# The Water–Energy–Food Nexus in a Climate-Vulnerable, Frontier Economy: The Case of Kenya

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# The Water–Energy–Food Nexus in a Climate-Vulnerable, Frontier Economy: The Case of Kenya

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## Abstract

In recent years, the complex set of interdependencies among water, energy and food systems – the WEF nexus – has emerged as a central issue within the overlapping fields of sustainable development and climate change resilience. This paper conducts a case study of the WEF nexus in Kenya, a dynamic, lower-middle-income 'frontier' economy that is of particular interest for several reasons. First, the country is acutely vulnerable to climate change and variability, given its geographical location in East Africa and its dependence on largely rain-fed agriculture for nearly one-third of its GDP. Second, Kenya is poised to begin production of oil in 2017, which could have a substantial impact on the country's ensuing development trajectory. Third, Kenya has been a leader within Africa in developing certain types of renewable energy, notably geothermal power. This paper explores the major global and national drivers affecting the WEF nexus in Kenya, such as a high rate of population expansion, rapid urbanisation and robust economic growth. It also identifies the country's main water, energy and food security vulnerabilities and risks, including climate variability and international oil and food price shocks. It then assesses the opportunities, risks and trade-offs inherent in the development of indigenous oil resources from a nexus perspective. The prospective benefits of new export and tax revenues and enhanced national energy security need to be weighed against the risks of negative environmental impacts and the 'resource curse'. The paper advocates for the use of a Sovereign Wealth Fund based on oil revenues as a vehicle for investments in sustainable infrastructure (such as dams and irrigation systems; geothermal and solar energy; food storage and transport systems; and water and energy efficiency enhancements) and for the government to purchase insurance against climate-related nexus risks. The policy recommendations are relevant to other sub-Saharan African and frontier economies with profiles similar to Kenya.

*Keywords*: water-energy-food nexus; sustainable development; climate resilience; natural resource management; Kenya

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# 1 Introduction

In recent years, the complex set of interdependencies among water, energy and food systems – or what is commonly termed the water-energy-food (WEF) nexus – has emerged as a central issue within the overlapping scientific fields of sustainable development and climate change resilience (FAO 2011; Hof 2011; World Economic Forum 2011; Rodriguez, Delgado, DeLaquil & Sohns 2013; Ringler et al. 2013; Stockholm Environment Institute 2014; WWAP 2014; IRENA 2015; Leck et al. 2015). Energy inputs are required at all stages of the food value chain (including on-farm production and harvesting, storage, processing and distribution to consumers) and the water system (including abstraction, conveyance, purification, distribution and wastewater treatment). Water is an essential input for agricultural production and food processing, and for various forms of energy production and power generation. In some countries, one or more agricultural crops are converted into biofuels. Furthermore, certain energy industries and agricultural production can have adverse impacts on water and soil quality. The precise nature and relative importance of these interlinkages differs according to a country's stage of socioeconomic development and, in particular, on the dominant socioecological regime – typically agrarian or industrial or a mixture of the two (Wakeford, Mentz Lagrange & Kelly 2016). In any given country, the WEF security nexus is influenced by a range of global and local drivers, including economic, social, demographic, geopolitical, technological and environmental factors, notably including climate change (Wakeford, Kelly & Mentz Lagrange 2015).

This paper conducts a case study of the WEF nexus in Kenya, a dynamic, lower-middle-income 'frontier' economy. Kenya is of particular interest for several reasons. First, it is experiencing a high rate of population expansion, rapid urbanisation and robust economic growth, which are all placing increasing demands on limited resources. Second, the country is acutely vulnerable to climate change and variability, given its geographical location in equatorial East Africa and its current dependence on largely rain-fed agriculture for nearly one-third of its gross domestic product (GDP). Third, following discoveries of oil resources in recent years, Kenya is poised to begin oil production in 2017, which could have a substantial impact on the country's ensuing developmental trajectory. Fourth, Kenya has been a leader within Africa in developing certain types of renewable energy, such as geothermal power and roof-top solar photovoltaic electricity.

The paper aims to address the following interrelated research questions. What are the major drivers affecting the WEF nexus in Kenya? What are Kenya's main nexus-related vulnerabilities and risks? What policies could be introduced to enhance resilience to shocks and to improve water, energy and food security in a sustainable manner? How can oil resources be managed in order to maximise their long-term benefits and minimise their negative effects on WEF nexus security? Finally, to what extent are governance arrangements conducive to sustainable management of resources and the WEF nexus, and how can they be improved? Rough estimates are also made of the costs of insurance and investments to mitigate WEF nexus vulnerabilities. The methodology involves a case study approach, making use of literature surveys, reviews of existing policy documents, and analysis of secondary data drawn from international and national databases, including the World Bank's *World Development Indicators*, the United Nations Food and Agriculture Organisation's FAOSTAT and AQUASTAT databases, and data from the Kenya National Bureau of Statistics (KNBS).

The paper is structured as follows. Section 2 discusses the main WEF nexus drivers and analyses the interdependencies among water, energy and food systems in Kenya. Section 3 identifies the extant vulnerabilities and risks inherent in Kenya's WEF nexus. Section 4 considers the opportunities and risks to the nexus posed by the development of oil resources. Section 5 puts forward a number of policy recommendations for boosting resilience within the WEF nexus in Kenya and for achieving sustainable development and management of natural resources. The final section concludes.

# 2 Analysis of Nexus Drivers and Linkages in Kenya

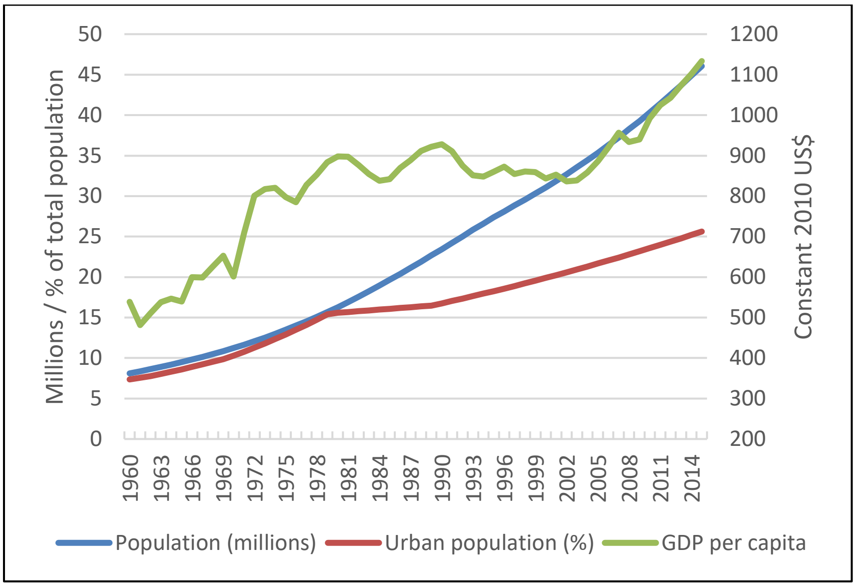
This section interrogates the three main elements of the WEF security nexus in Kenya and their interlinkages. It begins with a description of major international and national drivers that affect one or more of the three systems. It then analyses the water, energy and food systems in turn, highlighting the ways in which each dimension of the nexus depends on and affects the other two.

## 2.1 Drivers affecting WEF nexus security

There are two over-riding demand-side drivers affecting the WEF security nexus: demographic and economic trends (see Figure 1). Kenya's population, which stood at 46.1 million in 2016, is currently growing at a rate of about 2.6 per cent per annum. United Nations projections suggest Kenya's population could expand to 65.4 million in 2030 and 95.5 million by 2050 (UNDESA 2015). Like much of Sub-Saharan Africa, Kenya is undergoing a rapid process of urbanisation. The proportion of Kenya's population living in urban areas has expanded from 20.2% in 2001 to 25.6% in 2015 (World Bank 2016a). The country as a whole is urbanising at approximately 4.3 percent per annum (Cira, Kamunyori & Babijes 2016). Although urbanisation has been linked historically to economic development, rapid urbanisation can also bring several challenges, such as high unemployment rates, the development of slums, a mushrooming informal sector, growing inequality, and inadequate infrastructure for basic services and transport (Cira et al. 2016). Managing its urbanisation process in a planned fashion with a rapid roll-out of public services and infrastructure will be critical to ensuring water, energy and food security for Kenya's citizens over the coming decades. Urbanisation raises the demands on the commercial food production and distribution system, and means more investments need to be made for water conveyance, treatment and distribution, as well as electricity generation.

Kenya's rapid economic growth is also generating growing pressure on the WEF nexus. Real GDP grew by an average rate of 5.3% between 2006 and 2015 and the International Monetary Fund (IMF 2016) forecasts that the economy will continue expanding at close to six per cent per annum in the next four to five years. Economic growth brings with it rising incomes and an expansion of the middle class, which implies increasing demand for water and energy services and food. GDP per capita grew by an average rate of 2.5% over the past decade (World Bank 2016). In addition, if Kenya is to meet the sustainable development goals, then it will have to expand provision of basic necessities to the roughly quarter of the population living in poverty (i.e. on less than US$1.90 per day).

**Figure 1: Demand drivers acting on Kenya's WEF security nexus**




*Source: World Bank (2016)*

On the supply side of the nexus equation there are a number of key drivers. One of the most important is rainfall variability, which is itself affected by both climate change and the El Niño Southern Oscillation (ENSO), as will be discussed in section 3. The availability and quality of natural resources is also an important factor affecting WEF security. This includes the development, depletion and/or degradation of water resources, soils, forests and fossil fuels (see discussion in section 3.2). Technology is another driver, for example the rapid development of solar and wind power technologies, and associated rapid and substantial cost declines in recent years (REN21 2016).

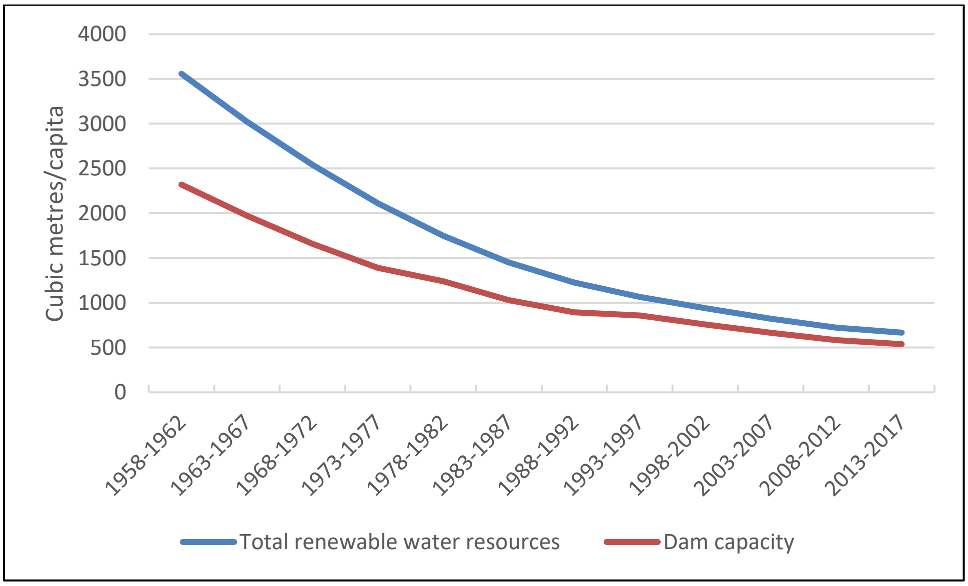
Geopolitical issues also play a role in WEF nexus security. In particular, Kenya shares access to water from Lake Victoria with its neighbours Uganda and the United Republic of Tanzania. It also shares several cross-border river basins with Ethiopia, Uganda and Tanzania. The Nile River basin, which Kenya shares with eight other countries, has been a source of contention for decades, although thus far outright conflict has been avoided (Salman 2012). A further geopolitical element of the nexus concerns regional energy trading arrangements. Kenya is currently a transit route for petroleum imports by Uganda, Rwanda and Burundi, and plans to import large amounts of electricity from Ethiopia in the future (Cuesta-Fernández 2015). Such arrangements rely on the continuation of good relations among these countries.

## 2.2 The water system

Average precipitation across Kenya is estimated at 630 mm per annum (FAO 2016a), but the distribution of rainfall is very uneven across the country. Annual rainfall ranges from about 200mm in Northern Kenya to 1800mm on the slopes of Mount Kenya (FAO 2005). Large parts of the northern, central and eastern areas, comprising over 80 per cent of the country, are classified as arid or semi-arid lands (ASALs). Rainfall amounts and distribution also vary greatly from year to year (Mekonnen & Hoekstra 2014). In 2014, total internal renewable blue-water resources were estimated at 20.7 billion cubic metres ($m^3$), while total external renewable water resources were 10 billion $m^3$, yielding total renewable surface water of 30.2 billion. Net additional renewable groundwater amounted to 0.5 billion $m^3$. Total renewable water resources per capita (from both external and internal sources) fell to 667 $m^3$ in 2014 from 939 $m^3$ in 2002 (FAO 2016a) – mainly a consequence of population growth (see Figure 2). Total internal renewable water resources per capita fell from 633 $m^3$ in 2002 to 450 $m^3$ in 2014. The dependency ratio on external water sources is 33 per cent. Annual freshwater withdrawals, totalling 3.22 billion $m^3$, represented 10.5 per cent of total renewable water resources in 2010. Of this quantity, 59 per cent was used for agriculture, 37 per cent for domestic uses and 4 per cent for industry (FAO 2016a). According to UN-Water definitions and using data on total renewable water resources per capita, Kenya is characterised by absolute water scarcity (less than 500 $m^3$ per capita per year), which is the most severe category of water stress (WWAP 2015). Total dam capacity reached 24.76 $km^3$ in 1995, and has barely increased since then, reaching 24.79 $km^3$ in 2015. Dam capacity per capita was 538 $m^3$ in 2015, down from 757 $m^3$ in 2000 (see Figure 2). However, a few years ago a giant aquifer with an estimated volume of 207 billion $m^3$ was discovered in the arid north-west Turkana region (The East African 2013). Together with other smaller aquifers with a combined groundwater resource of 43 billion $m^3$, these fossil water resources could potentially help to sustain Kenya's growing water needs for several decades, although recharge needs to be carefully studied.

In addition to using available water from domestic sources such as lakes, rivers and groundwater, Kenya consumes and exports 'virtual water' that is embodied in its imports and exports of agricultural products. Mekonnen and Hoekstra (2014) estimate that Kenya's virtual water exports were 4.1 $km^3$/year and its virtual water imports were 4.0 $km^3$/year between 1996 and 2005. They further estimate that 23 per cent of the country's agricultural water footprint was used to produce export products, while the balance of 77 per cent was due to production for domestic consumption.

**Figure 2: Total renewable water resources and dam capacity per capita, 1961-2014**




*Source: FAO (2016a)*

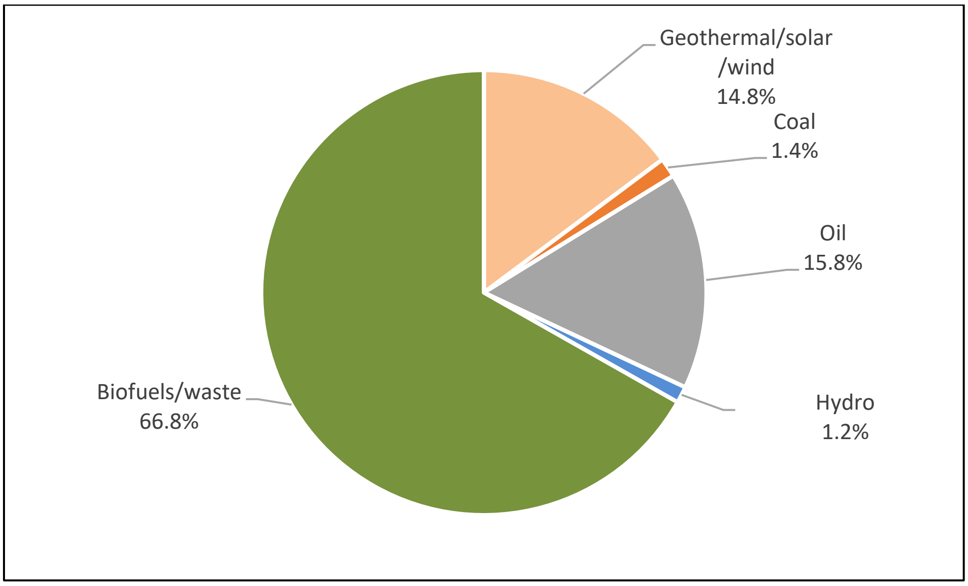
Energy is used at all stages of the water value chain, including abstraction, conveyance, treatment, distribution to consumers, and wastewater treatment. Unfortunately, statistics on energy use by the various components of the water system are not readily available in Kenya, as is the case in most countries. Abstraction takes place mostly from rivers and lakes, while groundwater (use of which typically requires more energy) represents just 1.6% of total freshwater resources. Unsurprisingly, areas of relatively high population density coincide to a large extent with areas with higher rainfall, implying that water generally does not have to be conveyed very long distances. Kenya's water treatment and distribution infrastructure is still limited, with only 25 per cent of the population living in urban areas and only 63 per cent of citizens having access to an improved water source (World Bank 2016). There were 27 municipal wastewater treatment facilities in 2010, with an annual capacity of 0.125 billion cubic metres (FAO 2016a).

Another aspect of water usage that requires energy inputs – in the form of electricity or diesel to run pumps – is irrigation. The total area equipped for full control irrigation in 2010 was 144,100 ha, of which 94 per cent (135,900 ha) was actually irrigated (FAO 2016a). A further 6,470 ha were equipped for spate irrigation. Overall, only 2.34% of the country's cultivated area was equipped for irrigation. Some 130,700 ha (87%) were equipped for irrigation by surface water, while 19,900 ha (13%) were equipped for irrigation by groundwater in 2010 (FAO 2016a). Of the area equipped for irrigation, 31,200 ha (20.7%) was power irrigated. Of the total harvested crop area under full control irrigation (140,000 ha), 88 per cent comprised temporary crops (including rice, maize, vegetables, sugarcane, cotton and flowers) and 12 per cent was under permanent crops (bananas, citrus, other fruits, coffee and tea). Irrigation water withdrawal accounted for 50% of total water withdrawal in 2010. Excessive irrigation can have negative impacts on soil fertility and hence on long-term yields. It was estimated that 30,000 ha of arable land were salinized by irrigation in 1999 (the latest data available) (FAO 2016a).

## 2.3 The energy system

As is the case in most sub-Saharan African countries, Kenya derives the bulk of its primary energy (67%) from traditional biomass fuels such as wood, charcoal and agricultural residues (see Figure 3). Oil, which is currently imported, contributes 15.8% of primary energy, while coal comprises just 1.4%. Hydroelectricity accounts for only 1.2% of Kenya's primary energy, but geothermal, wind and solar power contribute a sizeable 14.8%. Kenya relies on four energy carriers for final energy consumption, namely biofuels and waste (71%), oil products (22%), coal (2%) and electricity (5%) (IEA 2017). According to the IEA (2017), in 2014 the residential sector accounted for three-quarters of Kenya's total final energy consumption (TFEC), while industry consumed 8% and the transport sector 15%. Agriculture accounted for a miniscule 0.2% of TFEC, and commercial and public services for a further 0.7%. These figures demonstrate the underdeveloped nature of Kenya's energy economy. Kenya's energy imports, which were comprised of coal (7%), crude oil (13%) and refined oil products (80%), contributed 19.5% of the country's total primary energy supply in 2014 (IEA 2017).

**Figure 3: Kenya's total primary energy supply shares by source, 2014**




*Source: International Energy Agency (2017)*

Kenya generates electricity from both renewable sources including hydropower (35% of capacity), geothermal (27%), biomass, wind (1.1%) and solar PV, as well as from cogeneration (1.1%) and oil-based thermal sources (36%) (KNBS 2016). Total installed electricity generation capacity increased by 6.3% to 2,333.6 MW in 2015 (KNBS 2016), following a substantial increase in geothermal generation capacity in 2014 to 534 megawatts (MW) (KenGen 2016). Electricity net generation amounted to 9,258 gigawatt-hours (GWh) in 2014, with the largest percentage contribution from geothermal power (44%), followed by hydroelectricity (36%) and oil (19%), with negligible amounts from biofuels, wind and solar PV (IEA 2017). Electricity is consumed in three main sectors: industry (54%), residential (31%) and commercial and public services (15%).

Based on the foregoing statistics, it is clear that the energy system's reliance on water is somewhat limited because of Kenya's energy mix. Hydropower is the most direct use of water for energy, but this is non-consumptive aside from evaporation from dam surfaces. Although there is limited hydropower generation in Kenya itself, the country is investing heavily in electricity transmission lines to import hydroelectricity from neighbouring Ethiopia, which is itself vulnerable to droughts. Although geothermal power involves heating water to drive steam turbines, this is not a major consumptive use of water. Oil-based thermal power stations require little water. However, the extensive use of biomass energy is also clearly directly reliant on water to sustain tree and plant growth, but this is largely green water (rainfall and groundwater). Kenya does not have a modern (liquid) biofuels sector on any significant scale, and hence there is minimal direct reliance of the energy system on food crop production (and hence water resources) for bioethanol or biodiesel. Finally, water is used in the construction of energy infrastructure, but the amounts are impossible to quantify.

The energy system can have several negative impacts on water resources and security, and on land resources and food security. Deforestation and related soil erosion can lead to increased siltation of water reservoirs and loss of topsoil required for farming (Mati et al. 2008), while extensive deforestation can alter local precipitation patterns and make river flows more erratic (Mogaka et al. 2006; Mango et al. 2011). Forest area fell from an estimated 8.3% of Kenya's land area in 1990 to 7.8% in 2015 (World Bank 2016). Hydropower plants, when relying on dams, can be compatible with increased water security, but dams can have adverse consequences for downstream aquatic ecosystems. The other forms of energy that Kenya currently utilises do not pose undue threats to water. Geothermal power has a limited land footprint relative to the amount of power generated. However, spills or leaks of fuel from diesel or petrol generators and road vehicles can find their way into soils and watercourses.

## 2.4 The food system

Just under half (48.5%) of Kenya's land area is considered agricultural land, amounting to 276,300 square kilometres (World Bank 2016). Most of Kenya's land area is classified as arid or semiarid, much of which is suitable for pastoral activities; montane forests are located at higher altitudes (Odera et al. 2013). Arable land comprises 10.2 per cent of the total land area, or 5.8 million hectares (FAO 2016a). This results in a low average of 0.13 ha of arable land per person, compared to an SSA average of 0.2 ha. Permanent cropland occupied just 0.93 per cent of total land area in 2013 (530,000 hectares), although this has increased from 0.84 per cent in 2000. The main crop areas, known as the grain basket, are located in the Rift Valley and Western Provinces (Odera et al. 2013: 191).

**Table 1: Harvest area, production and yields of leading crops in Kenya, 2014**

| Crop | Area (hectares) | Production (tonnes) | Yield (tonnes/ha) |
|---|---|---|---|
| Maize | 2,116,141 | 3,513,171 | 1.66 |
| Beans, dry | 1,052,408 | 615,992 | 0.59 |
| Cow peas, dry | 281,877 | 138,673 | 0.49 |
| Pigeon peas | 276,124 | 274,523 | 0.99 |
| Sorghum | 213,520 | 177,553 | 0.83 |
| Tea | 203,006 | 445,105 | 2.19 |
| Wheat | 147,210 | 328,637 | 2.23 |
| Millet | 138,829 | 144,276 | 1.04 |
| Potatoes | 115,604 | 1,626,027 | 14.07 |
| Coffee, green | 110,000 | 51,500 | 0.47 |
| Pulses | 97,863 | 17,487 | 0.18 |
| Oilseeds | 90,551 | 37,315 | 0.41 |
| Vegetables, fresh | 73,639 | 605,923 | 8.23 |
| Sugar cane | 72,181 | 6,477,651 | 89.74 |
| Cassava | 63,725 | 858,461 | 13.47 |

*Source: FAO (2016b)*

Agriculture comprised 32% of GDP in 2015 (KNBS 2016), while about three-quarters of Kenya's labour force is engaged in the agriculture sector (Odera et al. 2013). Kenya produces numerous crops for domestic consumption, as well as cash crops such as tea, coffee and horticultural products (including vegetables and cut flowers) for export. Table 1 displays the main crops produced in Kenya in 2014 according to area harvested, along with production levels and yields. Maize and beans are the most important crops, occupying 37 percent and 19 per cent of total area harvested, respectively. Each of the other crops accounts for less than 5 per cent of the area harvested. The average maize yield of 1.66 tonnes per hectare (t/ha) is low compared to that in countries with more industrialised farming systems, such as South Africa (5.3 t/ha) and Egypt (7.75 t/ha) (FAO 2016b). The leading crops in terms of tonnes of production are sugar cane, maize and potatoes. There are two growing seasons: a "short-rains" season in the south-east and coastal regions, where sowing usually begins in mid-October with harvesting in February-March; and a "long-rains" season in the western and central regions, where planting typically begins in March followed by harvesting in the second half of the year (FAO 2016c). Kenya also produces significant quantities of livestock products, including meat from cattle (426,000 tonnes), chicken (26,000 tonnes), goats (61,000 tonnes), pigs (18,000 tonnes) and sheep (42,000 tonnes) (FAO 2016b).

Food production and security are critically dependent on water resources. Agriculture is by far the country's largest consumer of water, accounting for an estimated 59% of water usage (FAO 2016a). Mekonnen and Hoekstra (2014) calculated that Kenya's total water footprint related to crop production in the period 1996–2005 averaged 18.1 km3/y, comprising 97% green water, 1% blue water and 2% grey water. Maize accounted for the largest share (38%) of this water footprint, while the largest blue-water footprints were calculated for cultivation of coffee (51 million $m^3$/y) and rice (35 million $m^3$/y), which together contributed 40% of the total crop-related blue-water footprint. Only 0.037% of total agricultural land is irrigated (FAO 2016a). Because of a spatially irregular distribution of rainfall, crop yields are highly variable geographically. For example, maize yields of less than 0.5 tonnes per hectare are typical for areas such as Northern, North Eastern, and upper Coast Provinces (Odera et al. 2013), compared to a national average of 1.66 tonnes/ha. Processing of food products also requires water, but limited food manufacturing takes place in Kenya and so this does not represent a significant water demand sector at present.

The food system requires energy inputs for on-farm production, storage, processing into food products, distribution to consumers, and food preparation. Kenya's domestic food value chain is relatively simple compared to more advanced economies, as the majority of the population produce their own food through small-holder farming. Farming requires direct energy inputs, for example for tilling the soil, planting and harvesting. In Kenya, this is mostly accomplished by human and animal labour, while use of machinery such as tractors and harvesters is limited. The average number of tractors per square kilometre of arable land, estimated at 25.2 in 2002, is low compared the figure in more developed countries, such as South Africa (48 per $km^2$ in 2005) (World Bank 2016). Farming also requires inputs with embodied energy, such as synthetic fertilisers, pesticides, irrigation piping and packaging materials. Fertilizer consumption in Kenya amounted to 52.5 kilograms per hectare of arable land in 2013, compared to 4.7 in Tanzania, 2.3 in Uganda, 16.2 in Nigeria, 42.3 in Zambia, and 57.7 in South Africa (World Bank 2016). Kenya's agriculture sector accounts for just 0.2 per cent of the country's total final energy consumption, and according to the IEA (2017) all of this energy is derived from oil products. However, if one considers the whole food value chain, then other forms of energy are used as well, such as electricity for irrigation pumps and cold storage. As noted earlier, 20.7% of the area equipped for irrigation is power irrigated (FAO 2016a). Furthermore, most material inputs and agricultural machinery are imported, and have to be transported from the ports (principally Mombasa) inland on trains or trucks powered by petroleum. The distribution of food products to consumers also relies mostly on trucks, which convey domestically produced goods from rural areas to urban areas, as well as imports from the ports to the interior. Finally, energy is needed for cooking; over 80% of Kenyan households rely on traditional solid fuels such as wood and charcoal.

The food system can have various negative impacts on water quality and availability. Conversion of forested lands to agriculture can lead to soil erosion and subsequent siltation of water courses. Excessive use of fertilisers causes eutrophication of water resources, while pesticides (some of which are banned) also pollute lakes and rivers (Mogaka et al. 2006). Mekonnen and Hoekstra (2014: 453) "estimate that the grey-water footprint due to nitrogen fertilizer leaching from crop fields was about 300 million $m^3$/y over the period 1996–2005". At the very end of the food system, namely human waste disposal, "urban sewage is discharged directly into water bodies because many sewage treatment plants are either not working or only partly working" (Mogaka et al. 2006: 43).

# 3 Existing WEF Nexus Vulnerabilities

Kenya's WEF security vulnerabilities stem from endemic conditions, including deficiencies in water, energy and food access and consumption levels, as well as from specific risks emanating from external threats such as climate variability and oil and food price shocks. In terms of baseline conditions, both demand and supply side factors play a role. On the one hand, extensive poverty, which afflicts a quarter of Kenya's population, restricts the ability of many citizens to meet their daily requirements for water, energy and food. On the other hand, there is a lack of sufficient modern infrastructure to deliver water and energy services, and to provide and distribute adequate food supplies. This combination of weak purchasing power and undeveloped systems of supply results in considerable water, energy and food insecurities amongst the Kenyan population, as illustrated in Table 2.

Some 37 per cent of Kenyans lack access to an improved water source, compared to 32 per cent in sub-Saharan Africa (SSA) and just 10 per cent in lower-middle-income countries (LMICs). Kenya's renewable internal freshwater resources are estimated at just 461 cubic meters per capita, which is much lower than the averages for SSA (3986 $m^3$) and LMICs (3003 $m^3$). The median level of total water withdrawal per capita was 75.6 $m^3$ per inhabitant per year between 2008 and 2012 (FAO 2016a).

Energy insecurity is a significant challenge in Kenya, in terms of both access to modern energy sources and average levels of energy consumption. It is estimated that 23 percent of the Kenyan population had access to electricity in 2012; the proportion was 6.7 per cent in rural areas and 58.2 per cent in urban areas (World Bank 2016). This rate of access is substantially lower than the averages for SSA (35%) and LMICs (78%). Only 16% of Kenya's population had access to non-solid fuels for cooking in 2012, a slightly lower proportion than the SSA average (18%), and considerably less than the average for LMICs (41%). Average energy consumption was 492 kilograms of oil equivalent per capita in 2013, compared to 671 in SSA and 639 in LMICs.

Electric power consumption per person in Kenya was 168 kilowatt hours (kWh) in 2013, just over a third of the SSA average and less than a quarter of the LMIC average.

In terms of food security, only 79% of Kenyans had adequate nourishment as of 2015, but this has risen substantially from the 66% recorded in 2003 (FAO 2016b). The average level of the food supply deficit was 135 kilocalories per person per day (kcal/person/day) in 2016, compared to 130 in SSA and 99 in LMICs. Encouragingly, the deficit in Kenya has fallen substantially from 234 kcal/capita/day in 2004. The prevalence of food inadequacy was 32% on average in 2015, down from 43% in 2004-2006 (FAO 2016b). Of all Kenyan children under 5 years of age, 4% were affected by wasting, 26% were stunted, and 11% were underweight in 2014 (FAO 2016b). Another of Kenya's food security vulnerabilities derives from the fact that it is a net importer of grains. The cereal import dependency ratio averaged 36.4 per cent for 2009-2011 (the latest available data), while the value of food imports over total merchandise exports was 26 per cent in 2011-2013 (FAO 2016b). Food imports comprised 10.7 per cent of total merchandise imports in 2013 (World Bank 2016).

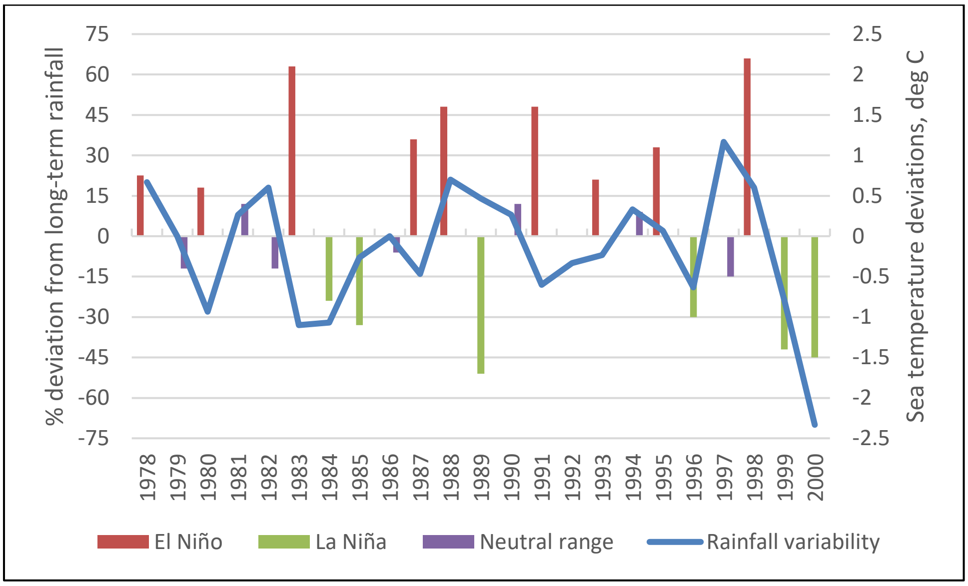
**Table 2: Indicators of water, energy and food security**

| Indicator | Year | Kenya | Sub-Saharan Africa | Lower-middle-income countries |
|---|---|---|---|---|
| Poverty headcount ratio at $1.90 a day (2011 PPP) | 2015 | 25.3 | 41 | 16.4 |
| Population with access to improved water source (%) | 2015 | 63 | 68 | 90 |
| Renewable internal freshwater resources per capita (cubic meters) | 2014 | 461 | 3986 | 3003 |
| Population with adequate nourishment (%) | 2015 | 79 | 82 | 86 |
| Depth of the food deficit (kilocalories/person/day) | 2016 | 135 | 130 | 99 |
| Population with access to electricity (%) | 2012 | 23 | 35 | 78 |
| Population with access to non-solid fuels (%) | 2012 | 16 | 18 | 41 |
| Energy consumption per capita (kilograms of oil equivalent per annum) | 2013 | 492 | 671 | 639 |
| Electric power consumption (kWh/capita) | 2013 | 168 | 488 | 745 |

*Source: World Bank (2016)*

In addition to the status quo described above, there are also several particular risk factors which impact negatively on WEF security in Kenya from time to time. These are examples of teleconnections, i.e. local impacts arising from occurrences in other parts of the world. The first threat is climate change and other variable weather patterns such as the El Niño Southern Oscillation (ENSO) (see Figure 4). The ENSO comprises alternating and irregular episodes of warming (El Niño) and cooling (La Niña) of surface waters in the central and eastern Pacific Ocean, which have knock-on climatic impacts in various parts of the globe. Kenya's main agricultural producing regions, located in the western and southern parts of the country, are susceptible to droughts during the La Niña phase of the ENSO, which can also curb hydropower production (Mogaka et al. 2006). Floods sometimes occur during El Niño episodes, and can result in the destruction of water supply infrastructure and damage crops (Mogaka et al. 2006). Mogaka et al. (2006) estimate that the El Niño-La Niña episode from 1997-2000 cost Kenya approximately 14 percent of its GDP annually, while over the long run the costs from floods and droughts were estimated to be roughly 2.4 percent GDP.

**Figure 4: Rainfall variability in Kenya and El Niño-La Niña episodes**




*Source: Adapted from Mogaka et al. (2006) and Trenberth (2016)*

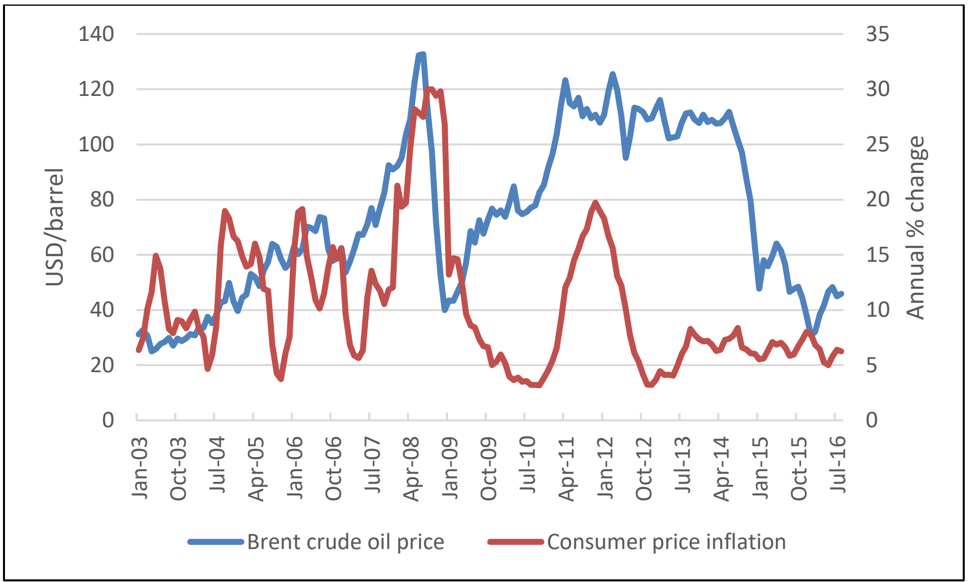
Odera et al. (2013) report scenarios for rainfall patterns according to four different global climate models. The models predict different rainfall changes across regions within Kenya, but on balance the predictions are generally positive for most areas. The models also have varying predictions about temperature increases across the country, but in general there is expected to be warming of between about 1-2$^{0}$C by mid-century, which could cause adverse impacts on agriculture such as temperature stress, crop diseases, an increase in pests, and elevated rates of evapotranspiration (Odera et al. 2013). The net effect of climate change on maize production is expected to be positive in several models, due to new areas receiving sufficient rain to support such cultivation. Projections based on all four climate models and on baseline, optimistic and pessimistic scenarios for growth of population and GDP per capita, and which incorporate anticipated technological improvements, suggest rising trends for production levels and yields of maize between 2010 and 2050.

Nevertheless, climate change is expected to bring greater annual variability in rainfall in Africa, so that periodic droughts and floods may become more frequent and more severe (Niang et al. 2014; Republic of Kenya 2013). Droughts lead to reduced food production, higher food prices, increased hunger and compromised nutritional outcomes, especially among the rural and urban poor. Reduced rainfall can also lead to hydropower outages, negatively affecting energy security and having knock-on impacts on food storage (refrigeration). Droughts, floods and extreme temperatures affected an estimated 6.5% of Kenya's population on average between 1990 and 2009 (World Bank 2016). According to Odera et al. (2013:187-8):

> "The adaptive capacity of the agricultural sector to climate change in Kenya is low mainly due to limited economic resources for investment in more resilient production systems, low levels of technological development or adoption of developed technology, heavy reliance on rainfed agriculture, frequent droughts and floods, endemic crop and livestock diseases, frequent incidences of pest infestation, relatively high levels of postharvest losses, and the general poverty among the majority of smallholder producers."

The second major external threat to WEF nexus security is presented by international oil price spikes. Kenya currently imports all of its refined petroleum fuels, which are used primarily for transport but also for electricity generation. Fuel price fluctuations in Kenya are caused by both variability in global crude oil prices and exchange rate fluctuations (Kiptui 2009). For example, the spikes in world oil prices in 2007-08 and 2010-11 contributed to soaring consumer price inflation in Kenya (Figure 5). Rising transport costs also feed through into higher food prices, thereby undermining food security.

**Figure 5: Crude oil price and Kenya's consumer price inflation**




*Source: EIA (2017) and FAO (2016b)*

A third significant risk factor is international food price spikes, which can be triggered by weather events (such as droughts, floods or extreme temperatures) in major food producing regions, or by trade policies such as food export restrictions or taxes in net food exporting countries. Speculation on international agricultural commodity markets, which occurred, for example, in 2008 (Timmer 2009; Wahl 2009), can also affect food prices in grain importing countries like Kenya. Higher food prices affect the ability of poor households, especially those in urban areas who are not engaged in food production, to afford their daily food requirements.

# 4 Development of Oil Resources: Opportunities and Risks

This section briefly considers the main opportunities and risks posed to nexus security prospects by the imminent development of Kenya's indigenous oil resources. The British-based firm Tullow Oil first discovered oil in Kenya's north-west region of Turkana in 2012, and has since made further discoveries in the South Lokichar Basin in collaboration with partners Africa Oil Corporation and Maersk Oil. In April 2016, the consortium revised upwards its estimate of recoverable resources to 750 million barrels (Tullow Oil 2017). Commercial production is expected to commence by mid-2017 and could ultimately yield between 60,000 to 100,000 barrels per day (b/d) (EIA 2016). The Government of Kenya has agreed on a pilot phase of oil development, during which initial oil production of approximately 2,000 b/d will be transported by road from Turkana to Eldoret, and from there by rail to the port of Mombasa (Njoroge 2016). However, substantial investments are required to upgrade the transport infrastructure, including the road link to Eldoret.

In April 2016 the government announced its intention to build a pipeline from Lake Turkana Basin to the city of Lamu on the coast. The 865-kilometre pipeline is slated to have a capacity of between 80 and 120 thousand barrels per day (kbpd) and to cost in the region of 210 billion Kenyan shillings (USD 2 billion) (Njoroge 2016). Construction is expected to begin in 2018 and to be completed in 2021. In August 2016, however, the government announced that the crude oil would be transported to Mombasa, where the Kenya Petroleum Refinery, which was closed in 2013, has recently been fully acquired by the state-owned Kenya Pipeline Company (Nyamori 2016). However, significant investment is required to rehabilitate and upgrade the refinery, which has a nameplate capacity of 35,000 b/d. Should Kenya’s annual oil production reach its full potential, there could be scope for both domestic refining and crude exports.

The development of Kenya’s oil resources has the potential to deliver considerable socio-economic benefits. Crude oil exports would generate foreign exchange and also royalties and tax revenues to support the government’s budget. In 2015, natural resource rents amounted to just 2.86 per cent of Kenya’s GDP, showing that currently the country has relies very little on natural resources (other than agriculture) directly to sustain government spending (World Bank 2016). Assuming an oil price of $50 per barrel and annual production of 100,000 b/d, this would generate economic value of about KES 188 billion (USD 1.83 billion) per annum, or roughly 3% of Kenya’s GDP. In addition, if Kenya does refine some of its crude oil domestically, this would facilitate a reduction of imported refined petroleum fuels and thereby save foreign exchange. Petroleum is Kenya's single largest import commodity, comprising about 14% of imports and costing the country over KES 200 billion (USD 2 billion) in 2015 (KNBS 2016). In 2014, Kenya imported an average of over 90,000 b/d of refined oil products, about ten per cent of which was re-exported to neighbouring countries (EIA 2016; IEA 2017). A new stream of domestically-produced fuel could boost national energy security significantly. Furthermore, oil sector development could lead to job creation in Turkana district, which had the highest district-level poverty rate in Kenya in 2006 at 93% (KNBS 2017). However, the employment potential should not be overstated as locals may lack the skills required by the oil industry, and thus most employment creation is likely to take place in supporting service sectors, road-building, and so on.

Exploitation of oil resources also carries potential environmental, social and economic risks, as is clear from the experience of many other oil-producing countries in Africa and elsewhere (O'Rourke & Connolly 2003; Humphreys, Sachs & Stiglitz 2007). Economically, Kenya will have to guard against the resource curse, which could include an appreciation of the exchange rate which harms other export industries, and create disincentives for economic diversification and industrialisation (Sachs & Warner 1995; Ross 1999; Baumeister et al. 2010).

Environmental risks associated with oil exploration, drilling, extraction and transport include: deforestation and destruction of ecosystems; the use of scarce water resources (Turkana district is one of Kenya's driest regions); and pollution of water and soils from oil production and spills (O'Rourke & Connolly, 2003: 594). Should the oil be refined in Mombasa, this could have local environmental impacts such as toxic water and air emissions (O'Rourke & Connolly, 2003). Such impacts could, in turn, disrupt the health and livelihoods of local inhabitants who depend on agricultural and pastoral activities, and thereby generate social conflict. In many countries, control exercised over oil resources and revenues by an authoritarian elite has worsened social inequalities and in some countries sparked long-running violent conflicts, such as in Nigeria and Ecuador (Bannon & Collier 2003; Frankel 2012).

# 5 Policy Recommendations for Nexus Resilience and Sustainability

A broad array of strategies and policies can foster economically, socially and environmentally sustainable development and improve WEF nexus resilience to shocks, including those related to climate change (especially droughts) and international energy and food prices (Wakeford et al. 2015). Of critical importance is to both expand access to and improve the quality of basic water, energy and food, while conserving scarce resources and protecting fragile ecosystems. The following subsections consider broad issues of governance and planning, technical solutions for boosting WEF nexus security, sound management of oil resources, and the cost of risk-mitigating investments.

## 5.1 Governance and integrated planning

Dealing effectively with the complexities and trade-offs inherent in the WEF nexus requires policy-makers to adopt an integrated approach to nexus security planning and should ideally receive support from the top echelons of leadership. The Kenyan government's overarching development strategy is articulated in its 'Vision 2030' national development programme (Republic of Kenya [RoK] 2007). The Vision 2030 sets the goal for Kenya to become a newly industrialising country and to reach upper-middle-income status by 2030, thereby "providing a high quality of life for all its citizens". Notably, the Vision does not include the environment as one of its three key 'pillars': economic, social and political. Rather, environmental issues are embedded within the social pillar, which aims to "build a just and cohesive society with social equity in a clean and secure environment". The Vision 2030 is to be implemented in a series of five-year Medium-Term Plans (MTPs). The MTP II (2013-17) prioritises the development of commercial agriculture in order to boost agricultural productivity and food security, as well as the development of oil and other mineral resources (RoK 2013a). Given the country's extreme vulnerabilities in certain aspects of the WEF nexus, especially with regard to climate variability and water scarcity, the nexus should arguably have featured more strongly in the national development plan. The section of the Vision 2030 dealing with its foundations does not mention water at all, although it does highlight energy and land use. Encouragingly, a key target included in the Vision is the planting of at least seven billion trees to address water, food and energy security.

In addition to top-level leadership, effective management of the WEF nexus will require vertical coordination among different levels of government, including national, regional and local spheres. In this regard, the process of devolution, as mandated in the 2010 Constitution, is a welcome development that could help to ensure better management of natural resource use and its impacts at a local level. A high degree of horizontal coordination is also needed, so as to align policies across government departments and sectors such as agriculture, water, energy, environment, land use and economy. Cooperation is required not just within government institutions inside Kenya, but also across regional borders. This applies especially to cross-border water basin management, but also to energy sharing. Kenya is a signatory of the Nile Basin Initiative along with eight of its neighbours. It is also a member of the East African Power Pool, and is making investments in transmission infrastructure to tap into Ethiopia's surging hydropower capacity (AfDB 2014). Another possible avenue for regional cooperation is the establishment of a regional food price stabilisation fund (see Wakeford et al. 2015).

Policy coordination will arguably happen most effectively within an overarching paradigm aimed at transitioning towards an inclusive green economy (Hof 2011; BMU 2012; Wakeford et al. 2015). The key principles of this approach are promoting resource efficiency, substituting renewable resources for non-renewable ones, and preventing environmental degradation and rehabilitating ecosystems. Another goal is to pursue technological 'leapfrogging' to adopt more sustainable forms of energy, water management and agriculture. The Kenyan government's commitment to a green economy is outlined in a draft Green Economy Strategy and Implementation Plan (GESIP), which aims "to support development efforts towards addressing key challenges such as poverty, unemployment, inequality, environmental degradation, climate change and variability, infrastructure gaps and food insecurity" (RoK 2015: 1). The GESIP includes many strategies that are compatible with WEF nexus management, including "investments in renewable energy, promotion of resource-efficient and cleaner production, enhanced resilience to economic and climatic shocks, pollution control and waste management, environmental planning and governance, and restoration of forest ecosystems" (RoK 2015: 2). While water supply, energy and agriculture are included among key sectors highlighted in the GESIP, the document does not specifically mention the complex interdependencies of the WEF nexus.

Another relevant policy document is the National Climate Change Action Plan 2013-2017 (NCCAP) (RoK 2013b), which seeks to implement mitigation and adaptation initiatives spelled out in the earlier National Climate Change Response Strategy (NCCRS) (RoK 2010). National leadership and cross-sectoral implementation are driven by a National Climate Change Council in the Office of the President, while a National Climate Change Secretariat (NCCS) has been established to lead on technical issues (RoK 2013b). The NCCAP identifies several "big win opportunities", which could have a major impact on climate mitigation and adaptation. These include geothermal power, distributed clean energy solutions, improved water resources management, restoration of forests, climate-smart agriculture and agroforestry, and infrastructure (including transport, energy and dams). These initiatives are broadly compatible with mitigating WEF nexus security challenges.

Awareness programmes can play an important part in shifting the country's trajectory to a more sustainable path and building capacity for climate adaptation. As noted by Odera et al. (2013), the high primary school enrolment rate in Kenya (111% in 2014), reasonable secondary enrolment ratio (67.6% in 2012), and decent adult literacy rate (78% in 2015) lay a foundation for effective communication of knowledge relevant to climate adaptation and WEF nexus management (data from World Bank 2016). Also of vital importance is government support for family planning so to limit the rate of population increase and alleviate the growing pressure on nexus resources and infrastructure. Key to this is adult education and providing girls with opportunities for secondary education (Odera et al. 2013).

## 5.2 Key technical interventions

A wide range of technical interventions can in principle be adopted in order to improve resilience and sustainability in the WEF nexus (see Wakeford et al. 2015 for a comprehensive review). A few key interventions that are appropriate for Kenya's water, energy and food systems are highlighted below.

Given the consistent decline in per capita dam capacity over the past several decades, there is an urgent need for expanded water storage capacity. In recognition of this, among the flagship projects identified in the Vision 2030 are the construction of dams on the Nzoia and Nyando rivers, with a combined capacity of 2.4 billion $m^3$, and 22 medium-sized, multi-purpose dams to serve domestic, irrigation and livestock uses in ASALs (RoK 2007:18). However, just as important is the proper management of erosion in catchment areas to prevent excessive silting, as well as the regular desilting of reservoirs (Mogaka et al. 2006: 78). Other nexus-related benefits of dams include the potential for hydropower generation and greater irrigation to bolster food security, especially during short droughts. Following a severe drought during the short-rains season in late 2016, President Kenyatta approved the construction of the first of many desalination plants on the coast, at an estimated cost of KES 25 million (USD 244,000) for a plant that caters for about 3,500 people (Del Bello 2016). The obvious problem from a nexus perspective is the highly energy-intensive nature of desalination, which will strain Kenya's limited power capacity in the short to medium term. An alternative way of improving water security in a water-scarce country is for Kenya to increase its imports of water-intensive products, such as grains, while exporting high-value products (including tea, spices and horticultural goods) that are less water intensive (Mekonnen & Hoekstra 2014: 451). Over the long term, however, Kenya should aim to export manufactured goods that tend to be less water intensive than agricultural products.

Aside from supply-side interventions, improvements in water-use efficiency are essential. This can be encouraged by "charging prices based on full marginal cost; stimulating water-saving technologies; and creating awareness among water users of the detrimental impacts of excessive water abstraction" (Mekonnen & Hoekstra 2014: 463). Specific water efficiency measures include drip irrigation and mulching in agriculture, rainwater harvesting, and repair of leaks in urban water supply systems (Wakeford et al. 2015). The use of gravity systems and efficient pumps with variable speed drives can help to minimize energy use for water conveyance (Wakeford et al. 2015).

Several interventions can help to promote energy security in a sustainable manner. First, Kenya has very large renewable energy potential that remains underutilised, including geothermal, hydro, solar, wind and biomass resources (Kiplagat, Wang & Li 2011). As a priority, the government should continue its plan to expand geothermal energy, since this provides competitively priced, renewable and clean base-load power that is not subject to climate-related risks. The government estimates the geothermal resource potential could be 10,000 megawatts (RoK 2013b). There is also a great opportunity to take advantage of Kenya's good solar radiation to invest in more solar PV, especially as the cost of solar panels has fallen by over 60% in the past few years (REN21 2016). These can be both grid-connected solar farms, as well as mini-grids and off-grid solar home systems (SHS), particularly in rural areas. The Government of Kenya introduced a feed-in tariff to promote green energy several years ago (RoK 2015), but the roll-out of solar PV could be accelerated through innovative financing models that enable poor consumers to pay off the set-up cost of SHS over a few years. A government study has determined that wind conditions in some parts of the country can support commercial wind power development (Kiplagat et al 2011). Construction of a 310 MW wind farm near Lake Turkana is currently under way (Lake Tukana Wind Power 2017). A considerable advantage of geothermal, solar and wind power is that they are less susceptible to droughts than hydro and biomass-to-power.

The second major avenue for improving energy security is to increase energy efficiency. This applies particularly to the household sector, where improved cookstoves could help to reduce both the rate of deforestation and adverse health impacts arising from smoke inhalation. In addition, the electricity transmission and distribution system can be improved, as losses amounted to 17% of output on average between 2009 and 2013 (World Bank 2016).

In the agriculture sector, one of Kenya’s key challenges is to raise yields of its staple crops, especially maize, while minimizing water footprints. One important intervention is the use of drought-resistant crop varieties. Another is to increase the extent of efficient irrigation systems. The Vision 2030 foresees an expansion of irrigated area from 140,000 to 300,000 hectares (RoK 2007: 18), which will increase demand for both water and energy. Rainwater harvesting and mulching to reduce evaporation and runoff can help to reduce water footprints (Mekonnen & Hoekstra 2014: 463). An additional means of boosting yields that may be considered is to increase the degree of mechanisation, which is currently low in Kenya. However, the use of tractors raises fuel demands and can damage soils. Conservation agriculture is a tried-and-tested method of reducing tillage, but was practised on just 0.56% of Kenya’s arable land area in 2011 (FAO 2016a). Other techniques being advocated in recent years include sustainable intensification, which refers to methods that improve productivity without increasing the land area under cultivation (Godfray 2015), and agroecology – the application of ecological principles to farming in order to improve resource efficiency and reduce negative environmental impacts (De Schutter 2012).

Considerable amounts of embodied water and energy could be saved by reducing food waste through investments in adequate food storage facilities. Furthermore, the upgrade and extension of transport systems will help farmers to get their produce to markets more quickly and cheaply, and thereby help to reduce food waste, and also enhance the resilience of farmers to climate shocks (Odera et al. 2013: 195). Odera et al. (2013: 206) advise that laws should be enacted to facilitate the movement of farmers from areas that experience drying as a result of climate change to areas that receive more water over time.

## 5.3 Mitigating potential negative impacts of oil resource development

Various policies and measures can be introduced to optimise the long-term impact of oil resources on sustainable development while mitigating negative impacts. Economically, the emphasis should be on ensuring sustainable use of oil revenues. Although the provision of subsidised oil products to the domestic population would deliver a short-term boost to energy security, the authorities should resist this temptation as in the longer term it is likely to be both economically unsustainable (for example if oil prices fell) and environmentally unsustainable (by disincentivising investments in clean energy). It would be more prudent to allocate oil revenues to more sustainable investments, including social spending on education and health, but also critically on sustainable infrastructure to boost WEF nexus security. Such investments will help to ensure economic diversification and ward off the crowding out that can accompany oil resource rents, although industrial policies will also play an important role in this regard. Another important institutional mechanism is to set up a Sovereign Wealth Fund (SWF), which can be used to smooth out the impact of volatility in oil prices and serve as a source of long-term investment funds. Kenya established a SWF in 2014, although it has not yet been fully operationalised (Hove 2016). Furthermore, “strong institutional and legal structures are needed to ensure an equitable share of oil revenues with foreign oil companies” (Wakeford & De Wit 2013: 137). Finally, effective monetary and exchange rate policies are required to avoid an excessive appreciation of the Kenyan currency, particularly when oil production is being ramped up or when oil prices rise; however, sufficient flexibility in the exchange rate should be maintained so as to avoid excessive expansion of the money supply and consequent inflationary pressures.

Mitigation of potential negative environmental impacts of oil production requires effective environmental and health regulations. These could include requiring oil companies to conduct Environmental Impact Assessments and to produce credible Environmental Management Plans; the government should also ensure that a Strategic Environmental Assessment by unbiased experts is conducted. Laws should be enacted that ensure the liability of oil companies for any pollution impacts, and to require companies to rehabilitate land and water resources affected by exploration and extraction activities. Effective environmental monitoring and enforcement of pollution abatement measures is essential. Another option is to incorporate the full environmental costs of oil extraction, transport and use in the price of fuels (Wakeford & De Wit 2013).

To mitigate the risk of negative social repercussions from oil extraction, the Kenyan government should ensure that the benefits accrue fairly among the broad population, while locals who experience the costs (such as adverse health, environmental and economic impacts) should be adequately compensated. Part of the revenues could be set aside for the districts in which the oil production takes place. This could include a dedicated fund for reskilling local inhabitants who lose access to land or water resources that are currently relied on for agricultural livelihoods. Transparency in the allocation of oil revenues can help to improve accountability and reduce the risk of social conflict. Another option is to allocate a portion of oil revenues directly to citizens in the form of a basic income allowance (which would be included in their taxable income). Evidence from other countries suggests that equitable revenue sharing mechanisms are especially important when there is ethnic exclusion of the communities living within the oil basin (Basedau & Richter 2011). Furthermore, “special efforts should be made to strengthen state institutions and implement policies designed to curb corruption related to resource rents” (Wakeford & De Wit 2013: 137).

## 5.4 Costs of risk-mitigating insurance and investments

It is beyond the scope of this paper to properly estimate the economic costs and benefits of the various mitigation and adaptation policies discussed above. Nevertheless, some other studies have estimated the costs of climate-related natural disasters, and these can be used to generate a rough estimate of the cost of insuring against such occurrences. In addition, some rough estimates can be made of some key nexus risk-mitigation investments.

The long-run costs arising from floods and droughts in Kenya were estimated to be roughly 2.4 percent of GDP per year by Mogaka et al (2006). In addition, "the costs arising from water resources degradation represent at least about 0.5 percent of the Nation's GDP and probably much more than that" (Mogaka et al. 2006: 78). The combined total is remarkably similar to an estimate by the Stockholm Environment Institute of the cost of climate change (2009: i): "aggregate models indicate additional net economic costs (on top of existing climate variability) could be equivalent to a loss of almost 3% of GDP each year by 2030 in Kenya." The SEI (2009) also estimates that climate adaption costs were in the region of USD 500 million per annum in 2012, potentially rising to USD 1 to 2 billion by 2030. [2] It would therefore be prudent for the Kenyan government to insure against climate-related natural disasters, covering an amount of its choice, possibly up to a maximum of 3 percent of GDP. Projecting Kenya's GDP forward from 2015 based on an annual 6 percent growth rate, 3 percent of 2017 GDP would be in the region of KES 210 billion. Assuming a 13.5 percent insurance premium, the annual cost of insuring such an amount could be on the order of KES 28.4 billion.[3] The African Risk Capacity, which pools drought risk amongst a group of participating African countries, provides insurance up to a maximum payout of USD 30 million (about KES 3 billion). Kenya was a member of the risk pools for the 2014/15 and 2015/16 rainfall seasons, but did not renew its participation for the subsequent round (ARC 2017).

Estimating the costs of water risk mitigation investments is not a simple task, as it involves diverse measures including infrastructure such as dams and irrigation systems, as well as reforestation programmes. In its 2016/17 budget, the Kenyan Treasury allocated KES 92.9 billion (3.7% of the total budget) for environmental protection, water and natural resources (National Treasury 2016). Of this, KES 62.3 billion (67%) was allocated to the Ministry of Water and Irrigation. Measures for flood control rainwater harvesting were allocated KES 38.5 billion, including KES 2.5 billion for construction of water pans and dams, KES 12.6 billion for water supply and sanitation, and KES 19.5 billion for environmental protection, conservation and management. In September 2016 the Government announced a ramped-up programme of reforestation, with the aim of restoring 5.1 hectares of forest, or 9 percent of the country's land area, by 2030 (Thomson Reuters Foundation 2016). The proposed construction of desalination plants at a cost of about KES 25 million for 3,500 people is of doubtful efficiency in the short term considering the extra burden it places on limited electricity supplies. However, in some drought-prone coastal areas it may be a necessary last resort that could be underpinned by expanded geothermal power generation. Other infrastructure that requires further development includes water purification plants, pipelines for bulk water conveyance and distribution within cities, and wastewater treatment plants.

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2 The Government of Kenya (2013) reports that droughts between 2008 and 2011 cost the country USD 12.1 billion, which amounts to about 4.7% of GDP annually. Of course, not all years are drought years, and so the long-run average cost of droughts could be somewhat lower than this percentage.

3 The African Risk Capacity (ARC) had a pool of $129m for a premium of $17m in 2014/5, and a pool of $179m for a premium of $24.8 in 2015/6, implying premium rates of 13.2 and 13.9 percent, respectively. See ARC (2016).

The two key energy-related risks that Kenya's WEF nexus faces are droughts interrupting hydropower generation and oil price spikes making thermal electricity generation more expensive. In principle, these risks can be mitigated by replacing existing hydropower capacity of approximately 820 MW and thermal (oil-based) power generation capacity of 840 MW with geothermal power. According to Ngugi (2012), the average installation cost of geothermal power in Kenya is about USD 3.6 million per MW equivalent (MWe). This implies a total replacement cost of approximately USD 3 billion (KES 300 billion) for each of hydro and thermal capacity.

Estimating costs of mitigating threats to food security is more difficult. The mitigation measures include skills training programmes (e.g. for conservation agriculture and agroecological farming techniques), the adoption of drought-resistant crop varieties, food storage facilities (e.g. grain silos and refrigeration), and expanding and upgrading road transport infrastructure to facilitate improved distribution of food products. Sina (2012) advocates the development of index-based weather insurance in the agriculture sector, which would provide small-holder farmers with financial protection against severe loss of income from droughts (or floods). The cost of such schemes would largely be borne by farmers themselves, although the government could subsidise premiums as a way of mitigating famine risks. Sina provides example from several countries which demonstrate that index-based insurance can be utilised by governments to respond effectively and promptly to disasters. Nevertheless, the commercial implementation of such schemes faces several practical difficulties, including complex product design, lack of financial literacy amongst farmers and lack of adequate historical data (Sina 2012). A company named Agriculture and Climate Risk Enterprise (ACRE) was formed in 2009 to provide index-based insurance to farmers in Kenya, Rwanda and Tanzania, with financial support from several donors (IFC 2017). ACRE caters to about 67,000 small-holder farmers in Kenya.

# 6 Conclusions

Kenya represents a useful case study of the water-energy-food nexus, as many of the major drivers are familiar to most developing countries, especially in sub-Saharan Africa. On the demand side these include population growth, rapid urbanisation, and rising incomes associated with economic growth, all of which increase demand for water, energy and food. On the supply side, the most important factors are resource limitations, especially with regard to freshwater and forests. The chief nexus interlinkages are the dependence of food production, hydropower generation and biomass energy on water supplies, and the reliance of food and water distribution on transport fuels. Kenya's primary nexus security vulnerabilities are erratic rainfall (including droughts and floods) driven by the ENSO and climate change, which threaten water, food and energy security, and to international oil and food price shocks.

The nascent development of Kenya's oil resources brings opportunities, risks and trade-offs. The major prospective benefits are new export and tax revenues, and a boost to energy security in the medium to longer term through substituting domestically refined oil for imported fuels. The risks relate both to environmental factors such as water usage and pollution, and economic and political factors encapsulated in the resource curse. Kenya could use its oil resources to modernise and mechanise its agriculture sector to boost yields, but this could cause damage to soil health in the long term and disrupt the social fabric, considering the extensive reliance on agricultural livelihoods and the likely increase in rural-urban migration that mechanisation would engender.

The Government of Kenya has already developed several policies and strategies that address nexus issues, albeit not directly and explicitly. These include elements of the Vision 2030, the Green Economy Strategy and Implementation Plan, and the National Climate Change Action Plan, as well as sector-specific policies and plans covering the water, energy and food sectors. A key governance question is whether the government will continue down the green economy trajectory once oil production begins, or whether it will be tempted to follow a more conventional path to modernisation that is reliant on fossil fuels. In practice, the country might end up taking a ‘middle road’. This paper advocates the use of a Sovereign Wealth Fund as a source of funds for investments in sustainable infrastructure (such as dams and irrigation systems; geothermal and solar energy; food storage and transport systems; and water and energy efficiency enhancements). It would also be prudent for the government to purchase insurance against climate-related nexus risks, especially droughts. Education and skills development programmes are also required to help farmers adapt to a changing climate. Many of the infrastructure investments have already been committed to by the government, but there needs to be enhanced vertical and horizontal integration of policies and planning informed by a nexus approach in order to maximise synergies and address trade-offs.

This paper represents an initial exploratory analysis of the WEF nexus in Kenya, and much work remains to be done. One of the factors that inhibits detailed analysis of the nexus is the paucity of data that quantifies the mutual interdependence of water, energy and food systems. Ideally, more detailed, on-the-ground studies will be required to extend and deepen the nexus analysis. Nevertheless, this case study and the broad policy lessons derived for Kenya are of relevance to other sub-Saharan African and frontier economies with similar profiles, especially those at early stages of industrial development and those that have newly discovered fossil fuel reserves.

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