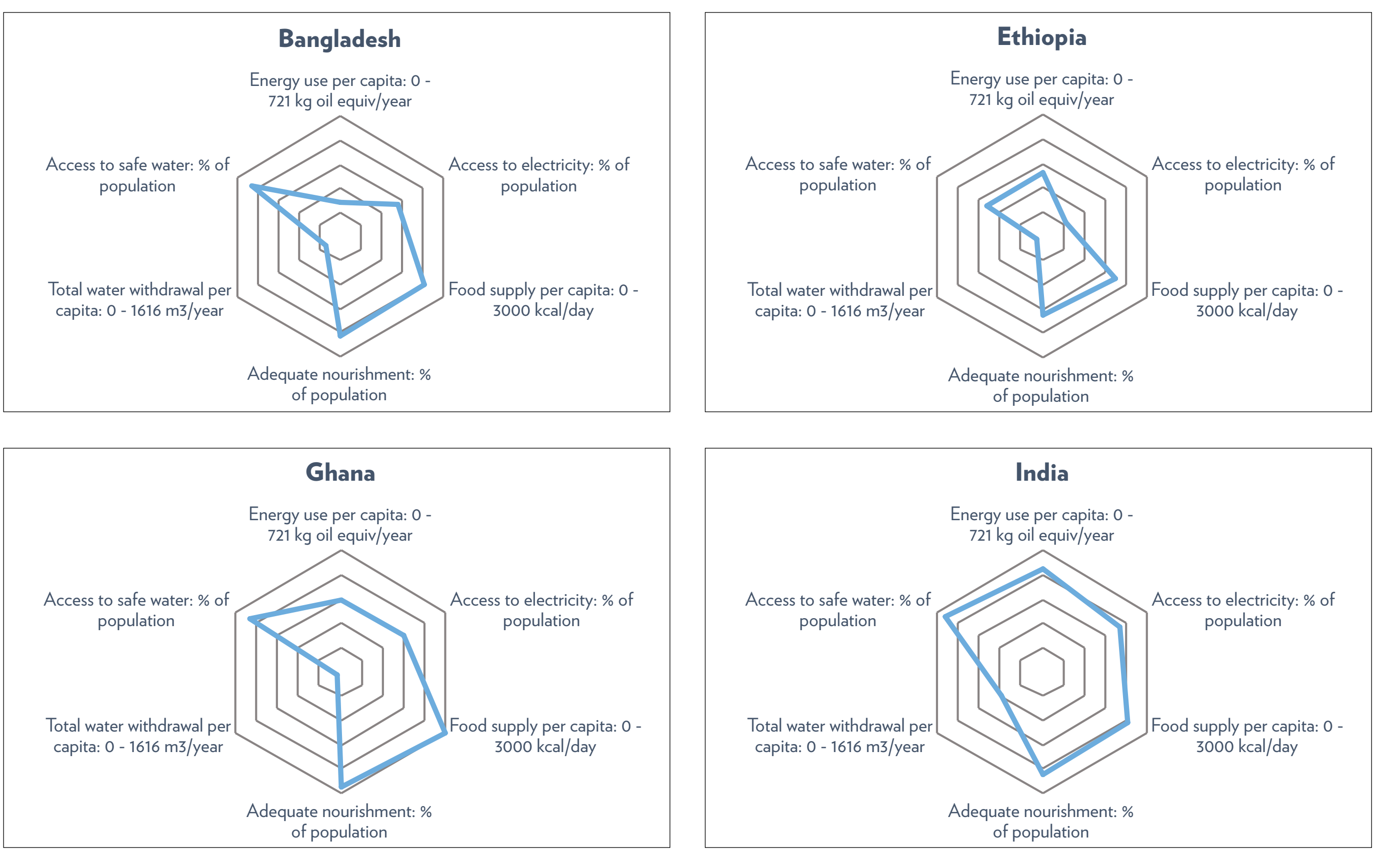
R-squared	0.366594	Mean dependent var	470.6088
Adjusted R-squared	0.304292	S.D. dependent var	454.3294
S.E. of regression	378.9522	Akaike info criterion	14.80995
Sum squared resid	8759890.	Schwarz criterion	15.03842
Log likelihood	-496.5381	Hannan-Quinn criter.	14.90048
F-statistic	5.884121	Durbin-Watson stat	1.759076
Prob(F-statistic)	0.000069		

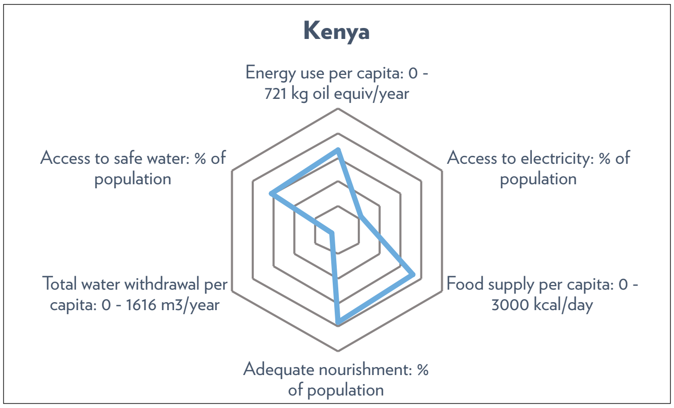
2.2.7 Key energy-food-water security indicators for DFID priority countries

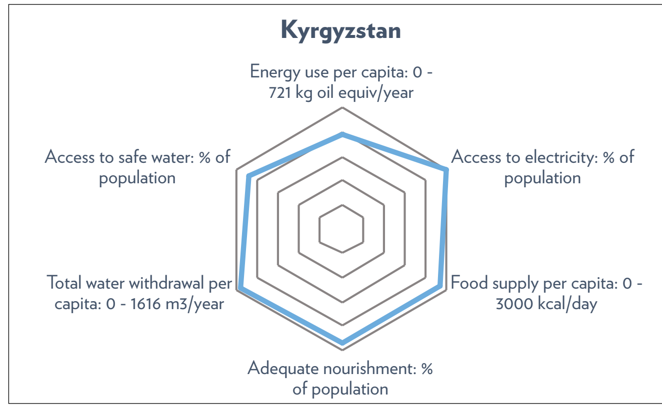
The charts in Figure 2-69 show six key indicators for each of 14 DFID priority countries for which there were sufficient data. Three indicators are expressed as percentages (access to electricity, prevalence of adequate nourishment and access to safe drinking water). The other indicators are expressed as a proportion of the highest value attained by a country within the group; for example, energy use per capita was 721kg of oil equivalent per year in Nigeria, which serves as a benchmark for the remaining countries.

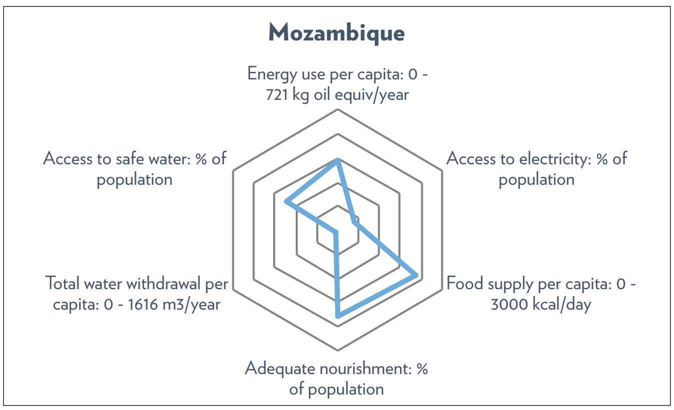
The patterns show marked similarities according to region and income level. Several low-income African countries (Ethiopia, Kenya, Mozambique, Zambia and Zimbabwe) exhibit a very similar 'bow tie' pattern, with low rates of access to electricity and low water withdrawal per capita relative to the other indicators. Electricity and water infrastructure is typically very limited in these poor countries (although less so in Zimbabwe). The indicator patterns of Ghana and Nigeria – both West African oil exporters – are quite similar, except that the latter has considerably higher per capita energy consumption. These two countries are not dissimilar to the other African countries, but generally perform better on most indicators (as one would expect from their lower-middle-income status). Bangladesh and Nepal – both low-income South Asian countries – display very similar features, such as high rates of access to water and low per capita energy use. India and Pakistan – two South Asian LMICs – display very similar patterns with the exception of water withdrawal per capita, which is somewhat lower in India. The pattern in Yemen is closest to Ghana; both are oil exporting LMICs. Tajikistan's spider diagram does not closely resemble any of the other countries, mainly because it has very high rates of electricity access and water withdrawal per capita (this country makes extensive use of hydropower). The most similar pattern is displayed by its Central Asian neighbour Kyrgyzstan, which performs consistently well relative to the other countries on all six indicators (and also uses its mountainous terrain and ample water resources to produce significant quantities of hydroelectricity).

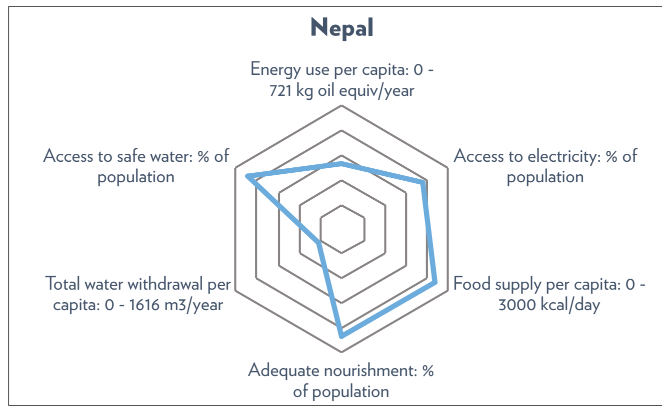
Figure 2-69: Key indicators for selected DFID priority countries

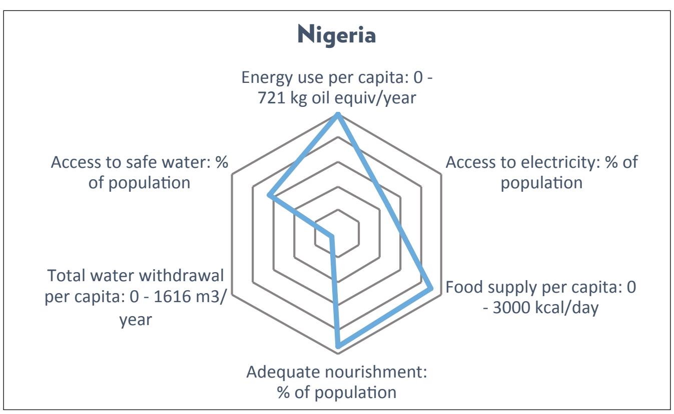


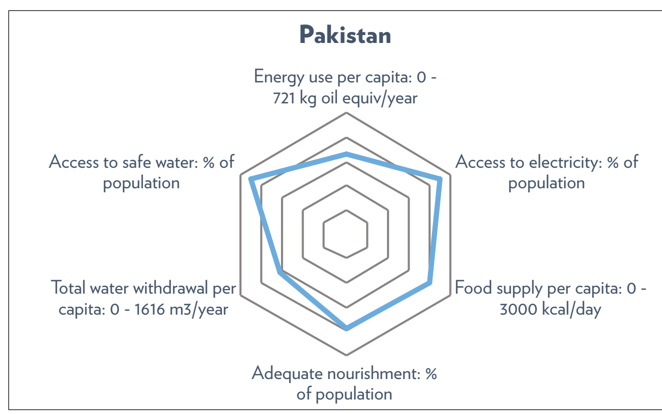

Kenya
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population

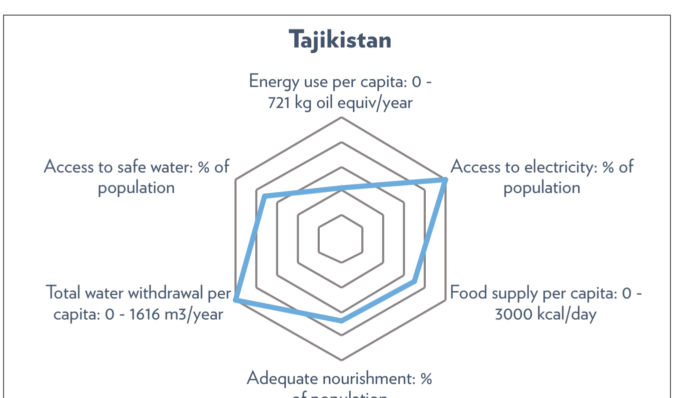

Kyrgyzstan
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population

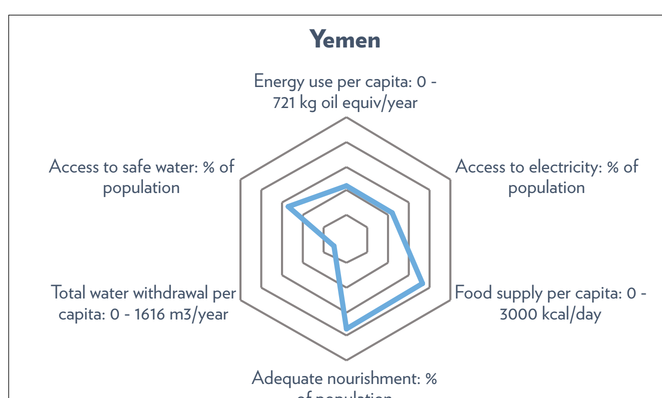

Mozambique
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population

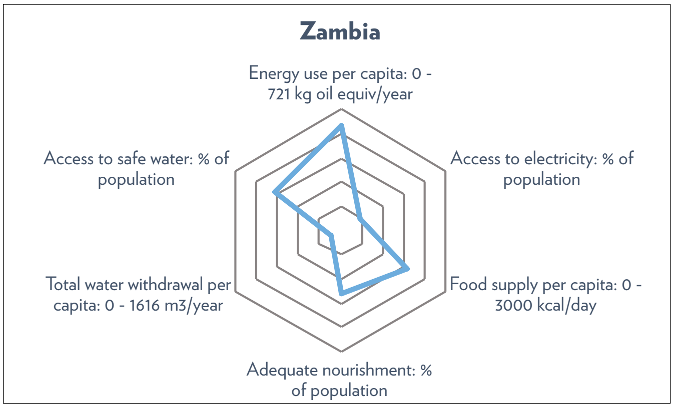

Nepal
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population

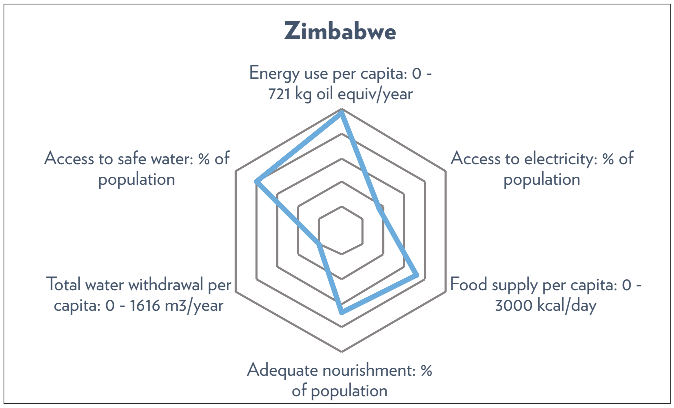

Nigeria
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population


Pakistan
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population


Tajikistan
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population


Yemen
Energy use per capita: 0 - 721 kg oil equiv/year
Access to electricity: % of population
Food supply per capita: 0 - 3000 kcal/day
Adequate nourishment: % of population
Total water withdrawal per capita: 0 - 1616 m3/year
Access to safe water: % of population





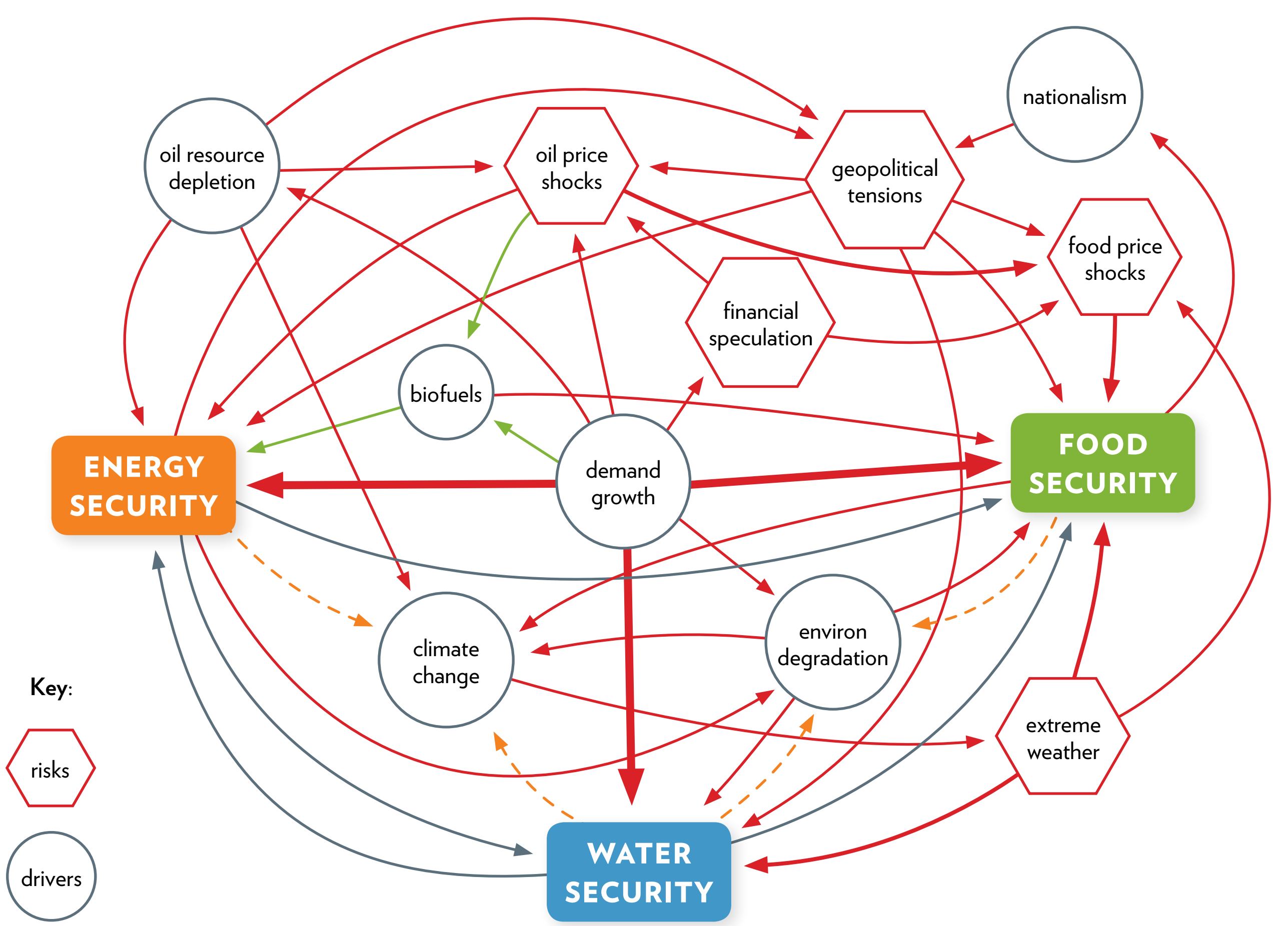
SOURCE: **FAO (2015a), FAO (2015b) and World Bank (2015b)**

2.3 Summary and Conclusions

Global risks and vulnerabilities

Figure 2-70 maps the main global drivers/trends and risks, and their influence on energy, food and water security. The major catalytic risks are: (1) extreme weather events including droughts and floods; (2) oil price shocks; (3); food price shocks; (4) geopolitical tensions; and (5) financial speculation in commodity markets. These risk categories were also discussed in Part 1 as the major societal teleconnections that arise as a result of the embeddedness of countries within a world trading system; impacts get transmitted to individual countries through global trade networks. For example, a geopolitical event (such as a civil war or regional conflict) in a key oil-producing country or region can affect global oil prices and thereby raise fuel prices in individual oil-importing countries across the world. Another example is global food prices being driven up by restrictions on food trade by major food exporting countries. Underlying drivers/trends that feed into the risks include demand growth (driven by urbanisation and growing populations, economies and middle classes) and supply-side factors such as climate change, environmental degradation, resource depletion and the growth of the biofuel market. As the figure makes clear, the nexus linkages and feedback loops create a web of interconnecting – and reinforcing – risks and impacts. One likely end result of these threats to food, energy and water security is heightened social instability within countries and regions.

Figure 2-70: Interconnected global nexus risks



Notes:

- The red arrows indicate the negative impacts that a driver or risk has on other drivers, risks or energy-food-water security aspects.
- Demand growth is placed centrally and has thicker connecting lines because it is such a fundamental driver of food, energy and water insecurity by placing increasing pressure on these systems to deliver.
- The grey arrows indicate the main nexus linkages (as described in detail in Part 1), for example, that water security is necessary for food security since it is essential for crop cultivation. Usually, a deterioration in one security aspect (such as water) has negative consequences for another (such as energy).
- The green arrows indicate that the relevant driver or risk tends to promote an increase in biofuel use, which in turn can boost energy security (provided the net energy return is positive).
- The dotted orange arrows indicate that improvements in one domain of energy-food-water security could have negative unintended consequences (e.g. for the climate or environment), depending on the how these improvements are generated. For example, increasing the use of fossil fuels in the energy (commercial farming) system would be negative for the climate (environmental degradation), while the use of renewables (organic farming) could be neutral (or could even help to restore the environment, by rehabilitating soils for example). Similarly, constructing dams could boost water security, but could increase carbon dioxide emissions (from cement manufacturing) and methane (from rotting vegetation); whereas the rehabilitation of wetlands and afforestation could improve water security while protecting the environment.
- There are several positive feedback loops, for example:
  - i. *Deteriorating food security can lead to a rise in nationalist sentiments, which stoke geopolitical tensions, which in turn threaten food security (e.g. if countries limit food exports or engage in land grabs).*
  - ii. *Climate change results in extreme weather events, which threaten water security, which in turn may limit hydropower generation, which could lead countries to rely more heavily on fossil fuels, which exacerbates climate change.*
  - iii. *Extreme weather events resulting from climate change can trigger food price spikes, which threaten food security and can result in more intensive use of fossil fuels in agriculture, which in turn can contribute to further emissions and climate change.*

As a consequence of rural/urban differences in the nexus that were discussed in Part 1, the risks and vulnerabilities faced by rural dwellers can differ considerably from those encountered by their urban counterparts. For example, climate change poses different risks for rural areas and cities. In the former, climate change poses risks to water supplies – notably for agriculture – as well as crop productivity; this can affect food security directly, especially in the case of subsistence farmers who depend on rainfed agriculture. In urban areas, the main direct threats from climate change are the impacts of extreme weather events (including heatwaves, storms, etc.) on infrastructure (such electricity grids, water distribution, and wastewater treatment). Dependence on highly interdependent energy, water and transport infrastructures, while necessary for efficiency, may make city dwellers more vulnerable to power outages that have cascading effects, such as interruptions to water supplies and sewage treatment (see Moser & Hart 2015).

Agrarian typology risks and vulnerabilities: key lessons from Malawi

- In Malawi's (largely) agrarian socioecological system, there are two main nexus vulnerabilities: (1) the low productivity of its largely subsistence agricultural sector (together with large post-harvest food losses) results in a high level of food insecurity; and (2) the over-reliance on traditional biomass fuels has major impacts, including deforestation, soil erosion, siltation and the resulting interference with water supplies and hydropower generation. Bioethanol production volumes are currently low, but do depend on sufficient production of sugarcane, which in turn requires reliable water supplies.
- Increasingly erratic rainfall patterns, linked to climate change, pose a threat to water security, food production (especially considering the overwhelming reliance on rainfed agriculture) and hydropower generation.
- Malawi's efforts to mitigate its food security risks, principally by expanding the use of fertilisers, brings other risks such as exposure to external fertiliser (and energy) price shocks and

exchange rate weakness, as well as the detrimental impacts of fertiliser use on aquatic ecosystems (e.g. eutrophication).

Industrial typology risks and vulnerabilities: key lessons from South Africa

- In the short- to medium-term, the major nexus vulnerability in South Africa is that its food system is highly dependent on energy inputs and is thus vulnerable to increased prices and interruptions to supplies of both liquid fuels and electricity. Energy shocks quickly get transmitted to food prices (and potentially food availability), which threatens food security for poorer households in particular.
- In the longer term, a primary nexus-related risk that is characteristic of the industrial typology concerns the degrading effect that the extensive use of fossil fuels (e.g. for energy production and agriculture) has on water and soil quality. This is especially a concern in South Africa because of the spatial overlap of major coal fields, arable land and key river systems.
- Although depletion of fossil fuel resources could pose a threat to South Africa's industrial regime in the longer term, water appears to be the major limiting resource in the medium term. The most pressing vulnerabilities in other countries will depend on the relative scarcity/abundance of different primary resources.

Ecological typology risks and vulnerabilities: key lessons from Cuba

- The aspects of Cuba's energy, food and water systems that exhibit characteristics of the 'ecological metabolism' generally help to reduce nexus-related risks. For example, renewable energy poses limited threats (in terms of dependencies and pollution impacts) to food and water systems – although a notable exception is the reliance on sugar bagasse for power co-generation. Agroecological food production has limited reliance on external inputs derived from fossil fuels and thus shields the country from external energy and food price shocks.
- Nevertheless, Cuba's overall energy system is still heavily reliant on oil (and to a much lesser extent natural gas), which implies significant energy security risks in terms of exposure to oil price shocks and geopolitical dependence on subsidised imports from Venezuela. Furthermore, the (renewed) growth of industrial agriculture is raising risks related to energy-intensive inputs such as fertilisers and irrigation water. Constraints on water availability and risks posed by climate change affect both the ecological and industrial components of Cuba's energy-food-water systems.

Energy, food and water security indicators

The key findings emerging from the presentation and analysis of indicators are as follows:

Low-income countries

- Agriculture plays an important role in most of their economies and accounts for over 40% of employment in all countries for which data are available.
- In almost all cases, biomass accounts for the bulk of primary energy supply.
- Energy consumption per capita varies considerably and is not closely tied to the level of per capita income.
- Energy productivity varies considerably.
- Access to electricity is very limited – below 30% of the population – in most countries and per capita electricity consumption is generally extremely low.
- Most LICs are net energy importers, rendering them vulnerable to energy price shocks.
- Diesel prices vary dramatically, and are highest in some land-locked African countries.
- The average food supply is relatively low, ranging between 2 000 and 2 850kcal per person a day.
- Access to food is a major challenge; more than 20% of the population are undernourished in most of these countries.
- Almost all LICs are net cereal importers, and many are very much exposed to higher international food prices.
- Fertiliser use is minimal in most LICs, and does not correlate with cereal yields.
- Water withdrawal is generally at very low levels and is not linked to income levels.
- Access to safe drinking water is a significant challenge in most countries, but with considerable variation in degree.
- The availability of renewable freshwater resources varies greatly, while dam capacity is generally very low.
- Water productivity is low in many of these countries, probably reflecting the fact that agriculture accounts for the largest share of freshwater withdrawals in most countries.
- There are two countries that are fairly consistent outliers within the LIC group. Tajikistan derives its energy from hydropower and fossil fuels and has achieved universal electrification and a low poverty rate, and has much larger

water withdrawals and dam capacity than the norm – but fails to convert this into water access. Bangladesh relies mainly on natural gas and oil, and has achieved high energy productivity but low per capita energy consumption; it has also recorded a comparatively high cereal yield with heavy reliance on fertilisers).

The high levels of dependence on traditional biomass energy means that LICs are vulnerable to deforestation, energy poverty (especially lack of access to electricity) and low-productivity agriculture.

Lower-middle-income countries

- Agriculture makes a substantial contribution to many LMIC economies, and generally accounts for between 25% and 50% of employment.
- Energy use per capita is mostly low, although some former Soviet countries are outliers.
- Energy productivity is highly variable.
- The composition of energy by fuel type varies greatly; some rely mainly on biomass, while others depend almost entirely on fossil fuels.
- Electricity access is highly variable and electricity consumption rates are generally low.
- Several countries are significant net energy exporters, while some are heavily reliant on energy imports.
- Diesel prices are highly variable, partly as a result of substantial subsidies in several countries.
- Daily food supply varies widely and does not correlate with income level.
- Undernourishment affects over 10% of the population in most countries in this group.
- All but a few are net cereal importers and many countries face large food import bills relative to their merchandise exports.
- Fertiliser consumption on a per capita basis is minimal in about half of the countries, but extremely high in Egypt and fairly high in some grain exporting countries.
- Water withdrawal per person varies enormously, depending on available water resources and water infrastructure.
- In most countries, more than 80% of the population has access to safe drinking water, and the proportion is even higher in the relatively wealthier countries within this group.
- Renewable internal freshwater resources vary greatly, and dam capacity is generally low, but there are a few outliers.
- Water productivity is highly variable.
- Agriculture is the predominant water user in most LMICs.
- There are several notable outliers amongst the LMICs. Zambia and Nigeria, and to a lesser degree Cameroon, exhibit many of the characteristics of LICs: high poverty rates, extensive agricultural employment, a predominance of biomass in energy consumption, low rates of electricity access and use, and limited access to water. Substantial copper and oil exports, respectively, boost these countries' per capita income but without improving the living conditions of the majority of the people. By contrast, some former socialist countries (e.g. Ukraine and Uzbekistan) have high energy consumption, extensive use of fossil fuels, and low energy productivity. Egypt stands out for its extensive fertiliser use and high cereal yield, and large dam capacity and water withdrawals.
- The Gambia demonstrates that it is possible for a country to achieve relatively high levels of food supply per capita (2 849 kcal/capita/day), a low rate of undernourishment (6%) and a high rate of access to water (90%) despite extensive poverty (34%) and low income (US$500/capita).

LMICs are at varying stages of transition from the biomass-based agrarian regime to a fossil fuel-based industrial regime, and there is a great deal of variability in the indicators across this diverse group of countries.

Upper-middle-income countries

- The agriculture sector plays a relatively minor economic role in most UMICs, although it still provides for more than 20% of total employment in a number of countries.
- Energy use per person and energy productivity vary greatly, with no apparent relation to income level.
- These countries are overwhelmingly dependent on fossil fuels as their major source of energy, with the exception of Angola and Gabon (ironically both oil exporters).
- Most have achieved near-universal access to electricity, apart from several highly unequal countries with high poverty rates.
- Some are heavily dependent on energy imports, while others are major energy exporters.
- Diesel prices depend significantly on the levels of subsidies and taxes.
- The average food supply is generally at a fairly good level, although several southern African countries are lagging behind.

- Undernourishment affects 5% or less of the population in most countries, although there are some outliers (again mainly in southern Africa).
- There is extraordinary variability in both the percentage of agricultural land that is irrigated and the use of tractors per square kilometre of arable land.
- Fertiliser consumption is low in most countries, but there a few with agricultural systems that depend heavily on fertilisers. There is no apparent association between fertilizer use and cereal yields.
- A number of countries are highly dependent on cereal imports for over 50% of their consumption, while there are just seven countries that are significant net cereal exporters.
- Most countries in this group have achieved fairly high rates of access to safe drinking water (above 85%), with the notable exception of Angola.
- The extent of renewable freshwater resources and dam capacity per capita are both characterised by low levels for most countries and much higher levels for a few outliers.
- Water productivity is highest in several African countries among this grouping.
- The allocation of water among agriculture, industry and domestic uses is highly variable across UMICs.
- The main group of outliers consists of Angola, Botswana and Namibia, which have relatively high rates of poverty and undernourishment, and low rates of access to electricity (and water in the case of Angola). In terms of many indicators, Angola in particular resembles LMICs more than UMICs.
- Other notable outliers are the former Soviet Republics of Kazakhstan and Turkmenistan, where energy use is very high and energy productivity very low; water withdrawal is also very high. These countries benefit from Soviet-era infrastructure and large energy resources.

The level of dependence on fossil fuels is very high in most UMICs, which partly explains why most countries are performing quite well in terms of basic energy, food and water security access and availability/consumption. However, several countries in southern Africa (Angola, Botswana and Namibia) are lagging far behind in many indicators; this relates to their high levels of income inequality and poverty.

Some general observations can be made based on the entire sample of developing countries. First, **there is a high degree of variability in the values of many of the indicators across countries**. Second, only a few of the indicators are correlated with income levels within each of the three income groups; however, access to energy, food and water is strongly related to income. Third, although energy is an important input into agriculture, **the fact that a particular country has abundant energy resources (such as oil or natural gas) does not automatically translate into energy or food security**. This could be because the country exports most of its fossil energy and there is extensive inequality in access to the proceeds of oil revenues, and widespread poverty (e.g. Angola and Nigeria).

Across the 96 developing countries in our sample, there is a **weak or negligible bivariate relationship between many pairs of energy, food and water security indicators**. This most likely reflects the complexity of the determinants of energy-food-water security and the greatly varying characteristics of the countries (e.g. population size, income level, geography, climate, natural resource endowments, etc.). It does mean that to a significant extent, **many of the risks and vulnerabilities are spread and are not concentrated within a select group of countries**. What is clear, however, is that the **per capita level of income is quite strongly related to key indicators of availability of and access to food, water and energy**. Poorer countries tend to have lower levels of consumption of basic necessities and fewer people have access to adequate food, modern energy and safe water. Thus many (especially low-income) countries could effectively tackle aspects of nexus security by reducing levels of poverty and inequality. In general, however, much more detailed, country-level research is needed to interrogate the reasons underlying the large variations observed in the many of the indicator values across countries, even within the same income group.

Link to Contents

part 3.

POLICY RECOMMENDATIONS FOR NEXUS RESILIENCE AND SUSTAINABILITY

Key Messages

- Nexus mitigation strategies should begin with efforts to build well-functioning institutions, effective governance systems and integrated policy frameworks, as these are prerequisites for the design of effective policies and the implementation of viable technical solutions to tackle nexus risks and vulnerabilities. Both vertical and horizontal coordination within governments is essential to ensure better policy coherence and effectiveness, while cooperation must be sought with stakeholders from all sectors of society to ensure sustainable and equitable governance of resources.
- Individual nations must devise strategies to build resilience to teleconnection impacts arising from their embeddedness in global trading systems and should engage in multilateral forums to improve international policy coordination in managing the nexus.
- Individual nexus interventions will be much more coherent and effective if they are designed and implemented within an overarching paradigm aimed at a transition to 'inclusive green economies'. This involves expanding access to food, water and energy services while transforming economic systems to be more resource efficient, less carbon intensive, and less damaging to the environment.
- Policy interventions should aim to identify win-win solutions that harness synergies and maximise co-benefits across the energy-food-water nexus, and policymakers must deal with unavoidable trade-offs by assembling relevant scientific information and involving stakeholders in consultative processes to inform policy decisions.
- A wide range of technical measures can be adopted to mitigate nexus-related risks and improve energy, food and water security in developing countries.
- There can be significant spatial differences in appropriate nexus mitigation strategies and policy interventions. In rural areas, the key issue is optimising land use to provide a range of services, while in urban areas the emphasis is on creating resource-efficient, low-carbon cities.
- The main priority for countries with a largely agrarian regime is to expand access to food, energy and water among their populations, while limiting negative impacts on ecosystems.
- In countries with largely industrial regimes that rely heavily on fossil fuels, the key nexus security challenges are to limit the vulnerability to international energy price volatility, reduce energy and resource intensity, and reduce the negative impacts of fossil fuel use on soils and water resources.
- Cuba provides an example of a country that achieved a significant reduction in the energy intensity of its food system while increasing nutritional quality and quantities, through concerted policy actions and positive social responses.

POLICY RECOMMENDATIONS FOR NEXUS RESILIENCE AND SUSTAINABILITY

3.

Part 1 of this report described the key interlinkages and dependencies among energy, food and water systems, and identified the major economic, social, geopolitical, environmental, technological and institutional drivers at work. Building on the global analysis and the empirical evidence from three case studies, as well as a broad set of quantitative indicators, Part 2 highlighted a range of risks and vulnerabilities developing countries faced in terms of their energy, food and water security. The aim of Part 3 is to address the following question:

> *What strategies, policies and measures can governments in developing nations (with support from multilateral agencies, donors and non-governmental organisations) adopt in order to mitigate nexus-related risks to energy, food and water security and to make energy-food-water systems more resilient and sustainable?*

Mitigation in the context of this report refers to strategies, policies and measures formulated and implemented to proactively lessen any future negative impacts of shocks to interconnected energy, food and water systems; i.e. actions that are taken ***in advance of*** shocks.[25] The following paragraphs briefly outline the foundation concepts – resilience, sustainable development and green economy transitions – that underpin the specific policy recommendations.

Resilience

Resilience has been defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker, Holling, Carpenter & Kinzig 2004:5). According to Rees (2010:5), resilience science recognises that socioecological systems are perpetually changing in response to both external and internal forces, such that "attempts to resist change or control it in any strict sense are doomed to failure." Resilience has been adopted as a central concept in the WEF's annual global risk assessment. Their approach defines a resilient country as "one that has the capability to (1) adapt to changing contexts, (2) withstand sudden shocks and (3) recover to a desired equilibrium, either the previous one or a new one, while preserving the continuity of its operations" (WEF 2013:37). The assessment considers ways to build the resilience of energy-food-water systems to a variety of shocks, including international energy and food price or supply shocks, as well as possible impacts of climate change and variability (such as droughts, floods, rising average temperatures and erratic rainfall).

Sustainable development

The recommendations put forward in this report are informed by a set of overarching policy goals that rest on the three pillars of sustainable development: social inclusiveness, economic productivity and environmental sustainability.[26]

- The first goal is to improve food, water and energy security for people living in developing countries, especially for those in the poorest segments. This requires improving access to basic services, since "[m]eeting minimum standards of access to safe water, adequate sanitation, healthy food and clean sustainable energy is a pre-requisite for human development and dignity" (BMU 2012:4). The goal, however, extends beyond meeting essential minimum standards to enabling

25 This use of the term 'mitigation' is broader than how it is understood within the climate change field, where it refers to actions taken to reduce emissions of greenhouse gases that cause global warming, as opposed to adaptation, which is action taken to reduce the resulting impacts on human societies and natural systems.

26 See Hoff (2011), BMU (2012) and UN-Water (2014).

livelihood opportunities that contribute to building quality of life, healthy societies and productive economies. In this way, addressing energy, food and water security is tantamount to ameliorating the effects of poverty.

- The second goal of enhancing economic productivity goes further than the conventional notion of economic efficiency because it recognises the limited extent of natural resources and therefore the necessity of raising the productivity of resource use (UNEP 2011b; UNEP 2014). This begins with waste reduction, but also includes the use of innovative technologies that allow more value to be created from fewer material inputs.
- The third goal involves improving environmental sustainability by protecting and restoring ecosystems and biodiversity levels, and enhancing their resilience to shocks. This feeds back into social and economic goals by ensuring a continued stream of ecosystem services, which underpin all socioeconomic systems. These include provision of fresh water, food (including crops and aquatic products), fibres and timber, and climate regulation services (BMU 2012).

Transitioning to green economies

The concept of transitioning to 'green economies' has gained increasing traction in global discourse in recent years as it offers a way in which to operationalise sustainable development objectives. UNEP (2010:5) defines a green economy as one that "results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities." Alternatively, "a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive" (UNEP 2011b:16). A key green economy principle is acknowledgement of the need to decouple economic growth from resource use and environmental impacts (Fischer-Kowalski & Swilling 2011). "Decoupling at its simplest is reducing the amount of resources such as water or fossil fuels used to produce economic growth and delinking economic development from environmental deterioration" (Fischer-Kowalski & Swilling 2011:xi). In the context of this report, the more specific aim would be to decouple energy and water consumption from economic growth and particularly from an increase in food production. Transforming economies through decoupling rests on a range of technical measures:

- Increasing resource productivity and efficiency – creating more value with fewer inputs.
- Substituting renewable inputs for non-renewable inputs.
- Reducing waste and losses, and using unavoidable waste as a resource in closed-loop production and consumption systems.
- Reducing environmental impacts including pollution and greenhouse gas emissions.
- Restoring ecological infrastructure and protecting biodiversity.

Through these measures, which are expanded upon in section 3.1.2 in general terms and subsequently in greater detail, societies can undertake a gradual transition to fundamentally new, more sustainable economic systems. The following generic policy tools can be used by national or local governments to facilitate the adoption of the technical measures aimed at greening economies, boosting resilience and achieving greater sustainability:

- **Public investment** (e.g. infrastructure systems, research and development).
- **Economic instruments** (e.g. pricing and tariffs, taxes and subsidies, pollution charges, creating new markets for purchasing and selling a service/resource).
- **Regulatory mechanisms** (e.g. prescribing and proscribing certain behaviours or actions on the part of individuals, communities and firms).
- **Education programmes** (e.g. awareness-raising campaigns aimed at shifting behaviour patterns).

Outline of Part 3

The rest of Part 3 is organised as follows:

- Section 3.1 presents generic, high-level policy recommendations that are broadly applicable to all (or at least most) developing countries. Recommendations include: (i) issues related to institutions, governance and policy coherence; (ii) ways to promote inclusive green economies; and (iii) specific technical options and supporting policy instruments to enhance energy, food and water security, chiefly by addressing nexus linkages.
- Sections 3.2 to 3.4 draw on the experiences of the case study countries (Malawi, South Africa and Cuba) to develop more nuanced policy recommendations specifically tailored to countries that predominantly exhibit characteristics of the agrarian, industrial and proto-ecological regimes, respectively.
- Section 3.5 summarises the recommendations, noting the key similarities and differences among the recommended strategies for the three regime types. It also discusses the applicability of the lessons drawn from the case studies to other countries, and presents the main conclusions and avenues for further research.

3.1 Generic Recommendations

In suggesting various opportunities for improving energy, food and water security through a nexus approach, Hoff (2011:36) cautions that the case study evidence on which he draws is "context specific, for example in terms of climate, production systems, social capital and governance cultures. Hence they are not immediately transferrable or scalable. There are no blueprint solutions or panaceas." Nevertheless, there are a number of generic recommendations for mitigating nexus risks that can be made on the basis of existing international research and practical experience.

3.1.1 Strengthening institutions, governance and policy coherence

Well-functioning institutions, effective governance systems and integrated policy frameworks are prerequisites for designing effective policies and implementing technical solutions to tackle nexus risks and vulnerabilities. These all create the enabling environment within which public, private sector and civil society actors can take informed decisions that better align with the socioeconomic and environmental goals discussed above. The following strategies and measures are applicable to some degree or other to all developing countries, although clearly to a greater extent in cases where current institutional capacity and coordination is weaker.

Building institutional capacity

The complexity of nexus issues and the many trade-offs involved in nexus policy choices implies a need for strong institutions with effective capacity. Hoff (2011:39) suggests that:

> *… while some new institutions may be required for alignment across sectors, such as inter-ministerial bodies or inter-agency programs, it is more important to strengthen existing institutions so they can build new links across sectors and deal with the additional uncertainty, complexity and inertia when integrating a range of sectors and stakeholders.*

Furthermore, institutions should be able to adapt in a flexible manner to rapidly changing conditions. Capacity-building programmes should promote multi- and transdisciplinary approaches and focus on the nexus as a basis for sound policymaking, and offer learning and management opportunities that develop abilities for systems thinking and the application of nexus assessment tools (discussed below) (BMU 2012). Sector-specific initiatives will also be needed, such as programmes for natural resource and environmental management. The technical skills for implementing new technologies include skills for managing water resources, evaluating environmental impacts, implementing energy-efficiency programmes, understanding renewable energy systems and their maintenance requirements, and so on (IRENA 2015). These and other nexus-related areas should be included in the curricula of training programmes at higher education institutions (BMU 2012).

Enhancing institutional and policy coordination

Responding to – and in some instances preventing – nexus challenges implies a strong need to transcend a silo approach to policymaking within governments. At the national level, there needs to be horizontal coordination across relevant ministries and sectors (such as agriculture, water, energy and environment) to enable collaboration in planning, the formulation of policies, management and monitoring (BMU 2012). Vertical coordination between different levels of government also needs to be enhanced, especially if decision-making occurs at different levels or scales in different, but related, sectors – such as centralised energy planning and local water resource allocation (IRENA 2015). For example, "[p]olicy-makers, planners and practitioners in water and energy need to take steps to identify and overcome the barriers that exist between their domains" and "practitioners need to engage with and fully understand one another" (UN-Water 2014:6). Other government policies, such as trade and industrial policies, should also consider nexus issues because of how these can impact on energy, food and water security through transnational flows of virtual (embedded) resources and externalities (BMU 2012). Nevertheless, it is important to recognise that there are "transaction costs associated with stronger integration across sectors" (Hoff 2011:5), and these costs need to be weighed against the benefits of greater coordination.

Adopting a nexus approach to policymaking and planning

Another imperative is to adopt a coherent nexus approach that is underpinned by sound science. At the broadest level, governments should adopt a 'green economy' paradigm that strives for socially inclusive, economically efficient and environmentally sustainable development. More specifically, adopting a nexus approach to policymaking would entail formulating resilient development trajectories that explicitly take into account the interconnections between energy, food and water systems, and manage the trade-offs that inevitably arise (BMU 2012:7; IRENA 2015; WWF 2014). "It is an approach that looks for synergies both horizontally across the three sectors and the broader policy environment including climate change and urban development, and vertically between international, regional, national and local levels" (BMU 2012:7).

A nexus approach must also integrate climate mitigation and adaptation policies and strategies with energy-food-water security policies, recognising that the former may positively or negatively affect energy, food and water security as well as ecosystems (BMU 2012).

Employing a nexus approach can bring benefits such as "more integrated and cost-effective planning, decision-making, implementation, monitoring and evaluation" (FAO 2014:3). There are, however, two important caveats. Firstly, that planners need to recognise that the political economy context, including the pace of market change, technological developments and governance, may differ across the sectors (UN-Water 2014). Secondly, a nexus approach needs to be based on "a coordinated and harmonized nexus knowledge-base and database indicators and metrics that cover all relevant spatial and temporal scales and planning horizons" (Hoff 2011:12).

Once a set of relevant institutions and stakeholders is constituted, they should use a nexus perspective to formulate a strategy to address energy, food and water security. Such a strategy could entail:

- Setting targets for improving energy, food and water security.
- Assessing institutional and procedural constraints to attainment of these targets.
- Assessing relevant natural resource constraints and environmental sensitivities.
- Identifying policy priorities within the national context, informed by an analysis of indicators.
- Designing and implementing effective policies.
- Monitoring and evaluating the effectiveness of the policy in achieving its objectives.

Employing nexus assessment tools

Nexus assessment tools can assist nexus-oriented decision-making by measuring the impact of policy interventions on different sectors, and quantifying the implications for natural resource use and environmental impacts (BMU 2012; IRENA 2015). Assessment tools differ in that some approaches take one perspective (e.g. energy policy) and do not consider the impacts on the other sectors (food and water). A middle-of-the-road approach "consists of a basic nexus tool that receives policy and data inputs regarding the energy sector and also basic inputs relevant to water and food/land, and provides outputs about the basic resource requirements (e.g., water and land) of the analysed energy policy" (IRENA 2015:88). These can be useful in beginning to address silo gaps when administrative and data resources are limited. The most comprehensive type of nexus tool "accepts detailed inputs of the three sectors and provides information on basic resource requirements (e.g., total land needed), complemented with quality aspects (e.g., types of land) or other issues related to scale, distribution/equity or governance, among others" (IRENA 2015:88). Of course, the data requirements for integrated models are much more onerous. Rodriguez et al. (2013) suggest that the simplest option for many countries is to include water resource and water use data into existing energy modelling frameworks, which are common in many developing countries; however, these frameworks do not include the food component.

Investment is needed to collect standardised and consistent datasets to operationalise nexus assessment tools. Sector-specific data can be difficult to obtain. It can be even more difficult to find data that addresses nexus linkages (such as the energy usage in different stages of the water value chain) (IRENA 2015). Furthermore, differing data collection methods and classifications make data comparability a major challenge. The differing temporal and spatial scales at which the water, energy and food systems are normally analysed and governed can make it difficult to have 'conversations' across sectors (Stockholm Environment Institute 2014). The institute therefore notes that data may need to be reworked to allow for comparative purposes and advocates using tools such as social network and institutional analysis, to assist with considering trade-offs between sectors over different scales and time spans (Stockholm Environment Institute 2014).

Enhancing cooperation among stakeholders

Effective management of nexus challenges requires cooperation among stakeholders at all levels (international, national, and local) and across all sectors of society (including government, the private sector, international and regional organisations, civil society, academic institutions and non-governmental organisations). This should begin with the creation of "an enabling framework for policy dialogue and coherence across sectors" (BMU 2012:17). WEF (2011:13) notes that "[t]he creation of multi-stakeholder platforms can help to generate the necessary consensus and also engage the wide range of expertise and implementation capacities that effective responses will require." Hoff (2012) argues that there is a need to complement global-scale analysis of the nexus with bottom-up learning, to allow smaller-scale best practices and policies to enhance learning. The Stockholm Environment Institute (2014) advocates for recognition of the importance of participatory approaches to ensure practitioners really understand how to operationalise the nexus, and get buy-in from stakeholders. An effective way to introduce the useful information provided by nexus analysis is to include such analyses in already existing policy processes (Stockholm Environment Institute 2014).

The institute warns that not all nexus analyses will produce easy win-win solutions for various resource conflicts, and many will produce only negative trade-offs. In these situations, scientists must ensure that policymakers and stakeholders have all the information needed about impacts, costs, externalities, and so on, to enable the public sector and society to decide on preferred options; this is often based on value judgements (Stockholm Environment Institute 2014). Participatory processes are important to ensure that vulnerable parts of society are also capacitated to advocate for themselves (Stockholm Environment Institute 2014).

Improving international cooperation

International and regional cooperation is vital to overcoming potential or actual intercountry rivalries and tensions over access to critical transboundary resources such as water (BMU 2012; UN-Water 2014). WWF (2014:1) suggests that stakeholders "[u]se trade, regional integration and foreign policy to manage nexus trade-offs more effectively, and contribute further to resilience at both country and global levels." Regional cooperation can take the form of basin-wide water resource management and regional power pools, for example.

Greater international cooperation is required to manage foreign direct investment in the agriculture sector. While various organisations are trying to develop frameworks to regulate land deals, these would need to be agreed upon quickly in order to meet the predicted huge increase in the demand for and scale of such deals in the coming decades (Hoff 2011; WEF 2011). "Key elements of integrated water and land resources planning and management are: secure property rights; transparency and accountability of contracts; participation through free, prior and informed consent; and effective anti-corruption measures" (Hoff 2011:9).

Similarly, countries need to work towards international policy frameworks that foster cooperation on international trade in agricultural products (and by implication, embedded energy and water) to ensure that spikes in food prices triggered by extreme events (e.g. geopolitical or weather events) do not get amplified and impact on import-dependent countries (Bailey et al. 2015). For example, countries can negotiate within the World Trade Organisation on conditions under which agricultural export countries can limit their exports during periods of drought or other natural disasters. Trade negotiations should also include key inputs such as fertilisers and seeds. Countries can also coordinate their management of emergency food stocks and strategic reserves (Bailey et al. 2015).

Ensuring sustainable and equitable governance of resources

Enhancing food, energy and water security requires that governments manage their countries' resources both fairly and sustainably for the long-term benefit of their citizens. Governance systems can be improved by including participatory processes; bolstering accountability, transparency, monitoring and anti-corruption measures; and recognising human rights (BMU 2012). Resources needing such governance include water (e.g. allocation rights that recognise, and prioritise among, competing uses); energy resources (e.g. fossil fuels and biomass such as forests); and land (e.g. a rights-based approach to land use that enables people to make a living from the land and access ecosystem services). The integrity and transparency of project implementation needs attention in order to reduce corruption, so as to avoid economic losses and biased decisions affecting resource use (BMU 2012).

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Water break at school, Ethiopia

While some direct forms of government investment will be necessary to support the achievement of energy, food and water security goals, distorting subsidies should be avoided. "Subsidies designed to support food, water and energy security have often had adverse consequences tending to disproportionately benefit the non-poor, reduce resource use efficiency (of water, energy and land), distort relative comparative advantage, displace investments in R&D [research and development] and innovation, and pose burdens on limited government budgets" (BMU 2012:8). Examples of distorting subsidies are those for electricity that lead to over-exploitation of groundwater, and those for fossil fuel consumption that lead to unnecessary carbon dioxide emissions. Therefore, there is a need for "[a]n integrated and comprehensive assessment of the economic, environmental and welfare cost of subsidies" (BMU 2012:8).

3.1.2 Promoting inclusive green economies

This section briefly discusses generic policy recommendations that address green economy goals and are broadly applicable to energy, food and water security. These recommendations are expanding access; improving resource productivity and reducing waste; restoring ecological infrastructure; reducing environmental impacts; and managing demand. These policy options are subsequently explored in greater detail within the context of energy, food and water systems, respectively.

Expanding access to water, food and energy services

Many of the vulnerabilities identified in Part 2 relate to existing deficiencies in access to modern or clean energy services, adequate nutrition and safe water. These insecurities need to be addressed directly as part of national economic development and poverty alleviation strategies. At the same time, provision of basic services such as energy and water is required for broader economic transformation and growth (UNEP 2011b). According to the Bonn 2011 Nexus Conference report, "[l]ack of access is generally not an issue of scarcity but one of commitment and enabling environment" and "a range of approaches are needed for urban, peri-urban and rural areas and for economies at different stages of development" (BMU 2012:9).

The first thing governments can do to support the achievement of access goals is to include national energy, food and water security targets along with more traditional targets for socioeconomic development such as GDP growth and employment. More concretely, expanding access to energy and water will require investments in infrastructure, which may take different forms in rural and urban areas, as explored in later sections. Governments can foster infrastructure investments by setting up private-public partnerships and by providing risk guarantees to leverage private funding (BMU 2012).

Expanding access to food requires ways to ensure adequate access to arable land and other inputs so that people can produce food and/or income-generation opportunities to enable households to purchase food. Governments should ensure that foreign land investments do not disadvantage local communities and compromise their access to land, water and energy resources. Synergies can be harnessed; for example "highways and access routes built for food delivery to remote areas can also support water supply and energy grids" (Bizikova et al. 2013:14). Economic instruments, such as subsidies and social safety nets targeted at the poorest consumers, can also be employed to boost resilience to food price shocks (UN-Water 2014; Bailey et al. 2015), although the caveat about distorting subsidies must be borne in mind. More detailed policy recommendations for improving energy, water and food access are provided in subsequent sections.

Improving resource productivity

One essential way of closing the existing and projected gap between demand for and supply of energy, food and water is to raise the productivity of resource use. This entails increasing the efficiency with which resources are used at all stages of the production-use chain so that more of the desired outcome (improved energy, food and water security) can be attained with less resource use. Boosting efficiency is closely related to reducing waste, whic h is discussed in the next section. Best practice technologies, equipment and management systems need to be adopted to enhance efficiencies in energy generation, agriculture, manufacturing and municipal water systems (BMU 2012).

Several types of policy instruments can be employed to help raise resource productivity. Public funds should be directed towards building more sustainable infrastructure systems that facilitate greater resource productivity and minimise waste (e.g. multi-use systems). Public funds should avoid sunk cost infrastructure investments that lock in unsustainable development trajectories. Governments can also allocate funds to research and development to improve the efficiency of technologies and operational systems.

A range of regulatory tools can encourage resource productivity. These include setting minimum standards for the energy and water efficiency of equipment and appliances, and green building codes. Governments can also create an enabling framework for innovation, including a national innovation system and networks for knowledge sharing.

Economic incentives are often the most effective policy instrument for shifting the choices of producers and consumers to less resource-intensive options. These include smart incentives provided to firms for efficiency gains, innovations and the adoption of new technologies; and subsidy reform to reduce or eliminate distorting subsidies that perpetuate inefficient processes and practices.

Finally, governments can launch education and awareness programmes that provide information about nexus connections and resource use, and encourage greater efficiency (BMU 2012; UN-Water 2014). Tools to leverage consumer behaviour towards more sustainable production and consumption patterns include eco-labelling; publication of water, energy and carbon footprints; and certification schemes. In the industry sector, the relevant government ministry can publicise innovations, best practices and technology options, and set up standard reporting practices for manufacturing.

Minimising waste and reducing losses

Policymakers should promote a minimum waste and recycling policy at national and local levels, and foster a culture of using remaining waste as a resource in multi-use systems (Hoff 2011; BMU 2012). A minimum waste and recycling economy can be promoted in various ways. Publicly-funded investments in new infrastructure in new or expanding urban areas should build in recycling systems, while existing infrastructure systems can be retrofitted (albeit at greater cost). Regulatory frameworks can be developed to deal with waste products and ensure recycling systems, which take into account human health, cultural and environmental concerns, are put in place (BMU 2012). Governments can levy appropriate tariffs on water and energy use to incentivise consumers to avoid wastage. They can tax waste streams generated by firms and households to encourage reuse and recycling and abolish subsidies that encourage the use of new resources over reuse and recycling.

Conserving and restoring ecological infrastructure

It is essential to protect and rebuild ecosystems to ensure continued delivery of the ecosystem services that underpin energy, food and water security. This requires reducing pollution (discussed in the next subsection) as well as taking measures to improve soil quality (which will benefit both agriculture and water quantity and quality through better moisture retention), and rehabilitating or protecting wetlands, forests and other natural systems that help regulate the hydrological cycle. A balance needs to be struck between ensuring the integrity of ecosystems and use of land for agriculture (BMU 2012). As discussed further in section 3.1.4, "[g]reen and conservation agriculture ('agro-ecosystems') can provide additional benefits such as carbon sequestration and resilience to climate risks e.g. through improved moisture retention, while generating additional jobs (reducing migration to cities), and improving food security" (Hoff 2011:39).

A range of policy interventions and tools can be employed to protect ecological infrastructure. First, systems need to be developed to ensure optimal management of ecosystems. This should begin with an assessment of the direct and indirect value of ecosystem services to energy, food and water security, as well as their broader economic contribution (BMU 2012). In addition, environmental impact assessments should be mandatory as part of the application process for new energy and water projects (UN-Water 2014). Critically important ecosystems and biodiversity can be protected by the establishment of nature reserves and protected areas, as well as multilateral and national conservation agreements. Local communities should be encouraged to participate in conservation of natural resources (BMU 2012). Second, governments should invest in the restoration of ecological infrastructure, such as the rehabilitation of wetlands and clearing of invasive alien vegetation from waterways. Third, sustainable financing mechanisms should be developed to support ecosystem services (BMU 2012). Examples include payments for ecosystem services; i.e. incentives paid to farmers or other landowners as compensation for managing their land to provide ecological services, benefit-sharing regimes, and ecotourism projects (Hoff 2011). An example is that of farmers receiving payments for sound ecosystem management practices from downstream water users. Fourth, governments should remove perverse incentives or subsidies that encourage the depletion of natural capital and the degradation of ecosystems.

Reducing harmful environmental impacts of economic activities

As described in Part 1, energy and food systems can have detrimental impacts on the environment, including various forms of water, air and land pollution. One of the fundamental principles of the green economy is to find ways of decoupling economic activities from environmental impacts such as pollution and emissions. This serves to protect ecosystems and reduce the future impacts of climate change. "In addition to the environmental benefits, reducing pollution loads at source will cut the costs of treatment (both financial and energy costs), the incidence of health impacts including water-borne diseases and respiratory problems and the accumulation of toxic contaminants" (BMU 2012:13).

There are two basic policy instruments that can be used to reduce pollution. The first is economic incentives, such as environmental taxes that address negative externalities and 'get the environmental prices right'. "Taxes or fees on pollution could be designed to reflect the social cost of pollution, including health impacts, ecological impacts, and impacts associated with anthropogenic climate change" (UNEP forthcoming). There are two types of environmental taxes: (i) "'polluter pays' focused on charging producers or consumers at the point that they are responsible for the creation of a pollutant; and (ii) 'user pays', which focuses on charging for the extraction or use of natural resources" (UNEP 2011a:31). Taxing pollution can encourage firms to innovate and adopt new technologies (UNEP 2011a). The second set of pollution-reduction instruments consists of regulations designed to limit unsustainable activities and behaviours; for example, by prescribing minimum standards for waste treatment or emissions, or proscribing the most polluting activities (UNEP 2011a:27). In some instances, such 'command and control' measures may be the most effective and cheapest policy option (UNEP 2011a).

Managing demand for resources

To complement the largely supply-side options discussed above, governments can also address the increasing pressure on scarce resources by managing the growth in demand for energy, food and water (and other goods and services that depend on them). This is particularly relevant in wealthier developing countries where the basic needs of most citizens are already being met and living standards are higher.

Various policies can target the main demand drivers discussed in Part 1, namely population growth, economic growth, urbanisation and changing consumption patterns.

- Although somewhat controversial, governments in countries with high fertility and population growth

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Solar energy-powered electric transmission, India

rates can implement policy interventions designed to reduce fertility levels. Measures include improving the educational opportunities for females, decreasing the child mortality rate through providing improved primary health care, and ensuring women have access to family planning services (Searchinger et al. 2014).

- Economic policies and national development plans can contribute to a structural transformation of economies towards less resource-intensive industries and activities (UNEP 2011b).
- Considering the anticipated 'second wave of urbanisation' over the coming decades in developing countries, and that fact that resource consumption tends to be concentrated in cities, there is a significant opportunity for building resource-efficient cities with infrastructure configurations (for energy, transport, waste, water and sanitation) that are designed to reduce overall resource use (UNEP 2013; GIZ & ICLEI 2014).
- Consumer behaviour and consumption patterns can be managed through a combination of awareness campaigns, economic incentives and regulations. For example, appropriate pricing regimes (e.g. stepped tariffs for water and electricity use) can be implemented to facilitate access and boost security among low-income households, while limiting overconsumption and waste by higher-income households and firms.

3.1.3 Energy security

This section applies the green economy lens to consider specific ways to improve energy security and mitigate risks within the context of the energy-food-water nexus. The measures described below aim to:

- Expand access to modern sources of energy, especially in low-income countries and among the poor more generally.
- Build resilience to external energy shocks.
- Improve energy efficiency and reduce waste all along the energy supply and use chain.
- Reduce the dependence of energy systems on water.
- Carefully manage bioenergy in order to avoid potential competition with food production.
- Reduce environmental impacts of energy systems, especially on water quality.

The following subsections explore ways to achieve these objectives through technical measures and supporting policy interventions.

Expanding access to modern energy

Access to reliable, affordable, safe and clean energy services can be expanded in developing countries through policies and measures that promote improved appliances and fuels for cooking, and broaden access to electricity through extending electricity grids or providing distributed electricity solutions.

There is a need to expand access to improved cookstoves (such as more efficient wood-burning stoves) in the rural areas of many developing countries. This would reduce the negative health impacts caused by air pollution and would serve to limit deforestation.[27] Furthermore, governments can promote the availability and adoption of various cleaner cooking fuels, such as biogas, ethanol, propane, or liquid petroleum gas (LPG). Biogas is a clean and renewable fuel that can be generated in small-scale anaerobic digeste rs, and offers the added advantage of contributing to sustainable waste management (UNEP 2011a). Solar thermal stoves rely on sunlight instead of a solid or liquid fuel, and are an increasingly cost-effective solution (UNEP 2014). As an example of what is possible, an "energy access project in Ethiopia led to the adoption of improved cookstoves by 2.6 million households in just five years" (SEA 2013).

The need for electricity in rural areas can be addressed through a variety of distributed electricity solutions. Micro- or mini-grids can be powered by locally available energy resources, whether renewable or conventional. For example, a company called "Husk Power Systems provides power to 25,000 Indian households through biomass based mini-power plants that use discarded rice husks" (SEA 2013). Other alternatives include off-grid micro-renewable energy systems such as solar home systems, which have "low operating costs and flexible, small-scale deployment options" (UNEP 2011a:11), and small-scale lighting and charging solutions such as solar lamps (SE4ALL 2012). The IEA has concluded that achieving universal access to electricity in urban areas can best be served through the extension of (large-scale) electricity grids (IEA 2011a).

Governments can support these opportunities for expanding modern energy access in various ways (see SE4All 2012). First, they should develop national energy plans and programmes of action with specific targets for energy access (e.g. the percentage of the population with access to electricity). They should seek to partner with international organisations and programmes that support this goal, such as the United Nations' SE4All campaign and the World Bank.[28] Second, governments can design regulatory frameworks and economic incentives that are tailored to local conditions and serve to incentivise commercially viable private investments in decentralised electricity solutions.

27 See http://www.africancleanenergy.com/ for an example of a highly efficient biomass-burning cookstove.

28 See SE4All (2012) for details of other multilateral bodies promoting expanded energy access.

Third, policymakers can help to stimulate markets for improved cooking and micro-grid solutions by conducting education campaigns and advising consumers about the health, gender, economic and environmental benefits of renewable energy. Fourth, governments can support capacity building and the training of entrepreneurs and small businesses to develop energy value chains.

Possibly the most important area for policy support is financing; this is a major challenge for LICS in particular. There is a need for governments to develop microfinance or other forms of financial support for poor households to enable them to surmount transaction and capital costs, and invest in clean energy. Some options include rotating saving and credit associations, community-based organisations, saving and credit cooperatives, microfinance institutions and postal banks (UNEP 2011b). A prominent example is the Grameen Shakti, a micro-credit scheme that finances rural electrification through solar home systems in Bangladesh. LIC governments, in particular, will also need to access bilateral and multilateral development assistance and to tap into global sources of funding such as the Green Climate Fund and Global Environment Facility.

Building resilience to external energy shocks

As noted in Part 2, one of the major threats to energy security in the medium to longer term is external (international) energy shocks, which can take the form of energy price spikes and possibly physical supply shocks. These risks apply mainly to oil since it is the paramount globally traded energy commodity, although the prices of other energy carriers such as coal and gas tend to follow oil prices quite closely. Short-run and long-run strategies to mitigate the varied impacts of oil shocks have been explored in detail by in a report by Wakeford and De Wit (2013) and are summarised here.

Short-term mitigation responses aim to provide buffers and boost resilience during acute oil price volatility or physical supply shortages. Measures aiming to support these responses are outlined below.

- To manage oil price spikes, net oil-importing countries can introduce a fuel price smoothing mechanism (e.g. administering fuel prices on the basis of a three-month moving average, with a dedicated fuel fund to absorb extra revenue when prices are low and release of funds to limit fuel price increases when the price of imported fuel rises); gradually phase out petroleum fuel subsidies, especially in times when oil prices are comparatively low; possibly provide temporary, targeted income support for critical users; and subscribe to a regional petroleum fund that serves as a pooled source of insurance that can be drawn upon when oil prices spike.

- To reduce the risks and impacts of short-run disruptions to the physical supply of oil, net oil-importing countries can seek to diversify their sources of oil imports (prioritising more geopolitically stable suppliers); build adequate strategic fuel stocks; prioritise fuel allocations to critical users such as emergency healthcare and police services, and for food production and distribution; and forge regional energy alliances with both oil-importing and oil-exporting countries to pool energy resources.
- For net oil-exporting countries, oil price volatility can cause budgetary problems and macroeconomic instability. These risks can be mitigated through flexible exchange rate management and foreign reserve holdings, as well as prudent fiscal policy that levels out windfall export receipts over time to compensate for periods of low oil prices.

Long-term mitigation strategies seek to minimise a country's exposure to energy shocks by reducing reliance on oil (and other imported fossil fuels) through improved energy conservation and efficiency and development of indigenous energy sources. Measures aiming to support these responses are outlined below.

- For net energy importers in particular, energy conservation and efficiency measures should be the first option. As discussed in a subsequent section, a range of technical options can be stimulated by appropriate incentives and regulations.
- Countries can also reduce their reliance on energy imports by developing indigenous energy sources, whether these are fossil fuels (oil, gas and coal), nuclear energy (currently restricted to a select few UMICs), or renewable energy sources (which are widely available in different mixes). A top priority should be to phase out oil-fired power generation, replacing this with alternatives such as natural gas (where available) and renewables.
- The long-term strategies available to net oil-exporting countries revolve around diversifying their economies to be less dependent on oil revenues; for example, by reinvesting oil revenues in education and skills development, healthcare, and infrastructure including more sustainable forms of energy and transport.

Developing **renewable energy** sources helps to mitigate external energy shocks, while also contributing to green economy goals such as climate mitigation, reduction of environmental degradation and job creation. Because renewable energy features strongly in this section on energy security, as well as in the food and water sections, policy measures to accelerate their deployment are elaborated upon here.[29]

- The point of departure for promoting renewable energy is to create an enabling policy framework that clearly communicates the government's long-term commitment to the sector's development; for example, via setting targets for investment in renewable energy capacity or its share of the energy mix. To realise these targets, which should be flexible to adapt to changing circumstances, policymakers will need to implement a broad range of policy measures, including economic instruments, public finance mechanisms, infrastructure and regulations, and support for technology transfer and skills development. These measures can help to mitigate a range of risks facing the renewable energy industry, including political, institutional and regulatory risks, as well as technical, business and market risks.
- A wide array of economic incentive mechanisms can be used to stimulate investment into renewable energy. A starting point would be to eliminate fossil fuel production and consumption subsidies, although care must be taken not to unduly harm the poor in the process; one mitigation option would be to provide income support targeted to the poor, or to redirect energy subsidies to spending on basic education and health services. More direct measures to support infant renewable energy industries include subsidies and grants, investment tax incentives, production tax deductions, preferential depreciation schemes and loan support. However, UNEP (2011a:29) cautions that "it is important that the support is stable and predictable, gives certainty to investors, and is phased out over time in order to motivate innovation." A carbon tax – designed to capture the social and environmental costs of fossil fuels – would likely be an effective instrument to divert investments from fossil fuels to renewables, and could be offset by reductions in other tax types (e.g. income taxes) so as to maintain revenue neutrality. A mechanism that has proved to be particularly

29 This section draws mainly on the renewable energy chapter of UNEP's *Green Economy Report* (2011a) and its companion *Synthesis for Policymakers* (UNEP 2011b).

successful in several countries around the world is a feed-in tariff, which guarantees a fixed price – usually at a premium over the prevailing power price – for electricity generated from renewable sources and fed into the national grid. To maximise effectiveness, incentives like this should be guaranteed for 15 to 20 years, although the price premium can be reduced as costs fall with technology development and learning.

- A similar option is so-called 'net metering' (whereby households or firms are given credits for electricity generated from renewable sources and supplied to the grid), which incentivises small-scale renewable power generation. Finally, emissions trading schemes can be considered in developing countries with relatively more advanced institutions and markets.
- Public finance mechanisms, which range from simple grants, to low-interest credit, to loan guarantees, to more complex conditional funding structures and public-private partnerships, can be used to mobilise private investment or help create new markets.
- Large-scale penetration of renewables into the energy sector also requires government support in the form of electricity grid infrastructure and supporting regulations. If intermittent renewable energy technologies are developed, such as solar PV and wind power, this will require more flexible grids with greater reserve capacity, storage mechanisms, or increased trade with neighbouring countries. Streamlined permitting procedures and grid connection processes can facilitate private-sector investment.
- Developing country governments also need to give attention to "creating capacity to facilitate technology transfer, adapt technologies to local market conditions and support private-sector players that install, manufacture, operate and maintain the technologies"(UNEP 2011b:233). This, in turn, will require policy support for skill development and innovation in the sector.

Enhancing energy efficiency

Energy efficiency improvements can reduce overall energy demand, reduce reliance on fossil fuels and hence greenhouse gas emissions, and through nexus linkages can also bring substantial water savings. Energy conservation and efficiency represent the 'low hanging fruit' of nexus interventions, as they are usually quicker to implement and less costly than building new energy supply infrastructure (IEA 2011b). There is a large body of literature devoted to energy efficiency, and this section merely summarises some of the key opportunities. UNEP (2014:44) reports that "the technical potential to reduce demand for energy through energy efficiency appears to be in the order of 50-80 per cent (factor two-five) for most technical systems." For example, Weizsäcker, Hargroves, Smith, Desha and Stasinopoulos (2009) provide a survey of technologies and measures that are already being implemented in sectors such agriculture and food, industry, transport and hospitality and that are achieving energy efficiency improvements of between 60% and 80%. Other research suggests that developing countries could reduce their yearly growth in energy demand from 3.4% to 1.4% over the next 12 years (UNEP 2014). Specific opportunities for improved energy efficiency arise at various stages of the energy lifecycle, including production, transformation, distribution/transmission and consumption.

Harnessing the potential for energy efficiency savings should begin with the formulation of national energy efficiency strategies, which should include targets and be informed by indicators and data collection on energy use, markets, technologies and efficiency opportunities. "Once in place, monitoring, enforcement and evaluation of such strategies are crucial to identifying gaps and achieving targets" (IEA 2011b:6).

Opportunities for enhanced efficiency exist at the production, transformation, and transmission stages of the energy value chain. This is largely the domain of big energy companies and power utilities, and, in cases where these are state-owned, governments can directly encourage greater efficiency by ensuring the best technology options are exploited.

At the energy production stage, combined heat and power offers considerable efficiencies[30] (see a later section dealing with water usage), as do modern technologies such as supercritical coal power generation. Care should be taken in energy transformation planning to maximise efficiencies; for example, "conversion of biomass into electricity yields on average 80% more transportation kilometres (when used in electric vehicles) than conversion into biofuel (when used in internal combustion vehicles)" (Hoff 2011:21). Battery technologies for storing electrical energy are improving rapidly, while pumped storage

30 State-of-the-art combined heat and power plants can reach 85% efficiencies (Bruckner et al. 2014).

offers another option that can be built in at various scales. There is scope for energy savings in electricity distribution and transmission, such as through the use of high-voltage direct-current power lines, as well as decentralised mini-grids (e.g. fed by renewable energy) (Bruckner, Bashmakov, Mulugetta, Chum, de la Vega Navarro, Edmonds, Faaij, Fungtammasan, Hertwich, et al. 2014). Furthermore, "[s]mart grids with variable cost pricing and micro-metering is a new area of development with the potential to provide increased demand flexibility and enhance energy efficiency" (UNEP 2011b:232).

Great opportunities exist for improving energy efficiency at the consumption stage of the lifecycle, including critical users such as buildings, residential, lighting, industry and transport. Many of these opportunities and policies are applicable to relatively wealthier developing countries with higher levels of energy consumption per capita and per unit of GDP. However, the earlier that LICs implement these policies and as their economies develop, the more energy they can save over the longer term – retrofitting and replacing is more costly than starting out with efficient equipment and infrastructure. Many of the policies are aimed primarily at urban consumers, since per capita energy consumption tends to be much higher in urban areas compared to rural areas (UN-Water 2014). In this regard, urban planners should encourage high density compact cities, as these generally have lower energy requirements for transportation and provision of basic services, such as water and sanitation (UN-Water 2014).

- In the **building sector**, governments can encourage greater energy efficiency through measures such as setting mandatory energy codes and minimum energy performance standards for new and renovated buildings; setting targets for net-zero energy consumption buildings and using such buildings as benchmarks for future standards; introducing policies to increase the energy efficiency of the existing building stock, including incentives to stimulate investments in long-lasting building envelope and system improvements; requiring certificates or labels for building energy performance that communicate relevant information to owners, buyers and renters; and implementing policies to enhance the energy efficiency of essential building components, including windows and heating, ventilating and cooling systems (IEA 2011b).
- In the **residential sector**, there is considerable scope for governments to encourage the uptake of energy-efficient appliances and equipment through the imposition of minimum energy performance standards and labelling with energy-efficiency ratings, supported by accurate energy performance measurement standards and protocols that draw on international experience (IEA 2011b). These end-user policies can be complemented by market transformation policies such as financial incentives, procurement programmes and endorsement schemes that encourage the production of the most cost-effective and energy-efficient models and designs.
- In a rural context, especially in LICs, there is significant scope for improving household energy efficiency through improved cookstoves (see the Malawi case study in section 3.2.1). These include solar thermal cookers, which can attain factor five efficiencies (UNEP 2014).
- Governments can facilitate the adoption of efficient lighting by passing laws to phase out inefficient lighting products such as incandescent bulbs, within constraints of economic viability and technical feasibility (IEA 2011b). For example, light-emitting diode (LED) lamps are about 80% more efficient than incandescent bulbs (Portela et al. 2010 in UNEP 2014:47). Governments can also introduce building codes that encourage the use of passive solar lighting and introduce minimum energy performance standards for new and existing lighting products and systems. For street and traffic lighting, fluorescent lights and LEDs can substantially reduce energy consumption and provide an added benefit of conserving resources since these products have longer service lives (UNEP 2014).
- In the **industrial sector**, governments can foster energy efficiency by encouraging the adoption of energy management protocols (such as ISO 50001), especially in large energy-intensive industries (IEA 2011b). Large amounts of electricity can be saved through the use of high-efficiency motors, the use of which can be promoted by minimum energy performance standards. Special policy packages should be designed for small and medium enterprises, including access to energy audits and information on best practice. UNEP (2014) provide examples of technologies that can substantially reduce fossil fuel consumption (and therefore carbon emissions) in industrial processes such as mining and minerals, steel, cement, paper and pulp, and chemicals. A variety of economic instruments can be implemented to facilitate energy efficiency practices, including targeted incentives, the removal of energy subsidies, environmental

taxes, and providing conditional access to financing (IEA 2011b).

- The **transport sector** – including both freight and passenger transport – offers massive scope for improved energy efficiency through travel demand management, improved vehicle design and modal shifts. Substantial fuel savings are possible in freight transport through the use of more efficient truck design (e.g. improved aerodynamics, reduced rolling resistance and more efficient engines) and ship design (e.g. low-drag hull coatings, air floatation devices, and advanced propeller technology) (Lovins, Datta, Bustness, Koomey & Glasgow 2004; UNEP 2014), which can be fostered via mandatory fuel efficiency standards. Even greater energy savings could be achieved through modal shifts, especially from road to rail (Gilbert & Perl 2008). Rail efficiency can be boosted through innovations such as better aerodynamics, regenerative braking and lighter rolling stock, as well as improved logistics (UNEP 2014).
- Similarly, very large energy conservation and efficiency improvements are possible in passenger transport (IEA 2005; Gilbert & Perl 2008; Kendall 2008). Measures can start with improved traffic management, which results in less fuel wasted in idling vehicles, and the promotion of eco-driving techniques and optimum vehicle maintenance through public-awareness campaigns. Improvements in vehicle efficiency can be stimulated by mandatory fuel-efficiency standards, vehicle fuel-economy labels, and taxes (e.g. on emissions) (IEA 2011b). A switch from internal combustion engines to more efficient electric hybrid and drive systems can be encouraged by feebates (taxes on inefficient vehicles and rebates for more efficient models), the provision of charging infrastructure for electric vehicles, and public procurement (Kendall 2008; UNEP 2011; UNEP 2014).
- Possibly the greatest energy savings can be achieved through modal shifts; for example, from private vehicles to mass public transit such as bus rapid transit systems, trams and trains (Gilbert & Perl 2008). Modal shifts can be encouraged by state investments in public transport infrastructure and by economic incentives such as congestion charges in cities, fuel levies or vehicle emission taxes, and the reduction or elimination of transport fuel subsidies where these exist – so as to ensure that travellers pay the economic, environmental and energy security-related costs of transport (IEA 2011b). Transport infrastructure planning should also be integrated with urban planning.

Reducing the water dependence of energy systems

Various technical options and policy measures can be considered for reducing the water dependence of energy systems through improving efficiencies of existing processes and technologies and by switching to less water-intensive energy sources. As detailed in Part 1, the main uses of water along the energy supply chain occur at the primary extraction stage and at the transformation stage – especially during power generation.

At the production or extraction stage of the energy cycle, water is used for coal mining, oil and natural gas extraction, and production of bioenergy including liquid biofuels (electricity generation is considered later). With respect to coal mining, the major issue is not so much consumption of water as the potential pollution of water resources arising from discard coal and acid mine drainage (Water in the West 2013). Although conventional oil and gas extraction uses some water, exploitation of unconventional resources is considerably more water intensive (see section 1.1.3). Countries with recoverable unconventional fuels need to weigh up the opportunity cost of the water that would be required to exploit them, and water-scarce countries need to carefully manage the allocation of water-use licences among competing uses. Ranking among the most water-intensive energy sources (depending on feedstock crop and other factors such as use of irrigation), liquid biofuels can present major challenges to water security (IRENA 2015). In considering biofuel development, policymakers need to balance a range of goals within a nexus context, including food and water security in addition to energy security and net greenhouse gas emissions.

Since the use of water for power generation varies greatly depending on the energy source and technology type, there is considerable scope for reducing water usage by switching between energy sources and adopting water-efficient technologies. In the first instance, water can be saved by substituting certain types of renewable energy (e.g. solar PV and wind power, which use negligible quantities of water) for thermal-based power generation, which typically consumes large quantities of water, especially for cooling (Rodriguez et al. 2013; IRENA 2015). UN-Water (2014:4) notes that "[u]se of geothermal energy for power generation is underdeveloped and its potential is greatly underappreciated. It is climate independent, produces minimal or near-zero greenhouse gas emissions, does not consume water, and its availability is infinite at human time scales." On the other hand, large hydropower

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Puhagan geothermal plant, Philippines.

schemes can be highly water-intensive when evaporation from reservoirs is taken into consideration; however, small-scale hydropower and run-of-the-river systems may obviate the need for building large dams (IRENA 2015). Concentrated solar power, like other thermal power technologies, requires considerable amounts of water for cooling.

A second approach is to seek ways to reduce the water requirements for cooling of existing thermal power plants. Rodriguez et al. (2013) outline three opportunities. The first is to adopt alternative cooling technologies, for example dry cooling (which uses air in place of water as the heat transfer medium) or hybrid cooling systems (which use a combination of wet and dry systems). According to IRENA (2015:68), "the use of dry cooling systems can reduce total water consumption by as much as 90%." However, since these systems tend to be less energy efficient and more costly than conventional cooling systems, incentives or regulations are required to encourage their use.

The second opportunity is to decrease waste heat in power plants, for example, by boosting fleet efficiency or by reusing a portion of the waste heat. Options include combined power and desalination plants (which can simultaneously produce electricity and drinking water), and combined heat and power (CHP) plants. Hybrid desalination plants use waste heat from a power plant for the desalination process. These systems are more energy and water efficient and reduce the cost of desalination, but there are challenges related to managing variable power demand. Combined heat and power plants use the heat generated by power generation for district heating as steam or hot water, thus reducing the quantity of water needed for cooling, boosting efficiencies (to as high as 90%) and potentially reducing greenhouse gas emissions (if the power station burns fossil fuels). However, the initial financial outlay is higher for these plants than for conventional power plants and the payback period can be longer.

The third opportunity for reducing freshwater requirements for cooling thermal power plants is to use non-freshwater sources, such as brackish water, grey water or seawater. Use can also be made of treated industrial and municipal wastewater (Water in the West 2013). A big advantage is that wastewater is available in most cities, but it may be more expensive because pollutants have to be removed.

Overall, at the fuel extraction, processing and transportation stage of the energy cycle, the use of renewable energy such as solar, wind, tidal, geothermal and hydropower can have very low water requirements compared to fossil fuels and can therefore contribute to managing energy-water nexus challenges (IRENA 2015:). According to IRENA (2015:68), "[g]lobal projections that assess the impacts of expanding renewables on water use in the energy sector find that a renewables-dominated energy system will be less water intensive compared to a business-as-usual expansion."

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Dome of bio-digester under construction

Developing bioenergy without compromising food security

The conversion of biomass to energy using modern technologies can contribute to green economy goals as long as it takes into account and mitigates possible conflict with food requirements over scarce land and water resources. Although the bulk of current bioenergy use is for traditional applications in heating and cooking, modern bioenergy has the potential to provide the full range of energy services including electricity, heating and liquid fuels for transport (IRENA 2015). Bioenergy development can provide localised solutions that boost energy security, while also creating economic opportunities and livelihoods for people in rural areas, thus helping to alleviate poverty. It can also contribute to fulfilling environmental goals, such as reducing carbon emissions under certain conditions. Modelling by IRENA (2014) suggests that by 2030, modern biomass use could double to 108 exajoules, and contribute 60% of total final renewable energy consumption. Biomass energy development can be supported by economic incentives such as credit extension, subsidies or tax rebates (e.g. for biogas digesters), which could be funded by pollution taxes on fossil fuels, and by blending regulations in the case of liquid biofuels.

However, expanding the production and use of bioenergy – especially liquid biofuels – also carries risks in terms of potential competition for resources with food production, as well as environmental impacts, and must therefore be done in a sustainable manner (FAO 2014). The type of bioenergy feedstock, location, irrigation requirements and other production methods determine the potential impacts (IRENA 2015). Minimising the negative impacts of bioenergy requires improved land use efficiency, production of energy crops on degraded or abandoned land where possible (e.g. using hardy crops), production of bioenergy from crop residues and wastes (e.g. bagasse and manure), and the exploitation of co-products such as animal-feed cakes derived from biofuel production. However, agricultural residues are also needed to maintain soil quality (e.g. as mulching or organic fertiliser), and to provide feed for animals and feedstock for biomaterials.

For the longer-term future, second-generation biofuels may hold greater promise for addressing energy security within nexus constraints. These fuels, currently still in the research and development stage, can be manufactured from non-food, cellulosic biomass; for example, residues from forestry and agriculture, and organic household waste (IRENA 2015). So-called third generation biofuels derived from algae may eventually deliver substantial freshwater savings (Hoff 2011). Nevertheless, "the trade-offs between food and fuel are not entirely resolved because of indirect land-use changes, and due to the potentially huge market demand for renewable energy in comparison to agriculture" (IRENA 2015:81).

More generally, it is important to consider the land-use footprints (and therefore potential competition with food production) of other energy sources and technologies, including wind and solar PV farms. While renewable energy technologies have varying and context-dependent land footprints (area used per unit of power generation), the fact that they are generally more dispersed than concentrated fossil fuels means that land use can be extensive. However, some can be used "on marginal lands that are generally underused, difficult to cultivate, have low economic value, and [have] varied developmental potential" (IRENA 2015:81). Furthermore, in some areas agricultural activities can overlap with renewable energy generation, such as wind farms combined with grazing lands, and solar PV interspersed with vegetable production (known as 'solar sharing' in Japan).

An attractive bioenergy option that circumvents the food-energy dilemma is the use of waste materials for energy generation. One potential source is waste biomass generated along the food value chain, which can be converted into biogas in anaerobic digesters. Similarly, biogas (e.g. methane gas) can be captured from landfill sites and used to generate electricity or heat, or to power road vehicles.

Limiting environmental impacts of energy systems

The negative impacts of energy systems and use on the environment, including air pollution, greenhouse gas emissions and water pollution, can be mitigated chiefly through impact assessment-based regulations, economic instruments, and investments in cleaner energy technologies. The chief pollution culprits are fossil fuels because they are the main contributor to global greenhouse gas emissions when combusted and can cause serious local air pollution. The extraction of unconventional oil and gas resources via hydraulic fracturing presents a major risk to water quality. Excessive use of biomass energy also produces air and carbon dioxide pollution and can indirectly affect water quality by contributing to soil erosion and siltation of waterways.

The first requirement for reducing the environmental impacts of energy systems is to monitor and assess the impacts of energy extraction, transformation, storage and use.

For example, authorities can commission studies to calculate the water and carbon footprints of different energy generation options, as well as their environmental and social externalities (BMU 2012). Regarding storage of petroleum fuels, "[r]esearch is also needed to estimate or determine the volume of leaked transportation fuels from underground fuel storage tanks into groundwater, and to evaluate the environmental impacts of leaked chemical compounds such as benzene and toluene associated with those fuel leaks" (Water in the West 2013:4).

With an adequate information base, authorities can put in place regulations designed to minimise environmental impacts, for example requirements that produced water is adequately treated before being returned to the natural environment. Economic instruments include environmental taxes and charges on waste streams and polluting activities. Finally, as in the case of water consumption by energy systems, a major policy choice that can reduce contamination of water arising from energy processes is to switch from relatively more polluting energy sources (such as coal, oil and natural gas) to less polluting sources (such as certain renewables like geothermal, solar PV and wind power). Moreover, improving energy efficiency will, all else being equal, result in less energy being consumed and therefore less environmental impact.

3.1.4 Food security

A fundamental transformation of the entire food value chain is required, from production through to consumption and waste. When thinking about how to mitigate the risks posed by the energy-food-water nexus, as outlined in the preceding parts of this report, governments and policymakers should keep in mind three overarching goals for food systems:

- Improved food security.
- Increased resilience of the food system.
- Reduction of the food system's negative impacts on both energy and water systems.

Improved food security would mean fewer people go hungry and nutrition levels improve; both the availability of food is improved, and people's access to it (food is affordable and people's incomes improve). A more resilient food system is one that is less susceptible to shocks such as international food price shocks, international energy price spikes and possible supply disruptions, and climate variability and associated extreme weather conditions. Boosting the resilience of food systems requires improved energy and water efficiencies, so that the availability and affordability of food is not unduly affected by nexus interdependencies.

Strengthening food system governance

The overarching message from various reports on the food system and the nexus is the need to take a much broader and more integrated view on policymaking. When considering national policies, governments need to consider that the global food system and their own national food system are linked to many others (Foresight 2011; Hoff 2011), as well as comprehending the complex web of interactions and dependencies on water and energy systems (WWAP 2014). While the scale of the challenges could paralyse decision-makers, it is imperative that urgent action is taken (Godfray et al. 2010; UNEP 2011a).

In line with the institutional recommendations discussed earlier (section 3.1.1), the FAO (2012b) suggests that the ministries responsible for food, agriculture, energy, health, transport, economic development and the environment should jointly coordinate policies regarding food and energy; however, they neglect to mention the water ministry.

Although some trade-offs will be of the lose-lose variety, the FAO (2012b) argues that many solutions to nexus problems can result in progress on broader developmental goals and can therefore serve to bring policymakers from different ministries closer together in the achievement of their aims.

Governments' ability to act collectively will be crucial to face future food challenges. For example, during the world food price crisis in 2008 several countries restricted exports to protect their citizens, with adverse impacts on the global food trading system, and this should not be allowed to happen again (Foresight 2011). Previous attempts to strengthen multilateral governance have been mostly unsuccessful, but perhaps our shared vulnerability (reliance on imports of various key resources) could be a motivating factor in "reaching global agreements to tackle issues of resource scarcity and seek to ensure security for all" (Freibauer et al. 2011:114). The FAO is an example of perhaps one of the more successful attempts at multilateral governance and governments should continue to support and engage in this forum (Freibauer et al. 2011).

Progress in multilateral discussions around food system governance is vital. Global discussions are key to analysing which, if any, developed country subsidies and trade policies negatively impact food security. Another discussion is needed around the role of commodity markets to gain a better understanding of their role in either increasing or reducing food price crises (Foley, Ramankutty, Brauman, Cassidy, Gerbert, Johnston et al. 2011; Foresight 2011; Godfray 2015).

Improving agricultural productivity sustainably

The key challenge is to increase agricultural productivity without negatively impacting the environment. Although improving food security is not only a function of increased agricultural production, a growing population requires a large food production increase in the coming century. The McKinsey Global Institute ranks increasing yields on large-scale farms as the second most important focus area for increasing efficiencies of resource use across all resources, and increasing yields on small farms as the seventh (McKinsey Global Institute 2011).[31] It also highlights that these two interventions receive very little attention in the media. A number of strategies can be employed to achieve these increases and there is heated debate about which approaches to use: intensification, genetically modified crops, 'green' agriculture, agroecology, or organic. The numerous reviews on the future of food security done in the wake of the 2008 food price crisis (Godfray 2015) point to the need to combine these approaches (The Royal Society 2009; FAO 2011a; Foley et al. 2011; Foresight 2011; Freibauer et al. 2011). A term that has been used in this context is 'sustainable intensification', which refers to the need to increase output on the same amount of land, with less environmental impact (Godfray 2015). This is discussed first, followed by more specific recommendations for developing country governments.

Limit the expansion of agriculture onto virgin lands

More land will be required for expanding cities as the human population grows, at the same time that climate change reduces the availability of agricultural land (Godfray 2015). Sustainable intensification is based on the understanding that the overall benefits to society of increased production on new land do not outweigh the associated negatives: loss of biodiversity and key ecosystem services, as well as increased carbon emissions (Foley et al. 2011; Godfray 2015).

This is especially applicable to forest clearing in the tropics, which is the fastest growing area of crop expansion (Foley et al. 2011). Despite the huge environmental costs, forest clearing has not added a significant amount to agricultural output. Foley et al. (2011) recommend

31 The McKinsey Global Institute suggests 15 focus areas that can help to achieve 75% of the total resource productivity increases required to meet resource demand in 2030, with the top three accounting for over one third of these increases. These are building energy efficiency, increasing yields on large-scale farms and reducing food waste (McKinsey Global Institute 2011).

that the clearing of tropical forests should be slowed, if not halted, and that the resulting production losses be recouped elsewhere (e.g. intensification in temperate zones, where greater output gains have been achieved). In the few areas where agricultural production in the tropics is fairly productive, the crops grown are sugarcane, soya beans and oil palm, which are mostly used for biofuels or feeds, and do not contribute significantly to overall nutrition (Foley et al. 2011). This raises the issue of whether countries that rely heavily on these crops could be expected to forgo the economic benefits thereof (Foley et al. 2011). These countries would need to be incentivised to protect forests; the Reducing Emissions from Deforestation and Degradation programme is one potential mechanism; ecotourism is another (Foley et al. 2011; UNEP 2011a).

Intensify agriculture on existing agricultural land

In the last few years, there has been a large amount of interest in 'sustainable intensification':

> *Calls for sustainable intensification are based on the premise that the damage to the public good through extensification outweighs any benefits of the extra food produced on new lands… Moreover, developing sustainable ways of increasing productivity from the majority of existing agricultural land might provide a buffer in food supplies to enable some elements of the farmed environment to be managed in ways that result in lower yields.* (Godfray 2015:201).

In other words, one of the major proposed benefits of sustainable intensification is that producing more on existing land means that it might be possible to reduce yields in certain areas that are, for example, particularly biodiverse (Godfray 2015). "The goal is no longer simply to maximize productivity, but to optimize across a far more complex landscape of production, environmental, and social justice outcomes" (Godfray et al. 2010:817).

Because the concept does not prescribe the means through which this intensification should happen, it has caused much resistance, as many feel it will lead to a reversion to high-input approaches with negative resource and environmental impacts in an 'increased output at any cost' strategy (Godfray 2015). Godfray acknowledges that discussion is required on what exactly is meant by the term in each country, but also points out that differences in worldviews often underlie these disagreements about the different approaches that could be taken under a 'sustainable intensification' programme.

Adopt agroecological practices

Agroecology has received high-level endorsement from several sources as an approach capable of improving the resource-efficiency of agriculture, reducing its negative environmental impacts and improving food security (IAASTD 2009; De Schutter 2010; De Schutter 2013; Foresight 2011; Lampkin, Pearce, Leake, Creissen, Gerrard, Girling, Lloyd, Padel, Smith, Smith, Vieweger & Wolfe 2015). The term can be used to apply to specific farming practices, a movement or a scientific approach, and even within this, varying definitions have developed (Wezel & Soldat 2009). Generally, though, "agroecological practices are seen as new, re-invented or adapted practices or techniques within more environmentally friendly agriculture, organic or alternative agriculture, or within traditional agriculture in developing countries" (Wezel & Soldat 2009:4).

One of the most widely used definitions is Gliessman's, which is based on Altieri's (the most prolific author on this topic): "the science of applying ecological concepts and principles to the design and management of sustainable food systems" (Wezel & Soldat 2009:13).

Some of the key agroecological methods that have been tested and found to be highly successful include (De Schutter 2013):

- Integrated nutrient management.
- Agroforestry, encompassing cultivation of multifunctional trees into agricultural systems.
- Water harvesting, which allows for rejuvenation of abandoned land, thereby increasing crop water productivity.
- Integrating livestock into farming systems, which provides protein to farming families while contributing to soil fertilisation. This includes incorporation of fish into irrigated rice fields.

When deciding which farming approach to promote, it is necessary to examine the full range of costs and benefits of different systems in different contexts; "in the end, to achieve sustainable food security we will probably need many different techniques – including organic, conventional, and possible 'hybrid' systems" (De Schutter 2013:231). Agroecological and organic systems should play a much bigger role than they do at the moment because currently less than 1% of global agricultural land is cultivated organically (Reganold 2012; Godfray 2015). Lampkin et al. (2015) found that agroecological approaches can contribute positively to sustainable intensification of agriculture, and should be included in all efforts to promote sustainable

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Organic vegetable farmer, Boung Phao, Laos

intensification. There is a need for reliable sustainability assessment tools that can be used by farmers and researchers to monitor progress towards greater sustainability for specific contexts (Lampkin et al. 2015).

Support small-scale farming

Improving food security in many developing countries, especially lower-income nations, requires increasing the productivity rates of small-scale (often subsistence) farming to increase the available food supply while maintaining affordability of food. Greening agriculture among small-scale farmers in developing countries will increase their yields and therefore their food security and livelihoods (UNEP 2011a; IFAD 2013; WWAP 2014). IFAD highlights the proven poverty-reduction benefits of increased yields; similar growth in manufacturing and services does not have the same poverty reduction impacts (IFAD 2013). Governments must prioritise spending on improving yields among small-scale farmers, sustainably. It is important that small-scale farmers do not focus only on producing cash crops for sale, but also produce food for their own consumption; and so promoting a diversity of crops is key and interventions such as kitchen gardens are also useful (IFAD 2013). Governments can promote and disseminate sustainable practices to small-scale farmers (see the following recommendation on extension services) (UNEP 2011a).

By greening agriculture, the ecosystem services and natural capital that the poor rely on will also be protected thus providing "a safety net against natural disasters and economic shocks" (UNEP 2011a:10). Other options to support sustainable agricultural livelihoods in rural areas include investments in natural capital (UNEP 2011a; IFAD 2013). UNEP (2011a) cites India's National Rural Employment Guarantee Act of 2006 as a replicable example. The scheme provides at least 100 days of work each year to rural households, and uses their labour to invest in natural capital, through tree planting, watershed management, and so on (UNEP 2011a). IFAD (2013) stresses the importance of supporting small-scale farmers as one of the key drivers of a sustainability revolution in agriculture; governments need to provide support by removing perverse subsidies that support environmentally damaging inputs and promoting measures that incentivise ecosystem protection.

A prerequisite for incentivising sustainable land management is the promotion of secure land tenure (an issue that receives very little attention in nexus literature) (FAO 2011c; Foresight 2011; IFAD 2013).

For example, China's successful increase in agricultural output was, in part, a direct result of their land tenure reforms (Foresight 2011). Land tenure issues should be addressed in the context of the energy-food-water nexus, and involve multiple stakeholders (FAO 2012b). Farmers can also be encouraged to use energy and water efficiently through land tenure-related policies that give landholders some kind of benefit for natural resource protection (FAO 2011a).

Small-scale farmers require access to credit, and governments may need to support credit programmes and find ways to reduce the associated transaction costs for this group (FAO 2011a; IFAD 2013).

Improve and build agricultural extension services

Many developing countries could substantially improve agricultural output just by applying existing knowledge and technologies; yet more is demanded of farmers in the resource-constrained future (Foresight 2011; IFAD 2013). Innovative peer learning, public-private partnerships and civil society advisory services can offer advice on how to improve output, while minimising environmental impacts and conserving resources (Foresight 2011; Freibauer et al. 2011). Governments need to look at how to most effectively upscale extension services that promote productive and sustainable farming (Freibauer et al. 2011), but they must also assist farmers with access to finance, so they can invest in improved methods (Foresight 2011).

A proven approach to helping farmers is the organisation of farmer field schools where farmers share knowledge with each other (IFAD 2013). Information and communication technology can play a useful role through the use of mobile phones and radio broadcasts to disseminate information in a low-cost manner (Foresight 2011; IFAD 2013). The Economist Intelligence Unit (2015) cites the example of a non-governmental organisation in India called Digital Green that helps farmers create short instructional videos on new techniques that they share with others in a farmer 'self-help' group using battery-powered projectors. The Indian government is funding the capital costs of this project, so it is a public-private partnership, and Digital Green is able to show that their cost-per-adoption factor is ten times less than the usual government-led extension system (Economist Intelligence Unit 2015).

Increase public spending on agricultural research

The IAASTD (2009) estimated that an additional US$1 billion investment in agricultural research is needed over the next 50 years to achieve the kind of changes required. In Brazil and China, increased public spending on agricultural research was a key success factor (Foresight 2011). Studies show return rates as high as 40% on investments in agricultural research. However, investments by the state are key because innovations are required that protect or produce public goods, and private investment needs to be incentivised into these kinds of projects (Foresight 2011). The Economist Intelligence Unit (2015) notes that government investment in research and development often motivates private-sector actors to invest and because they have a higher risk appetite they are able to try riskier projects or ventures than governments.

Urgent action is required due to the very long lead times for agricultural research and development, sometimes two to three decades from the start of basic research until new technologies are widely adopted (Economist Intelligence Unit 2015).

The Foresight Report (2011) recommends product development partnerships as a preferred model in which academia, civil society, industry, government and international agencies collaborate to solve a particular challenge (e.g. development of a drought-tolerant wheat variety for a particular place). This approach, which has shown success in the health sector, enables quicker response times, lower cost solutions and it opens the way for new entrants to produce similar research outputs (Foresight 2011).

Another key recommendation is improved coordination among government, private sector, funding agencies and academia in defining primary research areas (Foresight 2011; Freibauer et al. 2011) and then better links from this research to extension officers (IFAD 2013). Governments must ensure that agricultural training facilities incorporate sustainability issues and approaches into their curricula (Freibauer et al. 2011; IFAD 2013) and that extension workers take on more responsibility for promoting environmentally sound approaches (IFAD 2013).

Policymakers are likely to feel overwhelmed by the myriad factors they need to take into account when making nexus-related policy. Finding ways for policymakers to engage with scientists and experts, and to gain a deeper insight into the potential impacts of their decisions, is the main aim of the Agricultural Model Intercomparison and Improvement Project. Policymakers can ask this virtual team of climate, agriculture and economic scientists, backed by substantial institutional support and linked to local experts, to model the potential impacts of, for example, a decision to introduce fertiliser subsidies (Economist Intelligence Unit 2015).

Reducing the energy intensity of agricultural production

Ensure energy and food policies are jointly designed and implemented

The FAO (2011a, 2012b) has heavily promoted 'energy-smart' food systems in recent years – those systems that reduce energy use in agriculture, or replace it with low-carbon alternatives, and are therefore also 'climate-smart'. Designing and implementing energy policies must be done in conjunction with food and agriculture policies (FAO 2011a). Governments should also assess current energy policies to ensure they encourage sustainable energy use in the food system (FAO 2011a).

Increase energy efficiency of production

Increasing energy efficiency on farms is the first priority (Heinberg & Bomford 2009). Most interventions require some initial investment, the costs of which are recouped within a few years, so government could provide grants, tax breaks or low-interest loans to assist farmers with the initial cash outlay (Heinberg & Bomford 2009). They could also stimulate investment in energy-efficiency innovations by providing micro-financing to entrepreneurs (FAO 2011a).

Agroecology advocates contend that this production system is intrinsically less energy dependent than conventional farming practices. At the production stage, certain key energy-intensive inputs, such as nitrogen fertilisers made using natural gas and pesticides derived from oil, are limited, while animal traction and reduced-tillage practices reduce the need for oil-powered machinery (Rosset et al. 2011). Evidence shows that agroecological practices do depend less on external energy inputs, which is a key factor in increasing their resilience in light of future shortages of oil and other energy resources (Ziesemer 2007).

But this is only one side of the equation: energy efficiency relates to the energy content of the food produced relative to the energy content of the inputs. Agroecological or organic farming systems may use less energy per ha, but may also produce less food per ha than conventional farming, which would mean their energy efficiency ratios are not much different (as found by Gelfand et al. 2010). Niggli (2015b) ascribes the slightly lower yields from organic farming to the fact that organic farmers also focus on producing public goods. For example, a study in Switzerland found that it was more cost-effective for the state to make direct payments to organic farmers than to target agricultural and environmental goals separately. Niggli (2015a:86) rebuffs those who are focused only on the yield gap between organic and conventional agriculture because the "environmental benefits, as provided by organic farms, are absolute goods and cannot be relativised by the fact that yields are lower than in conventional agriculture."

Ziesemer (2007) points out that it is important to consider not only the energy efficiency of the production system, but also that of the value chains both up- and downstream of the farms, to be able to properly compare alternative agricultural systems. Reganold (2012) notes that farming systems are only sustainable when a number of goals are met: adequate yields (productivity), the ability of the system to enhance the natural resource base, provision of stable income for farmers, and ability to contribute to social wellbeing for farming communities. While conventional systems have done well at increasing outputs, they have often done so at the detriment of these other goals (Reganold 2012).

Encourage farms to become producers of renewable energy

Integrated farm-energy systems are one of the key strategies promoted by the FAO for energy-smart agriculture (FAO 2011a). For example, biomass and other wastes on the farm could be used to produce fuel for transport on the farm, and electricity generated on-farm could also be sold back to the conventional grid where possible (FAO 2011a; IRENA 2015). In this way, farms become part of the climate change mitigation strategy of a country (FAO 2011a). These integrated systems are particularly useful in large-scale operations where wastes accumulate and could be used to produce bio-energy (FAO 2011a). On small farms, integrated systems could provide some degree of energy self-sufficiency (FAO 2011a). However, Freibauer et al. (2011) caution against the use of farm waste for energy production and advise that the priority use should be re-using wastes for soil building. The FAO (2011a) also sees the potential for larger integrated regional-scale farm-energy systems that allow for a balance between larger monoculture systems and the need for integration of livestock, pastures and crop rotations. In this model, large-scale farms in an area would work collectively to share these functions between them, allowing for more specialised and efficient division of labour (FAO 2011a).

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Composting method, Ecuador

Improve soil fertility management with integrated nutrient management to reduce reliance on synthetic fertilisers

A key principle of most sustainable agricultural systems is building soil health as the starting point for a more sustainable and productive farm (IFAD 2013). UNEP (2011a) lists a focus on soil fertility as one of five focus areas for greening agriculture, and providing the base for increasing yields in the future. As argued earlier in the report, synthetic fertilisers are likely to become more expensive in the future due to their energy-intensive nature; historically, international oil and fertiliser prices have been tightly correlated. The Foresight Report (2011) encourages other farming systems to incorporate the focus from organic agriculture on using local or farm-derived inputs and generally increasing input efficiency. Synthetic fertiliser application can be reduced by increased use of compost, animal manures (Hoff 2011; UNEP 2011a) and nitrogen-fixing legumes (FAO 2012b). Governments should encourage integrated mixed crop, livestock and agroforestry systems, which can be more efficient in water and energy terms (Hoff 2011; IRENA 2015) and promote soil fertility (IFAD 2013).

Wastes from one part of the farm can be used as a resource for other parts of the system: crop residues and animal manures turned into compost, or household sanitary waste and grey water being treated via wetlands to be reused for irrigation (Hoff 2011; FAO 2012b). Subsidies and other financial incentives that promote the use of fertilisers need to be seriously reassessed in terms of their long-term benefits and negative impacts (FAO 2011a).

Farmers should be trained in the most efficient use of fertilisers (FAO 2011a). Nowadays, technology (like biosensors that monitor soil nutrient levels) can assist in precision application of fertilisers (FAO 2011a; Hoff 2011; FAO 2012b).

However, soil testing is usually out of reach of most of the world's small-scale farmers, who would also require advice on how to interpret the results (Economist Intelligence Unit 2015). The Earth Institute at Columbia University and the Indian government are both attempting to remedy this. The Earth Institute has created on-site soil testing kits that extension officers can use to test soil nutrient properties without needing electricity or distilled water. They can send the results to the lab, and farmers get the results in a few days, with soil remediation suggestions (Economist Intelligence Unit 2015). India has a similar concept, but uses mobile soil testing labs that visit a farm and provide results and advice to farmers within the day (Economist Intelligence Unit 2015).

Invest in plant breeding and improved weather forecasting

A consequence of climate change is that crop varieties need to be hardier and more suited to local conditions (Heinberg & Bomford 2009; Searchinger et al. 2014). One key recommendation is for government to support the collection and preservation of crop genetic resources to retain diversity (FAO 2011a). To truly help farmers, the systems that connect plant breeding, seed production and delivery thereof to farmers need to be efficient and cost-effective (FAO 2011a). There is a definite need to invest in public plant-breeding programmes and to support farmer-seed saving and local seed-production enterprises (Heinberg & Bomford 2009; FAO 2011a; IFAD 2013; Searchinger et al. 2014). While genetic modification could be beneficial for faster breeding response times for drought and pest resistance, it is unlikely to offer new traits in crops (like improved nutrient absorption or reduced water loss) as the research on this is still decades away (Searchinger et al. 2014). Searchinger et al. (2014:6) argue that conventional breeding practices still provide the best way to breed crops for higher yields, and that this justifies "increases in conventional breeding budgets". Another impact of climate change is that weather patterns are becoming more unpredictable, and farmers need accurate and improved weather forecasts to determine the best time to plant or they risk crop failure (Searchinger et al. 2014).

Promote integrated pest management systems and use of natural pesticides

Integrated pest control, which uses biological management techniques for animal and plant health and aims to minimise pesticide use, should be one of the key focus areas when greening agriculture (UNEP 2011a). The use of lower-risk pesticides and local production of biological control products should be encouraged (IFAD 2013). Governments need to remove any subsidies for pesticides, and enact and enforce stricter pesticide regulations (IFAD 2013). Foresight (2011) cites the organic agriculture practice of increasing on-farm biodiversity as something that can and should be incorporated into all farming systems owing to its ability to provide support to ecosystem services and protection from pests.

Promote intercropping and crop rotation

Intercropping and rotating crops suppress pathogens (IFAD 2013), reduce the rate at which pests and diseases spread, and provide nutrients to the soils, thereby reducing the need for fertilisers and pesticides (Hoff 2011; IFAD 2013). An example of intercropping is agro-forestry, where nitrogen-fixing trees are intercropped with annual crops on the same piece of land (IRENA 2015). Studies in Malawi showed that yields of maize intercropped with trees (and given no fertilisers) were 5 tons per ha in good years, and 3.7 tons per ha on average, compared with 0.5 to 1 ton per ha with no trees or mineral fertilisers used (IRENA 2015).

Employ tillage reduction practices to reduce the need for diesel fuel on farms

Traditional tillage practices require the pulling of ploughs through hard dry soils, often at significant depth. This is disruptive to soil life and soil carbon cycles.

It is also an extremely energy-intensive exercise. Various forms and degrees of tillage reduction exist. These range from mild reductions in the frequency and depth of tillage, to the complete cessation of any form of soil disturbance. Conservation agriculture is often associated with zero or minimum tillage, which is one of its various prescriptions to improving soil quality by physically protecting soil from sun, rain, and wind in order to maintain soil organisms (IFAD 2013), and rotating crops to improve soil quality (FAO 2011a).

According to the FAO (2012b:8), "no-till or low-till methods can reduce fuel consumption for cultivation by between 60 to 70 percent (Baker et al. 2006). These methods also improve soil water retention, reduce soil erosion by incorporating crop residues into the surface and minimize soil carbon losses." The main drawback to tillage reduction when applied to large monoculture systems is that mechanical weed control (tillage) is replaced by chemical weed control (herbicides). This highlights the need to consider tillage reduction as part of a much wider agroecological approach.

Minimum tillage may be advanced through removing subsidies that promote tillage (IFAD 2013) and promoting those that rather: (i) support the development of tillage reduction practices through research funding; (ii) improve the uptake and integration of existing knowledge through extension worker briefing, training and support, and agricultural curriculum revision; and (iii) target subsidies to support farmers in replacing outdated tillage and planting machinery.

Improving the energy efficiency and sustainability of food processing, distribution and storage

Renewable energy can be substituted for fossil fuels at various stages of the food chain beyond the farm gate (IRENA 2015). For example, renewable energy could be used to power milling and threshing activities. Electricity and heat from renewable energy can also offer alternatives for processing. Having access to decentralised renewable energy opens up opportunities for rural agro-processing businesses. Wood biomass and solar energy can also be harnessed for drying foodstuffs (FAO 2011a; IRENA 2015).

Several technologies and practices can reduce the amount of energy – or substitute for fossil fuels – used for food storage. Simple methods for reducing energy use are to focus on general maintenance and running efficiency of plants, while slightly more medium-cost investments might include optimising combustion efficiency, and choosing the optimum size of electric motors (FAO 2011a). Other possible improvements to increase the energy efficiency of food storage include: i) better ventilation; ii) the use of high efficiency, variable-speed fans; and iii) improved logistics when transferring food from road containers to rail containers or from shipping containers to refrigerated holds (FAO 2011a).

Solar cooling could in principle be used for refrigeration, although the FAO (2011a) cautions that the technology is not yet mature enough to be economically viable. Instead, it recommends the energy-saving benefits of passive evaporative cooling (FAO 2011a). Technologies already exist for low-heat solar drying; this has the added benefit of reducing food losses and waste where farmers can preserve foods that would otherwise have gone bad and not been saleable (IRENA 2015). Another way to think about reducing energy use in storage is to pool food for bulk storage and preservation and focus on supplying local markets first (FAO 2012b). Trucks used to distribute food could be fuelled by biofuels derived from food wastes (e.g. methane gas or biodiesel derived from vegetable or cooking oils).

Several interventions can contribute to improving the often low energy efficiency of smaller-scale food processing plants in low-GDP countries, such as general maintenance on old processing plants, optimising combustion efficiency, heat recovery from exhaust gases and selecting the optimum size of high-efficiency electric motors (FAO 2011a). Processing operations can use by-products (such as tomato rejects and skins) to produce biogas (FAO 2011a).

While non-nexus focused reports like the Foresight Report (2011) recommend improving transport infrastructure to help develop rural livelihoods and agriculture in developing countries, these recommendations need to be considered more holistically, in terms of a resource-constrained future. The lack of existing infrastructure could be regarded as an opportunity in the sense that new infrastructure can be designed to be energy- and water-efficient from the outset.

Production, processing and storage operations could be located closer to highly populated areas to reduce the need for transportation and increase resilience to energy shocks (Heinberg & Bomford 2009; FAO 2012b). However, the FAO points out that because bulk transportation of food products by rail or shipping can be done in a relatively energy efficient manner it would make sense to produce some food stuffs in more favourable regions and transport them to where they are needed, as this could be more energy efficient than trying to produce food in unsuitable locations (FAO 2012b). Government policy should prioritise rail and water transport of food (Heinberg & Bomford 2009).

Relocalising food production and consumption systems could help to reduce reliance on food imports and energy (especially oil,) and thereby boost resilience to energy price or supply shocks (Heinberg & Bomford 2009). In many countries, an unexpected disruption to the supply of energy could empty supermarket shelves within a few days. Governments can support urban and peri-urban production, introduce policies to build local food networks (e.g. making food safety regulations appropriate to the scale of production, providing mobile abattoirs to provide such services – usually centralised – to smaller-scale food systems) and invest in infrastructure such as farmers' markets. Government procurement could also prescribe a certain minimum level of local procurement for food to be provided in hospitals, schools, and so on. Regulations to minimise the use of plastics in food packaging can also help to indirectly reduce reliance on energy (Heinberg & Bomford 2009).

Recent research on urban and peri-urban agriculture by the Swedish University of Agricultural Science (2014) indicates that agricultural systems will increasingly penetrate the urban fabric due to high urbanisation levels. The global urban population has surpassed the rural population for the time in human history. However, while in certain countries such as Asia, where urbanisation is generally paralleled by a decrease in poverty and thus offers opportunities for high-value perishable goods produced in urban areas, this might not be the case in an African context, when urbanisation is often accompanied by extreme poverty.

Thus in African cities, food production might be more of a subsistence nature than commercial. Notable challenges arising from urban and peri-urban agriculture include an increase in the (opportunity) costs of land, the higher cost of accessing water in urban environments and using untreated sewage water for irrigation, as well as low-cost fertiliser, which poses health risks to farmers and consumers. These practices might be aggravated with faster urbanisation rates and a lack of adequate infrastructure development. The production of food in highly polluted environments with poor water and waste management and regular wastewater discharges are a serious concern to the safety of consumers, who are potentially exposed to high levels of pathogens when purchasing food in certain markets. A critical element is thus the need to collect unused waste for the production of fertiliser, which can include the use of slurry left from biogas production, or the production of protein products (worms and larvae) intended for animal feed.

Waste management systems could be retrofitted to allow for the collection of food waste and other waste streams for conversion to compost and livestock feed, for distribution to local producers (Heinberg & Bomford 2009).

Raising water productivity in agriculture and food production

Simple techniques can improve the efficiency of irrigation. For example, mulching (covering the soil with organic matter such as crop residues or wood chips) can vastly reduce evaporation and the need for irrigation (Foley et al. 2011; FAO 2012b; IFAD 2013). Reduced tillage also decreases moisture losses from the soil (Foley et al. 2011; Hoff 2011). Another simple solution involves regularly checking existing irrigation infrastructure to reduce leaks, and conducting maintenance to improve energy efficiency (e.g. in the running of pumps) (FAO 2012b).

For high-value crops, technology can provide increased water use efficiency. Technologies include precision irrigation, low-flow drip irrigation, weather forecasting and soil moisture readings to improve the timing of irrigation activities (FAO 2012b; IFAD 2013). These can be extremely useful, although they often come with high capital costs that would not be suitable for small-scale farmers (IFAD 2013).

Governments should focus plant breeding and genetic resource conservation efforts on improving and protecting drought-tolerant crop varieties (FAO 2011b; IFAD 2013). These could be the product of plant breeding programmes (see earlier section on plant breeding and seeds) or discovered and promoted from traditional varieties that have not been commercialised yet.

In certain areas, using renewable energy provides an opportunity to reduce reliance on fossil fuels and also save farmers, and the state, large amounts of money (IRENA 2015). In India, over 80% of freshwater is used for agriculture, most of it pumped from groundwater by electric or diesel-powered pumps, and heavily subsidised by the government (WWAP 2014; IRENA 2015). Solar-powered pumping presents many benefits. It enables expansion of the water supply to underserved areas, savings on electricity and diesel, and reduces environmental impacts of these energy sources (IRENA 2015). Solar pumping is a mature technology and evidence of its success exists in the Sahel region (IRENA 2015). The Indian, Moroccan and Tunisian governments all have plans to start replacing electric or diesel pumps with solar ones. Here, the benefit of a nexus approach becomes clear for, although solar pumping is seen as a positive option from an energy perspective, the relatively low cost of using these pumps could encourage over-pumping. Some projects therefore package the solar pumps with drip irrigation; although this too has a high infrastructure cost and is not suitable for all situations (IRENA 2015).

Measures should be introduced to protect and recharge groundwater aquifers. In India, where subsidised electricity for pumping has resulted in heavy withdrawals from groundwater, the government has been advised to ration farm power supply, which effectively rations water supply (WWAP 2014). Modernising canal irrigation infrastructure can result in farmers relying less on groundwater and water productivity improving (WWAP 2014). Managed aquifer recharge is key and can be energy consumptive (e.g. aquifer storage and recovery) or non-consumptive (e.g. infiltration ponds) (WWAP 2014).

Watershed management is key to effectively manage water resources. Governments need to facilitate broad partnerships to manage water resources in upstream catchment areas (WWAP 2014). By optimising catchment areas and storage capacity and use, water efficiency in agriculture can be increased and maintained (WWAP 2014).

Managing demand and encouraging more energy-efficient diets

Encourage dietary shifts to foods requiring less water and energy inputs

It is also important for policymakers to manage the demand side of food systems, especially by encouraging dietary shifts to foods requiring less water and energy inputs (Heinberg & Bomford 2009; Foresight 2011; Chemnitz & Becheva 2014). Changing consumer behaviour is fraught with complexity, but an informed consumer may make more socially responsible decisions (Foresight 2011), which can, in turn, trigger more sustainable supply responses (Freibauer et al. 2011). Simple, consistent messaging about the importance of balanced diets and a reduction of livestock product intake is key (Foresight 2011); for example, through product labelling and advertising campaigns. Consumers should be encouraged to consume locally produced and seasonal foods that are less processed (Heinberg & Bomford 2009; FAO 2011a), as proposed by WWF's (2011) Livewell Report. The Livewell diet meets dietary recommendations, while reducing greenhouse gas emissions by 70% by 2050. Providing role models and examples of the changes required helps consumers understand the changes needed and inspiration as to how to these changes in their own lives (McKinsey Global Institute 2011). Hoff (2011:40) underlines the role that awareness-raising can play in more sustainable consumption patterns, and makes the point that "healthier diets (e.g. less meat, fat and sugar) can at the same time also improve environmental health and reduce resource exploitation."

In addition to awareness-raising and demonstration of alternatives, governments can reinforce such messages with supportive incentives and mechanisms (McKinsey Global Institute 2011). One method would be setting sustainability standards that prevent the production and consumption of unsustainable products (Freibauer et al. 2011). Compulsory labelling on food products of the energy and water used throughout the value chain could encourage consumers to make more sustainable choices (FAO 2011a). Calculating these amounts is a complex process and would require international standards for measurement in lifecycle assessment methods (FAO 2011a). The FAO does not discuss the cost implications of these measurements, which would likely be passed on by producers to consumers.

Although behavioural change is extremely difficult to bring about, governments should remember that it is possible to build societal consensus to support intervention; in the tobacco industry, although took decades to build a solid evidence base, eventually a consensus was built on the dangers to public health and the need for policy action (FAO 2011a; Foresight 2011).

Pre-emptively manage increased meat demand

Searchinger et al. (2014) recommends that countries with high meat consumption rates reduce their intake, highlighting that this reduction will allow poorer countries to increase their intake to nutritionally advantageous levels, where culturally appropriate.

It will also be important to put pre-emptive measures in place to keep livestock consumption in LICs from reaching the same overly high levels now seen in developed countries (not only to control resource use, greenhouse gas emissions and environmental impact, but also to prevent negative health outcomes associated with a high meat-intake diet). The FAO (2011a) acknowledges the difficulty in persuading people to change their diets, and suggests linking efforts to public health objectives such as reducing heart disease and obesity. Financial incentives (like taxes) could be used to discourage people from eating foods with high levels of animal fats (FAO 2011a). Public procurement of food is another mechanism through which to reduce the consumption of energy-intensive meat products (FAO 2011a).

The approach to reduction of livestock consumption needs to be nuanced. As was illustrated earlier, not all livestock production systems are equal in terms of their impacts on the environment (Searchinger et al. 2014). Beef is one of the most inefficient uses of energy, converting just 1% of the total energy in its feed to energy for people (Searchinger et al. 2014).

Far more land is dedicated to pasture-reared livestock than to growing feed crops for these livestock (3.38 billion ha versus 350 million ha), and together these represent almost 75% of global agricultural land (Foley et al. 2011). Searchinger et al. (2014) highlight the fact that we often do not count the land used for pasture when we calculate the environmental and resource impacts of livestock. Foley et al. (2011) warn that any cropland used to produce feed for animals, instead of food for humans, represents a net drain on global food supply, no matter how 'efficiently' those feed crops are managed.

Other reasons to nuance the approach to reducing livestock consumption is that livestock production represents almost half of agricultural income worldwide (Searchinger et al. 2014), is culturally important to many communities, and also beneficial to the environment in certain agro-ecological zones especially where the land is not suited to crop production (Foley et al. 2011; Foresight 2011). In fact, integration of livestock into cropping systems is highly recommended in agroecological farming systems (Foley et al. 2011) because it offers multiple benefits, especially when their manure and urine is used to improve soil fertility. Even small shifts of future livestock consumption growth to other more resource-efficient livestock could have a significant impact (Chemnitz & Becheva 2014; Searchinger et al. 2014).

Reducing food waste

Significant attention should be given to reducing food waste because the loss of embedded food and water resources along the value chain is significant. Developing countries lose the largest share of their food at the post-harvest or processing stages, so attention should be focused on improving storage and distribution (Foley et al. 2011; McKinsey Global Institute 2011). Most of the opportunity to reduce waste is in protecting perishable foods, so the interventions could include improved use of ethylene and management of microbes, low-carbon refrigeration, re-engineering of manufacturing processes and improved supply chain management practices (Searchinger et al. 2014). Some of the interventions required are capital-intensive; for example, improved road and transport infrastructure and refrigerated cold chains (McKinsey Global Institute 2011). There is a clear role for the public sector in investing in some of this infrastructure (especially roads) (McKinsey Global Institute 2011).

Governments with limited resources should focus attention on strategies to reduce wastage in the most resource-intensive foods, like dairy and meat (Foley et al. 2011).

Finding ways to coordinate small-scale farmers so that they can pool resources and invest in cold chains is key; governments could encourage cooperative behaviour and encourage the private sector to invest and provide their expertise (McKinsey Global Institute 2011).

In LICs, reducing food losses at the post-harvest stage requires adequate energy supplies (FAO2011b). Using renewable energy to help preserve and store food is one energy-efficient option, especially from decentralised sources that do not require extensive grid infrastructure (FAO 2011a; IRENA 2015). The FAO (2012b) argues that a relatively easy way to reduce food losses is to educate small-scale farmers in developing countries because there are often fairly simple and cost-effective solutions that already exist (e.g. storage bags and crates (Searchinger et al. 2014)). Improved packaging can be used to prolong the shelf life of food products, although affordability may be a constraint in LICs where this is most needed (FAO 2012b).

Governments should also raise awareness among consumers to prevent an increase in food waste from this group as income levels rise; however, changing behaviour patterns, as mentioned earlier, can take a long time and can meet with major resistance (FAO 2012b). Alternatively, governments could institute higher charges for the disposal of organic wastes to landfill to encourage less wastage and recycling of food waste (FAO 2011a).

Looking to developed countries for inspiration on what works, the United Kingdom has conducted a number of successful interventions on consumption-level food waste, such as construction of community-level biogas digesters, and public awareness campaigns that include discouraging supermarkets from providing discounts for 'buying in bulk' (FAO 2011a). Governments could also intervene by adjusting food sell-by and use-by labelling practices, reduce portion sizes in catering operations and restaurants, and ensure home economics is taught in schools and communities (Searchinger et al. 2014).

Multi-use or integrated agricultural systems use wastes as inputs into other parts of the system (Hoff 2011). Examples include biogas generated from agricultural waste and use of crop residues for animal feed.

3.1.5 Water security

On the basis of green economy principles, this section presents specific technical measures and supporting policy instruments that can be deployed to enhance water security within the context of the energy-food-water nexus. The specific objectives are to:

- Improve the management of water resources.
- Expand access to safe water.
- Increase the efficiency of water systems throughout the water value chain.

- Reduce the reliance of water systems on energy in general and fossil fuels in particular.
- Improve resilience to climate-related shocks.
- Minimise waste of water and use wastewater as a resource.
- Safeguard water quality by reducing pollution and restoring ecological infrastructure.

Adopting integrated water resource management

Water resource allocation cannot be left to markets because water is linked to human rights and public good attributes; governments must manage and regulate water to ensure that social, economic and environmental goals related to the resource are met (WEF 2011). In recent years, the concept of integrated water resources management has gained traction as a holistic way of addressing the complex water sector. Almost two-thirds of countries have developed such plans and a further third have plans in advanced stages of implementation (UN Water 2012). UNEP (2012:73) reports that "44% of medium and high HDI countries and 24% of low HDI countries reported high economic impacts from integrated approaches to water resources management", including increased levels of efficient water use, as well as social benefits, including improved human health, which encompasses reduced child mortality rates. In addition to social and economic goals, UNEP (2012:9) argues that "the environment's water needs should be treated as a vital priority in order to ensure the steady supply of the basic regulatory ecosystem services that underpin the delivery of social and economically-valuable provisioning services." UNEP advocates the use of the decoupling framework (i.e. decoupling economic activity from water use and water pollution) for managing water security (2012; UNEP forthcoming). Furthermore, Bizikova et al. (2013:1) recommend that "a broader watershed/catchment-scale perspective is important for understanding impacts, synergies and benefits." The multiplicity and diversity of stakeholders in the water space implies a need for coalitions, but this can be difficult to achieve in practice due to competing interests (WEF 2011).

Integrated urban water management offers considerable potential for water (and energy) savings in cities. Cities that are in the process of expanding (as in much of the developing world) should incorporate these practices to build in water efficiencies and conservation from the onset (UN-Water 2014). This management practice includes high-density, mixed land-use settlements, configuring water systems to make use of multiple water sources (e.g. rainwater harvesting, stormwater management and wastewater reuse), and treatment of water to the standard needed for its use rather than treating all water to potable standard (UN-Water 2014).

On a practical level, a variety of analytical tools can be used as a basis for better water management aiming to decouple water use from economic growth and ensure greater equity in wastewater allocation (UNEP 2012; UN-Water 2014). These tools include water audits, water registers, water and ecosystem capital accounting, water balance assessments, water scarcity and vulnerability indices, water footprint analysis, and lifecycle analysis.

Enhancing access to clean water

Expanding access to safe water should be a high priority in many developing nations, especially LICs. In many cases this will require investment in water supply infrastructure, particularly in "those countries that have limited infrastructure but abundant water resources and therefore have the potential to convert that natural resource into available, accessible, and reliable water" (2030 Water Resources Group 2009:69). In urban areas, access to water can be improved through treating water and piping it to households. In more developed contexts where water delivery is linked to electrical grids, using renewable energy can reduce the environmental impact by replacing conventional energy sources (IRENA 2015). In rural settings where people have to travel long distances to procure water, renewable energy such as solar PV-based pumping technologies can be used in off-grid applications to improve access to reliable water services.

Obtaining financing is crucial for expanding water supply infrastructure. In developing countries, about three-quarters of water infrastructure investments are funded by public sources (Rodriguez, van den Berg & McMahon 2012). However, there is a need for governments to facilitate public-private partnerships and to create an enabling environment to encourage private investment in water infrastructure. "Such an environment includes, among other features, coordinating efforts by the private sector, governments and international institutions; enhancing capacity-building of local institutions; improving public spending and its monitoring; and reducing investment inefficiencies and helping utilities to move towards cost recovery" (UN-Water 2014:49). Governments can employ public expenditure reviews and results-based financing to garner and leverage private financing (Rodriguez et al. 2012). Proper integrated water resource management based on sustainability criteria can also help ensure that new infrastructure is less costly, has lower maintenance requirements and is more efficient (UN-Water 2014).

Boosting water efficiency in abstraction, conveyance, treatment and distribution

Many opportunities exist at various stages of the water supply chain for improving water efficiencies, reducing energy consumption by water systems, and substituting renewable energy for fossil fuels. Education and awareness-raising about water conservation and efficiency should be advocated among all stakeholders throughout the value chain (Sharma & Vairavamoorthy 2009). Governments can also promote investments in more efficient and sustainable water infrastructure and equipment.

Abstraction

At the abstraction stage, sustainable groundwater management is essential, and this involves ensuring adequate recharge rates (UN-Water 2014).

> *Managed aquifer recharge (MAR) is the process of intentionally banking, and in some cases treating, water in aquifers. MAR is used both to prevent degradation of groundwater resources and to generate additional sources of drinking water via storage or bioremediation of wastewater. The use of MAR... could have measureable energy savings...* (UN-Water 2014:25).

In urban areas in particular, rainwater harvesting can boost water supplies in a sustainable and energy-efficient manner, although Sharma and Vairavamoorthy (2009) caution that "the use of the rainwater should be limited for certain uses due to quality issues." In water-scarce areas where desalination is considered, planners should note that desalination of brackish water is less energy intensive than desalination of seawater (Hoff 2011). Furthermore, for some desalination technologies it is possible to substitute renewable energy (e.g. solar PV, wind or concentrated solar power) for fossil fuels for the thermal or electrical energy required (IRENA 2015). According to IRENA (2015:60), "concentrated solar power (CSP) with thermal energy storage shows significant potential for combined production of electricity and fresh water in the MENA region." However, technical hurdles need to be surmounted, and renewable energy-based desalination is generally more costly than conventional techniques.

Conveyance

There are several opportunities for reducing the energy required for water conveyance; i.e., the transport of raw (untreated) water. Gravity-fed systems should be implemented where possible to avoid the need for energy-driven systems.

Where this is not possible, proper repair and maintenance of existing pumps can save energy. "Replacing older pumps with variable speed drives (VSD) can substantially improve pump performance by 5 percent to 50 percent, particularly when functioning at lower loads, as pumps are more efficient closer to full load" (Water in the West 2013:26). Other ways to save electricity include increasing the pipe diameter to minimise friction losses and switching pumping loads to off-peak times to reduce peak demand strains on power grids (Water in the West 2013). Electricity can even be generated from water conveyance. So-called 'conduit hydroelectricity' can be generated from water flowing in a canal, aqueduct or pipeline. "The most promising technology is through the replacement of pressure-reducing valves (PRVs) with a "reverse pump" which can reduce the pressure in a water system while simultaneously generating electricity" (Water in the West 2013:26). Possibly the greatest scope for saving water (and the embedded energy contained in it) in conveyance is to minimise leaks, although many conduits are "built underground, making it challenging to find leaks and very expensive to excavate and repair" (Water in the West 2013:27). Recycling water and using local sources reduces the need for energy-intensive water conveyance, although studies have shown that desalination is generally more energy-intensive than long-distance conveyance (Water in the West 2013).

Processing/treatment

Energy use during the treatment stage of the water cycle can be reduced through technical energy efficiency measures such as "adjusting operation schedules, increasing water storage, utilizing generators, optimizing cogeneration and installing efficient water system equipment, variable frequency drives (VFDs) and advanced equipment controls" (Water in the West 2013:34). Of these, using the most efficient pumps and motors is possibly the easiest and most effective measure. However, relying on healthy ecological infrastructure to purify water naturally can avoid the need for considerable amounts of energy for treatment (Water in the West 2013).

Distribution

Water and energy can be saved in the distribution to users' process in several ways. First, gravity-based systems should be used wherever possible. Second, as in the case of conveyance, minimising leaks is an effective way to ensure water efficiency and reduce unnecessary waste of embedded energy; this requires proper maintenance of distribution infrastructure. It has been estimated that India could reduce its municipal water consumption by a quarter just by fixing leaks (McKinsey Global Institute 2011). Third, engineers should ensure that efficient pumps are used to maintain water pressure in distribution systems. Fourth, reducing the pressure of water in distribution systems can reduce water losses substantially (UNEP forthcoming). These measures can be optimised through the use of modern software for distribution management systems, including "leakage data loggers, pressure-reducing and-controlling valves, geographic information system, maps and network modelling and management softwares" (Sharma & Vairavamoorthy 2009:217). Especially relevant for cities undergoing expansion is the installation of "separate water distribution systems for potable water and for water intended for uses other than drinking" (Water in the West 2013:34). Such separation might be easier in decentralised systems (UNEP forthcoming). Another possibility is to install micro-hydro technologies in large pipes to generate electricity, although the transmission of power generated in this way could be challenging (Water in the West 2013).

Wastewater treatment

Efficiency gains can be realised in the collection and treatment of wastewater. For example, where possible, wastewater treatment facilities should be located downstream and at a lower elevation to take advantage of gravity and reduce the need for pumping, and infrastructure should separate stormwater from sewage collection systems to minimise the burden on wastewater treatment plants (Water in the West 2013). At the treatment stage, use of the most efficient pumps and optimised aeration can reduce energy costs (Water in the West 2013).

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Simple drip irrigation system, Bungoma, Kenya

Managing water demand and enhancing efficiencies in consumption

Given the increasing demand pressures on limited water resources in many countries, an essential policy response is to use demand management tools to encourage users to reduce needless consumption and wastage of water, particularly in relatively wealthier developing countries. According to UN-Water (2014:102), "historically, the price of water has been so low that there has been little or no incentive to save it in many places around the world." Thus appropriate incentive structures are required to encourage conservation and efficiency among users, such as stepped block tariffs to discourage over-use and waste by higher-income households and firms while retaining affordable tariffs for low-income households.

In addition, the establishment of water markets has been effective in encouraging water use efficiency in some instances (e.g. Australia and Chile) (UNEP 2012), although market allocation may be limited by some of the characteristics of water, such as (partial) public good attributes, high transaction costs and the dispersed nature of water (UNEP forthcoming). The following sections discuss ways to manage demand and improve technical efficiencies in the main consuming sectors: agriculture, industry and the residential sector.

Agriculture

As the largest water consumer in most countries, the agricultural sector presents considerable scope to gain technical efficiencies and reduce demand. Conserving and raising the productivity of water also generally implies energy savings, because of the extensive dependencies of water on energy.

- A good starting point is with techniques that increase the productivity of rainfed agriculture, which implies that less energy-intensive irrigation is required (Hoff 2011).
- Efficient rainwater management includes innovations such as “micro-dams, terracing, rainwater tanks, and flood diversion approaches”, which “collect surplus water falling as rain and channel runoff to areas where it can be applied to crops” or “contribute to groundwater recharge” (UNEP forthcoming).
- Where irrigation is required, efficient water delivery systems such as sprinklers can be used. These have been shown to generate savings of 30% relative to conventional technologies (Weizsäcker et al. 2009).
- Other efficient technologies include knowledge-based precision irrigation (UN-Water 2014) and drip irrigation, although the latter is more energy and capital intensive and may constrain groundwater recharge (IRENA 2015). Nevertheless, up to 50 to 80% efficiencies can be achieved and drip irrigation can be affordable in the developing world (UNEP 2014).
- Deficit irrigation, whereby less water is applied than is needed to fulfil crop transpiration needs, can result in water savings as long as the reduction in crop yield is less than the reduction in water inputs (UNEP forthcoming).
- “So-called ‘smart’ irrigation scheduling provides a means to evaluate water needs in real time and then schedule irrigation applications to maximize yield benefits” (UNEP forthcoming).
- Other techniques farmers can employ to reduce water needs include agricultural land management (e.g. mulching) to improve soil moisture retention and boost crop yields, hydroponics, the use of crop varieties with reduced transpiration requirements such as drought- and salt-tolerant crops, and no-tillage practices (UNEP 2014).

Governments can promote the adoption of the foregoing technical innovations by educating farmers, designing appropriate volumetric water pricing and, in some cases, water markets and trading (which allow the market to determine the opportunity cost of water use in agriculture) (UNEP forthcoming).

Industry

Technologies and practices that can bring substantial water savings in industry include the following (UNEP 2014; UNEP forthcoming):

- Using water-free heat transfer systems and improving the quality of water in heating systems.
- Optimising the use of water in cooling towers.
- Improving efficiency in washing, including mechanical cleaning using brushes and scrapers instead of water.
- Implementing closed-loop cooling systems.
- Using “Water-efficient technologies: Waterless conveyor belt lubricants, water-efficient spray nozzles and spray guns nozzles/guns, clean in place technologies (i.e sensors), steam traps and condensate return systems, water efficient cooling tower technologies” (UNEP forthcoming).
- Establishing on-site water harvesting technologies, such as rainwater tanks, stormwater harvesting systems, and constructed wetlands.
- Initiating on-site water treatment technologies, including “settling ponds, dissolved air flotation (DAF), membrane filtration (micro/nano/ultra-filtration), membrane bioreactors, sequential batch reactors (SBR), ion exchange, disinfectants (ultraviolet light, chemicals, ozone)” (UNEP 2014:124).
- Installing waterless urinals and hybrid dry air/water-cooling systems in commercial buildings.

The most effective policy tool to encourage the adoption of these measures is volumetric water pricing, although this “requires a water resources management authority with the ability to implement a pricing policy” (UNEP forthcoming).

Residential sector

Only a small proportion of domestic water use in middle-class households is for drinking and cooking; much household water is used to flush the toilet, bathe and shower, and wash clothes. Water savings can be achieved through (Sharma & Vairavamoorthy 2009; UNEP forthcoming):

- Installing low-flow showerhead designs and low-flow aerators in kitchen and bathroom faucets, which can reduce water flow by up to half and also reduce the energy costs of heating water.
- Using dual-flush or low consumption toilets, which can save up to 50% of water per flush.
- Establishing waterless sanitation such as dry or composting toilets.
- Ensuring efficient laundry practices; for example, appropriate loads and wash cycles.
- Using drip irrigation, drought-tolerant plants, mulching, optimal watering in low sun conditions (to minimise evaporation) and when it is not raining (to improve soil moisture retention) in urban gardens and general agriculture.

These devices and practices, as well as other water conservation efforts, can be encouraged through (i) public awareness campaigns about the need to conserve water; (ii) regulations that impose restrictions on water use (e.g. for watering gardens or washing cars); and (iii) economic measures such as full-cost water pricing, increasing block tariffs and water metering. However, water pricing must ensure access to water for the poor to meet basic health and sanitation needs. It is imperative that water allocations are made fairly, and that charging and collecting revenue is efficient (UNEP 2011). Removing distorting water subsidies is also important (FAO 2011a; UNEP 2011b; IFAD 2013).

In both the residential and commercial sectors, water heating is one of the most energy-intensive stages of the water cycle, and solar and geothermal energy can substitute for fossil fuels (IRENA 2015). Global solar water heating capacity has grown steadily since 2000 to reach 326GW-thermal. While upfront costs of solar water heaters are high, lifecycle costs are lower than conventional systems (IRENA 2015).

Using wastewater as a resource

Significant opportunities exist for recycling and reusing wastewater, as well as recovering energy from wastewater. Harnessing these nexus potentials requires integrated planning of infrastructure for water, wastewater and energy, especially in urban areas (Hoff 2011). It also requires a paradigm shift so that planners, utilities and consumers view wastewater as a resource (BMU 2012). Technologies and approaches need to be tailored to local conditions and cultures (BMU 2012).

Recycling and reusing water can reduce the demand for primary water abstraction, especially in developing countries where wastewater collection and treatment tends to be very limited (UNEP forthcoming). In a rural setting, recycled wastewater can be used for irrigation and to recharge groundwater aquifers. In urban areas, water utilities can use a cascading approach to water uses, whereby water of increasingly lower quality is reused for purposes requiring progressively lower water quality (Hoff 2011). Recycled greywater can be used in urban and peri-urban agriculture, for flushing toilets in a residential environment and for certain industrial uses. Clearly, if wastewater is to be recycled for higher-end uses then it requires more extensive treatment (BMU 2012). If consumers are to use recycled water supplied by a water utility, this will require dual reticulation piping (UNEP 2014). Benefits of recycling water include "reduced energy consumption associated with production, treatment and distribution of water; a drought-resistant and stable source of local water; and significant environmental benefits" (Water in the West 2013:49).

Several policies can encourage water recycling: (i) public investment in urban water infrastructure that facilitates water recycling; (ii) appropriate pricing of water to encourage recycling and reuse, such as stepped block tariffs; (iii) regulations mandating water recycling, for example by industries; and (iv) public awareness campaigns that educate consumers on the need for and benefits of recycling water. "Payback times for investments for water efficiency and waste water treatment tend to be in the vicinity of five years (provided water is sold at an adequate price)" (UNEP 2014:44). Nevertheless, various barriers have to be overcome, such as public perception, the additional cost of dual plumbing, higher costs of treatment relative to fresh water supplies in many cases, and capital investment requirements (Water in the West 2013; UN-Water 2014).

Reclaiming energy from wastewater

"[W]astewater contains energy in the form of potential energy, thermal energy and chemically bound energy, all of which can be harnessed and utilized" (UN-Water 2014:66). Potential energy can be harnessed by micro-hydro turbines when there is a sufficient gradient between the source of the wastewater, the treatment plant and the outlet. The thermal energy contained in wastewater when it exits a building can be used to pre-heat clean water that needs to be heated, via heat exchangers or heat pumps. Chemical energy is contained in wastewater in the form of carbon (e.g. in sewage sludge), and can be converted into methane gas in anaerobic digestion processes. This has many benefits, including producing biogas that "can be sold as gas for heat and cooking, as vehicle fuel or as fuel for a power plant, or can be burnt on-site to produce electricity and heat for the treatment plant" (UN-Water 2014:52).

Biogas can be collected in large-scale, centralised systems in cities, or in small-scale, decentralised digesters in rural (or urban) areas, which has the advantage of reducing the cost of transporting and pumping wastewater. Other benefits of anaerobic digestion of sewage are a reduction of sludge volumes and disposal costs, the elimination of pathogens, and the creation of organic material that can be used as a fertiliser (UN-Water 2014). Phosphorous is a key nutrient required by plants, yet naturally occurring concentrated reserves are finite and depleting (McKinsey Global Institute 2011), which makes it important to recover phosphorus from sewage. While energy is required to treat wastewater, the net energy contained in this waste is estimated to be about 10 times greater (IRENA 2015).

Enhancing the climate resilience of water systems

Global climate change implies greater uncertainties and risks surrounding changing hydrological cycles and impacts on freshwater availability. The prediction of rising average temperatures (and hence enhanced evaporation) combined with more frequent and intense droughts and floods in some regions, implies a need for adaptation measures in many countries (Jiménez Cisneros et al. 2014). The Intergovernmental Panel on Climate Change recommends "a flexible portfolio of solutions that produces benefits regardless of the impacts of climate change ('low-regret' solutions) and that can be implemented adaptively… because it allows policies to evolve progressively, thus building on—rather than losing the value of—previous investments" (Jiménez Cisneros et al. 2014:253). Governments should, firstly, take steps aimed at restoring and protecting ecological infrastructure such as wetlands, freshwater habitats and natural floodplains, and take remedial and preventive action against deforestation and soil erosion (such as conservation tillage, maintaining vegetation cover, planting trees in fields with steep gradients, and mini-terracing) (Jiménez Cisneros et al. 2014). Secondly, dams can be an effective instrument for storing water and minimising flood damage. However, authorities should practice sustainable dam management, which incorporates assessment of the social and environmental impacts of dams and reduces negative impacts such as those on downstream aquatic ecosystems or the displacement of local communities (UN-Water 2014). Furthermore, planners should optimise the use and management of dams to meet multiple objectives, including hydropower generation (UN-Water 2014). Third, rainwater harvesting can improve water security, especially in an urban context.

Boosting water security through trade in virtual water

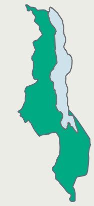
Countries facing severe water shortages could prioritise their trade patterns to increase imports of water-intensive products (such as grains and other food crops) and specialise in the production and export of goods and services with low water requirements (UNEP forthcoming). This strategy is, however, a zero-sum game for the world as a whole.

Protecting water quality by reducing pollution and valuing ecological infrastructure

Reducing water pollution requires a mix of regulatory measures, economic tools and public investments that are informed by current scientific information (UN-Water 2014). Setting regulations for water discharge, including allowable concentrations of pollutants and the extent of treatment required, can be effective in reducing water contamination – especially when backed by financial penalties for transgressions. Such regulations are particularly needed and relatively easy to enforce in the case of industries with concentrated waste streams.

City-level authorities can encourage the "co-location of synergistic production processes [that] can turn waste streams from one into input streams for another, thereby also reducing the waste being discharged to water, land, and air" (BMU 2012:13). Economic measures such as fees charged for the disposal of wastes into water bodies can be effective in reducing pollution (UNEP forthcoming). The fees generated could be used to cover monitoring and enforcement costs. Furthermore, governments should invest in adequate sanitation services, and water and sewage treatment facilities, to ensure that water bodies are not contaminated. Investments in ecological or green infrastructure that can (partially) substitute for engineered infrastructure in performing water purification services are just as important.

Link to Conclusions



3.2 Agrarian Typology: Lessons and Policy Recommendations

This section aims to review the nexus-related policy experience in Malawi and to draw lessons from this experience that can be used as a basis for recommending suitable strategies and policies for similar developing countries. As described in Part 1, an agrarian socioecological regime such as Malawi's is typically characterised by low-productivity, rainfed subsistence agriculture and extensive (and inefficient) reliance on biomass energy, most of which is used in the residential sector (especially for cooking). The expansion of agriculture and the over-use of biomass energy (mainly wood fuel and charcoal) are driving an unsustainable rate of deforestation, which is contributing to soil erosion and the siltation of major rivers. This, in turn, has negative impacts on Malawi's very limited hydropower generation capacity.

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Picking Jatropha nuts

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Press for manufacturing biodiesel in Malawi

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Solar cooker demonstration, Malawi

Consequently, nexus interventions in Malawi must aim at:

- Significantly increasing the productivity and diversity of the agricultural sector to enhance food security.
- Expanding and modernising access to energy.
- Improving access to safe water, especially in the context of increasing climate variability.

Meeting these multiple objectives will require management of certain potential trade-offs, such as those between using water resources for expanding irrigation and using them for hydropower generation. A major question for countries falling within the agrarian typology is whether they can leapfrog the fossil fuel-intensive pathway of development that industrialised countries typically followed, and make a more direct transition to a green economy powered by renewable energy sources and based on sustainable agricultural practices and water usage. This issue will be revisited in the conclusion to Part III (section 3.5). The following subsections deal with policies relevant to energy, food and water security, respectively, followed by a brief conclusion.

3.2.1 Energy security

There are four main risks and vulnerabilities regarding energy security in Malawi (see section 2.1.2):

- Very low rates of access to modern energy services stemming from extremely limited electricity infrastructure and high cost of imported fuels.
- Unsustainable reliance on biomass energy, with attendant environmental impacts.
- Exposure to international oil price and supply shocks as a result of a very high degree of oil import dependence, particularly relevant to the transport sector.
- Vulnerability of the very limited hydropower capacity to variability in water supply.

In line with the green economy principles outlined in section 3.1.2, Malawi's three-pronged energy policy promulgated in 2003 was designed to make the energy sector robust and efficient; to build and expand on the back of the more liberalised, private sector-driven energy supply industry; and to transform the country's energy economy from one overly dependent on biomass to one with a more modern energy mix (GoM 2003). Despite policy intentions aimed at diversifying the national energy mix, very little progress has been made towards meeting these targets (Gamula et al. 2013).

Areas of intervention that will increase resilience to external shocks and should be prioritised from a nexus perspective include:

- Defining sustainable solutions to modernise access to biomass, which meets up to 88.5% of the country's needs and expanding production.
- Extending electricity access through investment in infrastructure.
- Constructing adequate oil storage facilities.

Modernising access to biomass

The lack of political focus on improving the supply and efficiency of biomass is concerning as it is most likely to remain a major energy source for the foreseeable future. The 2009 Biomass Energy Strategy stands out as an attempt to take a proactive approach towards managing and developing the biomass energy sector, but it has not (yet) achieved the large-scale shift required to genuinely transform the biomass energy sector (Gamula et al. 2013). There are, however, several initiatives that have been undertaken by the government that illustrate its attempts to respond to the energy/biomass crisis and that can be viewed as nexus interventions, even though they were not, at the time of implementation, heralded as such. Measures that support the modernisation of the energy sector from an energy-food-water nexus perspective include:

- The use of improved cooking stoves enables improved combustion and energy efficiency, which brings socioeconomic benefits (by reducing the amount of fuel wood that users – especially women – need to gather, hence freeing up their time for other productive activities); health benefits (by reducing particulate emissions); and a lower impact on forest ecosystems. Compared with traditional open fires, the use of more efficient biomass cooking stoves can reduce the demand for traditional fuel wood by 50% (Intergovernmental Panel on Climate Change 2011b in FAO 2011a). Several improved cooking stove programmes have been launched in Malawi, including the Programme for Biomass Energy Conservation (Gamula et al. 2013). The National Improved Cookstoves Task Force, launched in 2013, has the goal of getting 2 million households to adopt the stoves by 2020 (Nielsen et al. forthcoming). However, further promotion efforts should ensure that subsidies do not hinder the development of efficient marketing programmes as reported in many developing countries (Nielsen et al. forthcoming).

- There have been attempts to promote biogas digesters, with the construction of a number of units as pilot projects for rural communities, but local acceptance was found to be limited (Gamula et al. 2013).
- The production of bagasse from sugarcane and rice hulls has steadily increased over the past decade from 680 000 metric tons to reach 994 000 metric tons in 2011 (UN 2014). Illovo sugar Limited's plants are able to use bagasse as a cogeneration fuel to cover their plants' energy needs (Illovo 2015).
- Promoting sustainable forestry management principles can help to prevent forest degradation and deforestation, while enabling communities to benefit from the many services offered by forest ecosystems, be it in the form of wood or non-timber forest products (Shackleton & Schackleton 2004).
- This includes, for instance, the development and management of woodlots, while containing the risk of invasion by exotic species.[32]
- Malawi has a competitive advantage in terms of its technical expertise and experience in the production of liquid biofuels, especially ethanol from sugarcane, which it should further capitalise on. In 2009 MERA set a compulsory 10% ethanol to 90% petrol blending ratio (MERA 2010), which has since been increased to a 20:80 ethanol-petrol ratio (ETHCO 2015). The country should focus on further promoting biofuel development that is suited to local needs, capitalising on regional niche knowledge and adopting international best practices. Producing different non-food biofuel feedstock by converting unused land for biofuel crop production could bolster the country's energy security (Gamula et al. 2013). However, there is a need for studies that examine the lifecycle impact of expanded ethanol or sugarcane production on energy, food and water security in Malawi.
- More generally, the government should promote efforts to systematically identify ways to improve biomass usage throughout the food value chain. For instance, fish smoking activities in Malawi are reported to consume about 6 500 tons of firewood a year (Kabwazi & Wilson 1998). Solar energy has been successfully used for both dry and cold storage and could be used to reduce the use of biomass in the fishing sector.

32 Countries are referred to the Sustainable Forest Management Toolbox, an online technical package of tools and examples to facilitate and guide the implementation of sustainable forest management, recently launched by the FAO. See: http://www.fao.org/sustainable-forest-management/toolbox/en/.

A key challenge in driving the recommended modernisation of biomass usage in Malawi is the fact that mandates relating to the biomass sector fall under different government departments. The Forestry Act (1997), National Forest Policy (1997) and the Land Policy Act (2002) deal with the supply side of biomass energy, while general energy supply issues fall under the Energy Policy (2003) (Gamula et al. 2013). Interdepartmental coordination within government is essential to ensure better policy coherence and effectiveness.

Weak institutional capacity is another obstacle. For instance, the government keeps on confiscating charcoal produced from illegal felling, but close to 40% of urban households still use charcoal as a cooking fuel, which indicates strong inefficiencies in implementing regulations (Gamula et al. 2013). Cultural factors and a lack of local acceptance can also to a large extent explain the limited success of some renewable energy ventures. The conversion of ethanol to gel and liquid fuels for both domestic and industrial use, which the government attempted to promote, is an illustration of this point because use of cooking gel was found not to be suited to local cooking practices (Gamula et al. 2013).

Expanding electricity access through investment in infrastructure

Lack of investment in generation, transmission and distribution infrastructure (Lapukeni 2013) has stalled the power sector (and the economy more generally) and resulted in heavy losses of electricity (Gamula et al. 2013). A key challenge for the government is to create the conditions to encourage greater involvement by the private sector. Malawi's target is to generate 7% of primary energy from renewables by 2020 (IRENA 2012a).

It is essential that public spending be streamlined with a focus on energy-smart infrastructure, characterised by decentralised small grids relying on renewable energy sources such as solar, particularly to provide electricity in rural areas. Malawi has large untapped energy generation potential from renewable energy sources – with solar, hydro and geothermal showing high potential and wind and biomass showing medium potential (IRENA 2012a). Engaging with the private sector to develop these sources as opposed to importing fuel to power diesel generators would be a far better use of resources. This includes, for instance, developing micro-hydro schemes on the 14 potential sites that have been identified in Malawi (GoM 2010 in Gamula et al. 2013). Generating hydropower can be non-consumptive regarding water, especially if it is a run-of-the-river system like the existing plant on Malawi's Shire River. In 2012, a 75KW micro hydropower project with mini-grid was in its final stages of completion and a 10MW small hydropower project about to start (IRENA 2012a). Malawi plans to build wind farms with total installed capacity of 120MW. Malawi's electrical capacity in 2012 was 315MW and suppressed demand for electrical power was then at about 350MW, with projections that it would reach 600MW in 2015 and 1 200MW in 2025 (Gamula et al. 2013).

Malawi's existing electricity investment plan aims to bridge the gap between demand and supply by 2016 (GoM 2011b:78) by promoting the use of renewable energy sources and public-private partnerships in energy generation and distribution.[33] By introducing measures that support the deployment of renewable energy technologies in rural areas, the government can help improve access to energy for agricultural communities. The latter option can supply energy directly into the local food system (see FAO 2011a for details).

Establishing oil storage facilities to mitigate the risk of oil supply disruptions

The recent establishment of the National Oil Company of Malawi to manage fuel purchases and the construction of new oil storage facilities is expected to mitigate the risk of future fuel shortages (African Manager 2015). Following research commissioned to define strategies to alleviate fuel shortages in the country, the government intends to introduce a bulk procurement system. This system will help to address the historically fragmented sourcing of oil through oil marketing companies, which has resulted in the loss of economies of scale. Furthermore, instead of continuing to use the marketing companies (which only have a holding capacity of 15 days) as depots, the ordered petrol would be 'delivered duty unpaid' to a named depot within Malawi (Khanhe 2014). Through these interventions Malawi should manage to establish strategic fuel reserves for itself and possibly also pay lower average prices for imported oil.

33 These two dimensions are covered extensively in the Cuba case study (section 3.4) and significant lessons could be learnt from Cuba's experience to scale-up progress on these fronts.

3.2.2 Food security

It is commonly accepted that food systems in developing countries, especially agrarian economies such as Malawi, which only marginally contribute to global greenhouse gas emissions, will need to use more energy if they are to increase agricultural productivity and improve livelihoods, especially of the poor (FAO 2011a). This can be done in an energy-smart manner through leapfrogging technologies; alternatively, countries might increase their reliance on fossil fuels by default.

The major challenges the Malawian agricultural sector faces relate to its vulnerability to weather conditions and low levels of productivity among small-scale farmers; the currently low levels of oil dependence present opportunities to address these issues in ways that do not increase reliance on oil (Robinson & Wakeford 2013). This dependence is low because of the limited use of machinery and tractors, and limited use of irrigation;[34] however (as will be discussed later), the proportion of small-scale farmers using inorganic fertilisers is fairly extensive. These opportunities pertain not only to production methods, but also to the management of agricultural water, a dimension that is critical given the risks of food insufficiency, combined with the rising pressure of commercial irrigated agriculture on water resources. From a nexus perspective, the opportunities that arise in terms of increasing food production in an energy- and water-wise manner are detailed below.

Adopting low-input, high-diversity agricultural systems

The adoption of low-input, high-diversity agricultural systems such as agroecology could increase food production, alleviate pressure on woodlands and improve water quality and flow (Altieri et al. 2012). Within these systems (described in more detail in section 3.1.4), diversity in crop choice and practicing crop rotation minimise the risks of yield reductions from abiotic and biotic stresses. The Ministry of Agriculture and Food Security recognises the benefits of combining more efficient fertiliser use with organic manure management. To this end, it has pledged to support conservation agriculture through the Agricultural Development Program–Support Project and the Green Belt Initiative (Holden & Lunduka 2012). Agroecology includes the practice of agroforestry, in which trees are incorporated into annual food crop systems, also known as 'Evergreen Agriculture'

34 Only 0.5% of small scale farmers are reported to irrigate their fields (Nielsen et al. forthcoming:69).

(Garrity, Akinnifesi, Ajayi, Weldesemayat, Mowo, Kalinganire, Larwanou & Bayala 2010), which Malawi has been promoting with the support of the World Agroforestry Centre since the 1980s (Beedy et al. 2012). The centre implemented the Malawi Agroforestry Food Security Project that ran from 2007 to 2011, and which is reported to have reached about 1.3 million of the poorest Malawians (Garrity et al. 2010). Under this programme, farmers adopting agroforestry practices generally increase their yields from 1 ton per ha to 2 to 3 tons per ha. The most common practice on small farms (<0.5ha) is intercropping maize with nitrogen-fixing tree species and pigeon peas (Garrity et al. 2010). There is, however, considerable room to further promote these agroforestry practices, given that a large proportion of farmers (61%) apply inorganic fertilisers and only a small share applies organic inputs (11.5%) (Nielsen et al. forthcoming:69, based on 2011 data).

Over and above the promotion of agroecological diversified systems, governments can promote integrated food-energy systems, in which food and energy are produced concomitantly on farms to achieve sustainable crop intensification. Several successful examples exist at both large- and small-scales and could be replicated in Malawi (see Bogdandski, Dubois, Jamieson & Krell 2010). Integrated food-energy systems can provide a balance between monoculture productions and 'mixed farming' systems, which integrate livestock, pasture and crop production within the same perimeter. This would allow for a more specialised, and perhaps more efficient, division of labour. Such systems could support rural development objectives and could be specifically relevant in agrarian-regime countries, which in the future will need to maintain labour-intensive means of production.

Promoting crop diversification

The risks inherent in Malawi's heavy reliance on a single stable crop (maize) – which has limited resilience to climate change – and (emergency) food aid can be mitigated by policies that promote crop diversification. Wood and Moriniere (2013) found an inverse relationship between the climate resilience of six major crops in Malawi and the dominance of the crop in terms of ha planted. Traditional crops that deal well with biotic stresses, such as sorghum and pigeon peas, have over the last few decades been gradually replaced by maize, mostly as a result of the FISP's focus on this crop. Their research also showed, however, that "some farmers are already moving away from hybrid maize varieties, and back to traditional varieties that are more climate-resilient and less dependent on substantial inputs of mineral fertilizers" (Wood & Moriniere 2013:74). Such spontaneous efforts to diversify and revert back to traditional crops and to save seeds can be supported by knowledge-sharing interventions and policies directed at protecting farmers' rights to freely save and exchange seeds. This critical dimension of food security will be jeopardised should the Malawian government, a member of the African Regional Intellectual Property Organisation, opt to ratify the recently adopted regional legal framework for the protection of plant breeders' rights, known as the Arusha Protocol for the Protection of New Varieties of Plants (the 'Arusha PVP Protocol'). The protocol proposes to grant strong intellectual property rights to breeders, while restricting the age-old practices of African farmers to freely save, use, share and sell seeds and/or propagating material (Alliance for Food Sovereignty in Africa 2015).

Diversifying agricultural exports

Malawi should also focus on diversifying its agricultural exports, which are already a key source of foreign currency earnings. Lack of financial resources to purchase food imports has often aggravated the food crises the country has experienced. Malawi's commercial crops include tobacco, tea, sugarcane and cotton, which account for about 75% of total exports, with tobacco alone contributing about 52% (Gamula et al. 2013). This high dependence on tobacco exports exposes the country to the vagaries of the global tobacco market.

Reforming the Farm Input Subsidy Programme (FISP)

As discussed earlier, the subsidisation of fertilisers – directed predominantly at maize production – has been heralded as the main factor behind the increased maize yield per ha in Malawi over the past decade. The programme is, however, contentious, not only because of the financial cost of the fertiliser, but also due to the long-term negative impacts of synthetic fertilisers on soil and water quality. For example, Holden and Lunduka underline how continuous maize cropping with inorganic fertiliser is associated with declining yields on African soils (2012:305). Furthermore, increasing dependency on synthetic fertilisers (which rely extensively on natural gas for their manufacture and oil for their transport to farmers) exposes Malawian farmers to external energy price shocks. Several options to reform the FISP in a manner that takes nexus issues into consideration are suggested below.

- Precise application of fertilisers aims to improve the accuracy and timing of applications (FAO 2011a) and can contribute to lower greenhouse gas emissions per unit of output and possibly avoid excess nitrates being discharged into aquifers and surface waters. Progress has been made with the development of medium and low-tech diagnostic tools for this purpose, which can easily be used by small-scale farmers for *in situ* measurement of the crop's nitrogen status and thereby determine the appropriate timing and amounts of necessary application (Mondal & Basu 2009).
- Wood and Moriniere (2013) recommend the expansion of FISP in ways that promote and support climate-resilient crops and crop mixes for each climate zone identified in the country, thus supporting increased crop diversification and intensification.
- They further recommend linking FISP subsidies to increases in investments in conservation agriculture practices and sustainable natural resource management, as a means to mitigate the ill-effects associated with the use of fertilisers, insecticides, and herbicides (Wood & Moriniere 2013).
- Although it was found that fertiliser use and manure use intensity are positively associated in Malawi, farmers' knowledge of how to make organic manure[35] from crop residues and green leaves is inadequate (Holden & Lunduka 2012) and should be an important focus area of the Ministry of Agricultural and Food Security's extension services. Increased use of nitrogen-fixing crops and agroforestry trees could also reduce the need to import inorganic nitrogen fertilisers and improve soil quality.
- An altogether different recommendation would be to thoroughly investigate the short- and long-term trade-offs of policies that offer financial incentives to access fertilisers (FAO 2011a). Ecker and Qaim (2011) emphasise that programmes aimed at subsidising the price of the country's staple food, even though they tend to increase production and caloric intake, may hamper the intake of micronutrients and therefore compromise nutrition. They recommend income-related policies as an alternative to food production input subsidies, since they are less likely to distort markets (and to cause environmental damage) and more likely to improve micronutrient consumption. This way farmers may naturally revert back to farming a greater diversity of (traditional) crops, such as groundnuts, pigeon peas, sorghum and cowpeas, that are less vulnerable to climate change and generally have lower production costs than maize (Wood & Moriniere 2013). A focus on welfare interventions (such as the Brazilian Bolsa Familia discussed in section 3.1.5) and income growth interventions (such as cash transfers and employment programmes), rather than on input subsidies is more likely to improve food security (Nielsen et al. forthcoming).
- Limits to fertiliser application could be set and quality fertiliser management practices promoted by providing training services to farmers on precise application methods to support the policy interventions described above (FAO 2011a).

35 Organic manure includes crop residues, tree leaves, green manure, compost, and animal manure.

Promoting urban and peri-urban agriculture

Although the percentage of Malawians living in urban areas is currently low (15%), the urbanisation rate is 4.2% a year (CIA 2015a) and the urban share of the population is projected to expand to 30% by 2050 (UNDESA 2014). The extent to which Malawian households already use the economic opportunities presented by urban and peri-urban agriculture demonstrate that urban agriculture provides an important livelihood diversification strategy. For example, Mkwambisi et al. (2011) found that, overall, urban households surveyed in 2005 produced an average of 228kg per capita of cereal (or cereal equivalents).

This was well above the 181 kg per capita that the government recommends as an adequate food budget implying that the surveyed households involved in farming could support themselves entirely on the food they produce on urban agricultural plots. The potential of urban and peri-urban agriculture as a source of food security and income remains under-realised in Malawi (e.g. marginal land on which crops could be grown is not used, and urban animal husbandry is limited). Lessons learnt from the promotion of urban and peri-urban agriculture in Cuba could be worth replicating in Malawi, starting with livestock production, which is currently not authorised. Allowing livestock production in urban areas with adequate measures to compost animal manure could offer great opportunities in nutrient recycling and production of energy (biogas), thus contributing to improved waste management, food security and employment creation (Swedish University of Agricultural Science 2014).

Expanding irrigation

The Green Belt Initiative, introduced by the government in 2009, is a prime example of a nexus intervention aiming at higher agricultural output of food and cash crops with the goals of increasing macro- and micro-level food security and decreasing poverty (Nielsen et al. forthcoming). Through the initiative, the government has set the target of expanding irrigation usage to small-scale farmers and commercial farmers to 1 million ha, mainly by using the country's three biggest lakes and perennial river resources (Chinsinga & Chasukwa 2012). In the process, small growers farming on customary land are relocated, as the land is converted to private or public land to the disadvantage of the local community (Chinsinga et al. 2013).

Improving irrigation efficiency

Energy inputs can be reduced through water management policies and regulations that promote the introduction of more efficient irrigation methods, such as precision irrigation, low-head drip irrigation, and wastewater recycling and fertigation (using liquid fertilisers). In terms of food production, public investments should focus on the smart expansion of irrigation infrastructure. The public irrigation sector is battling to meet the demand for infrastructure expansion and has been severely constrained by heavy operation and maintenance costs. Hence Malawi should invest in 'knowledge-based precision irrigation' that provides reliable and flexible water application. Both water and energy inputs can be reduced by adopting sensor-based, demand-led irrigation systems. The use of solar PV and wind-powered irrigation systems should also be considered. Such an approach also allows for deficit irrigation and wastewater reuse (FAO 2011a).

Improving policy coherence

The establishment of a National Conservation Agriculture Task Force and the new Agricultural Sector-Wide Approach–Support Program (will play an important role in aligning agricultural programmes such as the FISP and Green Belt Initiative and integrating conservation agriculture measures (discussed in section 3.1.4) (Holden & Lunduka 2012).

3.2.3 Water security

Per capita water availability in Malawi is rapidly declining owing to the country's expanding population, especially in its urban and peri-urban areas (World Bank 2011). Addressing the water dimension of the nexus in agrarian regimes entails focusing on improved access to domestic water and wastewater management and moving towards smart agricultural water management. Key policy interventions and measures to improve efficiency and manage demand in this sector include the following.

Limiting deforestation

Forest degradation can be contained through schemes such as tree planting programmes, Reduced Emissions from Deforestation and Degradation and payment for ecosystem services. Malawians' sourcing of wood from natural forests and the expansion of the agricultural sector are drivers of environmental degradation, which leads to soil erosion and aggravates siltation of water bodies. A first level of intervention at the household level would be to emulate the tree-planting programme implemented in Cuba, which made it compulsory that any tree cut down be replaced. Such a programme, however, requires strong institutional capacity and a strong forestry sector, which may not be present in Malawi (see below).

Ensuring the sustainable implementation of integrated water resource management principles for Malawi's main water bodies

Malawi is implementing integrated water resource management principles and approaches, but allocation schemes are reportedly still implemented in a haphazard manner, given the lack of capacity needed to deal with the country's growing water scarcity issues. These will be compounded by competition between users, including municipalities, hydropower companies, and small-scale and commercial farmers. Anticipating that small-scale farmers who currently rely on rainfed agriculture might divert water toward small-scale irrigation, these management frameworks will have to focus on incorporating unregulated small-scale users (Wood & Moriniere 2013).

Lake Malawi and the Shire River already benefit from significant governmental investment through the World Bank-financed Shire River Basin Management Programme. But Wood and Moriniere (2013:72) recommend specific support for Lake Chilwa, arguably a more neglected hydrological system, including the setting up of a Water Dispute Resolution Council, piloting community water stress projections with basin communities, facilitating global priority-setting and allocation of water resources, establishing integrated water resource management principles, and promoting conservation agriculture to preserve soil moisture and contain soil erosion.

Addressing the degradation of water quality

Water quality can be preserved by developing waste management schemes in urban areas. This could involve the collection of organic waste and urban animal farming for reuse as fertiliser (Swedish University of Agricultural Science 2014). Development of proper sanitations systems is crucial to protect water quality.

Promoting water harvesting for domestic and agricultural use

Given current trends in urbanisation and decaying infrastructure, large-scale promotion of rainwater harvesting is an important measure not only to increase water for consumption in a sustainable manner, but it can also be designed in such a way that the water harvested is primarily directed to recharging ground water aquifers. Research conducted by UN-Habitat (n.d.) examined global best practices of legal and administrative frameworks for rainwater harvesting. The report can be used as a reference manual of measures that can be taken in this field. These could be mandatory, promotional, or incentive-based (possible fiscal incentives include subsidies to install systems or rebates in property tax). They can also take the form of financial assistance for retrofitting rainwater harvesting systems in existing buildings.

Improving water access in rural and urban areas

The National Water Development Project (NWDP II) makes provision for increasing access to sustainable water supply and sanitation services from 67% to 79% by 2012 with a universal coverage projected to be achieved by 2025 (GoM 2011b). In rural areas, especially those that are not adjacent to Lake Malawi, water access could be improved through the use of solar PV pumps.

Investing in multipurpose water resources projects

Promoting the development of efficient water infrastructure in cities and towns can be done through regulatory frameworks. Malawi should also consider the development of multipurpose water resources projects. For example, a "dam can be developed for water storage and raw water can be sold in bulk and used in irrigation, water supply, fisheries and electricity generation" (Kumambala & Ervine 2009:540). Such multipurpose water resources development would typically support hydropower, irrigation and water supply and would require careful economic viability and environmental impact assessments, taking all aspects of the nexus into consideration. Kumambala and Ervine (2009) identified three rivers (the Dwambazi, Wovwe and Luweya) with the capacity to sustain run-of-river projects.

Managing trade-offs

It is important for the government to investigating the trade-offs involved in the expansion of existing water transfer schemes from government to small-scale farmer management, such as irrigation management transfers, of which the Green Belt Initiative (GoM 2009) is the best known illustration. The initiative directly improves agricultural water security by increasing water access. Most irrigation schemes are, however, located near Lake Malawi, which could decrease the lake's water levels and water flowing out of rivers, making it difficult to maintain sufficient water levels to produce hydro-energy. Other caveats of such irrigation management transfers are of a social nature; land grabbing through commercial farmers and investors acting under the Green Belt Initiative has been a problem since customary land without official land rights is taken from small-scale farmers. Moreover, small-scale farmers who participate in the initiative must comply with seasonal land collectivisation, which constrains them to plant a prescribed crop and shift away from their usual intercropping and diversification practices (Chinsinga & Chasukwa 2012). This not only undermines small-scale farmers' safety nets, but also detracts from the aforementioned imperative to diversify the country's agricultural production. Since the initiative's impact on water, energy and food security may be substantial and remain unknown, a comprehensive analysis of macro- and micro-level nexus effects is essential to appraise the actual trade-offs (Nielsen et al. forthcoming).

3.2.4 Conclusions

Malawi needs to choose between following the fossil fuel-based industrial pathway or attempting to leapfrog this stage of development to create a more sustainable system, which is based on renewable inputs. Government's keenness to exploit potential oil reserves in Lake Malawi indicates a leaning towards the fossil fuel-based industrial pathway. There are signs that the agricultural sector is in the early stages of industrialisation. These signs include the escalation of FISP and the expansion of the Green Belt Initiative, which has harmed small-scale farmers. The heavy reliance of the industrial pathway on fossil fuels is risky, particularly for a landlocked country that imports liquid fuels at premium prices. This risk will increase because of escalating costs as the world approaches the peak oil era.

There are, however, many opportunities for Malawi to transition towards a more sustainable green economy given the country's still limited reliance on fossil fuels. Local initiatives that support this transition and require greater attention include agroforestry, improved cooking stoves and conservation agriculture programmes. More can be done to support small-grid energy systems and the uptake of agroecological farming methods. The focus should be on cultivating a labour-intensive growth path as well as a knowledge-intensive approach. This will, however, require significant investments in education and training. Supporting farmers in rural areas and decentralising economic growth could also slow down the urbanisation process that will otherwise put more pressure on natural resources and infrastructure systems.

Primary school rainwater tank, Kirwa, Rwanda

Link to Conclusions

3.3 Industrial Typology: Lessons and Policy Recommendations

This section reviews the nexus-related policy experience in South Africa to show the kinds of technical measures and policy tools that can be implemented in other developing countries that predominantly exhibit characteristics of the industrial socioecological regime. As described in Part I, an industrial regime such as South Africa's is typically characterised by extensive use of fossil fuels in the economy in general and in the agriculture sector in particular, which exposes the country to external energy (chiefly oil) price shocks. In addition, a major issue is the impact of fossil fuel production and use (for example in power generation and in agriculture through the use of chemical inputs) on the quality of water resources. South Africa is also experiencing power shortages that are hampering economic activity and that pose a threat to the energy-intensive water supply chain.

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Solar photovoltaic farm, IPP Greefspan, Douglas, South Africa

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Gariep dam, South Africa

Consequently, interventions to mitigate nexus risks in South Africa aim to:

- Reduce the risks of heavy reliance on fossil fuels by boosting energy efficiency, while continuing to expand access to energy and addressing power-supply constraints.
- Improve the resilience of the food system to energy-related shocks by reducing energy intensity along the food value chain.
- Address growing water scarcity (which is likely to be exacerbated by climate change) with a combination of supply-side and demand management policies, and to halt and reverse declining water quality.

South Africa has taken important steps towards integrated planning that addresses various aspects of the energy-food-water nexus, but there are still some notable gaps and areas that require improvement. On the positive side, "[t]he National Planning Commission (NPC) processes, the representation of different sectors within clusters to ensure coordinated decision-making, the interdepartmental task team processes for energy planning and the regular meetings between Eskom and the DWA [Department of Water Affairs] (among others) all point to good structuring for integrated planning" (Goga & Pegram 2014:3). The National Development Plan, which is the broadest policy framework guiding the country's development path, as well as the Industrial Policy Action Plan, both advocate a transition towards renewable energy in order to reduce the carbon and water intensity of the economy. In the agricultural arena, the DWA's National Water Resource Strategy 2 acknowledges the need to integrate water, land and agrarian reform programmes (Baleta & Pegram 2014). There is some level of vertical coordination in integrated planning between national, provincial and municipal levels.

Nevertheless, there is a lack of coordination in some key areas of the nexus. In general, the National Development Plan does not specifically address the nexus and how it can be aligned with developmental planning and policies (von Bormann 2014). Although South African government departments have devised integrated energy plans and integrated water plans and there is some alignment between these, they do not adequately account for the intricate connections in the energy-water nexus and the risks involved in their interdependence (Gulati 2014).

Most concerning, however, is the disjuncture between plans for the expansion of agriculture through irrigation contained in the National Development Plan and Industrial Policy Action Plan, and the reality of water resource constraints (Goga & Pegram 2014). Thus there is a need for greater coordination and integration of planning across the water, energy and agriculture/food sectors, especially to ensure proper management of water resources and quality. Furthermore, "South Africa will have to resolve tough trade-offs between agriculture, key industrial activities such as mining and power generation, and large and growing urban centres" (2030 Water Resources Group 2009:10). The following subsections discuss concrete policy solutions that are being or could be introduced to enhance energy, food and water security and mitigate nexus risks.

3.3.1 Energy security

There are four main aspects of South Africa's quest for greater energy security:

- Further expanding access to modern energy services, especially in rural areas.
- Reducing oil import dependence by developing indigenous energy resources.
- Increasing electricity generation capacity to address power supply constraints that are hobbling the economy.
- Reducing the very high carbon intensity of the energy mix by reducing dependence on coal and expanding the use of renewable energy and nuclear power.

Energy efficiency and demand side management are also important, and thus far have been largely used as emergency responses to electricity shortages.

Expanding access to modern energy

From the mid-1990s Eskom, the state-owned monopoly electricity supplier, embarked on an Integrated National Electrification Programme to expand access to the grid for previously unconnected households in both urban and rural areas. The national electrification rate grew 34% in 1994 (DoE 2015) to 66% in 2000 and 85% in 2012 (World Bank 2015b). Eskom provides a free basic electricity allowance of 50kWh per month, which provides a small degree of protection for the poorest electricity users – although this monthly allowance is not sufficient to meet cooking needs. Nonetheless, affordability of power has continued to be a major challenge for low-income households, especially as average electricity tariffs have more than doubled in the past few years.

The DoE has also promoted the use of liquid petroleum gas for cooking, although there are supply-side capacity constraints. There have also been small projects aimed at expanding the use of ethanol-gel fuel stoves in urban informal settlements, mainly to reduce reliance on paraffin, which causes health problems and fire hazards. Even more sustainable options for clean cooking include efficient biomass cookstoves and solar cookers (see section 3.1.3).

Reducing oil import dependence

The DoE is currently developing a Liquid Fuel Roadmap, but beyond promoting domestic oil exploration, the government as yet has no meaningful plan to deal with the threats posed by global peak oil (Wakeford 2013). South Africa has various options to reduce its dependence on oil imports by developing substitutes using indigenous energy resources (see Wakeford & Swilling 2014).

The first option is to pursue exploration for offshore conventional oil reserves.

The government is broadly supportive of oil (and gas) exploration and development, although the policy environment has remained uncertain as the Mineral and Petroleum Resources Amendment Bill, which proposes changes to the governance of oil exploration and production rights, has undergone several revisions and has not yet been finalised. The plunge in oil prices in 2014/15 has also dampened oil companies' enthusiasm for exploring deep offshore areas where no discoveries have been announced to date.

The second option is to increase capacity for coal-to-liquid fuel production, currently produced by Sasol Limited in a 160 000 bpd facility. However, Sasol has shelved a proposed new coal-to-liquid plant, citing affordability constraints as well as risks related to climate change mitigation and the carbon tax that has been proposed by the National Treasury (Wakeford & Swilling 2014).

The third option is to expand production of gas-to-liquid fuels. However, this will require new sources of gas feedstock. PetroSA, which operates the country's existing gas-to-liquid plant, has recently determined that a floating storage facility offshore of its plant at Mossel Bay is not commercially viable (Wakeford & Swilling 2014). The government has high hopes for the development of shale gas in the Karoo basin, but as of September 2015 no exploration using hydraulic fracturing had taken place and so the existence of economically recoverable reserves is uncertain. Also, it is unclear where the very large amounts of water required for shale gas production would come from because the Karoo region is arid, and there are major concerns about the potential pollution impacts of shale gas production on the limited groundwater resources.

A fourth option is liquid biofuels. In December 2007 the government approved a Biofuels Industrial Strategy (DME 2007), which aimed to stimulate job creation in the agriculture sector and make a modest contribution to energy security by reducing oil imports. After public consultation, the government prohibited the use of maize (South Africa's staple food) for ethanol production, preferring sugarcane, sugar beet and grain sorghum; approved biodiesel feedstocks include sunflower, canola and soya beans (DME 2007). However, several factors initially thwarted the take-off of the biofuel industry, including the lack of financial incentives, policy uncertainty, the targeting of previously disadvantaged farmers (who showed resistance to biofuel production), and the banning of maize as a feedstock (Letete & Von Blottnitz 2012 in Brent 2014:10). To provide further stimulus, in August 2012 the DoE gazetted regulations pertaining to the mandatory blending of biofuel with petrol and diesel in South Africa. The regulations stipulate that bioethanol must comprise 2% to 10% of petrol on a volumetric basis, while biodiesel should have a minimum concentration of 5% of diesel volumes. The regulations are due to come into effect on 1 October 2015 (DoE 2013). The small-scale, localised production of biodiesel from recycled vegetable oil presents a sustainable opportunity for using waste as a resource, although the total quantities of available feedstock are small relative to South Africa's demand for transport fuels.

All four of these domestic substitutes for imported oil are potentially problematic from an environmental point of view, either in terms of pollution risks and greenhouse gas emissions, or in terms of excessive water usage. In light of these limitations, a more sustainable alternative is to reduce the demand for liquid fuels through a comprehensive suite of policies and technologies that encourage greater fuel efficiency and a gradual switch to electrified transportation (Wakeford 2013; Wakeford & Swilling 2014; see section 3.1.4 for details).

Increasing power generation capacity while capping emissions

As noted in section 1.3.1, South Africa has been faced with serious power capacity constraints in recent years. The Integrated Resource Plan for Electricity 2010-2030, promulgated by the DoE in 2011, delineates the government's projection of electricity demand until 2030 and scenarios for how that demand could be met by expanding power generation capacity across the full range of energy technologies (DoE 2011). The Integrated Resource Plan aims to double the national power generation capacity to over 80GW by 2030, with 42% of the new capacity slated to come from renewables, 23% from nuclear power and 2.4% from gas. This would reduce the share of electricity actually generated from coal from 90% to 65%, and raise the share from renewables to 9% (taking into account the lower load factors for intermittent solar and wind power).

Eskom is already building two new coal-fired power stations – Medupi (4 788MW) and Kusile (4 800MW), as well as the Ingula pumped storage scheme (1 332MW), and a 100MW wind farm (EIA 2014). It is also in the design phase of a 100MW concentrated solar power plant. In addition, a stream of privately funded and built renewable energy installations has come on line since 2013, under the DoE's REIPPPP. A total renewable capacity of 5 037MW has been commissioned under the first four phases of the REIPPPP, of which 53% is wind, 38% is solar photovoltaic PV, 8% is concentrated solar power and less than 1% each is landfill gas, small hydro and biomass plants. The REIPPPP has proved to be a successful model in galvanising over US$10 billion in foreign and domestic private finance, and the timeline for projects is much shorter than for conventional power plants.

The Zuma administration has repeatedly stated its commitment to expanding nuclear power capacity by up to 9.6GW over the next two decades. During the course of 2014 it entered into 'framework agreements' with the governments of Russia, China, France, South Korea and the United States. The cost of the nuclear build programme has been mooted at more than R1 trillion (Mail & Guardian 2011), but there has been no indication of how the government plans to secure this level of funding at a time when the public debt is approaching unsustainable levels and several state-owned enterprises, including Eskom, have been suffering heavy financial losses or financing constraints. The nuclear plans appear to be driven mainly by a political agenda rather than economic and sustainability considerations (Gottschalk 2014).

South Africa is also looking to the region to help meet its future electricity demand. After years of delays, a treaty was finally signed between South Africa and the Democratic Republic of Congo in 2013, according to which South Africa will be allocated 2 500MW of the 4 800MW from the Inga 3 hydropower project on the Congo River.

Reducing water dependence of energy systems

The overwhelming reliance on coal-fired power generation implies large demands for water for cooling. Eskom has shifted towards dry-cooled coal-fired power stations, which "have 5 to 10% of the water requirements of wet-cooled stations" (Gulati 2014:20). The last coal power station to be built (Matimba) was dry-cooled, and the Medupi plant currently under construction will be the largest dry-cooled plant in the world.

The Integrated Resource Plan modelling process takes into account water requirements of different electricity generation technologies, but it is not clear to what extent these affect the recommended technology choices. Furthermore, the plan does not explicitly "model the risks of potential water scarcity for the planned generation capacity and resulting electricity supply" (Gulati 2014:23).

If additional new coal-fired power stations were to be commissioned, they may need to incorporate carbon capture and storage technology in order to meet the government's climate mitigation commitments. However, "[carbon capture and storage technology] CCS could increase water consumption of power plants by between 46 and 90% depending on the technology of the plant" (von Bormann & Gulati 2014:17).

Although the DWA has recommended dry-cooling technology at new power plants, it has not promoted a transition to less water-intensive renewable energy technologies (Goga & Pegram 2014). Most of the renewable energy systems being implemented under the REIPPPP (as discussed above) have minimal water requirements, especially wind and solar PV farms, which constitute the bulk of investments to date. As a thermal technology, concentrated solar power requires more water, although it can also make use of dry-cooling technology, but developers are not incorporating dry cooling in their REIPPPP bids due to the considerable extra costs and lack of regulations (Gulati 2014). As with the existing Koeberg nuclear power station, any new nuclear power plants will be built along the coastline so that they can make use of seawater for cooling. The DWA has recommended that no water be used for producing biofuels under irrigation (Goga & Pegram 2014), but it is not clear whether this will be enforced. Where possible, power stations should make use of water of a lower quality than drinking water or irrigation water (Gulati 2014).

Promoting energy conservation and efficiency

Energy demand management has been implemented in South Africa largely through necessity to address the country's power crisis. From time to time over the past several years, Eskom has had to request large industrial users (accounting for more than 40% of the country's power demand) to cut consumption when capacity was unable to meet peak demand. Since late 2014, Eskom has been forced to implement regular 'load shedding' across the country as available generation capacity cannot meet demand. In addition, average electricity tariffs have more than doubled over the past few years and this has encouraged electricity conservation and efficiency measures among industrial, commercial and residential users. A stepped blocked tariff system encourages high-end users to reduce wasteful consumption. Eskom provided a temporary subsidy for households to replace incandescent lamps with compact fluorescent lights. Eskom and the DoE have encouraged electricity conservation with awareness campaigns on television, while many municipalities have provided leaflets to users that explain ways to save electricity.

In 2008 the government announced a solar water heating rebate programme and set a target of 1 million solar water heaters to be installed by 2014. Eskom was mandated with the rollout of the programme, which has fallen far short of expectations with 400 000 systems having been installed by the end of 2014 (Steyn 2015). However, this is still one of the largest programmes of its kind in the world. A high-pressure solar water heater can reduce a typical household's electricity bill by about a quarter (Steyn 2015).

More limited policy interventions aimed at improving energy efficiency have been applied to other energy carriers. In the case of road transport, a modest vehicle emissions tax has encouraged consumers to purchase more fuel-efficient vehicles. A rising national fuel tax over the past few years has probably been more effective at curtailing demand, even though this was not the main objective of the tax. Inefficient use of liquid fuels in a transport sector dominated by private road vehicles is beginning to be addressed by national and local government investments in public transport infrastructure.

Bus rapid transit systems are being constructed in several of the largest cities, while the Department of Transport has recently authorised a 20-year programme to upgrade the long-neglected passenger rail system. In addition, the state-owned logistics company Transnet is investing heavily in upgrading the national freight rail system. While much of this expenditure is aimed at expanding commodity export lines, there is also an intention to shift a significant portion of general goods freight from road to rail transport.

The National Treasury has proposed the introduction of a nation-wide carbon tax. If this is successfully implemented, it will incentivise energy users to increase efficiency and minimise waste of all fossil fuel-derived energy carriers.

3.3.2 Food security

As discussed in Part 1, food security is a complex issue with many determinants. In the South African context, currently existing food insecurity arises largely from income poverty and lack of access to land and other productive resources. This implies a need for measures to improve the affordability of food for poor households. While national food availability is currently sufficient (through domestic production and imports) its future status is threatened by risks (spelled out in section 2.1.3) such as heavy reliance on energy inputs and limited water resources.

Therefore this section also explores policies that have been or could be introduced to improve energy efficiency and water productivity in South Africa's food system.

Improving the affordability of food for poor households

There are several ways in which household food security could be enhanced in a South African (or similar developing country) context, including the following:

- Direct measures to make food more affordable for low-income households, such as subsidies or fixed prices for staple foods, have generally not been implemented by the South African government; one exception is the zero-rating for value-added tax of a number of basic foods. The government does, however, provide targeted income support in the form of various social grants (old age, disability and child support grants), which reach nearly a third of the population and have had a major impact on reducing poverty and hence increasing household-level food security (National Planning Commission 2011).
- Given that poor households spend a significant portion of their incomes on energy for cooking (Mason-Jones et al. 2014) the free basic electricity allowance could be increased to allow more households to use this energy source for cooking. The affordability of the electricity and of cooking appliances is an issue.
- As the extent (or lack) of competition within the food retail sector is an important determinant of food prices (Mason-Jones et al. 2014), there is a role for the Competition Commission to foster increased competition and to eliminate anti-competitive food pricing practices. In fact, the South African Competition Commission has investigated uncompetitive practices among bread producers and fined some companies for price fixing (Flanagan, Smillie & Tromp 2007).
- In a rural context, von Bormann and Gulati (Brent 2014 in Bormann & Gulati 2014:17) argue that "[i]f bioenergy and food are handled as integrated systems that depend and complement each other, multiple benefits such as sustainable rural development, sustainable land use, and energy and food security for the poor through access to modern energy sources and increased food productivity are possible." Thus by enhancing energy security and incomes at a household level, bioenergy could improve food security, rather than detract from it, as may be the case with large-scale commercial biofuels.
- More broadly, investment in agricultural research and development, training and infrastructure should yield long-term productivity benefits and thus help to boost food supplies and stabilise or reduce food prices (von Bormann & Gulati 2014). This is especially important for the emerging or small-scale farming sector.

Reducing fossil energy use in agricultural production

The extensive dependence of food production on energy inputs and resulting vulnerability to energy price rises can be mitigated through the adoption of less energy-intensive farming methods, such as conservation agriculture and agroecological farming techniques.

As mentioned in section 3.1.4, conservation agriculture involves minimal soil tillage, which reduces the need for diesel fuel. It has been estimated that a third of South Africa's cultivable area has been subject to reduced tillage farming practices (Du Toit 2007:2). A recent study on conservation tillage practices in maize production across four climatic zones in South Africa reported a more modest 40% reduction (see Table 3-1) in on-farm diesel consumption over conventional tillage systems (Blignaut, Knot, Smith, Nkambule, Crookes, Saki, Drimie, Midgeley, de Wit, von Loeper & Strauss 2015). Another study on rainfed wheat production suggested reductions in diesel use of up to 75% (Metelerkamp 2011). In both of these cases, crop yields also increased and total profit margins increased, while fertiliser application was reduced substantially.

Table 3-1: Diesel usage in different tillage systems for South African maize production (litres/ha)

PROVINCE	NORTH WEST	WESTERN FREE STATE	EASTERN FREE STATE	KWAZULU-NATAL	AVERAGE
Conventional tillage	79.3	89.2	67.0	68.7	76.05
Conservation tillage	49.7	44.4	41.9	47.0	45.75

SOURCE: Adapted from Blignaut et al. 2015

The general arguments in favour of agroecological and organic farming were spelt out in section 3.1.4. In South Africa, organic farming has grown quite rapidly in recent years from a very small base. As of 2012, it was estimated that there were about 250 organic farms occupying about 45 000ha of certified land in South Africa – a tiny fraction of total commercial agricultural land (Wakeford & Swilling 2014). The knowledge-intensive nature of agroecological innovations means that policy and institutional support is required (Hine, Pretty & Twarog 2008; Altieri 2009). Support could be provided through agricultural extension services; training and skill acquisition programmes for emerging farmers; increased funding for research; and the strengthening of networks involving scientists, farmers, civil society organisations and government departments (Wakeford & Swilling 2014).

Another way in which fossil fuel use in the agriculture sector can be reduced is to use renewable energy for water pumping (to replace pumps running on diesel and coal-fired electricity). IRENA (2015) notes that with over a quarter of a million conventional energy pumps in use in agriculture in South Africa, solar pumping represents a very large potential market.

Improving the efficiency of food distribution

Energy efficiency in the distribution of food to consumers can be enhanced through logistical improvements and a (partial) relocalisation of agriculture to reduce distances between producers and consumers, for example by promoting urban and peri-urban agriculture. Targeted interventions should be made to enhance logistical efficiencies of supply chains operating between input suppliers and farms, and between farms and consumers (Vink & Van Rooyen 2009). Resilience to possible fuel supply interruptions can be enhanced by building in redundancies and increasing inventories, noting, however, that this carries costs (Heinberg & Bomford 2009).

As discussed in section 3.1.4 above, relocalisation aims to decentralise food economies so as to shorten supply chains. This would require a reversal of the recent trend in South Africa toward larger centralised food processing and distribution centres, and the concentration of retail outlets in malls. Local food economies may help to improve resilience to external shocks, but be limited in their capacity to meet diverse nutritional needs of some communities and be constrained by environmental conditions, such as extreme climates or degraded ecosystems (Schulschenk 2010).

Some small projects have attempted to promote urban agriculture in South Africa, but these have had limited success thus far. Factors inhibiting urban and peri-urban agriculture include a lack of security, lack of finance for inputs, and cultural factors (e.g. some recently urbanised residents see food production as a step backwards towards the rural lifestyle that they left behind in search of better prospects in the cities) (Thornton 2008). Thornton (2008) recommends that the Department of Agriculture widen its extension services to cover urban townships and informal settlements.

Government can also help to establish localised agricultural markets and promote farmers' markets by, for example, making public spaces available in urban areas and rural towns. Some municipalities (e.g. in Durban and Cape Town) have encouraged trading in locally produced food products by establishing markets. Government can also support 'buy local' campaigns and use procurement rules to stimulate local food production by requiring public institutions to source some of their food requirements locally (Wakeford & Swilling 2014).

Improving water productivity in agriculture

The lack of high-level coordination between the water and food sectors evidenced in the National Development Plan (Goga & Pegram 2014) means that improvements in the productivity of water use in agriculture are essential to close the gap between future aspirations for irrigation and current water resource scarcity. Such productivity improvements can result from various technical solutions and innovations, and be supported by a range of policy tools; many of these were discussed in section 3.1.5 and are broadly applicable to South Africa and similar developing countries. Since different crops have greatly varying water requirements, the water intensity of agricultural products should be taken into consideration alongside economic and social dimensions.

For example, South Africa exports highly water-intensive fruit and wine products, but the foreign exchange generated helps to fund imports of staples such as rice and wheat.

Low-tech, improved farming practices based on agroecological practices and in-field water harvesting can play a role in limiting irrigation needs and reducing the risk of crop failure. Research conducted in South African between 1993 and 2005 showed that irrigation needs could be reduced by as much as 50% through techniques allowing an increased infiltration of plant available water. These basic interventions include level swales (contour bunds) to retain water and the planting of Vetiver grass mulch to reduce evaporation (Auerbach 2005 2011). By improving soil moisture retention, conservation agriculture may also reduce the need for energy-intensive irrigation. Other interventions to improve the efficiency of water use in agriculture as recommended by the 2030 Water Resources Group (2009) are summarised in section 3.3.4 below.

Market mechanisms can play a useful role in terms of incentivising efficient use of water (Baleta & Pegram 2014). These tools include appropriate water pricing, recognising that historically water has been underpriced in South Africa, and also that a universal water price applied across the country would not be feasible due to variations in water intensity and economic margins by crop type. Tradable water rights, within an appropriate legislative framework, can also help to ensure that water is directed to its most productive uses. Another market-related option would be to increase imports of water-intensive foodstuffs instead of cultivating the crop inefficiently in South Africa. In terms of regulatory approaches, the allocation of water use licences among farmers should also be informed by the productivity of water use (among other considerations). Educating consumers about the water intensity of food production (e.g. through product labelling) could also help to shift consumption patterns towards less water-intensive products and thereby alleviate water pressures faced by farmers (Baleta & Pegram 2014).

Reducing food waste

The extensive loss of food along the food supply chain in South Africa, which also implies losses of embedded energy and water, can be tackled in various ways. While these measures may not improve food security (which is largely an issue of affordability rather than availability in South Africa), they can alleviate pressures on the agricultural system arising from water scarcity and climate change (Notten et al. 2014). However, one way that reducing food waste can boost food security among the poor is through the redistribution of excess food and food that has passed its 'sell-by date'; some retailers and non-profit organizations such as FoodBank SA are already doing this (Notten et al. 2014). Government could support such donations by making food safety legislation more flexible and banning food waste deliveries to landfills – although adequate health standards still need to be maintained.

Notten et al. (2014:24) argue that "there is insufficient knowledge of food waste generation in South Africa to provide an action list [for reducing food waste] specific to South Africa", but they nevertheless offer suggestions of actions drawn from the international and (limited) local literature:

- At the producer level, government – with support from international agricultural organisations – can provide information and training through agricultural extension agencies (especially to emerging farmers) on innovations to reduce losses during harvesting, handling and storage of agricultural produce, tailored to the specific crops and livestock involved. Also important is the provision of low-interest finance to enable farmers to invest in the requisite equipment.
- At the processing and packaging stage, food processors can be encouraged to adopt technologies that prolong product life, design packaging to keep food fresh for longer (e.g. smaller quantities instead of bulk packaging), and improve the logistics of food delivery systems.
- At the retail stage, food waste can be reduced through requirements for 'use-by' and 'sell-by' food labelling, avoiding 'buy-bulk-and-save' promotions for perishable items, giving discounts on nearly expired produce, providing information to consumers on good food storage practices, and accepting night-time deliveries of perishable products (to avoid heat or sun damage).
- At the consumer level, education about food management in the home (primarily in middle- and high-income households) can encourage people to reduce food waste through actions such as buying local and seasonal produce, purchasing from local markets, smart shopping and meal planning to avoid excesses, and freezing leftovers.

In the South African case, the largest quantities of food waste occur in the processing and packaging of fruit and vegetables, the post-harvest handling and storage of cereals, and the distribution of fruit and vegetables (Notten et al. 2014). In terms of embedded energy and water costs, however, the meat value chain is the highest priority area, followed by cereals (Notten et al. 2014). Other developing countries will need to conduct research to quantify where along the food value chain the major waste occurs, and formulate appropriate remedial policies.

To the extent that some food waste is unavoidable, it can be used as a resource if the right regulatory frameworks and incentives are put in place (Notten et al. 2014). One application is to use organic waste to generate energy, for example in anaerobic digesters that produce biogas that can be combusted to produce power and heat; liquid biofuels may also be produced from certain types of food waste. Another option is the use of organic waste for composting, which is promoted by The National Organic Waste Composting Strategy. A third possibility, which is most applicable at the production stage, is to use food waste as animal feed (e.g. feed excess milk to pigs). South Africa has several policy frameworks and regulatory acts that govern the management of food waste, but these are complex and somewhat fragmented, partly because both waste management and energy policies are involved. Better data and more research are needed to optimise the use of waste (Notten et al. 2014).

Minimising the risks of food contamination

The food sector faces risks of contamination in the form of high metal concentrations resulting from mining and smelting, acid rain from coal combustion, endocrine-disrupting chemicals from industrial effluent and microbial contamination from inadequate sewerage facilities – partly through direct soil pollution, but also via the pollution of irrigation water (Oberholster & Botha 2014). In South Africa, there is a need for improved regulations and guidelines – and enforcement of these – to limit the contamination of agricultural soils in order to minimise the risks to consumers of exposure to pollutants including toxic metals. In particular, steps need to be taken to reduce the risks of soil pollution by heavy metals and sulphur emissions from coal-fired power stations.

While there are already environmental regulations on emissions standards from power stations, Eskom has been granted exceptions for some of its older power plants in order to safeguard energy security. This shows the importance of taking a holistic nexus perspective when developing and enforcing environmental regulations.

Another critical action that government authorities should undertake is the proper maintenance and upgrading of municipal sewerage systems and extension of these services to those in informal settlements, so as to safeguard the food industry (Oberholster & Botha 2014). Furthermore, "[a]ny food crops grown with contaminated water will inevitably have to be tested and monitored to verify the presence of dangerous contaminants" (Oberholster & Botha 2014:11). Several other policy options for mitigating the risks of water pollution are discussed in the next section.

3.3.3 Water security

As mentioned in section 1.3, water security is one of South Africa's biggest challenges. Proper integrated planning (as discussed earlier) and a mix of supply-side and demand-side solutions are needed to close the projected water gap over the coming years. In general, most, if not all, of the policies presented in section 3.1.5 above are relevant to South Africa. The following paragraphs discuss some particularly relevant policies that have been implemented and recommend additional avenues for policy development.

Enhancing water supply

According to the 2030 Water Resources Group (2009), the largest potential sources of expanded (blue) water supply are new dams, enlarged dams, groundwater and artificial recharge, and gravity transfers. Smaller potential sources, which are typically more expensive, include rainwater harvesting (agricultural and domestic), pumped transfers, and desalination.

South Africa already relies heavily on water transfers from neighbouring Lesotho, as well as extensive internal interbasin transfers. This is because many of the largest water demand centres are geographically separated from significant river basins or local supply is inadequate. Examples include the Olifants Basin, where much of the country's mining and coal-fired power generation take place, as well as Gauteng province, which contains the industrial heartland and about a fifth of the population of the country. The National Water Resources Strategy notes that development of the Waterberg coalfields in the north of the country will likely depend on water transfers from other regions (Goga & Pegram 2014). South Africa has one desalination plant, which was built in a water-scarce municipality on the southern coast to service both the residential sector and the country's gas-to-liquid fuel plant. However, the energy requirements and economic costs of this plant are significant. In view of these supply limitations, the water authorities should give much more attention to reusing and recycling water and treating brackish water.

Since South Africa is currently a net exporter of blue water and such exports appear to be increasing over time (Dabrowski 2014), there is scope to consider using agricultural trade policies to increase virtual water imports and decrease virtual water exports in order to address domestic water scarcity. In particular, South Africa exports maize with relatively high blue water content to neighbouring countries in southern Africa that produce maize with lower blue water content, implying a net loss of blue water within the region.

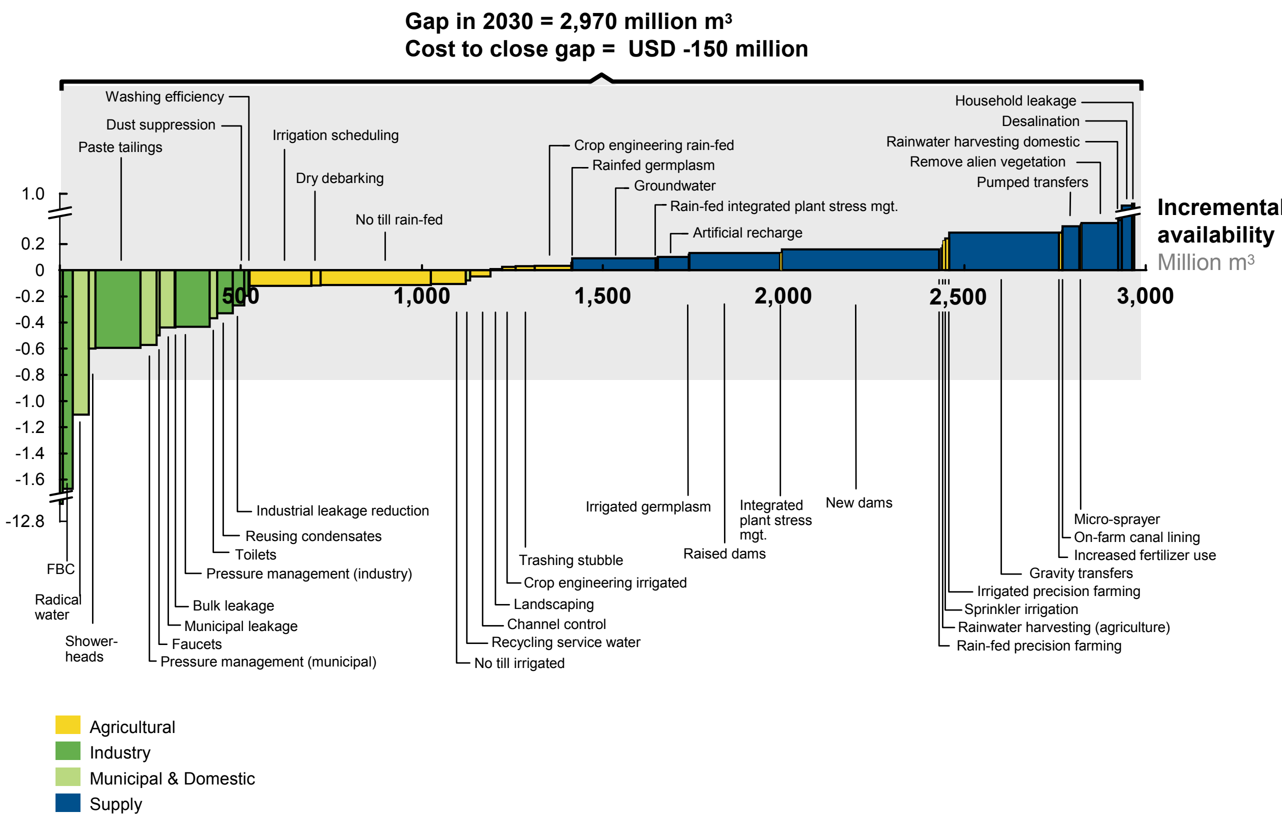
However, the economic (and social and environmental) value of such saved or imported virtual water needs to be weighed against the value of the traded goods for the economy. "Further research should be carried out on the natural, social, economic, environmental and political implications of using virtual-water trade as a national strategic instrument in water policy." (Dabrowski 2014:10).

Protecting water quality

Perhaps even more important than expanding supplies, water policy must urgently address the serious decline in water quality that is occurring in many parts of the country. This will require better enforcement of the National Water Act (no. 36 of 1998) (von Bormann & Gulati 2014), which includes regulations governing the use of water and emissions of pollutants. Specific opportunities include:

- In the energy sector, policies should be based on a sound assessment of water impacts and should discourage technologies that present high risks to water quality (Gulati 2014). Since coal-fired power stations are a major source of water pollution, an increased commitment to expand alternative electricity generation capacity could contribute significantly to safeguarding water quality. Von Bormann (2014:5) states that "[t]he argument for a judicious reduction of our reliance on coal therefore becomes more than a climate-change or carbon-emissions argument – it becomes one, perhaps most crucially, about water."
- The regulations governing the environmental management of mining waste and mine sites need to be strengthened and enforced so as to reduce mining pollution and acid mine drainage. In addition, the government should "strictly enforce the 'polluter pays' principle with an emphasis on mining (including past polluters), industry and large-scale irrigated agriculture" (von Bormann 2014:13).
- There is an urgent need for upgrades and extensions of wastewater and sewage treatment facilities in many municipalities across the country, as these pose unacceptable risks to water quality – especially from underserviced informal settlements. Encouragingly, the "DWA is already increasing regulatory pressure on municipalities to comply with stricter effluent discharge standards" (Gulati 2014:23).
- Protecting ecological infrastructure, as mentioned earlier, is a cost-effective way of ensuring greater water quality and quantity. For example, "[v]egetated buffer strips are suggested to be one of the most effective ways of mitigating the non-point source microbial, phosphorus and metal pollution of water resources" (Oberholster & Botha 2014:12). The Department of Water and Environmental Affairs runs effective Working for Water and Working on Wetlands programmes, which encompass eradicating alien vegetation and rehabilitating wetlands across the country. Another useful initiative is the Land-user Incentives Programme introduced by the department to encourage farmers to plan and design their use of agricultural land in ways that reduce impacts on freshwater ecosystems (WWF-SA 2012).

Figure 3-1: Cost curve for water supply and efficiency measures in South Africa



SOURCE: 2030 Water Resources Group (2009)

Managing water demand and improving water productivity

Given the already scarce water resource status of South Africa and the anticipated impacts of climate change, demand-side interventions aimed at improved water conservation and efficiency are essential. The 2030 Water Resources Group (2009) has identified a range of technical solutions that can help to close the projected gap between water demand and supply by 2030. These "solutions reflect the geographic differences within South Africa: at least seven water management areas are almost entirely dependent on agricultural improvements, while the economic centres of Johannesburg and Cape Town are dominated by industrial and domestic use" (2030 Water Resources Group 2009:83).

Sectoral interventions include:

- In the agriculture sector, several interventions can not only reduce water usage, but also bring about net cost savings. These include major savings from irrigation scheduling and no-till farming (both rainfed and irrigated), and smaller contributions from dry debarking, using recycled municipal water, and channel control. Additional efficiency measures that do carry net costs include landscaping, crop engineering, rainfed and irrigated precision farming, sprinkler irrigation, increased fertiliser use and on-farm canal lining.
- The industry sector presents the largest scope for water savings, through techniques such as paste-thickening and water-recycling in mining, dry-cooling and pulverised beds in power generation, leak reduction, reuse of condensates, and pressure management. These measures could generate over US$400 million in yearly savings.
- In the municipal and domestic sector, measures to improve water efficiency that would also bring net cost savings include municipal water pressure management, leak repair, low-flow showerheads, aerated faucets, and dual-flush toilets.
- In addition, the issue of food waste should be addressed so as to reduce the loss of water embedded in food products (see section 3.3.3).

The water authorities have several policy tools at their disposal to encourage water efficiency and conservation. Since most of South Africa's blue water is consumed in the agriculture sector, it is vital that the water authorities ensure a rational allocation of water-use licences among farmers that takes into account opportunity costs. However, this also applies to water licences for the industrial sector. Secondly, appropriate water pricing that reflects true costs is very important and has long been lacking in South Africa. Some municipalities do already make use of stepped block tariff structures, and this principle should be extended more widely to balance access with efficiency. Third, while there are awareness programmes encouraging residents to conserve water in some particularly water-scarce parts of the country, a public campaign should be rolled out at a national level. More specifically, "[o]ptions such as the certification and labelling of all products to reflect embedded water and energy use in their manufacture or usage could go a long way in promoting the sustainable use of energy and water" (Gulati 2014:26).

Reducing reliance of the water system on energy

Many of the water efficiency measures listed above will lead to energy savings because energy is used so extensively along the water-use cycle. This is particularly important from a cost point of view, given the steep increase in electricity tariffs in recent and future years. New water system technologies should take energy costs into consideration and try to minimise these (Scheepers & Van der Merwe-Botha 2013 in Gulati 2014:23). Two additional examples are worth mentioning:

- The eThekwini Water and Sanitation utility serving the Durban metropolitan area has embarked on a programme to retrofit mini-hydropower plants to replace pressure-reducing valves on water supply infrastructure, thus generating electricity that can be fed into the city's grid and reduce carbon emissions (IRENA 2015).
- The government's solar water heating initiative described earlier is an effective response to the large demands for energy for water heating by residential and commercial users, and this programme should be continued and expanded.

3.3.4 Conclusions

Although South Africa has made notable achievements in recent years in developing green economy policies that address aspects of the nexus challenges, there is still a need to mainstream the energy-food-water nexus within the policy agenda and better coordinate planning across sectors. This will require broadening the awareness of nexus challenges and responses among all stakeholders and at both national and local levels. The National Planning Commission is the logical national institution that could play a coordinating role in managing the nexus through integrated planning and bringing together numerous government departments and other stakeholders. This needs to be based on improved nexus-related data and scientific research. South Africa should also cooperate with its regional neighbours to manage the risks posed by nexus challenges and climate change.

While much attention has been given to energy policy and planning, there needs to be greater emphasis on transitioning to less water-intensive energy technologies. In particular, the potential of renewable energy to meet multiple goals (including expanded energy access, improved national energy security, reduced pollution and greenhouse gas emissions and reduced water use) and the success of the REIPPPP thus far provide ample motivation for a much more rapid expansion of renewables.

A programme of support for small-scale agroecological farming, twinned with effective land reform, holds the potential to meet several goals including improving household and national food security levels, reducing reliance on fossil fuel inputs, and creating sustainable rural livelihood opportunities. Agricultural policy must afford greater recognition to water constraints and focus on raising water productivity, while considering the potential for improving the virtual water trade balance.

Water must become a much greater priority in integrated planning for sustainable development, as water is likely to be South Africa's most critical binding natural resource and environmental constraint in the years to come. Furthermore, urgent steps need to be taken to halt and reverse the degradation of the country's limited freshwater resources.

The major obstacles and constraints on the implementation of the policies recommended above are likely to be vested interests within the incumbent sociopolitical regime together with technological lock-in, both of which favour continued exploitation of fossil fuels.

Link to Conclusions

3.4 Ecological Typology: Lessons and Policy Recommendations

As described in Part 1, an emerging agroecological, socioecological regime such as Cuba's is characterised by comparatively high social equity and sustainable development indicators. A significant percentage of the population still lives in rural areas and urbanisation trends have been contained. Importantly, a large proportion of the arable land is farmed using agroecological practices, which has enabled significant decoupling of food production from energy usage (see section 1.4.2).

Wind farm, Venezuala

Urban food market, Cuba

Despite such characteristics, Cuba still has a certain degree of vulnerability to external shocks, mainly arising from its economic dependence on some key food and fuel imports. Furthermore, although agroecological farming generally has limited environmental impacts, the pollution of waterways and soil degradation arising from industrial farming methods (especially with regard to sugarcane) represent critical issues. Nexus interventions therefore need to focus on further bolstering its resilience to shocks by:

- Limiting its dependency on fuel and food imports.
- Protecting the country's agroecological legacy by further ensuring a delinking between food production, fossil-fuel based inputs and energy use.
- Carefully assessing the nexus trade-offs associated with specific agricultural products and exports.
- Strengthening water security.

These goals need to be achieved while the country negotiates a gradual transition from a socialist economy to a more market-based economy, characterised by an emerging middle-class, changing consumption patterns and the opening of the country's economy to incremental imports and tourism flows as the United States embargo is progressively lifted.

3.4.1 Energy security

Valuable lessons can be learned from the way Cuba tackled its energy challenges during the country's 'Special Period'. This essentially entailed regulatory measures to limit demand and a variety of interventions aimed at bolstering domestic energy production. The following summary of policies and measures adopted in Cuba can also be considered in countries facing similar energy constraints and/or wanting to mitigate the effects of rising oil prices.

Creating institutional structures

Cuba's energy revolution has been enabled by a wide range of transforming institutional structures. Interestingly, at the time of the country's initial energy transition in the 1990s, Cuba did not have a dedicated Ministry of Energy (IAEA 2008). The Technical Department of Energy, which fell under the auspices of the national Ministry of Economy and Planning, was responsible for planning the country's energy infrastructure and reportedly had access to renowned renewable energy and energy efficiency expertise (Cherni & Hill 2009). A National Energy Commission (IAEA 2008) was also established, which enacted most of the policy measures described below. A sub-ministry for renewable energies attached to the Ministry of Basic Industry, as well as the National Group for Renewable Energy Sources, Energy Efficiency and Cogeneration, were other important institutions that were created to implement Cuba's new energy paradigm (Alberto 2008). The Financial Fund for Energy Efficiency, an inter-ministerial commission headed by the president of the Central Bank, was created to facilitate investments in the field of energy efficiency (IAEA 2008).

Formulating guidelines to encourage government entities to meet new energy targets

The 1993 National Energy Sources Development Programme focused on encouraging government entities to use renewable energy sources to satisfy growing demand, achieve higher efficiency in the use of bagasse and other crop residues, and to increase the use of domestically produced crude oil and associated gas in electricity generation as a substitute for imported fuel oil. This led to government officials and members of the Cuban scientific community mobilising to expand domestic energy supply to key infrastructural nodes such as schools, hospitals, clinics and community centres, especially in the poorest, most isolated communities (Barclay 2003). This led, for instance, to the replacement of fuel oil by bagasse in raw sugar production and to a reduction of fuel usage in the sugar refinement process (IAEA 2009).

Promoting energy demand-side management programmes and improving energy supply through inter-ministerial cooperation and a mix of policies

The Cuban Electricity Conservation Programme, the Energy Conservation Programme of the Ministry of Education and the 2006 Energy Revolution Programme underpinned the transition of the country towards a new energy paradigm and rested on the integration of technical, educational, social and economic measures (Alberto 2008). The energy revolution, which occurred during the Special Period, proved to be a cost-effective manner of changing the way in which the country transforms and uses its energy sources and technologies (Suarez et al. 2012).

It essentially entailed:

- Substantial public investments to rehabilitate and decentralise the national electricity grid. The energy revolution led to the replacement of large old power plants with smaller plants (notably through introducing cleaner gas-fired combined cycle turbines), and the adaptation of the grid for use of domestic crude oil (IAEA 2008). By 2008, over 40% of Cuba's electricity was generated by small-scale distribution plants, ranking Cuba amongst the countries with the highest proportions of distributed generation in the world. Although around half of this generation stems from diesel generators, these are far more efficient and environmentally friendly than the former large oil-fired power plants (Alberto 2008). Such decentralised grids presented the dual merit of expanding access to energy to remote communities as well as sheltering the national grid from the shocks of cyclones. The Cuban government has promoted expansion of energy access through small-scale renewable energy installations in rural areas, which enabled the country to leapfrog the conventional pathway of using fossil fuel-based energy sources (Cherni & Hill 2009).
- Rolling out a national programme to phase out inefficient appliances. Cuba was the first country in the world to phase out inefficient lighting through the subsidisation of millions of energy-efficient light bulbs (Guevara-Stone 2008). Over 3 million Cubans benefited from bank loans and they were sold (by the government) highly efficient models of appliances such as refrigerators, electric pressure cookers, water pumps and fans (Alberto 2008; Piercy et al. 2010). This initiative helped to entice people to switch from liquid petroleum gas and kerosene to electricity as a source of energy for cooking (Alberto 2008). More recently, the government expressed its plans to install 13 million light-emitting diode lamps in homes and 250 000 in public spaces, and to introduce 2 million inductive stovetops to kitchens (Ferris 2015).
- Introducing a new electricity tariff structure. Another important measure was a new tariff structure, which encouraged people to limit their energy consumption. When using less than 100kWh per month, people would be entitled to keep on paying the (previously subsidised) low rate. For every increase of 50kWh per month the tariff structure would increase significantly (Alberto 2008).
- Increasing the exploration, production and use of domestic fossil fuels to meet energy needs. Cuba's policy focus on the indigenisation of energy sources included increasing the share of oil and natural gas in its combined cycle gas-fired power stations. The country implemented several policies to increase the use of associated gas, liquid petroleum gas and city gas in Cuba, which contributed to decreasing the country's dependence on external sources and to producing low cost electricity. This entailed, for instance, consuming all gas that had previously been flared (IAEA 2008). The country also succeeded in increasing the share of oil refined domestically (an increase of 40% in refining between 2002 and 2003), especially thanks to the trade agreement with Venezuela.

Education and awareness programmes have been a cornerstone of Cuba's improved energy demand-side management. As early as the 1970s, energy education has targeted schoolchildren, through curriculum development and through community-level 'click patrols' entrusted with promoting energy saving at home (Alberto 2008).

Awareness-raising initiatives complemented these educative measures, such as the broadcasting of a weekly programme on national television and billboards promoting energy conservation, which played a key part in shifting people's behaviour in terms of energy consumption (Alberto 2008).

Diverse measures were taken to mitigate the transportation crisis that accompanied the oil crisis. Cuba both imported and manufactured bicycles, which became a primary mode of transportation for professionals. The public transport fleet was also redesigned to maximise users while reducing fuel usage (Piercy et al. 2010), which saw the advent of 'camel transporters' and 'truck buses' that could transport up to 300 people at a time. The optimisation of vehicle use was fostered by the development of multi-share taxis and by making it compulsory for civil servants to pick up hitchhikers (Piercy et al. 2010).

Cuba's spatial planning policy was reconfigured to reshape the functioning of the economy through relocalisation to complement these measures. The principle of relocalisation is to reduce commuting distances by improving travel patterns. In Cuba this meant focusing on decentralising the locations of key services – especially those in the education and health sectors – to outlying areas (Piercy et al. 2010). Spatial divisions of labour were also reversed through relocalising socioeconomic activity to suburbs and smaller communities by promoting 'local workplaces' and supporting the development of amenities away from urban centres.

Promoting and subsidising renewable energy technologies accelerated the take-off of this sector. Under these policies, the use of wind energy for water pumping and electricity generation, and solar thermal energy for water heating for domestic, institutional and industrial purposes steadily expanded over the years (Alberto 2008). Given the very high initial capital costs for renewable energy technology, government (and international donors) played a key role in subsidising not only the expansion of renewable equipment in rural communities, but also in meeting the recurrent costs of power generation (Cherni & Hill 2009). Solar power and wind energy especially became more affordable as a result of the decreased costs associated with technological progresses since the 1990s. In an effort to further diversify its energy portfolio, the government aims to produce 24% of its electricity from renewable sources by 2030.

Further recommendations for Cuba

It is important to highlight that when discussing energy security in the context of Cuba, energy supply entails challenges that go beyond the traditional market and geopolitical dynamics that most countries have to contend with; they also encompass the United States embargo on the country that limits its access to markets and hinders access to international credit options. In light of the identified drivers and risks in the energy sector, a series of recommendations that could be explored to further address the energy challenges of Cuba and countries with similar developmental characteristics include:

- Cuba's heavy dependence on subsidised Venezuelan oil (for up to two-thirds of its supplies) renders its economy and especially its power sector vulnerable. General measures aimed at reducing oil dependencies have been outlined in section 3.1.3 (see also Wakeford & de Wit 2013).
- Specific measures for Cuba include: (i) increasing the use of gas associated with oil production for electricity generation; (ii) using associated gas in transport; and (iii) replacing use of diesel by compressed natural gas (some cars in Cuba have already been converted) (IAEA 2008).
- Renewable energy has significantly expanded and become more affordable over the past two decades, but analysts deem that Cuba is still not fully tapping into its renewable energy potential. The exploitation of solar PV remains low, with installations having been promoted mostly through social programmes aimed at electrifying schools and meeting other social objectives in isolated mountainous areas (IAEA 2008). PV power needs to become far more mainstream and implementation expanded to urban areas. The wind sector could also be expanded with the participation of different industries. Lastly, measures looking at the expansion of PV–wind power hybrid systems should be considered. The government has the intention of developing a chain of 13 wind farms along the island's north shore, complemented by 19 'bioelectric' stations fuelled by solar and bioenergy (Ferris 2015).
- Cuba is also overcoming its local capacity constraints to manufacture energy equipment and spare parts. A manufacturing plant was built outside the city of Cienfuegos. The government is also reported to be considering the possibility of manufacturing its own wind towers and components (Ferris 2015).
- The share of biomass in Cuba's energy mix declined in the 1990s, attributable mainly to the decline of sugarcane production combined with the voluntary closure of sugar mills and the conversion of about 1 million ha of sugar field to food production and reforestation (Koont 2004). Attempts to reverse this may present Cuba with difficult trade-offs within the nexus, for example the impact of sugar plantations on water use and soil quality. The government intends on increasing the share of cogeneration from the sugar industry; an increase in the use of sugar mill bagasse should focus on increased energy efficiency (e.g. higher efficiency boilers and new turbo generators in the operation of sugar mills).
- The emergence of a middle class with greater buying power (and therefore greater consumptive habits) added to the projected growth in tourism could lead to a significant expansion of the energy-intensive built environment. This will put more pressure on the grid and transportation networks, and will generate increased waste volumes and contribute to greenhouse gas emissions. Regulations that foster the adoption of best practices in the built environment and hospitality industry to maximise energy (and water) efficiencies can mitigate these impacts.

3.4.2 Food security

The political vision underlying the shift in Cuba's food production system (towards domestic food sovereignty) is very context specific, and arguably more feasible in a command and control regime than in a market-based economy. The government responded to the country's crippling food scarcity by reorganising the agricultural sector, which entailed converting large state farms into smaller cooperative farms geared towards productivity and the distribution of land in usufruct to small producers (Gonzalez 2003). It is challenging to assess the replicability of this experience for developing countries where the leasehold systems mostly consist either of private tenure rights or state-owned land entrusted to communities (communal land), although lessons learned from the distribution to small producers and the establishment of productive self-managing cooperatives could be valuable.

Building institutions to enhance food security

New institutions were created to support Cuba's food revolution, notably the formation of a ministerial department devoted to urban agriculture, entrusted with securing land-use rights for urban gardeners, making extension officers available to community gardeners, as well seed shops to supply seeds, and the provision of tools and bio-products (Piercy et al. 2010). The Crop Protection Institute is a pivotal institution that supports organic farming in the country, operating over 220 centres that provide beneficial insects and microorganisms as natural pest controls. The Centre for Genetic Engineering and Biotechnology and a network of institutions across the country are focusing on research and development of genetically modified crops that are free from corporate control and the global intellectual property-rights regime (Altieri & Funes-Monzote 2012).

Assisting the poor with food schemes

The food ration card and schemes targeting the vulnerable were pivotal interventions through which the Cuban government managed to keep food within physical and economic reach of its entire population (Pfeiffer 2006). Similar instruments that have been tested in market-based economies and that arguably present a similar outcome include the Brazilian Bolsa Familia programme. This social grant scheme aims at reducing poverty by providing a minimum income for vulnerable families and at breaking the cycle of poverty by making the grant conditional on school attendance and medical care (Callister 2013).

Promotion of farming as an occupation

The government enacted major land reforms in 1993 and introduced incentives for working in the agricultural sector, which played a huge part in the rejuvenation of the peasant class and the re-emergence of traditional farming knowledge. In urban agriculture, in particular, the agricultural working sector became among the top earning professions, contributing to the revaluing of agriculture and related professions in Cuban society (Wright 2008). This change was the product of the state's very interventionist approach in the shaping of its society; in a market-based democratic system, different ways of boosting the farming sector would, for instance, entail subsidising training programmes and access to equipment for farmers, or rolling out income tax rebates for farmers or creating exclusive zones for farming with preferential access to land.

Supporting agroecological farming

The widespread adoption of agroecological practices, both in an urban and in a rural context, has been the core engine of the Cuban food revolution. The state played a critical role in facilitating this shift of the agricultural production model by applying agroecological research results at scale to offset the shortage of synthetic inputs. The Ministry of Agriculture spearheaded a programme to convert the sector to low-input, self-reliant practices (Gonzalez 2003). From a nexus perspective, the rationale for adopting agroecological farming methods is to support the decoupling of food production from fossil fuel-based inputs, including synthetic fertilisers and pesticides. Cuba's success in boosting food supply per person, while substantially diminishing energy consumption in the agriculture sector was presented in Part 1, while the merits of agroecological farming were discussed in section 3.1.4.

Cuba managed to rely on an efficient social dynamic for a widespread adoption of agroecological practices, the CAC (peasant-to-peasant) movement.

Through CAC, a farmer who has discovered a solution shares it with other farmers. This grew into a nationwide movement in Cuba in the 2000s and resulted in 65% of the country's food being produced on only 25% of the land (Rosset et al. 2011).

Animal traction can be promoted as a way to reduce reliance on diesel for tractors, where technically feasible. After a decline in the use of animal power in Cuba following the "tractorisation" trend in the 1970s, it gained a renewed importance during the Special Period. Still today, the most commonly used animal unit is the *yunta*, or pair of oxen used mainly for tillage and the transport of agricultural products (Starkey & Sims n.d.). Innovative modern traction appliances that have versatile uses have been developed, and could be used in many countries where the land or landscape is not fit for mechanisation and where farmers can just not afford mechanisation.[36] Use of animal power, however, does requires additional land to be set aside for growing fodder.

Creating agricultural cooperatives

Critical to Cuba's food revolution, and also very specific to the country's communist political system, was the restructuring of state farms as private cooperatives (Koont 2004; Pfeiffer 2006). Cooperatives are increasingly heralded as an efficient means of agricultural production especially in the context of the developing world. Agricultural cooperatives have been heralded as essential for supporting small agricultural producers and marginalised groups in developing business models that enable them to expand their access to markets and natural resources, as well as access a wide range of services (information, communications, technologies, credit, training and warehouses), which contribute to the greater social and economic resilience of farming communities (IFAD, WFP & FAO 2011).[37]

The provision of electricity to rural households was aimed primarily at improving local wellbeing, but indirectly contributed to preserving a thriving small-scale farming community in the hinterland by discouraging rural-urban migration (Hernández 2002 in Cherni & Hill 2009).

Promoting urban agriculture

Since the Special Period, the promotion of urban agriculture in Cuba has helped to alleviate pressure on the hinterland to feed the country and has reduced reliance on energy-intensive transportation and refrigeration, as the produce were made locally available on urban markets (Gonzalez 2003). This is of vital importance as the total energy demand for food processing is estimated to be three times the direct energy consumed behind the farm gate (White 2007 in FAO 2011a).

Notable challenges arising from urban agriculture include an increase in the (opportunity) costs of land, the higher cost of accessing water in urban environments and the dangers of people using sewage water for irrigation as well as low-cost fertilisers, which poses health risks to farmers and consumers (Swedish University of Agricultural Science 2014).

The creation of cost-free 'new' farming land, especially in urban/suburban environments, entailed land reclamation or creation for the purpose of growing food, such as raised gardens made from manure and soil deployed on paved lots, use of fallow land (vacant lots, parks), and the cultivation of yards or patios next to people's houses (Koont 2004). This was complemented by the promotion of a *parcelas (*popular gardens) system, through which land is granted to private individuals on a rent-free basis, as long as it is kept productive (Koont 2004). Importantly, this land has been made available by the government cost-free, thus enabling all actors of society from industrial groups to hospitals, schools and pensioners, to make use of every piece of idle land to grow food for self-provisioning (Gonzalez 2003). Since the food produced in *parcelas* is grown on land that was made freely available by the state, there is a strong expectation that any excess will be redistributed in the form of voluntary donations. These donations often happen spontaneously, but the government also insists on these forms of 'social rent' (Koont 2004).

In the mid-1990s the Cuban government developed a regulatory framework that supported the emergence of many local food markets (where only the food produced in excess of the mandatory state quota could be sold). But because the food offered on these markets still remained inaccessible to some, in 1998 the state also created competition in the form of state-based markets, supplied by agricultural state enterprises, where food can be purchased (although with less diversity) at a ceiling price (Koont 2004). In the 2000s the state further reformed the food market sector, where food was still sold at a premium, by authorising the sale of food in various other outlets (including urban gardens and *parcelas*) at a fixed price. This is the way that most low-income Cubans buy their food (Gonzalez 2003). However, this price-fixing mechanism would not function in a market economy. Furthermore, organic producers usually need to sell their food at higher prices as their products are generally

36 For example, the French association PROMATA promotes the dissemination of light, versatile and multi-usage animal traction devices for small-sale farmers; see www.assoprommata.org/.

37 For details on cooperatives and how to establish them, see FAO (1998).

more expensive to produce than mass-produced commercial food, although prices could fall after the first few years as soil health recovers and yields rise.

Reducing dependence on food imports

Cuba is striving to minimise its dependence on cereal imports by increasing the domestic production of maize and soya. However, this presents trade-offs as these crops tend to have significant energy demands, including for irrigation. The production of meat declined markedly during the Special Period and Cuba still relies heavily on imported meat products. In developing countries in general, the promotion of locally suited animal breeds and local feed is recommended. Extensive pastoral systems for sheep, goats, deer and cattle tend to have lower energy inputs than intensive livestock systems. However, these extensive systems also often rely on some energy embedded in purchased feed or for forage crop production and hay and silage conserved on-farm (FAO 2011a).

Somewhat paradoxically for a country under food stress, Cuba has resorted to developing niche markets for food export products (such as coffee, citrus fruit, honey and shellfish) to generate foreign currency to enable imports of other vital foodstuffs (Koont 2004). This cross-subsidisation mechanism has played a part in Cuba's food security and is an approach that could be replicated elsewhere, depending on a given country's comparative advantages.

Expanding irrigation networks

Finally, the government invested in (or insured the channelling of foreign aid to) the upgrading of the irrigation system. The whole network was modernised and electrified (in this respect the country benefitted for instance from the financial support of the Organisation of Petroleum Exporting Countries). However the over-reliance of the irrigation network on the central electricity grid is a source of vulnerability and decentralised irrigation schemes powered by renewable energy (e.g. solar PV) should be considered as an alternative.

Further recommendations for Cuba and other countries

In light of the identified drivers and risks in the energy sector, a series of additional recommendations and tools that could be used to address the food security challenges of Cuba and similar countries include the following:

- The costs and benefits of staple crop production need to be carefully assessed and managed. Over-reliance on sugarcane production for export could have detrimental nexus consequences in terms of water usage and the impacts on soil quality. Sustainable options needs to be assessed on the basis of energy and water footprinting and lifecycle analysis of economic and environmental costs and benefits. Reducing the energy dependency of the agricultural sector may require limiting the expansion of irrigated (export) crops (e.g. citrus and sugarcane), as well as other commercial crops such as soya and maize that Cuba is wanting to grow more intensively (Altieri & Funes-Monzote 2012). A country such as Cuba that has such a widespread and deep-rooted agroecological tradition should arguably exploit its research and practical knowledge to intensify the production of such crops (maize and soya), which are unquestionably required for domestic food security, using agroecological practices that require less energy-intensive inputs and less water. Altieri reports that in most multiple cropping systems developed by small-scale farmers, "productivity in terms of harvestable products (such as maize or beans) per unit area is higher than under sole cropping with the same level of management. Yield advantages can range from 20% to 60%." (1999:199).
- As an illustration of what has been termed integrated food-energy systems (FAO 2011a), Cuba has introduced biogas digesters, which are used to capture methane gas from animal manure (especially on pig farms) for use as a cooking gas. More generally, bioenergy from small-scale, on-farm projects can be used to produce heat, power and biofuels for local use, thus reducing dependence on imported fossil fuels, strengthening food security, and offering new livelihood opportunities for rural communities.[38]
- Demand management measures can be implemented to shape food consumption patterns. The emergence of a middle class in Cuba will likely change consumption patterns towards livestock products, fish, and high-value crops (subject to availability of these food items and when the United States trade embargo is lifted). The introduction of taxes on more 'luxury' food items is one means – albeit unpopular – of influencing consumers to change their habits.

38 See FAO 2009, for an analysis of case studies in 12 countries in Latin America, Africa and Asia documenting such small-scale bioenergy initiatives.

3.4.3 Water security

Water security in Cuba has received considerably less attention in the literature compared to energy and food security. Nonetheless, there are several ways in which water security is being or could be improved, beginning with implementing those with lower energy requirements.

Restoring ecological infrastructure and soil quality

Although 60% of the country's land is degraded in some way (Suárez et al. 2012), efforts to reclaim marginal, unused or degraded land for the purpose of agricultural production, especially in urban and peri-urban areas, have played a positive part in restoring the quality of soils. Healthier soils generally help to improve the quality of water and to retain moisture – although this is not quantified by any specific research in Cuba.

Harvesting rainwater

Water shortages resulting from prolonged periods of droughts (Grogg 2012) are accompanied by food shortages and food price hikes that people can ill afford. Many cities rely on rainfall water stored in the county's 240 reservoirs for their water supply (Grogg 2012). The extent to which domestic rainwater harvesting is promoted in Cuba is unclear, but this certainly constitutes a priority to reduce risks of water scarcity, especially to sustain urban agriculture.

Expanding infrastructure for water transfers

The Cuban government is reported to have revived plans to transfer water from wetter mountain regions to drier areas through a vast network of reservoirs, canals and pipelines, and more than 80km of mountain tunnels (Grogg 2012). The trade-offs of such a vast engineering approach need to be carefully assessed. Assuming the water sources are indeed perennial, it is important to appreciate that should this plan comes to fruition, it will take Cuba's water system further into the industrial regime and be very energy-intensive in the construction phase, with further energy being required later for pumping.

3.4.4 Conclusions

Despite Cuba's achievements in boosting energy and food security by embracing key elements of the 'ecological' socio-metabolic regime, the country faces several challenges that serve as caveats to other developing countries. First, Cuba needs to find ways of sustaining and deepening the energy reforms and agroecological approach embraced during a contrived period of transition (the Special Period). This is already proving difficult, as evidenced by the continued dependence on fossil fuels and the apparent push towards increased industrial farming processes. Second, the economic reforms currently being implemented by the Cuban government may mean that the country might be able to rely less on a command and control political regime and will have to develop market-based policy tools to address nexus challenges. Third, with the likely progressive lifting of the United States trade embargo, Cuba's economy is likely to be subject to new pressures and opportunities, such as increased imports and tourism, which could place additional pressures on the country's natural resources and domestic food production capacity. Fourth, it may prove difficult for a country in Cuba's situation to source oil from other countries and thereby diversify its geopolitical risks.

It is also important to note that various aspects of Cuba's experience might not be replicable in other contexts. In the first place, the specific socio-political system that characterised Cuba in the 1990s – and largely still does today – was in many respects a necessary condition for the sweeping energy and food regime shifts that the country undertook. The socialist state rested on strong centralised systems of command and control to enact reforms and changes, meaning that it relied on a well-established network of civil servants to ensure the implementation of (especially energy-related) regulations.

Moreover, the agroecological revolution that was successfully conducted in Cuba is also specific to the climate and geography of the island and might be challenging to replicate in environments affected by greater resource constraints, for example, as regards rainfall and water resources. However, the practice of agroecology is context-specific and different knowledge systems are applicable to different bio-realms. The potential of agroecology also has limitations and it can be challenging to harness knowledge-intensive agroecological methods at scale to feed an entire nation. Adequate knowledge management institutions and social structures are required to disseminate this knowledge and resultant innovations. Another core challenge underlying the promotion of agroecology as the main agricultural paradigm in a given country lies in the difficulty of attracting external investment in the agricultural sector, as the agroecological approach is inherently less attractive to agribusiness (Freibauer et al. 2011). Governments therefore need to rely on their core resources or other innovative mechanisms to promote the wide use of agroecological practices.

Finally, an important lesson for other countries is that Cuba has invested heavily in educating its people, which was a pre-condition for the country's achievements in the areas of renewable energy and agroecological farming.

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Urban food garden, Cuba

3.5 Summary and Conclusions

In the early stages of the 21st century the world faces unprecedented challenges, which are set to intensify in the coming decades. There is increasing demand for resources to sustain the needs and desires of a growing world population that is becoming increasingly urbanised and affluent. The growth in supply of material goods, however, is beginning to encounter resource constraints (e.g. in terms of arable land, fresh water, and conventional oil) and is also increasingly threatened by the environmental impacts of current technologies and economic systems, including the degradation of ecosystems. Global climate change is increasing uncertainties and poses potentially severe threats to water and food supplies in some regions.

This escalating tension between increasing demand and limits on resources and environmental sinks threatens to create energy and food price shocks that ripple across integrated global markets, and result in local shortages of key resources (especially water). This, in turn, threatens to undermine energy, food and water security, and thereby reduce human welfare and possibly lead to social tensions and geopolitical conflict. Compounding these systemic challenges is the fact that energy, food and water systems are inextricably linked through numerous interdependencies and spill-over effects.

Enhancing food, energy and water security requires an integrated nexus approach that takes into account the linkages and interdependencies among food, energy and water systems and seeks to minimise the risks arising from these interconnections while also building resilience to external and internal shocks. This must begin with efforts to build well-functioning institutions, effective governance systems and integrated policy frameworks, as these are prerequisites for the design of effective policies and the implementation of viable technical solutions to tackle nexus risks and vulnerabilities. Both vertical and horizontal coordination within governments is essential to ensure better policy coherence and effectiveness, while cooperation must be sought with stakeholders from all sectors of society to ensure sustainable and equitable governance of resources.

Although the focus of this report has been largely on national-level nexus interconnections, risks and mitigation responses, the international dimension is also important and was raised on a number of occasions. The fact that countries are embedded within global trading networks (especially for food and energy commodities, but also virtual water) means that they are susceptible to societal teleconnections; that is, disturbances in one part of the world can quickly get transmitted to other parts of the world. Nexus issues in a particular country are therefore affected by the decisions taken by other countries. This means that individual nations must devise strategies to build resilience to such teleconnection impacts. Part of their response must be to engage in multilateral forums to improve international policy coordination in managing the nexus. Specific examples of international cooperation included regional food and oil stockpiles, power pools, strategic funds, and multilateral governance of subsidies and trade policies that involve agricultural goods.

Individual nexus interventions will be much more coherent and effective if they are designed and implemented within an overarching paradigm aimed at a transition to 'inclusive green economies'. This involves expanding access to food, water and energy services – particularly for the billion or so poorest people who face daily struggles to meet their basic needs – while transforming economic systems to be more resource efficient, less carbon intensive, and less damaging to the environment. In short, economic growth must be decoupled from resource use and environmental impacts, for example through increased resource productivity, a reduction of waste, and the adoption of closed loop production systems. Transitioning to green economies entails avoiding lock-in to unsustainable technologies and infrastructure systems. In particular, countries need to undergo shifts from fossil fuels to renewable energy systems, and from fossil fuel-intensive industrial agriculture to more sustainable farming practices such as agroecology. However, questions remain as to whether these alternative systems will deliver sufficient quantities of energy and food to a growing population. Hence it is also vital to manage demand – especially within relatively affluent communities – to reduce excessive consumption and waste.

A nexus approach includes two key principles. First, policy interventions should aim to identify win-win solutions that harness synergies and maximise co-benefits across the energy-food-water nexus. By way of example, certain renewable energy technologies present opportunities for synergistic solutions that widen energy access, reduce reliance on polluting fossil fuels, and limit the need for water in energy generation. Second, policymakers must deal with unavoidable trade-offs by assembling relevant scientific information and involving stakeholders in consultative processes to inform policy decisions. Examples are increasing agricultural productivity through the use of synthetic fertilisers at the cost of increased vulnerability to fertiliser prices shocks (related to oil price shocks) and long-term environmental damage; and the use of water resources for expanding irrigation or for run-of-river hydropower generation.

A wide range of technical measures can be adopted to mitigate nexus-related risks and improve energy, food and water security in developing countries. In line with the green economy principles mentioned above, many of these technical measures are aimed at increasing resource efficiency and reducing waste (see the summary in Table 3-2). Other measures have to do with protecting ecosystems and reducing negative environmental impacts such as pollution. It is important to bear in mind, however, that the 'developing country' category spans a wide spectrum of nations with diverse characteristics. The applicability of these measures will therefore depend on regional, national and local contexts, such as a country's level of development, geographic and climatic conditions, availability of different energy resources, suitability of agricultural crop and livestock mixes, and so on.

Furthermore – as discussed in Parts 1 and 2 – nexus linkages, risks and vulnerabilities differ to some extent between rural and urban environments. Consequently, there can be significant spatial differences in appropriate nexus mitigation strategies and policy interventions. In rural areas, the key issue is optimising land use to provide a range of services. This involves, *inter alia*, management of ecosystems to provide a sustainable stream of services, choices of whether to use land to produce food or biofuels, taking steps to minimise harmful impacts of agriculture such as soil erosion and salinization, and preventing the pollution of water resources. A holistic approach can tackle poverty through rural development programmes, such as the creation of jobs in sustainable agriculture. In many rural areas the best way to improve access to energy – and thereby to enable better access to water and food production – is through decentralised, off-grid or mini-grid energy solutions. Interventions to tackle food waste must be aimed at reducing post-harvest losses through improved storage and packaging. In urban areas, by contrast, the emphasis is on creating resource-efficient, low-carbon cities. This is partly about how to configure infrastructure systems to be as efficient as possible, such as integrated planning of infrastructure for energy, water and wastewater access. Centralised grid systems tend to be more efficient in high-density urban settings. Another important issue is how to manage demand and reduce waste and emissions from industry and households, since resource consumption tends to be concentrated in cities. The development of urban and peri-urban agriculture can help to reduce dependence on long food supply chains and associated carbon emissions.

A suite of policy instruments are needed to encourage and facilitate the adoption of technologies and practices that mitigate nexus risks. Table 3-3 summarises the main generic types of policy tools that can be implemented by national or local governments, including public investments, economic incentives, regulatory mechanisms, and education and awareness programmes. Again, the appropriate combination of policy instruments will depend on the specific priorities, institutional capacity and local context within each country. Some instruments (e.g. taxes, loan guarantees and many regulations) can be used in the short to medium term, while others (e.g. infrastructure investments and training programmes) are of a longer-term nature. Many policies are relevant to the national scale, while other interventions are applicable on a local or regional scale.

Table 3-2: Summary of technical mitigation measures for energy, food and water systems

STAGE OF LIFECYCLE	ENERGY SYSTEM	FOOD SYSTEM	WATER SYSTEM
PRODUCTION	▪ Combined heat and power plants ▪ Renewable energy generation ▪ Supercritical coal power stations ▪ Production of bioenergy	▪ Sustainable intensification ▪ Conservation agriculture ▪ Agroecological farming ▪ Integrated nutrient management ▪ Plant breeding ▪ Integrated pest management and natural pesticides ▪ Intercropping and crop rotation ▪ Tillage reduction ▪ Soil rehabilitation (mulching, composting)	▪ Sustainable groundwater management ▪ Rainwater harvesting ▪ Desalination ▪ Preservation and rehabilitation of wetlands and aquatic ecosystems ▪ Prevention of soil erosion and deforestation
TRANSMISSION/ CONVEYANCE	▪ High-voltage direct-current power lines	▪ Urban agriculture	▪ Gravity-fed systems ▪ Repair and maintenance ▪ Minimising leaks ▪ Pumps with variable speed drives ▪ Conduit hydroelectricity
STORAGE	▪ Improved batteries ▪ Pumped storage	▪ Use renewable energy to help preserve and store food	▪ Maintenance of dams
PROCESSING		▪ Improved maintenance of processing plants ▪ Optimising combustion efficiency ▪ Using high-efficiency motors	▪ Technical energy efficiency measures ▪ Ecological infrastructure
DISTRIBUTION	▪ Decentralised mini-grids ▪ Smart grids ▪ Off-grid energy systems	▪ Improved logistics ▪ Road and rail infrastructure ▪ Relocalising food production and consumption systems ▪ Developing urban and peri-urban agriculture ▪ Local food markets	▪ Gravity-fed systems ▪ Efficient pumps ▪ Minimising leaks ▪ Software for control systems ▪ Micro-hydro technologies in pipes
CONSUMPTION	▪ High density compact cities ▪ Efficient building design ▪ Efficient appliances and cookstoves ▪ Solar water heating ▪ Efficient lighting ▪ Eco-driving ▪ Traffic management systems ▪ Efficient vehicle designs ▪ Electric and hybrid vehicles ▪ Transport modal shifts to public transit and freight rail	▪ Encourage dietary shifts to foods requiring less water and energy inputs ▪ Pre-emptively manage increased meat demand	▪ Sprinklers, precise irrigation, drip irrigation, deficit irrigation, 'smart' irrigation scheduling ▪ Mulching, reduced tillage, drought-resistant crops ▪ Various water efficiency technologies for industry ▪ Low-flow showerheads, dual-flush toilets, efficient washing machines ▪ Solar water heaters, geothermal heating
WASTE		▪ Reduce post-harvest losses by building storage and refrigeration facilities and improving packaging ▪ Improve distribution, e.g. improved road and transport infrastructure	▪ Gravity-assisted reticulation in wastewater conveyance ▪ Efficient pumps

Table 3-3: Summary of policy instruments to support nexus resilience and sustainability

PUBLIC INVESTMENT	■ Public spending and investment (expenditure switching) ■ Infrastructure designed for resource efficiency and recycling (e.g. public transport, smart grids, greywater reticulation) ■ Restoration of ecological infrastructure ■ Procurement ■ Innovation and research and development expenditure ■ Training programmes ■ Extension services for agriculture ■ Public finance (e.g. grants, low-interest credit, microfinance, loan guarantees, public-private partnerships)
ECONOMIC INSTRUMENTS	■ Green subsidies (price support measures, tax incentives, direct grants and loan support) ■ Environmental taxes (e.g. carbon tax; tax on waste) ■ Charges and levies (e.g. stepped block tariffs for water and power) ■ Feed-in tariffs for renewable energy ■ Eliminate harmful/distorting subsidies ■ Payments for ecosystem services ■ Tradable water rights and water markets
REGULATORY MECHANISMS	■ Efficiency standards (e.g. for appliances, equipment and vehicles) ■ Bans on inefficient/obsolete technologies (e.g. incandescent lamps) ■ Green building codes (e.g. minimum energy performance standards) ■ Environmental impact assessments ■ Establishment of nature reserves and protected areas ■ Bans on polluting activities ■ Emission standards (e.g. industries, vehicles) ■ Maximum effluent concentrations ■ Requirements for treatment of water before discharge ■ Certification (e.g. organic farms) ■ Waste disposal and recycling regulations
EDUCATION AND AWARENESS	■ Public awareness campaigns (e.g. radio and television) ■ School education programmes and curricula ■ Tertiary education programmes ■ Eco-labelling ■ Publication of water and energy footprints

Lessons from the case studies

In order to gain greater insight into the kinds of policies and technical measures that are applicable to different kinds of developing countries, this report investigated the experience of three case study countries. Table 3-4 presents a summary of the main policy recommendations for Malawi, South Africa and Cuba, which represent predominant aspects of the agrarian, industrial and emerging agro-ecological socioecological regimes. The key lessons emerging from these countries are as follows.

To address nexus vulnerabilities, the main priority for countries with a largely agrarian regime is to expand access to food, energy and water among their populations, while limiting negative impacts on ecosystems. Countries such as Mozambique and Tanzania, which have recently discovered large fossil fuel reserves, will of course be tempted to use these resources to catalyse a traditional process of industrialisation. However, many LICs are devoid of fossil fuels resources; their choice is between risky and expensive reliance on imported oil, gas and coal, versus developing indigenous renewable energy resources. The burning question is whether such countries can leapfrog to a more sustainable socioecological regime, without following the conventional fossil fuel-based pathway of industrial development that exposes economies to volatile international fuel prices.

The still limited reliance on fossil fuels in countries like Malawi can be viewed as an opportunity to undertake a direct transition towards a more sustainable green economy. Such an economy could be powered increasingly by decentralised, small-grid or off-grid renewable energy systems using local energy resources. Governments should promote small-scale sustainable agriculture and agroforestry, which seek to increase food production based on knowledge-intensive systems and possibly in conjunction with bioenergy production to stimulate rural economies. Local water supply options such as rainwater harvesting and solar pumps could help to improve water access in rural areas and reduce the need for long-distance water transfers to urban areas. If policies to support these outcomes are successful, they could help to slow down the pace of urbanisation and therefore alleviate the growing pressure on urban infrastructure and services. The main obstacles to the achievement of this agenda are likely to be lack of institutional capacity, finance and household purchasing power. LICs will therefore need the support of the international community. As much as possible, governments should promote labour-intensive solutions and invest in knowledge-building and skills development for the long term.

In countries (such as South Africa) with largely industrial regimes that rely heavily on fossil fuels, the key nexus security challenges are to limit the vulnerability to international energy price volatility, reduce energy and resource intensity, and reduce the negative impacts of fossil fuel use on the environment (notably soils and water resources). The starting point should be a concerted effort to manage energy demand through incentives and regulations designed to enhance energy efficiency and conservation. On the supply side, increasing the renewable energy share of the energy mix can bring multiple benefits, including expanded energy access, and reduced pollution, carbon emissions and water consumption. To boost the resilience of the food system, a range of measures should be introduced to reduce energy intensity in agricultural production and food distribution. A programme of support for small-scale agroecological farming holds the potential to meet several goals including improving household-level food security, reducing reliance on fossil fuel inputs, and creating sustainable rural livelihood opportunities. In the water sector, governments should implement regulations and incentives to reduce environmental impacts of industrial activities (including industrial agriculture and extensive use of fossil fuels for power generation) to halt and reverse the degradation of freshwater resources. A potential obstacle to such measures aimed at 'greening' industrial systems is the lock-in to fossil fuel-based infrastructure systems that deliver energy services, food and water, and supporting socio-political regimes with dominant interests heavily invested in the status quo. However, falling prices of renewable energy, and investor appetite for renewable energy investments, are beginning to demonstrate that an alternative, more sustainable path is viable.

Cuba provides an example of a country that adopted radical measures in its energy and food sectors in order to deal with a sudden and drastic limitation on oil imports, on which the country had relied heavily for energy and agricultural production. As such, it exhibits certain characteristics of an 'ecological' regime that might emerge to replace the industrial regime as more countries shift away from fossil fuel dependence.

Cuba's 'energy revolution' was enabled by a wide range of transforming institutional structures and policies, which included: energy targets; energy demand side management programmes including regulations on energy efficiency and phasing out inefficient appliances; public investments for the rehabilitation and decentralisation of the national electricity grid; energy-efficient transportation options such as bicycles and large buses; and spatial planning to promote localisation of economic activities. The government responded to the country's crippling food scarcity by reorganising the agricultural sector, converting large state farms into smaller cooperative farms geared towards productivity. The widespread adoption of agroecological practices has been the core engine of the Cuban food revolution. The government also promoted urban agriculture, partly through making land available and establishing local markets. In addition, food schemes were introduced to support vulnerable households. However, Cuba's success in reconfiguring its energy and food systems rested on a context-specific socio-political system (state socialism supported by a strong bureaucracy) and hence its experience with sweeping policy changes might be difficult to achieve (or less desirable) in other contexts. Nonetheless, another important lesson to be drawn from Cuba is that the country invested heavily in educating its people, which helped to shift behaviours and facilitated the adoption of new technologies and practices.

Despite exhibiting major differences in their status quo challenges, all three case studies seem to be pointing in the direction of more sustainable 'green economies' as a way of mitigating risks in the energy-food-water security nexus. This suggests that countries further behind on the path to prosperity can potentially gain from a leapfrogging opportunity, since the ultimate target for all countries is similar. Rapidly falling costs of new some technologies – such as solar PV and wind energy – are turning this notion of leapfrogging from rhetoric to reality in countries with leaders who display sufficient vision.

By drawing on a growing international literature and three case studies, this report has sought to show that a broad array of policy measures and technical solutions are available to address the risks inherent in energy-food-water nexus. These interventions will form a critical part of societal transition toward greater resilience and sustainability in the face of global and local environmental, resource and population pressures.

Table 3-4: **Comparison of key policy recommendations from the case studies**

	MALAWI	SOUTH AFRICA	CUBA
GOALS	▪ Expand and modernise access to energy ▪ Increase the productivity and diversity of the agricultural sector ▪ Improve access to safe water	▪ Reduce the risks of fossil fuel reliance by boosting energy efficiency ▪ Reduce energy intensity along the food value chain ▪ Improve water security by managing demand and protecting quality	▪ Limit dependency on fuel and food imports ▪ Consolidate agroecological farming practices ▪ Strengthen water security in the face of climate change risks
ENERGY SECURITY	▪ Modernise access to biomass, with improved cookstoves, biogas digesters, biofuel production and sustainable forestry ▪ Expand electricity access through investment in infrastructure, including decentralised renewables and mini-grids ▪ Establish adequate oil storage facilities	▪ Introduce fuel conservation and efficiency measures to reduce oil import dependence ▪ Increase power generation capacity with renewable energy sources ▪ Reduce the water dependence of energy systems (e.g. expand solar and wind power) ▪ Promote energy conservation and efficiency measures	▪ Maintain guidelines for energy targets and energy efficiency regulations ▪ Further expand renewable energy ▪ Diversify sources of oil imports ▪ Increase cogeneration of heat and power ▪ Adopt best practices in the built environment and hospitality industry to maximise efficiencies
FOOD SECURITY	▪ Adopt low-input, high-diversity agricultural systems and integrated food-energy systems ▪ Promote crop and export diversification ▪ Reform the FISP, e.g. linking it to conservation agriculture and precise application of fertilisers ▪ Promote urban and peri-urban agriculture ▪ Expand irrigation and improve its efficiency	▪ Use income support, competition policy, and support for small-scale farmers to boost food security ▪ Reduce fossil energy use in agriculture through conservation agriculture, agroecology and solar pumps ▪ Improve the efficiency of food distribution through localisation ▪ Improve water productivity ▪ Reduce food waste	▪ Consolidate agroecological farming ▪ Continue urban agriculture ▪ Expand irrigation networks ▪ Assess costs and benefits of staple crop production (especially sugar)
WATER SECURITY	▪ Limit deforestation ▪ Apply integrated water resource management ▪ Develop urban waste management ▪ Promote rainwater harvesting ▪ Use solar PV pumps ▪ Invest in multipurpose water resources projects	▪ Enhance water supply with dams, groundwater, transfers and rainwater harvesting ▪ Protect water quality with regulations and by restoring ecological infrastructure ▪ Manage water demand and improve water productivity in agriculture, industry and residential sectors ▪ Reduce reliance of the water system on energy	▪ Restore ecological infrastructure and soil quality ▪ Harvest rainwater ▪ Expand infrastructure for water transfers

Applicability of the case studies to other countries

Malawi

Malawi is in most respects a fairly typical exemplar of the agrarian regime: extensive reliance on biomass energy; low rates of access to and consumption of electricity, food and water; extensive reliance on agriculture for GDP and employment, but with comparatively little use of industrial inputs (such as fertilisers and irrigation); and heightened vulnerabilities such as high fuel prices and susceptibility to extreme weather events (see Table 3-5). Most of the other low-income countries whose indicators were analysed in Part 2 share these essential characteristics, including Benin, Burundi, Central African Republic, Democratic Republic of Congo, Ethiopia, Kenya, Liberia, Madagascar, Niger, Rwanda, Sierra Leone, Tanzania, Togo, Uganda and Zimbabwe. In addition, the data analysis revealed that three lower-middle-income countries, namely Cameroon, Nigeria and Zambia, exhibit many of the agrarian characteristics – although mineral exports (oil and copper, respectively), raise their per capita GNI substantially. Many of the lessons drawn from the Malawi case study are therefore applicable to these other countries.

However, certain other countries in the low-income category are different in many respects from their peers; for many of the energy-food-water nexus indicators reported in Part 2, they exhibit outlying values. One consistent outlier is Tajikistan, which derives its energy exclusively from hydropower and fossil fuels, has achieved universal electrification and a low poverty rate, and has much larger water withdrawals and dam capacity than the norm (making use of its mountainous terrain). Apart from its low average income level and food supply, therefore, Tajikistan appears more like a LMIC or even a UMIC in terms of its nexus characteristics. The other major outlier among the LICs is Bangladesh, which relies mainly on natural gas and oil, has achieved relatively high energy productivity, and has recorded a comparatively high cereal yield with heavy reliance on fertilisers. Manufacturing is more established in Bangladesh than most other LICs. Mozambique and Chad are the only notable fossil fuel exporters within the LIC group, and as such share certain nexus vulnerabilities (such as pollution risks) with other energy exporters, such as South Africa. However, in most respects they are closer to Malawi.

South Africa

South Africa is broadly representative of industrial regime countries, in that it has a heavy reliance on fossil fuels, an industrialised agriculture sector, and extensive infrastructure for delivery of electricity and water to the population (although not universal coverage). Many of South Africa's key nexus indicators are similar to the averages for the upper-middle-income group, such as relatively high rates of access to electricity, food and water (Table 3-5). However, energy use is higher (per capita and per unit of GDP) and as an arid country, water resources are smaller than average. South Africa has an above-average cereal yield and is nearly self-sufficient in cereals, in contrast to many of its UMIC peers, which are net cereal importers. Although South Africa is a net energy exporter, this status derives from coal exports and the country is a net importer of oil, as are many other UMICs – which renders them vulnerable to oil price and supply shocks.

In general, however, there is a larger degree of variability in the indicators of UMICs, partly because this income band (US$4 126 – $12 736) is considerably wider than that of the LMICs (US$1 046 – $4 125) and LICs (less than US$1 045), which indicates greater variation in levels of economic development. Hence, not all of the lessons from the South African case study are applicable to all members of the UMIC group. In particular, there are several outliers among the UMICs along different indicator vectors. Kazakhstan and Turkmenistan are both very energy intensive with very high levels of energy consumption per capita (even higher than in South Africa), but these countries differ from South Africa in having high water withdrawals per capita. Albania has a large agriculture sector (22% of GDP), which employs 42% of the workforce – even higher than the LMIC average; but per capita energy consumption is relatively low. Angola, Botswana and Namibia share some important characteristics with their regional neighbour, South Africa, such as relatively high rates of poverty and inequality; but these three countries perform considerably worse than all other UMICs in terms of access to electricity and undernourishment (and in the case of Angola, access to safe drinking-water as well). Gabon's profile is similar to that of other African oil exporters like Nigeria: the benefits of oil revenues have not transformed the broader economy nor the lives of most citizens.

Broadly speaking, the data in Part 2 showed that for many of the nexus indicators the LMICs lie in between the LICs (represented by Malawi) and the UMICs (represented by South Africa). Thus the lessons of these two case studies are to an extent less directly applicable to LMICs. However, certain individual LMICs do share commonalities with either Malawi or South Africa. For example, as already mentioned, large sections of Cameroon, Nigeria and Zambia's economies and populations fit within the agrarian regime. In addition, some LMICs – notably countries of the Former Soviet Union such as Ukraine and Uzbekistan – resemble South Africa's high energy intensity and electricity consumption. Egypt's fertiliser-intensive agriculture sector is not unlike South Africa's.

Cuba

The applicability of the Cuba case study to other countries lies not so much in its current profile, but in how it has transformed its energy and (especially) agriculture systems. Up till 1990, Cuba's agricultural system was highly industrialised and dependent on intensive use of fossil fuel-based inputs (diesel, fertilisers and pesticides) purchased at subsidised prices from the Soviet Union. In many respects, the country was similar to today's industrial regime countries and therefore Cuba's experience of energy shortages and its responses to these are relevant to energy-intensive countries.

Cuba's current nexus indicator profile displays some of the important changes that have taken place since 1990. In particular, while the country is still largely dependent on (imported) fossil fuels, it has achieved the highest level of energy productivity of all the 96 countries examined in Part 2, as well as 100% electrification. Energy and electricity use per capita have been reduced through energy efficiency programmes. In the food security arena, Cuba has attained a per capita food supply above the UMIC average, while using only a quarter of the average level of fertilisers. This is partly because the country imports a lot of its grains (which is a key vulnerability), but also because of the development of organic food production. Water withdrawal per capita and access to safe drinking-water (94%) are very similar to the UMIC averages.

While there are important lessons to be learned from the Cuban case, as discussed in section 3.4 the particular political dispensation in Cuba may limit the extent to which its experience in implementing wide-ranging energy and food sector reforms can be replicated in other (more market-oriented) countries.

Table 3-5: Comparison of average indicator values

Indicator	Units	LICs	LMICs	UMICs	Malawi	S. Africa	Cuba
SOCIO-ECONOMIC							
Poverty headcount ratio at $1.25 a day (PPP)	% of population	50	17	4	72	9	
Agriculture value added	% of GDP	32	16	8	27	2	5
Employment in agriculture	% of total employment	65	36	19		5	20
ENERGY SECURITY							
Energy use per capita	kg oil equivalent	364	738	1 753		2 742	992
GDP per unit of energy use	PPP $/kg oil	5	8	10		4	19
Biomass energy	% of energy	68	31	11	84	10	13
Fossil fuels	% of energy	25	61	82	12	87	87
Nuclear & alternative energy	% of energy	6	9	7	4	3	0
Access to electricity	% of population	25	78	93	9	83	100
Electric power consumption	kWh/capita	314	925	2 611		4 606	1 327
Net energy imports	% of energy use	3	-42	-55		-15	49
Pump price for diesel fuel	US$/litre	1	1	1	1.90	1.42	1.30
FOOD SECURITY							
Food supply	kcal/capita/year	2 352	2 633	2 951	2 334	3 007	3 277
Prevalence of adequate nourishment	% of population	77	85	91	78	95	95
Agricultural irrigated land	% of agric. land	12	12	7	1	2	
Agricultural machinery	tractors/sq km	1	112	199		48	203
Fertilizer consumption	kg/ha arable land	26	92	214	40	62	50
Cereal yield	kg/ha	1 664	2 497	2 801	2 087	3 689	2 812
Average value of food production	I$/capita	155	255	352	181	239	245
Cereal import dependency ratio	%	21	23	26	2	3	76
Value of food imports/merchandise exports	%	66	18	14	17	4	35
Droughts, floods, extreme temperatures	% of population	3	1	1	8.8	1.8	0.7
WATER SECURITY							
Total water withdrawal per capita	m^3/inhab/year	219	514	689	99	271	618
Access to safe drinking-water	% of population	68	85	93	85	95	94
Renewable internal freshwater resources	m3/capita	7 090	7 362	12 087	986	843	3 384
Dam capacity per capita	m3/capita	951	1 265	1 215	3	583	833
Annual freshwater withdrawals	% internal resources	9	192	86	8	28	12
Water productivity	2005 US$ GDP per m^3	11	12	20	3	26	
Annual freshwater withdrawals, agriculture	% of total withdrawal	67	70	54	86	63	56
Annual freshwater withdrawals, domestic	% of total withdrawal	25	16	24	11	31	27
Annual freshwater withdrawals, industry	% of total withdrawal	8	13	23	4	6	17

Further research

The energy-food-water nexus is a nascent area of interest, and there is considerable scope for broadening and deepening research into many of the issues that have been raised in this report. At a **global scale**, one of the critical issues is to map out the ways that increasingly scarce resources can be harnessed to meet the new Sustainable Development Goals (SDGs), and how the individual SDGs dealing with food security, water availability and energy access can be addressed within a holistic framework that takes account of nexus trade-offs and maximises synergies. Processes need to be developed for dealing with nexus issues within multilateral forums, to handle issues such as land and virtual water grabs, agricultural trade policies that exacerbate food price crises, and other societal teleconnections. Cross-country comparative studies require more and better data on nexus indicators to fill the many gaps, especially for low-income countries.

There is also a need for **regional studies** that explore possibilities for inter-country cooperation in responding to nexus challenges that are especially acute in some parts of the world (such as water scarcity/pressures in the Middle East, Southern Africa and South Asia). Africa, as the continent with the lowest attainment levels in energy, water and food security, and which is expected to suffer some of the most severe impacts of climate change, needs a large amount of attention. One of the important questions is what impact rapid African urbanisation will have on the nexus.

Perhaps the greatest scope for further nexus research lies at the **country level**, because the nexus can play out very differently in different contexts, depending on factors such as resource endowments, climate and topography, and level of development. Some key questions are as follows:

- What are the main determinants of food, energy and water security, in terms of availability, affordability, access and reliability?
- What are the major nexus risks and vulnerabilities, in terms of probability of occurrence and magnitude of potential impact?
- What is the nature of the trade-offs and synergies in the nexus, and how can these be quantified and assessed comparatively?
- What are the costs and benefits of different technology options for improving resilience and sustainability? For example, are 'green' technologies affordable in low-income countries?
- How well integrated and aligned are energy, water and agriculture/food policies?
- How can the nexus be better integrated into government policies and planning?
- How can the generic recommendations be tailored to fit specific country circumstances?
- What financing mechanisms are available to enable countries to build resilient infrastructure systems?

There are a number of technical aspects of the nexus that also require further attention. One example is the need to calculate the water intensity of different energy technologies in a developing country context (e.g. data on water use for various electricity generation options). Another is life cycle analyses of food systems to quantify the energy use and dependence along the value chain. Of particular importance are more detailed studies to quantify the energy inputs versus yields of organic/agroecological farming systems compared to conventional farming systems, especially in a developing country context. The levels of food waste at different stages of the food system also need to be better quantified in developing countries. More research is needed to enable assessments of the best use of biomass among competing uses (e.g. for soil fertility versus for energy production). More generally, a vital question concerns the technical potential for developing countries to leapfrog to more sustainable energy, food and water systems (such as sustainable agriculture, urban agriculture, renewable energy, and so on)?

Governance issues surrounding the nexus is another area that needs more in-depth research. For instance, how can the nexus be better integrated with national development plans, green economy strategies and implementation plans for the SDGs? How can transitions that enhance EFW nexus security be managed in a context of limited institutional capacity? What kind of obstacles or inhibiting factors are likely to be encountered to such transitions, such as financing constraints, or perhaps cultural attitudes about new technologies and practices such solar cookers, recycling and grey water use? Will rural and newly urbanising communities willingly adopt decentralised energy and water solutions rather than conventional grid-based systems?

Management of the energy-food-water nexus is emerging is one of the largest and most pressing challenges facing humanity this century. It is hoped that the overview of key nexus issues, drivers, risks and mitigation options provided in this report can lay the foundation for more specific and detailed research and policy formulation in the developing world, especially at a national level.

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APPENDICES

Appendix 1.1: Scarce water, whose rights? Electricity generation, agriculture and food security at a crossroads in Vidarbha, India

By Luke Metelerkamp & Dr Tarak Kate

Introduction

About 25 years ago, during the regime of privatisation, liberalisation and globalisation, India opened its doors to international markets in an effort to attract capital to boost its economy. This has resulted in unprecedented growth of the urban middle class and a rise in consumerist behaviour; it has encouraged urbanisation and driven industrialisation in the country. All of these changes have contributed to the tremendous increase in demand for electricity – not only for industrial use and to support the more energy-intensive nature of urban life, but also to provide energy for irrigation pumps in the rural areas and to electrify the 56.5% of rural households still without electricity – comprising about 300 million people (Central Electricity Authority 2012).

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A dry land farmer in central India ploughs his field below recently erected power lines.

Access to electricity is recognised as a key driver of rapid economic growth and poverty alleviation (National Electricity Policy 2005). In 1950, electricity generation capacity stood at 1 735MW with per capita consumption rates of 15kWh; this had risen to 186 655MW and 814kWh by December 2011 (Central Electricity Authority 2012). Despite this massive increase in supply, growth in demand has outstripped the ability of the generation sector to provide reliable energy and there have been substantial power shortages in the country, reaching a high of 10.3% between 2010 and 2012 (Govind 2012).

According to the Economic Intelligence Unit, India's appetite for energy will increase by 54% between 2011 and 2020 (Adams 2012). Boyle, Krishna, Myllyvirta and Pascoe (2012) estimate that demand for irrigation water will increase by 50% by 2050. The resultant increase in demand for pumps along with increasing mechanisation of farming will drive up agricultural energy demand (Ghosh 2012). India has the world's 5th largest coal reserves and in 2012 close to 60% of its electricity was generated by burning coal (Adams 2012). Although the National Electricity Policy advocates a shift from coal to other non-fossil fuels to enter into a low carbon-emission regime (Central Electricity Authority 2012), it is likely that coal will continue to dominate the scene as a major fuel for thermal power stations in the years to come. This proliferation of water-intensive coal-fired power generation is set to take place in spite of the fact that India is already in a condition of water stress, and national demand for water is projected to outstrip supply in less than 30 years (Boyle et al. 2012). The residential, services, agriculture and industrial sectors will increasingly compete for access to a constrained electricity grid, which is reliant on increasingly scarce water resources. This short case study of the Vidarbha region is presented as an example of conflicting demands between electricity generation and food production in the context of increasing tension over regional water allocation.

Introducing Vidarbha

Vidarbha is a regional entity on the eastern flank of India's Maharashtra state. It encompasses an area of 97 321km^2 and, according to the 2011 census, is populated by 23 million people (Wikipedia nd). Historically, this region has not been a focus for industrialisation and its agricultural sector has remained relatively underdeveloped compared to other parts of India. Despite this, 65% of the population depends on agricultural activities for their livelihoods. The region is a net energy exporter (Boyle et al. 2012).

A conflict around water access and availability

Due to its abundant coal reserves and central location in the country, Virdarbha has emerged as a central node in India's expanding network of coal-based power generation. By 2010, 71 thermal power plants, with a total installed capacity of nearly 55 gigawatts (GW), were in various stages of approval in Vidarbha[1] (Boyle et al. 2012). The generation capacity of these proposed new power plants is roughly equal to the total installed capacity of coal-fired power plants in all of southern Africa.

The planned installation has raised many concerns about higher levels of pollution in the region, environmental damage and loss of arable farmland. However, the biggest concern raised by civil society organisations and local residents revolves around current water rights allocation in the region and the 2 billion m^3 of water the power plants will require each year for evaporative cooling and related processes. The proposed developments are so water thirsty due largely to low levels of water efficiency within Indian power plants (see Table A1-1). In the Vidarbha region this has already begun to pit state and private-sector energy companies against the region's small-scale farming system.

This present and potential future diversion of water from agricultural needs to industrial purposes has implications for crop yields and food production. Maharashtra state has set developmental targets to improve irrigation coverage in

Table A1-1: Comparative water consumption by typical sub-critical plants in India and Australia

	Comparative water consumption per megawatt (m^3/MWh)	By a 1000MW power plant (MCM/year)	Equivalent irrigation water (hectares of Indian farmland)
Most coal plants operating in India	6 – 7	44 – 60	8 760 – 12 264
Some more recently built coal plants in India	3.5 – 4	31 – 35	6 132 – 7 008
Typical Australian plant	1.9	17	N/A

SOURCE: Boyle et al. (2012)

Vidarbha and about 18 major and more than 300 medium and minor irrigation projects have been implemented so far (Krishna & Kesbhat 2012). By 2009, more than 44 major irrigation projects were under construction; however, many practical problems have prevented the increase of actual farmland under irrigation in the region and electricity supply to many existing farm pumps remains erratic. Irrigation is stagnated at 600 000 hectares while the water demands of the proposed power plants will be equivalent to over 400 000 hectares of irrigation capacity. The current poor supply of irrigation has increased the risk of crop failure by leaving farmers extremely dependent on increasingly erratic monsoon rains. This has contributed to the plight of farmers in the region while also compromising agricultural employment.

Water-grabbing or just good business?

In 2012, the Bombay High Court ruled in favour of the state's decision to divert 87.6 million cubic metres of water from the Upper Wardha Irrigation Project (situated in Vidarbha) to a thermal power plant set up by a private energy company. The opposing advocate K.H. Deshpanda said in response to the verdict that:

> *On the one hand, the government is developing the irrigation sector in the district because of specific directives from the governor. On the other hand, it is casually diverting water to thermal power projects, leaving the poor dry crop farmers again at the mercy of private money lenders and cooperative banks. (Bharucha 2012)*

As there was no excess capacity in the dam prior to approval of the power plant (Water Resources Department, Government of Maharashtra 2008), the reallocation directly deprived farmers of water on 23 219 hectares of potentially irrigable land. Reflecting on the Upper Wardha Irrigation Project case, Wagle, Warghade and Sathe (2012) argue that the state is able to legitimise this form of water-grabbing due the new political coalition that has emerged at the behest of the on-going economic liberalisation. The Vidarbha case is cited as a prime example of legitimising water-grabbing in the name of enhancing economic efficiency by reallocating water rights to activities with higher economic values (i.e. from agriculture to industry) with little regard for socio-ecological constraints (Wagle et al. 2012).

Failing agricultural modernisation and the implications for the energy-food-water nexus

Like the rest of India, Vidarbha embraced the package of 'Green Revolution' farming technologies in the mid-1960s. The use of improved seeds and synthetic fertilisers, combined with expanded irrigation, did result in substantial yield increases during the initial adoption phase and both farmers and the region's urban dwellers have benefitted from these increases. These systems were implemented on a credit-based system allowing resource-poor farmers to purchase the required inputs. However, ecological degradation, particularly of soils, as a result of poor management of these technologies began to erode the substantial gains made in early years. As the regularity of crop failure has increased, so too has farmer indebtedness. In recent years, the Vidarbha region of Maharashtra has been witnessing an unprecedented agrarian crisis as evidenced by the high number of farmers' suicides, which are largely as a result of farmer indebtedness as the economic underpinnings of the production systems are strained to breaking point (The Hindu 2007).

The allocation of water rights and access to irrigation water has significant implications for this crisis and the viability of Green Revolution technologies that were once hailed as the saviour of the Indian food system. The improved seeds promoted as part of the package are high-yielding varieties that rely on high levels of fertiliser and irrigation water to produce according to their stated potential (Pimentel 1996). This, added to the abandonment of traditional practices of soil management, has led to a loss of organic matter in the soil (Singh 2000), which reduces soils' natural water-retaining capacity – and hence water availability in dry periods. This reduced ability of soils to store water for dry periods is compounded by volatile rainfall patterns, making irrigation an increasing prerequisite for stable food production.

In short, the agrarian system which was once geared almost entirely towards using rainfall for its water requirements, has shifted from a number of angles (seed, fertiliser, soil and climate change) to become more reliant on irrigation water for its survival. The intensification of agriculture has helped ramp up production and assist India achieve food security at a national level in the context of rapid population growth. However, population growth continues while agricultural yields gains are stagnating, meaning that threats to irrigation resources in places like Vidarbah pose a direct threat to agrarian livelihoods and regional crop production.

Farmers now need irrigation and irrigation requires electricity, but little of the energy generated by the coal-fired plants in the region reaches its farmers – despite the threat that these plants pose to agriculture in the region through the diversion of water to run the plants. Through the massive roll-out of inefficient coal-fired power in Vidarbha, the interests of big industry and the urban population are being pitted directly against those of the poor rural majority in the fight to secure access to the region's surface and groundwater resources.

Conclusion

The Vidarbha case study illustrates not only the conflict between different 'needs' – electricity supply and food production – but also the dynamics of a much wider issue around the political economy of water scarcity in the context of urbanisation and industrialisation. Most Indians desire increased energy supply – whether rich or poor, rural or urban dwellers – but the current tensions evident in the case of Vidarbha testify to the difficult position the Indian state finds itself in when mediating between different visions for economic growth, job creation, poverty alleviation strategies and ensuring food security.

India's population is expected to increase to 1.5 billion by 2030, from the current figure of 1.3 billion, with an accompanying increase in an energy-hungry middle class (United Nations Population Division 2015). This will increase the type of tensions displayed in this case study as conflicts around water allocation for food and energy intensify. Finding ways to democratically navigate increasing water scarcity will become ever more important to ensure social well-being and sustained food security. This journey will need to include plans to increase the water efficiency of India's power plants and agricultural production, while developing technological innovations capable of creating symbiotic relationships between the energy and agricultural sectors' water needs.

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Appendix 1.2: The food-energy nexus in oil exporting countries: A comparison of key trends in Angola and Nigeria

By Florian Kroll

Introduction

Angola and Nigeria are sub-Saharan African countries that rely heavily on oil extraction to generate foreign exchange revenue and whose macro-economic position is dependent on changes in oil prices and the performance of the oil sector (Akpan 2009a; World Bank 2014a,b,c). Has the reliance on oil revenues in these countries facilitated inclusive economic growth, poverty reduction and improved food security? What are the vulnerabilities of the food and energy sectors in these countries, especially in the context of global environmental change? How are energy exploitation and consumption affecting food production? These are the questions explored in this brief case study.

Nigeria has been exploiting oil reserves since the 1950s through a series of political regimes including military juntas (Akpan 2009b). Angola recently emerged from a period of civil war spanning the period 1972–2002, which was funded by oil and diamonds (Otaha 2012). Its recent history has been described as a transition "from afro-Stalinism to petro-diamond capitalism" (De Carvalho, Chianeque, L. & Delgado, A. 2011).

Both countries are rapidly urbanising, a trend that is partly driven by rural poverty and food insecurity. Poverty is endemic, although urban levels are lower. Angola has one of the highest GINI coefficients in the world, reflecting deep inequalities (AEO 2014), while Nigeria has a moderate GINI rating (World Bank 2014b).

Economy

Angola's GDP reveals a heavy reliance on oil and gas compared to Nigeria, which reflects greater economic diversity. However, Angola's reliance on oil has reduced by approximately 20% since 2008. Agriculture makes a significant contribution to GDP in both countries.

Agriculture

Agriculture in both countries is primarily rain-fed, of subsistence nature and low in productivity. Most people in both countries rely on subsistence agriculture: 70% in Angola (World Bank 2013), and 60% in Nigeria (Legg et al. 2005). Landmines hamper agricultural production in Angola. Each country has 13 agroecological zones with inhabitants practising diverse livelihood strategies (Famine Early Warning Systems Network [FEWS] 2013; FEWS 2014). Angola's main crops include cassava, bananas, vegetables, maize and sweet potatoes. It exported 23 000 tonnes of crops in 2013,

Table A2-2: GDP contribution of select sectors, 2013

GDP CONTRIBUTION	Angola	Nigeria
Oil and gas	42%	15.8%
Agriculture	11%	22.1%
Food manufacturing	No data	4.4%

SOURCE: World Bank (2014a,b)

Table A2-1: Key socio-economic indices in Angola and Nigeria

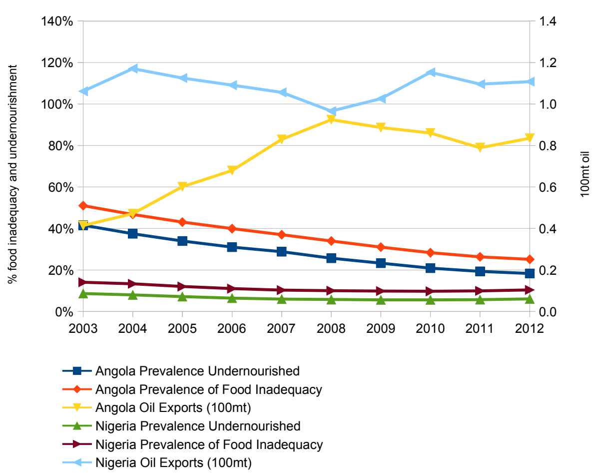
	Population 2003/2013	Urbanisation 2013 status (% of population)/ growth rate	GDP/capita 2013 (US$)	GINI	Poverty headcount ratio, 2012/2013 (% pop)
Angola	15.4 million/21.5 million	42% 5% growth	7 298.2	0.586	37% Urban 19% Rural 58%
Nigeria	132.6 million/ 173.7 million	46% 4.7% growth	5 676.3	0.34	33% Urban 13% Rural 45%

SOURCE: African Economic Outlook 2014; World Bank 2014a,b including palm oil and seafood. Nigeria's main crops are cassava, yams, vegetables, fruits and maize. Nigeria exported 751 000 tonnes of crops including cocoa beans, tree nuts and sesame seed in 2013. Both countries experience a high percentage of crop wastage due to post-harvest losses (FAOSTAT 2015a).

Food security status

Food insecurity in Angola declined considerably between 2003 and 2012, with food inadequacy decreasing from 51% to 25%. This trend started well before oil exports grew, so it cannot be attributed to oil exports directly. By comparison, Nigeria reports very low levels of food inadequacy, which remained fairly constant throughout the period (FAOSTAT 2015a). In Nigeria, oil revenue and food imports play a negligible role in alleviating food insecurity (Dada Eme 2011). Rapid urbanisation and urban poverty mean that both countries are facing rising urban food insecurity, which is set to become a key development challenge for the 21st century (Crush & Frayne 2010).

Figure A2-1: Selected food security indicators and oil exports in Angola and Nigeria



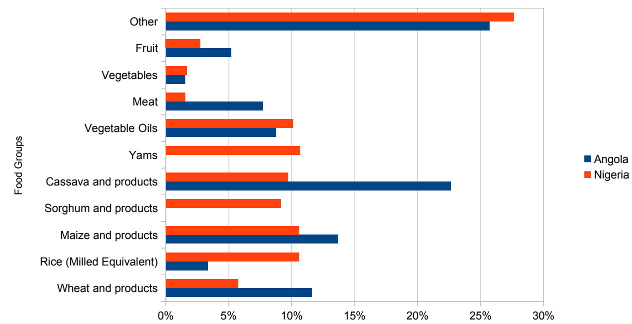
SOURCE: International Energy Agency (2015); FAOSTAT (2015a)

Food consumption patterns

Cassava is central to the diets of both countries, followed by maize. Angolans also consume significant quantities of wheat, whereas yams and rice are more important in Nigeria. Vegetable oils constitute a notable proportion of energy intake in both countries.

Meat is a small, but significant source of caloric intake in Angola – mainly pork and chicken.

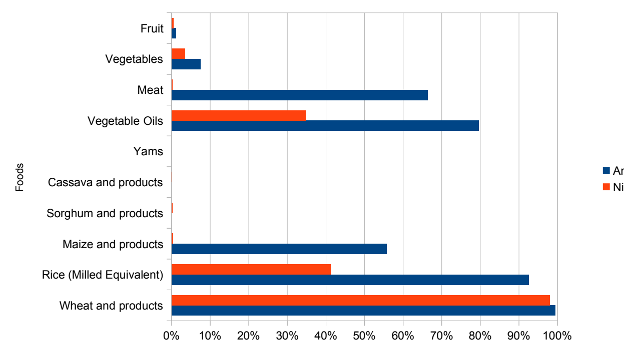
Figure A2-2: Dietary energy composition in Angola and Nigeria



SOURCE: FAOSTAT (2015a)

Angola depends far more on food imports than Nigeria (34.4% versus 13.6% of total caloric consumption, respectively), deriving almost all wheat, rice, vegetable oils and a majority of its maize from imports. Nigeria's primary food import dependency is for wheat and rice. Angola imports most of its meat. This trend has steadily increased from 2003 to 2012. The dependency on food imports is likely to affect urban populations in Nigeria and Angola as imported foods are prevalent in urban diets (Obaleyu, Okoruwa & Oni 2009) and urban dwellers source food mainly through purchase; but maize also is important for rural populations. Reliance on imports exposes poor urban consumers, in particular, to international commodity price and exchange rate fluctuations.

Figure A2-3: Import dependency for key foods in Angola and Nigeria, 2013

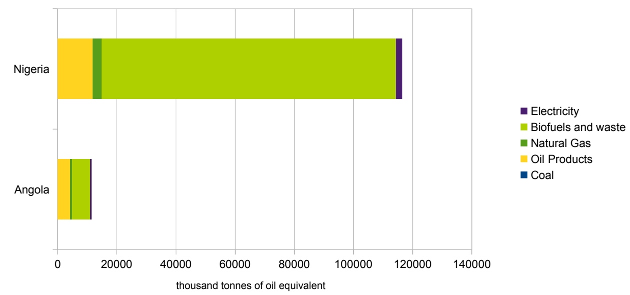


SOURCE: FAOSTAT (2015b)

Energy consumption

Both Angola and Nigeria rely heavily on biomass (wood), especially for household energy consumption; in 2012, biomass constituted 54% and 85% of total final energy consumption, respectively. Minimal refining capacity means that the bulk of refined petroleum fuels are imported, despite the countries' large crude oil exports. These statistics clearly show that the most of the two countries' populations do not directly benefit from domestic oil production in terms of access to modern energy.

Figure A2-4: Final energy consumption in Angola and Nigeria, 2012



SOURCE: International Energy Agency (2015)

Environmental challenges

Key environmental challenges in Angola include soil degradation, deforestation, air pollution and loss of biodiversity (African Economic Outlook 2014). The demand for wood fuel drives deforestation (FAO 2013). In Nigeria, environmental issues include deforestation, desertification and air and land pollution (Omofonmwan & Osa-Edoh 2008). Oil spills in Nigeria are causing extensive damage in the Niger delta, compromising agriculture and fisheries (UNEP 2011; Kadafa 2012). Both countries are vulnerable to flooding and droughts, exacerbated by rapid deforestation and soil loss. Flooding, droughts and insurgencies (Nigeria) compromise agricultural productivity and contribute to urbanisation.

The resource curse and governance challenges

The 'resource curse' expresses the negative effects of oil revenue dependence on economic growth and development, as it involves wasteful and imprudent expenditure, appreciating exchange rates, and disincentives for investment in non-oil sectors (Otaha 2012). In both countries, decades of alleged fiscal mismanagement, corruption and embezzlement have meant that the potential development benefits of oil extraction have not materialised for most people. Trends in the Human Development Index in Angola (0.51) and Nigeria (0.47) indicate gradual improvements, but apparent gains are spurious when adjusted for inequality (United Nations Development Programme [UNDP]. 2013a,b).

It appears that the exploitation of oil reserves has actually deepened the divide between wealthy urban government and corporate oil elites (who rely heavily on food imports) and the masses that remain underemployed, impoverished and food insecure.

Oil exports entrench the elites' dependency on transnational corporations and institutions that have the necessary capital to exploit oil reserves and influence government policy (Otaha 2012).

Conclusion

Despite both countries' exports of massive volumes of crude oil, development benefits have been very unevenly spread, with high levels of poverty and inequality remaining. The majority of both populations rely on biomass for their domestic energy needs, driving relentless deforestation, while the bulk of refined fuels used for transport are imported. Rural subsistence farmers reliant on rainfall are exposed to increasingly unstable weather conditions, while oil spills in Nigeria threaten to further undermine agricultural productivity and resilience. Investment in agriculture, food processing, energy and water management infrastructure has been very limited. While Nigeria's economy is diverse, Angola's GDP is dominated by oil revenues, with stunted manufacturing and trade sectors. Large percentages of staple foods are imported, exposing especially the urban poor to global commodity price hikes.

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Link to Contents

Appendix 2.1: List of countries included in the quantitative analysis

	LOW-INCOME	LOWER-MIDDLE-INCOME	UPPER-MIDDLE-INCOME
1	Afghanistan	Armenia	Albania
2	Bangladesh	Bolivia	Algeria
3	Benin	Cameroon	Angola
4	Burkina Faso	Congo, Rep.	Argentina
5	Burundi	Cote d'Ivoire	Azerbaijan
6	Cambodia	Egypt	Belarus
7	Central African Republic	El Salvador	Bosnia & Herzegovina
8	Chad	Georgia	Botswana
9	Congo, Dem. Rep.	Ghana	Brazil
10	Eritrea	Guatemala	Bulgaria
11	Ethiopia	Honduras	China
12	Gambia, The	India	Colombia
13	Guinea	Indonesia	Costa Rica
14	Kenya	Kyrgyz Republic	Cuba
15	Liberia	Moldova	Ecuador
16	Madagascar	Mongolia	Gabon
17	Malawi	Morocco	Hungary
18	Mali	Nicaragua	Iran
19	Mozambique	Nigeria	Iraq
20	Nepal	Pakistan	Jordan
21	Niger	Paraguay	Kazakhstan
22	Rwanda	Philippines	Lebanon
23	Sierra Leone	Senegal	Macedonia
24	Tajikistan	Sri Lanka	Malaysia
25	Tanzania	Sudan	Mexico
26	Togo	Syrian Arab Republic	Montenegro
27	Uganda	Ukraine	Namibia
28	Zimbabwe	Uzbekistan	Panama
29		Vietnam	Peru
30		Yemen	Romania
31		Zambia	Serbia
32			South Africa
33			Thailand
34			Tunisia
35			Turkey
36			Turkmenistan
37			Venezuela

Appendix 2.2: List of countries excluded from the quantitative analysis

Excluded countries: Small Island Developing States

LOW-INCOME	LOWER-MIDDLE-INCOME	UPPER-MIDDLE-INCOME
Comoros	Cabo Verde	American Samoa
Guinea-Bissau	Guyana	Belize
Haiti	Kiribati	Dominica
	Micronesia	Dominican Republic
	Papua New Guinea	Fiji
	Samoa	Grenada
	Sao Tome and Principe	Jamaica
	Solomon Islands	Maldives
	Timor-Leste	Marshall Islands
	Vanuatu	Mauritius
		Palau
		Seychelles
		St. Lucia
		St. Vincent & the Grenadines
		Suriname
		Tonga
		Tuvalu

Excluded countries: Insufficient data

LOW-INCOME	LOWER-MIDDLE-INCOME	UPPER-MIDDLE-INCOME
Korea, Dem. Rep.	Bhutan	Libya
Myanmar	Djibuti	
Somalia	Kosovo	
	Lao	
	Lesotho	
	Mauritania	
	South Sudan	
	Swaziland	
	West Bank & Gaza	

Appendix 2.3: List of indicators and data sources

CATEGORY	INDICATORS	DATA SOURCE
SOCIOECONOMIC	GNI per capita (current US$)	WDI
	Population (millions)	WDI
	Poverty headcount ratio at US$1.25 a day (PPP) (% of population)	WDI
	Agriculture, value added (% of GDP)	WDI
	Employment in agriculture (% of total employment)	WDI
ENERGY SECURITY	Energy use (kg of oil equivalent per capita)	WDI
	GDP per unit of energy use (constant 2011 PPP $ per kg of oil equivalent)	WDI
	Combustible renewables and waste (% of total energy)	WDI
	Fossil fuel energy consumption (% of total)	WDI
	Access to electricity (% of population)	WDI
	Electric power consumption (kWh per capita)	WDI
	Energy imports, net (% of energy use)	WDI
	Pump price for diesel fuel (US$ per litre)	WDI
FOOD SECURITY	Food supply per person (kcal/capita/day)	FAOSTAT
	Prevalence of undernourishment (% of population)	WDI
	Agricultural irrigated land (% of total agricultural land)	WDI
	Agricultural machinery, tractors per 100km^2 of arable land	WDI
	Fertiliser consumption (kgs per hectare of arable land)	WDI
	Cereal yield (kg per hectare)	WDI
	Average value of food production (International $/capita)	FAOSTAT
	Cereal import dependency ratio (%)	FAOSTAT
	Value of food imports over total merchandise exports (%)	FAOSTAT
	Droughts, floods, extreme temperatures (% of population, average 1990–2009)	WDI
WATER SECURITY	Total water withdrawal per capita (m^3/inhabitant/year)	AQUASTAT
	Total population with access to safe drinking-water (%)	AQUASTAT
	Renewable internal freshwater resources per capita (m^3)	WDI
	Dam capacity per capita (m^3/person)	AQUASTAT
	Annual freshwater withdrawals, total (% of internal resources)	WDI
	Water productivity, total (constant 2005 US$ GDP per cubic meter of total freshwater withdrawal)	WDI
	Annual freshwater withdrawals, agriculture (% of total)	WDI
	Annual freshwater withdrawals, domestic (% of total withdrawal)	WDI
	Annual freshwater withdrawals, industry (% of total withdrawal)	WDI

NOTE:
WDI: World Development Indicators (World Bank, 2015)
FAOSTAT: Food and Agriculture Organisation FAOSTAT database (FAO, 2015a)
AQUASTAT : FAO AQUASTAT database (FAO, 2015b)

Appendix 2.4: Data tables for energy-food-water security indicators

Socioeconomic indicators: Low-income countries

SOURCE	WDI	WDI	WDI	WDI	WDI
INDICATOR	Population	GNI per capita	Poverty headcount ratio at US$1.25 a day (PPP)	Agriculture value added	Employment in agriculture
UNITS	millions	current US$	% of population	% of GDP	% of total employment
YEAR	2013	GNI per capita	2012 or latest	2013 or latest	2012 or latest
Burundi	10.2	260	81	40	
Malawi	16.4	270	72	27	
Central Afr. Rep.	4.6	320	63	54	
Niger	17.8	400	41	37	57
Liberia	4.3	410	84	39	49
Congo, D.R.	67.5	430	88	21	
Madagascar	22.9	440	88	26	80
Guinea	11.7	460	41	20	
Ethiopia	94.1	470	37	45	79
Eritrea	6.3	490		15	
Gambia, The	1.8	500	34		
Togo	6.8	530	52	31	54
Uganda	37.6	600	38	25	66
Mozambique	25.8	610	61	29	81
Rwanda	11.8	630	63	33	79
Sierra Leone	6.1	660	57	59	69
Mali	15.3	670	51	42	66
Afghanistan	30.6	690		24	
Nepal	27.8	730	24	35	66
Burkina Faso	16.9	750	44	23	85
Benin	10.3	790	52	37	43
Tanzania	49.3	860	43	34	77
Zimbabwe	14.1	860		12	65
Cambodia	15.1	950	10	34	51
Tajikistan	8.2	990	6	27	56
Bangladesh	156.6	1,010	43	16	48
Chad	12.8	1,030	37	52	
Kenya	44.4	1,160	43	30	61
Average	27	642	50	32	65
Median	15.2	620	44	31	66
Standard deviation	33	245	22	12	13

Energy security indicators: Low-income countries

SOURCE	WDI	WDI	WDI	WDI	WDI	WDI	WDI	WDI	WDI
INDICATOR	Energy use per capita	GDP per unit of energy use	Biomass energy	Fossil fuels	Nuclear & altern. energy	Access to elec-tricity	Electric power con-sumption	Net energy imports	Pump price for diesel fuel
UNITS	kg of oil equiv.	constant 2011 PPP $ per kg of oil equiv.	% of total energy	% of total energy	% of total energy	% of popula-tion	kWh per capita	% of energy use	US$ per litre
YEAR	2011	2011	2011	2011	2011	2010	2011 or latest	2011	2012
Afghanistan						41		17	1.21
Bangladesh	205	12.6	28	72	0	55	259	44	0.76
Benin	385	4.3	56	42	0	28	84		1.26
Burkina Faso						13			1.28
Burundi						5		29	1.47
Cambodia	365	7.2	71	26	0	31	164		1.27
Central Afr. R.						9			1.69
Chad						4			1.16
Congo, D.R.	383	1.9	93	4	3	15	105	22	1.48
Eritrea	129	8.8	78	22	0	33	49	6	1.71
Ethiopia	381	3.1	93	6	1	23	52		0.94
Gambia, The	87					31			
Guinea						20			1.34
Kenya	480	5.4	72	20	8	23	155	-32	1.26
Liberia						4			1.22
Madagascar						14			1.22
Malawi						9			1.90
Mali						17		-25	1.25
Mozambique	415	2.4	79	10	14	15	447	-59	1.23
Nepal	383	5.3	84	13	3	76	106		1.09
Niger						9			1.12
Rwanda						11			1.73
Sierra Leone						12			1.05
Tajikistan	306	7.2	0	43	58	100	1714	7	
Tanzania	448	4.8	88	11	1	15	92	18	1.27
Togo	427	3.0	82	15	0	28	104		1.22
Uganda						15		8	1.35
Zimbabwe	697	2.3	64	28	6	37	757		1.40
Average	364	5	68	24	7	25	314	3	1.30
Median	383	4.8	78	20	1	16	106	8	1.26
Std Deviation	152	3	27	19	16	22	465	30	0.25

Food security indicators: Low-income countries

SOURCE	FAOSTAT	WDI	WDI	WDI	WDI	WDI
INDICATOR	Food supply	Prevalence of adequate nourishment	Agricultural irrigated land	Agricultural machinery	Fertiliser consumption	Cereal yield
UNITS	kcal/capita/day	% of population	% of total agricultural land	tractors per 100km² of arable land	kg/ha of arable land	kg per hectare
YEAR	2011	2013	2012 or latest	2005-2008	2012	2012
Afghanistan	2 107	75	5		5	2 030
Bangladesh	2 429	83	53		279	4 394
Benin	2 594	90			19	1 336
Burkina Faso	2 664	79			11	1 203
Burundi					6	1 102
Cambodia	2 411	84			17	3 178
Central Afr. R.	2 154	62				1 684
Chad	2 062	65				856
Congo, D.R.					1	770
Eritrea					1	608
Ethiopia	2 103	65	1		24	2 047
Gambia, The	2 849	94			6	910
Guinea	2 553	82			3	1 513
Kenya	2 170	76	0		44	1 657
Liberia	2 251	70				1 164
Madagascar	2 085	70	2		2	2 700
Malawi	2 334	78	1		40	2 087
Mali	2 833	95		2.2	26	1 527
Mozambique	2 259	72			6	608
Nepal	2 614	87	27		28	2 714
Niger	2 546	89	0		1	519
Rwanda	2 148	66			4	2 169
Sierra Leone	2 333	75				1 553
Tajikistan	2 101	68	15		59	2 891
Tanzania		65			4	1 315
Togo	2 366	85		0.6	5	1233
Uganda	2 279	74			2	2029
Zimbabwe	2 200	68			29	806
Average	2 352	77	12	1	26	1664
Median	2 306	75	2	1.4	6	1520
Std Deviation	237	10	18	1	56	899

Food security indicators: Low-income countries

SOURCE	FAOSTAT	FAOSTAT	FAOSTAT	WDI
INDICATOR	Average value of food production	Cereal import dependency ratio	Value of food imports over total merchandise exports	Droughts, floods, extreme temperatures
UNITS	constant I$ per person (3-year average)	% (3-year average)	% (3-year average)	% of population
YEAR	2011-2013	2009-2011	2009-2011	av. 1990-2009
Afghanistan	112	23.6	258	1.1
Bangladesh	138	10.8	24	4.6
Benin	201	22.2	42	0.9
Burkina Faso	134	9.8	17	1.3
Burundi		21.4	66	2.4
Cambodia	279	-1.4	6	6.6
Central Afr. R.	211	21.4	37	0.2
Chad	118	9.6	4	2.7
Congo, D.R.		33.7	18	0.0
Eritrea		50.7	572	7.3
Ethiopia	110	10.7	55	3.3
Gambia, The	65	43.6	181	0.2
Guinea	170	13.8	26	0.2
Kenya	156	36.4	29	6.5
Liberia	79	61.1	95	1.9
Madagascar	152	8.7	27	0.9
Malawi	181	1.6	17	8.8
Mali	220	4.7	17	0.7
Mozambique	111	27.3	24	3.7
Nepal	203	3.9	59	0.7
Niger	166	7.3	22	7.5
Rwanda	208	23.7	50	1.3
Sierra Leone	187	19.7	58	0.2
Tajikistan	149	43.7	40	5.4
Tanzania	173	13.2	20	1.5
Togo	124	14	18	0.5
Uganda	147	9.1	31	0.9
Zimbabwe	93	48.6	31	
Average	155	21	66	3
Median	152	16.9	30.0	1.3
Std Deviation	50	16	113	3

Water security indicators: Low-income countries

SOURCE	AQUASTAT	AQUASTAT	WDI	AQUASTAT	WDI
INDICATOR	Total water withdrawal per capita	Population with access to safe drinking-water	Renewable internal freshwater resources	Dam capacity per capita	Annual freshwater withdrawals
UNITS	m3/capita/year	%	cubic metres per capita	cubic metres per capita	% of internal resources
YEAR	latest	2012 or latest	2013	2010 or latest	2013
Afghanistan	913.4	64	1 543	67	43
Bangladesh	231.9	85	671	42	34
Benin	17.53	76	998	2	1
Burkina Faso	57.46	82	738	321	7
Burundi	40.92	75	990		3
Cambodia	158.9	71	7 968		2
Central Afr. R.	17.65	68	30 543		0
Chad	82.25	51	1 170		6
Congo, D.R.	11.95	46	13 331	1	0
Eritrea	111.7	60	442	7	21
Ethiopia	79.46	52	1 296	61	5
Gambia, The	69.24	90	1 622		3
Guinea	61.17	75	19 242	160	0
Kenya	72.45	62	467	574	13
Liberia	42.59	75	46 576	57	0
Madagascar	985.9	50	14 700	22	5
Malawi	98.95	85	986	3	8
Mali	407.5	67	3 921	916	9
Mozambique	45.77	49	3 883	3 074	1
Nepal	366	88	7 130	3	5
Niger	69.28	52	196	4	28
Rwanda	16.69	71	807		2
Sierra Leone	39.18	60	26 264	37	0
Tajikistan	1616	72	7 732	3 683	18
Tanzania	144.8	53	1 705	2 181	6
Togo	32.98	60	1 687	259	1
Uganda	17.53	75	1 038	2 201	1
Zimbabwe	332.6	80	866	7 246	34
Average	219	68	7 090	951	9
Median	70.9	69.5	1 582.8	64.0	4.7
Std Deviation	368	13	1 1178	1 781	12

Water security indicators: Low-income countries

SOURCE	WDI	WDI	WDI	WDI
INDICATOR	Water productivity	Annual freshwater withdrawals, agriculture	Annual freshwater withdrawals, domestic	Annual freshwater withdrawals, industry
UNITS	constant 2005 US$ GDP per m3 of total freshwater withdrawal	% of total freshwater withdrawal	% of total freshwater withdrawal	% of total freshwater withdrawal
YEAR	2013	2013	2013	2013
Afghanistan	1	99	1	1
Bangladesh	3	88	10	2
Benin	46	45	32	23
Burkina Faso	11	51	46	3
Burundi	5	77	17	6
Cambodia	5	94	4	2
Central Afr. R.	18	1	83	17
Chad	11	76	12	12
Congo, D.R.	28	11	68	21
Eritrea	2	95	5	0
Ethiopia	5	94	6	0
Gambia, The	9	43	37	19
Guinea	7	53	38	9
Kenya	10	79	17	4
Liberia	10	9	54	36
Madagascar	0	98	1	1
Malawi	3	86	11	4
Mali	1	98	2	0
Mozambique	13	78	19	3
Nepal	1	98	2	0
Niger	5	67	30	3
Rwanda	31	68	24	8
Sierra Leone	12	22	52	26
Tajikistan	0	91	6	4
Tanzania	4	89	10	0
Togo	17	45	53	2
Uganda	49	38	48	14
Zimbabwe	2	79	14	7
Average	11	67	25	8
Median	6.0	77.6	17.1	3.5
Std Deviation	13	30	23	10

Socioeconomic indicators: Lower-middle-income countries

INDICATOR	Population	GNI per capita	Poverty headcount ratio at $1.25 a day (PPP)	Agriculture value added	Employment in agriculture
UNITS	million	current US$	% of population	% of GDP	% of total employment
YEAR	2013	2013	2012 or latest	2013 or latest	2012 or latest
Armenia	3.0	3 800	2	22	39
Bolivia	10.7	2 550	8	13	32
Cameroon	22.3	1 290	28	23	53
Congo, Rep.	4.4	2 590	33	4	35
Cote d'Ivoire	20.3	1 450	35	22	
Egypt	82.1	3 140	2	15	29
El Salvador	6.3	3 720	3	11	21
Georgia	4.5	3 560	14	9	53
Ghana	25.9	1 770	29	22	42
Guatemala	15.5	3 340	14	11	32
Honduras	8.1	2 180	16	13	35
India	1252.1	1 570	24	18	47
Indonesia	249.9	3 580	16	14	35
Kyrgyz Rep.	5.7	1 210	5	18	34
Moldova	3.6	2 470	0	15	26
Mongolia	2.8	3 770		16	33
Morocco	33.0	3 020	3	17	39
Nicaragua	6.1	1 790	9	17	32
Nigeria	173.6	2 710	62	21	45
Pakistan	182.1	1 360	13	25	44
Paraguay	6.8	4 010	3	22	27
Philippines	98.4	3 270	19	11	32
Senegal	14.1	1 050	34	18	34
Sri Lanka	20.5	3 170	4	11	39
Sudan	38.0	1 550	20	28	
Syria	22.8	1 850	2	18	14
Ukraine	45.5	3 960	0	10	17
Uzbekistan	30.2	1 880		19	
Vietnam	89.7	1 740	2	18	47
Yemen	24.4	1 330	10	10	25
Zambia	14.5	1 810	74	10	72
Average	81	2 467	17	16	36
Median	20.5	2 470	13	17	35
Std Deviation	225	961	18	5	12

Energy security indicators: Lower-middle-income countries

INDICATOR	Energy use per capita	GDP per unit of energy use	Biomass energy	Fossil fuels	Nuclear & altern. energy	Access to electricity	Electric power consump-tion	Net energy imports	Pump price for diesel
UNITS	kg of oil equiv.	2011 PPP US$/kg oil equiv.	% of total energy	% of total energy	% of total energy	% of populn	kWh per capita	% of energy use	US$ per litre
YEAR	2011	2011	2011	2011	2011	2010	2011 or latest	2011	2012
Armenia	916	7.4	0	72	32	100	1 755	67	1.15
Bolivia	746	7.3	25	73	3	80	623	-134	0.54
Cameroon	318	8.2	68	27	6	49	256	-22	1.01
Congo, Rep.	393	14.2	47	49	4	37	172	-905	0.92
Cote d'Ivoire	579	4.7	78	22	1	59	212	-6	1.2
Egypt	978	10.9	2	96	2	100	1 743	-14	0.18
El Salvador	690	10.7	17	48	35	92	830	48	1.17
Georgia	790	8.0	9	73	19	100	1 918	68	1.37
Ghana	425	8.1	57	37	6	61	344	4	0.95
Guatemala	691	10.1	62	34	4	82	539	28	1.04
Honduras	609	7.1	44	52	5	81	708	51	1.15
India	614	7.8	25	72	3	75	684	28	0.86
Indonesia	857	9.8	25	66	8	94	680	-89	0.47
Kyrgyz Rep.	562	5.2	0	68	39	100	1 642	48	0.79
Moldova	936	4.5	2	95	1	99	1 470	96	1.4
Mongolia	1 310	5.7	4	95	0	86	1 577	-435	1.22
Morocco	539	12.6	3	94	1	99	826	96	0.96
Nicaragua	515	8.2	41	50	10	74	522	50	1.19
Nigeria	721	7.2	82	17	0	48	149	-117	1.09
Pakistan	482	8.8	35	61	5	91	449	23	1.2
Paraguay	739	9.7	46	34	20	97	1 228	-51	1.31
Philippines	426	13.4	17	60	23	83	647	41	1.01
Senegal	264	8.2	46	53	1	57	187	53	1.53
Sri Lanka	499	16.2	47	49	4	85	490	49	0.93
Sudan	355	8.8	67	30	3	29	143	-109	0.51
Syria	910		0	99	1	93	1 715	-18	0.36
Ukraine	2 766	3.0	1	80	19	100	3 662	32	1.25
Uzbekistan	1 628	2.7	0	98	2	100	1 626	-20	0.87
Vietnam	697	6.8	24	71	4	96	1 073	-9	1.06
Yemen	312	12.1	1	99	0	45	193	-161	0.47
Zambia	621	5.7	80	9	12	19	599	8	1.48
Average	738	8	31	61	9	78	925	-42	0.99
Median	621	8	25	61	4	85	680	8	1.04
Std Deviation	475	3	27	26	11	24	767	190	0.34

Food security indicators: Lower-middle-income countries

INDICATOR	Food supply	Prevalence of adequate nourishment	Agricultural irrigated land	Agricultural machinery	Fertiliser consumption	Cereal yield
UNITS	kcal/capita/day	% of population	% of total agricultural land	tractors per 100km² of arable land	kg/ha of arable land	kg per hectare
YEAR	2011	2013	2012 or latest	2005-2008	2012	2012
Armenia	2 809	94	9		34	2 649
Bolivia	2 254	81			10	2 015
Cameroon	2 586	90			10	1 597
Congo, Rep.	2 195	69			9	848
Cote d'Ivoire	2 784	85			25	2 766
Egypt	3 557	95		391	575	7 269
El Salvador	2 513	87	1		173	2 782
Georgia	2 731	90	4		45	2 180
Ghana	3 003	95	0	5	35	1 768
Guatemala	2 485	86			159	2 029
Honduras	2 651	88			83	1 644
India	2 455	85	35		164	3 020
Indonesia	2 712	91	16		195	5 082
Kyrgyz Rep.	2 828	94	9		22	2 367
Moldova	2 837		9	198	19	1 359
Mongolia	2 463	78			25	1 564
Morocco	3 334	95	5		28	1 017
Nicaragua	2 564	83			54	1 944
Nigeria	2 706	94		7	5	1 401
Pakistan	2 426	78	70		167	2 645
Paraguay	2 614	89		69	83	3 036
Philippines	2 572	89	9		114	3 493
Senegal	2 426	83	1		8	1 310
Sri Lanka	2 491	75			200	3 843
Sudan	2 346		1	13	11	472
Syria			10		30	1 643
Ukraine	3 142		5	103	41	3 185
Uzbekistan	2 675	94			204	4 645
Vietnam	2 716	87			297	5 462
Yemen	2 206	74	3		10	1 064
Zambia	1 907	52			18	2 689
Average	2 633	85	12	112	92	2542
Median	2 600	87	7	69	35	2180
Std Deviation	335	10	18	141	119	1488

Food security indicators: Lower-middle-income countries (*continued*)

INDICATOR	Average value of food production	Cereal import dependency ratio	Value of food imports over total merchandise exports	Droughts, floods, extreme temperatures
UNITS	Intl$ per person (3-year average)	% (3-year average)	% (3-year average)	% of population
YEAR	2011-2013	2009-2011	2009-2011	av. 1990-2009
Armenia	348	56	48	0.5
Bolivia	323	19	6	1.3
Cameroon	234	26	19	0.1
Congo, Rep.	98	93	4	0.3
Cote d'Ivoire	292	52	10	0.0
Egypt	264	44	37	0.0
El Salvador	145	42	26	0.4
Georgia	161	69	44	0.8
Ghana	287	26	14	1.0
Guatemala	269	43	17	1.3
Honduras	216	57	15	1.3
India	186	-3	5	4.4
Indonesia	237	13	6	0.2
Kyrgyz Rep.	291	23	27	2.1
Moldova	362	-13	21	0.3
Mongolia	294	35	9	2.6
Morocco	272	36	19	0.1
Nicaragua	249	32	31	0.8
Nigeria	200	22	6	0.1
Pakistan	178	-12	17	1.1
Paraguay	732	-144	8	0.7
Philippines	208	22	10	0.8
Senegal	96	47	55	0.6
Sri Lanka	118	25	18	2.2
Sudan		26	20	2.8
Syria		43	26	0.5
Ukraine	487	-60	6	0.3
Uzbekistan	358	18	7	0.1
Vietnam	294	-11	7	1.6
Yemen	74	81	30	0.1
Zambia	124	-8	3	4.2
Average	255	23	18	1.0
Median	249	26	17	0.7
Std Deviation	131	43	14	1.2

Water security indicators: Lower-middle-income countries

INDICATOR	Total water withdrawal per capita	Population with access to safe drinking-water	Renewable internal freshwater resources	Dam capacity per capita	Annual freshwater withdrawals, total
UNITS	m^3/capita/year	%	m^3 per capita	m^3/ inhabitant	% of internal resources
YEAR	latest	2012	2013	2010 or latest	2013
Armenia	991	100	2 304	468	43
Bolivia	199	88	28 441	56	1
Cameroon	58	74	12 267	719	0
Congo, Rep.	14	75	49 914	2	0
Cote d'Ivoire	86	80	3 782	1 877	2
Egypt	1 000	99	22	2 084	3 794
El Salvador	346	90	2 465	616	14
Georgia	418	99	12 955	783	3
Ghana	50	87	1 170	5 854	3
Guatemala	250	94	7 060	31	3
Honduras	224	90	11 196	732	2
India	615	93	1 155	193	53
Indonesia	527	85	8 080	93	6
Kyrgyz Rep.	1 560	88	8 555		16
Moldova	290	97	281	854	107
Mongolia	197	85	12 258	89	2
Morocco	321	84	879	538	43
Nicaragua	258	85	25 689	5 342	1
Nigeria	89	64	1 273	270	6
Pakistan	1 024	91	302	155	334
Paraguay	361	94	17 200	5 014	2
Philippines	843	92	4 868	71	17
Senegal	214	74	1 825	18	9
Sri Lanka	638	94	2 578		25
Sudan	724	55	81	571	673
Syria	857	90	312	1 005	235
Ukraine	412	98	1 167	971	36
Uzbekistan	2 100	87	540	776	343
Vietnam	948	95	4 006	309	23
Yemen	168	55	86	22	170
Zambia	148	63	5 516	7 183	2
Average	514	85	7 362	1 265	192
Median	346	88	2 578	571	14
Std Deviation	475	12	10 756	1 958	684

Water security indicators: Lower-middle-income countries (*continued*)

INDICATOR	Water productivity, total	Annual freshwater withdrawals, agriculture	Annual freshwater withdrawals, domestic	Annual freshwater withdrawals, industry
UNITS	2005 US$ GDP per m3 of total freshwater withdrawal	% of total freshwater withdrawal	% of total freshwater withdrawal	% of total freshwater withdrawal
YEAR	2013	2013	2013	2013
Armenia	2	39	30	4
Bolivia	7	92	7	2
Cameroon	23	76	17	7
Congo, Rep.	190	9	70	22
Cote d'Ivoire	14	38	41	21
Egypt	2	86	8	6
El Salvador	9	68	22	10
Georgia	5	58	20	22
Ghana	20	66	24	10
Guatemala	11	57	25	18
Honduras	8	73	20	7
India	2	90	7	2
Indonesia	4	82	12	7
Kyrgyz Rep.	0	93	3	4
Moldova	4	3	14	83
Mongolia	9	44	13	43
Morocco	7	87	10	3
Nicaragua	5	77	19	5
Nigeria	14	54	31	15
Pakistan	1	94	5	1
Paraguay	5	79	15	6
Philippines	2	82	8	10
Senegal	5	93	4	3
Sri Lanka	3	87	6	6
Sudan	1	96	4	0
Syria	2	88	9	4
Ukraine	5	6	24	70
Uzbekistan	0	90	7	3
Vietnam	1	95	1	4
Yemen	5	91	7	2
Zambia	10	73	18	8
Average	12	70	16	13
Median	5	79	13	6
Std Deviation	33	27	14	19

Socioeconomic indicators: Upper-middle-income countries

INDICATOR	Population	GNI per capita	Poverty headcount ratio at $1.25 a day (PPP)	Agriculture value added	Employment in agriculture
UNITS	millions	current US$	% of population	% of GDP	% of total employment
YEAR	2013	2013	2012 or latest	2013 or latest	2012 or latest
Albania	2.9	4 510	0.5	22	42
Algeria	39.2	5 330		11	11
Angola	21.5	5 170	43.4	10	
Argentina	41.4	6 290	1.4	7	1
Azerbaijan	9.4	7 350	0.3	6	38
Belarus	9.5	6 730	0.0	9	11
Bosnia & Herz.	3.8	4 780	0.0	8	21
Botswana	2.0	7 770	13.4	3	30
Brazil	200.4	11 690	3.8	6	15
Bulgaria	7.3	7 360	1.9	5	6
China	1357.4	6 560	6.3	10	35
Colombia	48.3	7 590	5.6	6	17
Costa Rica	4.9	9 550	1.4	6	13
Cuba	11.3	5 890		5	20
Ecuador	15.7	5 760	4.0	9	28
Gabon	1.7	10 650	6.1	4	24
Hungary	9.9	13 260	0.1	4	5
Iran	77.4	5 780	1.5	10	21
Iraq	33.4	6 720	3.9		23
Jordan	6.5	4 950	0.1	3	2
Kazakhstan	17.0	11 550	0.1	5	26
Lebanon	4.5	9 870		7	6
Macedonia	2.1	4 870	0.3	10	17
Malaysia	29.7	10 430	0.0	9	13
Mexico	122.3	9 940	1.0	3	13
Montenegro	0.6	7 250	0.2	10	6
Namibia	2.3	5 870	23.5	6	27
Panama	3.9	10 700	4.0	3	17
Peru	30.4	6 270	2.9	7	26
Romania	20.0	9 050	0.0	6	29
Serbia	7.2	6 050	0.1	9	21
South Africa	53.2	7 410	9.4	2	5
Thailand	67.0	5 340	0.3	12	40
Tunisia	10.9	4 200	0.7	9	16
Turkey	74.9	10 970	0.1	8	24
Turkmenistan	5.2	6 880		15	
Venezuela	30.4	12 550	6.6	6	8

Energy security indicators: Upper-middle-income countries

INDICATOR	Energy use per capita	GDP per unit of energy use	Biomass energy	Fossil fuels	Nuclear & alternative energy
UNITS	kg of oil equivalent	2011 PPP US$/kg oil equivalent	% of total energy	% of total energy	% of total energy
YEAR	2011	2011	2011	2011	2011
Albania	748	13	10	61	17
Algeria	1 108	11	0	100	0
Angola	673	11	58	39	3
Argentina	1 967		4	90	5
Azerbaijan	1 369	12	1	98	2
Belarus	3 114	5	6	90	0
Bosnia & Herz.	1 848	5	3	94	5
Botswana	1 115	13	22	65	0
Brazil	1 371	10	29	55	15
Bulgaria	2 615	6	5	75	24
China	2 029	5	8	88	4
Colombia	671	17	12	76	13
Costa Rica	983	13	16	48	36
Cuba	992	19	13	87	0
Ecuador	849	12	5	86	7
Gabon	1 253	14	58	39	3
Hungary	2 503	9	7	73	17
Iran	2 813	6	0	100	1
Iraq	1 266	10	0	97	1
Jordan	1 143	10	0	96	2
Kazakhstan	4 717	4	0	99	1
Lebanon	1 449	11	2	96	1
Macedonia	1 484	8	6	82	4
Malaysia	2 639	8	5	94	1
Mexico	1 560	10	4	89	6
Montenegro	1 900	7	20	60	9
Namibia	717	12	13	66	8
Panama	1 085	15	11	80	9
Peru	695	15	15	76	9
Romania	1 778	10	10	78	12
Serbia	2 237	6	6	89	5
South Africa	2 742	4	10	87	3
Thailand	1 790	7	18	80	1
Tunisia	890	11	15	85	0
Turkey	1 539	12	3	90	7
Turkmenistan	4 839	2	0	100	0
Venezuela	2 380	7	1	89	10

Energy security indicators: Upper-middle-income countries (*continued*)

INDICATOR	Access to electricity	Electric power consump-tion	Net energy imports	Pump price for diesel fuel
UNITS	% of population	kWh per capita	% of energy use	US$ per litre
YEAR	2010	2011 or latest	2011	2012
Albania	100	2 195	32	1.79
Algeria	99	1 091	-248	0.17
Angola	35	248	-579	0.42
Argentina	88	2 967	4	1.33
Azerbaijan	100	1 705	-377	0.57
Belarus	100	3 628	85	0.90
Bosnia & Herz.	100	3 189	35	1.62
Botswana	43	1 603	56	1.25
Brazil	99	2 438	8	1.02
Bulgaria	100	4 864	36	1.68
China	100	3 298	11	1.28
Colombia	97	1 123	-281	1.18
Costa Rica	99	1 844	48	1.36
Cuba	100	1 327	49	1.30
Ecuador	97	1 192	-119	0.29
Gabon	82	907	-615	0.91
Hungary	100	3 895	57	1.91
Iran	98	2 649	-67	0.12
Iraq	98	1 343	-253	
Jordan	99	2 289	96	0.97
Kazakhstan	100	4 893	-105	0.67
Lebanon	100	3 499	97	0.94
Macedonia	99	3 881	43	1.55
Malaysia	99	4 246	-11	0.59
Mexico	99	2 092	-23	0.85
Montenegro	100	5 747	33	1.75
Namibia	44	1 549	79	1.31
Panama	88	1 829	80	1.02
Peru	85	1 248	-14	1.41
Romania	100	2 639	23	1.73
Serbia	100	4 490	31	1.80
South Africa	83	4 606	-15	1.42
Thailand	100	2 316	42	0.97
Tunisia	100	1 297	21	0.69
Turkey	100	2 709	71	2.33
Turkmenistan	100	2 444	-164	0.20
Venezuela	100	3 313	-186	0.01

Food security indicators: Upper-middle-income countries

INDICATOR	Food supply	Prevalence of adequate nourishment	Agricultural irrigated land	Agricultural machinery	Fertiliser consumption	Cereal yield
UNITS	kcal/capita/day	% of population	% of total agricultural land	tractors per 100km² of arable land	kg/ha of arable land	Kg/ha
YEAR	2011	2013	2012 or latest	2005-2008	2012	2012
Albania	3 023		17	122	91	4 884
Algeria	3 217	95	2	140	22	1 678
Angola	2 407	82			10	552
Argentina	3 155	95	1	88	39	4 359
Azerbaijan	2 952	95	30	148	18	2 660
Belarus	3 253		0	87	271	3 486
Bosnia & Herz.	3 130				99	3 001
Botswana	2 285	73	0	121	54	325
Brazil	3 286	95	2	117	182	4 585
Bulgaria	2 877		2	172	122	3 678
China	3 080	89	10	82	648	5 851
Colombia	2 696	89			744	3 338
Costa Rica	2 898	94	1		705	2 735
Cuba	3 277	95		203	50	2 812
Ecuador	2 477	89	13	91	247	3 258
Gabon	2 781	95			17	1 685
Hungary	2 968		2	262	97	3 665
Iran	3 058	95	19	153	26	2 296
Iraq	2 489	77		112	57	2 319
Jordan	3 149	95	9	302	1260	1 556
Kazakhstan	3 107	95			2	762
Lebanon	3 181	95	20		283	3 476
Macedonia			7	1244	57	2 839
Malaysia	2 855	95			1571	3 867
Mexico	3 028	95	5	98	72	3 453
Montenegro	3 568				12	2 864
Namibia	2 086	63			6	551
Panama	2 646	89		147	64	2 538
Peru	2 632	91			104	4 147
Romania	3 363		1	201	50	2 363
Serbia	2 724		1	18	175	3 116
South Africa	3 007	95	2	48	62	3 689
Thailand	2 760	93		281	153	3 138
Tunisia	3 362	95	4	143	56	1 674
Turkey	3 680	95	14	395	106	2 956
Turkmenistan	2 883	95				1 778
Venezuela	2 880	95			168	3 054

Food security indicators: Upper-middle-income countries (*continued*)

INDICATOR	Average value of food production	Cereal import dependency ratio	Value of food imports over total merchandise exports	Droughts, floods, extreme temperatures
UNITS	Constant intl $ per person (3-year average)	% (3-year average)	% (3-year average)	% of population
YEAR	2011 – 2013	2009 – 2011	2009 – 2011	average 1990 – 2009
Albania	386	41	38	5.3
Algeria	196	68	11	0.0
Angola	187	51	4	1.0
Argentina	983	-169	2	0.2
Azerbaijan	266	38	3	1.1
Belarus	598	1	5	0.0
Bosnia & Herz.	235	35	25	0.5
Botswana	151	81	11	0.7
Brazil	675	-3	3	0.5
Bulgaria	409	-92	9	0.0
China	361	2	3	8.0
Colombia	272	63	7	0.7
Costa Rica	595	82	11	0.7
Cuba	245	76	35	0.7
Ecuador	465	36	6	0.3
Gabon	157	82	5	
Hungary	499	-81	3	0.1
Iran	329	29	7	3.1
Iraq	83	57	9	0.0
Jordan	185	96	29	0.4
Kazakhstan	460	-51	4	0.2
Lebanon	244	88	42	0.0
Macedonia				0.3
Malaysia	481	76	5	0.1
Mexico	283	31	6	0.1
Montenegro	272	89	83	0.0
Namibia	180	56	5	3.4
Panama	247	71	93	0.2
Peru	291	48	7	2.0
Romania	383	-23	8	0.1
Serbia	398	-32	7	0.0
South Africa	239	3	4	1.8
Thailand	422	-42	2	3.8
Tunisia	346	55	11	0.1
Turkey	488	1	5	0.1
Turkmenistan	444		3	0.0
Venezuela	231	57	7	0.2

Water security indicators: Upper-middle-income countries

INDICATOR	Total water withdrawal per capita	Population with access to safe drinking-water	Renewable internal freshwater	Dam capacity per capita	Annual freshwater withdrawals
UNITS	m^3/capita/year	%	m^3/capita	m^3/capita	% of internal resources
YEAR	latest	2012 or latest	2013	2010 or latest	2013
Albania	414	96	9 284	1 275	5
Algeria	176	84	287	148	51
Angola	40	54	6 893	454	0
Argentina	920	99	7 045	3 175	13
Azerbaijan	1 286	80	862	2 310	148
Belarus	440	100	3 930	130	12
Bosnia & Herz.	86	100	9 271	760	1
Botswana	107	97	1 187	226	8
Brazil	377	98	28 254	3 496	1
Bulgaria	841	99	2 891	896	29
China	406	92	2 072		20
Colombia	247	91	46 977	233	1
Costa Rica	482	97	23 193	410	2
Cuba	618	94	3 384	833	12
Ecuador	695	86	28 111	489	2
Gabon	96	92	98 103	135	0
Hungary	506	100	606	26	93
Iran	1 299	96	1 659	422	73
Iraq	2 615	85	1 053	4 631	188
Jordan	166	96	106	39	138
Kazakhstan	1 299	93	3 777	4 914	33
Lebanon	316	100	1 074	49	27
Macedonia	490	99	2 563	1 087	19
Malaysia	418	100	19 517	768	2
Mexico	665	95	3 343	1 241	20
Montenegro	259	98		1 655	
Namibia	147	92	2 674	314	5
Panama	273	94	35 350	2 365	1
Peru	456	87	54 024	190	1
Romania	316	88	2 117	488	16
Serbia	431	99	1 173	238	49
South Africa	271	95	843	583	28
Thailand	867	96	3 350	1 022	26
Tunisia	304	97	385	246	68
Turkey	577	100	3 029	2 126	18
Turkmenistan	5 753	71	268	1 202	1989
Venezuela	818	93	26 476	5 183	3

Water security indicators: Upper-middle-income countries (*continued*)

INDICATOR	Water productivity, total	Annual freshwater withdrawals, agriculture	Annual freshwater withdrawals, domestic	Annual freshwater withdrawals, industry
UNITS	2005 US$ GDP/m³ of total withdrawal	% of total freshwater withdrawal	% of total freshwater withdrawal	% of total freshwater withdrawal
YEAR	2013	2013	2013	2013
Albania	9	39	43	18
Algeria	22	61	24	15
Angola	83	21	45	34
Argentina		74	15	11
Azerbaijan	3	84	4	19
Belarus	11	19	27	54
Bosnia & Herz.	40			15
Botswana	73	41	41	18
Brazil	16	60	23	17
Bulgaria	6	16	16	68
China	9	65	12	23
Colombia	18	54	27	19
Costa Rica	12	57	32	11
Cuba		56	27	17
Ecuador	6	81	13	6
Gabon	83	29	61	10
Hungary	20	5	12	83
Iran	3	92	7	1
Iraq	1	79	7	15
Jordan	20	65	31	4
Kazakhstan	4	66	4	30
Lebanon	25	60	29	11
Macedonia	7	12	21	67
Malaysia	19	22	35	43
Mexico	13	77	14	9
Montenegro	18	1	60	39
Namibia	37	70	25	5
Panama	29	43	56	1
Peru	9	89	9	2
Romania	18	17	22	61
Serbia	7	2	17	82
South Africa	26	63	31	6
Thailand	4	90	5	5
Tunisia	15	76	13	4
Turkey	16	74	15	11
Turkmenistan	1	94	3	3
Venezuela	9	74	23	4

Appendix 2.5: Correlation matrix for indicators

The following table provides pairwise correlation coefficients for the set of indicators across the full sample of countries. The coefficients are calculated according to the available data for the pair of indicators in question (i.e. some coefficients are based on fewer than 96 observations due to data non-availability).

Indicator	GNI per capita	Poverty headcount ratio	Agriculture's share of GDP	Agriculture's share of employment	Energy use per capita	GDP per unit of energy use	Biomass share of energy supply	Fossil fuel share of energy supply	Nuclear & alternative share of energy	Access to electricity	Electric power consumption	Net energy imports	Diesel price	Food supply per capita	Adequate nourishment	Agricultural irrigated land	Agricultural machinery	Fertilizer consumption	Cereal yield	Average value of food production	Cereal import dependency ratio	Food imports to total exports ratio	Droughts, floods, extreme temps	Water withdrawal per capita	Access to safe drinking water	Renewable freshwater resources	Dam capacity per capita	Annual freshwater withdrawals	Water productivity	Agriculture's share of water use
GNI per capita		-0,62	-0,70	-0,73	0,65	0,33	-0,56	0,54	0,07	0,65	0,69	-0,09	-0,08	0,58	0,51	-0,18	0,13	0,32	0,33	0,52	-0,01	-0,23	-0,31	0,21	0,60		0,13	0,01	0,15	-0,27
Poverty headcount ratio			0,64	0,76	-0,48	-0,35	0,82	-0,77		-0,89	-0,58	-0,11	0,20	-0,62	-0,59				-0,45		0,06	0,27		-0,45	-0,74		-0,09	-0,13	0,09	-0,03
Agriculture's share of GDP				0,75	-0,46	-0,46	0,64	-0,64		-0,70	-0,54	0,14		-0,49	-0,45				-0,30		-0,10	0,12		-0,16	-0,64		-0,11	-0,03	-0,20	0,11
Agriculture's share of employment					-0,57	-0,35	0,73	-0,73		-0,77	-0,65	-0,01		-0,63										-0,21	-0,74					0,32
Energy use per capita						-0,28	-0,53	0,57		0,52	0,81	0,01	-0,10	0,49										0,51	0,41					
GDP per unit of energy use							-0,26	0,23		0,24	-0,13	-0,18	-0,08						0,14	-0,06									0,28	
Biomass share of energy supply								-0,94	-0,22	-0,84	-0,65	-0,12	0,20	-0,54	-0,50		-0,32	-0,28	-0,40	-0,39	0,02	0,21								0,07
Fossil fuel share of energy supply									-0,09	0,78	0,60	0,04	-0,29	0,57	0,54		0,28	0,28	0,35	0,34	0,00	-0,19		0,39	0,62					
Nuclear & alternative share of energy										0,27																				
Access to electricity											0,63	0,13		0,68	0,67	0,16									0,80					
Electric power consumption													0,18																	
Net energy imports													0,36								-0,22	0,12						-0,03		
Diesel price														-0,04			0,17	-0,17			-0,26	0,19						-0,35		
Food supply per capita															0,86	-0,11	0,56	0,24	0,40	0,54	-0,07	-0,16	-0,34	0,14	0,65	-0,11	0,01			-0,19
Prevalence of adequate nourishment																-0,04	0,20	0,28	0,35	0,50	-0,02	-0,14	-0,30		0,59					
Agricultural irrigated land																	0,13	0,10	0,25	-0,20	0,01	-0,02	0,11				-0,09			
Agricultural machinery																		0,13	0,15	0,03	0,09	0,16	-0,11							
Fertilizer consumption																			0,40	0,54	-0,07	-0,16	-0,06							
Cereal yield																				0,44	-0,25	-0,20	0,00			0,02			-0,25	
Average value of food production																					-0,57	-0,33							-0,16	
Cereal import dependency ratio																						0,16	-0,05	-0,14				0,05	0,31	
Food imports to total exports ratio																							0,23					-0,02	-0,10	
Droughts, floods, extreme temperatures																								-0,12	-0,27	-0,15	-0,03			
Water withdrawal per capita																									0,12	-0,15	0,14	0,46	-0,26	0,30
Access to safe drinking water																										0,06	0,04			-0,19
Renewable freshwater resources																											-0,03			
Dam capacity per capita																												0,04	-0,13	
Annual freshwater withdrawals																													-0,11	
Water productivity																														-0,42
Agriculture's share of water use																														

SOURCE: Calculated from data drawn from FAO (2015a,b) and World Bank (2015b)