07

Achieving Environmental Sustainability

The Nile River and its delta taken on July 17 2009 from the Earth-orbiting Space Shuttle Endeavour. © NASA

The entire suite of development goals, including economic growth, improved education, gender equity and the reduction of disease and hunger, will be difficult to achieve without reversing the current degradation of the environment. An estimated 24 % of global disease burden is associated with environmental factors, and 25 % of all deaths in developing countries are linked to environmental risks, compared to 17 % in the developed world.[1]

While it is tempting to think of MDG 7 – with its broad environmental sweep – as somewhat more removed than agriculture and health from the immediate needs of the world's poor, this is actually not the case. Recent studies of global environmental change conclude that the poor suffer most as a consequence of environmental decline.[2] Research has demonstrated that poor people are most likely to be affected by disasters brought about, or exacerbated by, environmental degradation, such as landslides and flooding.[34]

The main reason for the close relationship between environmental sustainability and poverty reduction is that poor communities in developing countries are much more dependent on environmental services, particularly renewable natural resources, than those in developed countries. Over 1.3 billion people rely on forests, fisheries and agriculture for their livelihoods, accounting for nearly half of all jobs worldwide. Natural resources are also essential sources of food, energy, shelter and medicine. In Africa, more than seven out of every ten poor people live in rural areas, where their livelihoods are renewable resource-dependent.[5]

Besides supplying basic human necessities, natural resources in developing countries – such as export crops and minerals – underpin national economic growth and incomes. Natural capital – including land, minerals and forests – constitutes 5 % of the world's wealth but more than 40 % of the wealth of developing countries.[1]

1. Millennium Development Goal 7

A quick glance at the targets of MDG 7 reveals significant variation in the breadth and depth of targets and indicators (see Table 7.1). The diverse focus of these targets has been influenced by the recent history of international efforts to integrate environmental and development issues. Governments at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 adopted Agenda 21, the Rio Declaration on Environment and Development, and the Statement of Principles for the Sustainable Management of Forests.[6] This generated new initiatives on climate change, forestry and biodiversity, and established "sustainable development" as a shared, international objective, integrating economic growth, equity and environmental protection. Then in 2002, the World Summit on Sustainable Development in Johannesburg reaffirmed the principles of sustainable development and placed particular emphasis (linking to the Millennium Declaration), on water and sanitation, biodiversity conservation, climate change and energy.[7]

All of these different environmental initiatives became separate targets and indicators of MDG 7. Target 7C and 7D, dealing with water and sanitation, and urban slums respectively, were quite precise. Targets 7A and 7B in contrast, had a complex set of overlapping indicators (Table 7.1).[†]

† Indeed, depending on what international agency's website you consult, you will find that the five or seven indicators of Targets 7A and 7B are distributed across both targets in quite different ways. Here we use the UNSTATS interpretation, which identifies seven indicators across Targets 7A and 7B. This list of MDG indicators is available at: milleniumindicators.un.org/unsd/mdg/Host.aspx?Content=Indicators/OfficialList.htm [Accessed 16 Nov 2009].

Table 7.1 Goal 7: Ensure environmental sustainability[8]

Target 7.A – Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources. **Target 7.B** – Reduce biodiversity loss, achieving, by 2010, a significant reduction in the rate of loss.	**7.1** Proportion of land area covered by forest. **7.2** CO_2 emissions, total, per capita and per US$1 GDP (PPP). **7.3** Consumption of ozone-depleting substances. **7.4** Proportion of fish stocks within safe biological limits. **7.5** Proportion of total water resources used. **7.6** Proportion of terrestrial and marine areas protected. **7.7** Proportion of species threatened with extinction.
Target 7.C – Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation.	**7.8** Proportion of population using an improved drinking water source. **7.9** Proportion of population using an improved sanitation facility.
Target 7.D – By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers.	**7.10** Proportion of urban population living in slums.

In this Chapter, we will consider the contribution that science and innovation make to acheiving the different targets of MDG 7. In Section 3 we will focus on those indicators in Targets 7A and 7B which are associated with reducing the loss of natural resources, specifically forests, fisheries and water, and the loss of biodiversity, in terms of protected areas and species extinction. In Section 4, we will consider the remaining indicator from 7A and 7B associated with climate change mitigation and CO_2 reduction, but not reduction of ozone-depleting substances, as this has largely been achieved. In Section 5 we will discuss the scientific aspects of Target 7C, which focuses on the supply of clean drinking water and sanitation. We will not consider Target 7D, on improving the lives of slum dwellers, but we note that a major indicator of this target involves urban water supply and sanitation.

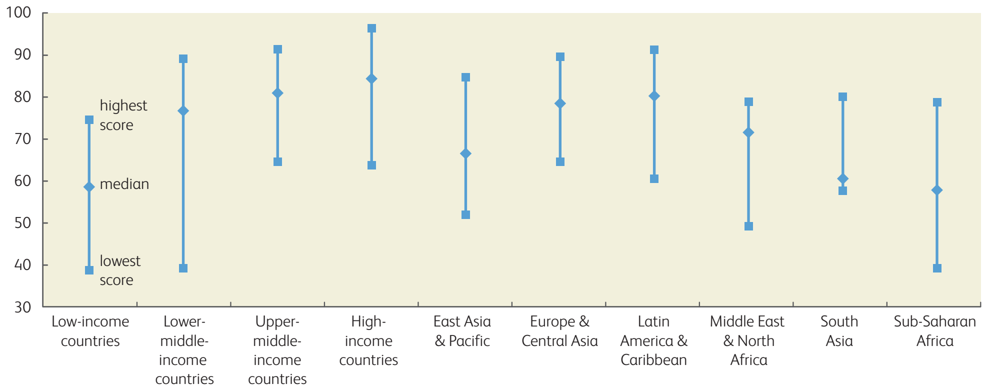
First, we will start with an overview on environmental policy and the general role of science in its development.

2. The role of science in environmental policy

The principal cause of the failure to meet MDG 7s environmental targets is poor governance of natural resources both at a national and local level. Without effective national environmental policies, open access resources, such as forests, fisheries and water, are easily over-exploited. The most effective policies are those that have recognized and engaged all stakeholders, and in particular the poor, in the management of these resources. Successful development of policies requires that rights are granted to communities that are dependent on the resource.

As part of an evaluation of progress towards environmental MDGs, the World Bank has assembled and compared measures of the quality of national environmental policy and institutions.[1] One of these, the Environmental Performance Index (EPI) takes broadly accepted targets for a set of 25 environmental indicators for: environmental health; air pollution; water resources; biodiversity; productive natural resources; and climate change; and ranks countries on the basis of their performance relative to these. Using the scores from 149 countries, the 2008 EPI, illustrated in Figure 7.1, revealed that lower income countries generally lag behind higher income countries, and account for the most poorly performing cases.

Figure 7.1 – The results of the Environmental Performance Index (EPI) showing the poorer performance of the low income countries[1]



A key reason for poor progress in environmental policy has been the failure of government to regard the environment as a critical aspect of all policy development, rather than as something which needs attention only when there is an environmental crisis. The solution – called *environmental mainstreaming* – involves "the informed inclusion of relevant environmental concerns into the decisions of institutions that drive national, local and sectoral development policy, rules, plans, investment and action."[9] Environmental mainstreaming encompasses both the process by which environmental issues are brought to the attention of policy makers – including the involvement of civil society organisations, scientists and others who contribute to the policy making process – and the inclusion of environmental measures in policy itself.

Science plays an important role in mainstreaming environmental policy. In fact, many policies are based on evidence provided by scientific research. We illustrate this in Box 7.1 for the development of forest management policy around certification schemes.

More generally, science provides a means of measuring and expressing the specific value of the environment to human well being and to international development. As we will see below, ecosystem science enables us to calculate the environmental benefits and costs associated with development activities, be they a new irrigation scheme, development of a fishing industry, a disease control campaign or an action to improve the environment itself. This helps us to make policies which are more sustainable.

Finally, as we shall see, particularly for climate change, water supply and sanitation, science can play its traditional role of supplying innovative technologies which underpin environmental policy.

Box 7.1 Policy and science in sustainable forest management

The specific role that science plays in environmental policy is illustrated in the widespread development and adoption of certification schemes for sustainable forest management. Governments use these schemes to regulate the practices of forest users and to report on the status of their forests to international processes and fora. In developing countries, certification schemes recognize that the poor who live in, and around, the forests have a critical role to play in forest conservation. Poor people can also benefit substantially from commercially viable, sustainable forest management. Indeed, if not engaged in and benefiting from managing forests, they may contribute to unsustainable harvesting of forest resources. Over 47million hectares of forest are under schemes endorsed by the Forest Stewardship Council (FSC), 18 % of which are in Asia, Africa and Latin America. While this proportion is relatively small, growth of certification schemes in more wealthy countries will affect timber markets and public opinion which should accelerate certification in poorer countries.

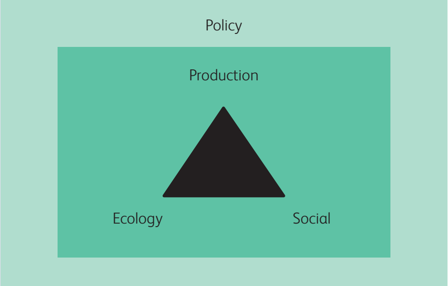


Figure 7.2 – A schematic representation of how ecological, production and social factors are linked in producing policy for sustainable forest management. The ecological component is derived directly from scientific research on forest ecosystems which identifies indicators of stable, sustainable forest systems[11]

Certification schemes require criteria and indicators (C&I) for sustainable forest management. While forests are extremely variable, ranging from rainforest to savanna woodland, they share similar ecological features and processes that make them self-sustaining. The Centre for International Forest Research (CIFOR), developed a C&I template which has served as the basis for the development of local management schemes by governments, communities and industries worldwide.[10,11] The template is based on a set of *principles* of sustainable forest management, to which are assigned *criteria, indicators of achievement*, and *verifiers* that can be measured for these indicators. Indicators cover four areas: policy, production, social dimensions and ecology, which are inter-related. Figure 7.2 captures this relationship.

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Figure 7.3 – A tropical rainforest on the island of Fatu Iva, French Polynesia

Ecological indicators are built on scientific knowledge and measurement, for example:

- Landscape pattern is maintained;
- Change of habitat diversity, as a result of human interventions, is maintained within critical limits, as defined by natural variation and/or regional conservation objectives;
- Community guild† structures do not show significant changes in the representation of especially sensitive guilds, pollinator and disperser guilds.

For a particular ecological indicator, there will be a number of verifiers that involve scientific measurement of plant and animal diversity and abundance. For instance, with respect to the community guild structure, a few verifiers are:

- The abundance of selected avian guilds is maintained within natural variation;
- The abundance of nests of social bees is maintained within natural variation;
- The abundance of seed in key plant species does not show significant change compared to undisturbed forest.

† A guild is a group of species of organisms, not always closely related, that perform a similar ecological function, for instance, a guild of bird and bat species may consume fruits of particular forest tress and distribute their seeds.

3. Reversing the loss of natural resources

Forests, fisheries, water, biodiversity – all of these natural resources are elements of ecosystems. An ecosystem is a dynamic complex of plant, animal and microbial communities and the non-living environment, interacting as a functional unit. In order to restore depleted natural resources, we need to understand the biological and physical processes within ecosystems that generate and regulate them. This is at the core of the science of ecology. These processes are not only complex, but highly inter-linked, such that the dynamics of one kind of natural resource directly affects the dynamics of another. Through ecological research, for instance, we have come to understand the critical role of plant cover and soils in retaining and regulating water flow in landscapes, and the role of ocean turbulence in maintaining nutrient flow, food chains and fish stocks.

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Figure 7.4 – A man illegally cutting wood in the Congo to sell in Kinshasa

As we have seen in Chapter 4, critical natural resources are declining on a global scale. While deforestation and afforestation are both occurring, there is a continuing net reduction in forest cover. Fisheries are growing increasingly unsustainable, water resources are in decline, the loss of protected natural habitats continues and the rate of species extinction is rising. All of these changes have serious implications for human well-being. They are the result of over-exploitation of renewable resources, that is, going beyond the level of sustainable harvesting that would guarantee and perpetuate the supply of these resources.

The Millennium Ecosystem Assessment (MA)

The same UN initiative that set in motion the development of the MDGs (see Chapter 4) led to the development of the Millennium Ecosystem Assessment (MA). The outputs of the MA in 2005 came too late to shape the design of MDG 7, but the MA findings remain critical for achieving its targets. The MA was run under the auspices of the United Nations (UN) to *"assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being"*. It was intended to address issues arising from other international initiatives, notably the inter-governmental Convention on Biological Diversity.

The MA presents a detailed analysis of the state of each of the world's different ecosystems and the processes affecting them, with a strong geographical focus. It also relates these changes to human well-being through the concept of ecosystem services. These are the part of ecosystems, and their processes, that are of specific benefit to people. These benefits can range from the provision of water or plants and animals for food to less obvious contributions such as supporting the insects that pollinate our crops, or the geochemical cycles that remove the pollutants we put into the air and water. The MA identifies four broad categories of ecosystem services:

- Provisioning services;
- Regulating services;
- Cultural services;
- Supporting services.

Box 7.2 presents a description of the specific ecosystem services under these categories.

Box 7.2 Categories of ecosystem services[12]

Category	Examples of ecosystem services provided
Provisioning services i.e. products obtained from ecosystems	• Food e.g. crops, fruit, fish. • Fibre and fuel e.g. timber, wool. • Biochemicals, natural medicines and pharmaceuticals. • Genetic resources; genes and genetic information used for animal/plant breeding and biotechnology. • Ornamental resources e.g. shells, flowers.
Regulating services i.e. benefits obtained from the regulation of ecosystem processes	• Air-quality maintenance: ecosystems contribute chemicals to and extract chemicals from the atmosphere. • Climate regulation e.g. land cover can affect local temperature and precipitation; globally, ecosystems affect greenhouse gas sequestration and emissions. • Water regulation: ecosystems affect e.g. the timing and magnitude of runoff, flooding etc.

...continued

Category	Examples of ecosystem services provided
Regulating services continued	• Erosion control: vegetative cover plays an important role in soil retention/prevention of land/asset erosion. • Water purification/detoxification: ecosystems can be a source of water impurities but can also help to filter out/decompose organic waste. • Natural hazard protection e.g. storms, floods, landslides. • Bioremediation of waste i.e. removal of pollutants through storage, dilution, transformation and burial.
Cultural services i.e. non-material benefits that people obtain through spiritual enrichment, cognitive development, recreation etc	• Spiritual and religious value: many religions attach spiritual and religious values to ecosystems. • Inspiration for art, folklore, architecture etc. • Social relations: ecosystems affect the types of social relations that are established e.g. fishing societies. • Aesthetic values; many people find beauty in various aspects of ecosystems. • Cultural heritage values: many societies place high value on the maintenance of important landscapes or species. • Recreation and ecotourism.
Supporting services, necessary for the production of all other ecosystem services	• Soil formation and retention. • Nutrient cycling. • Primary production. • Water cycling. • Production of atmospheric oxygen. • Provision of habitat.

In an effort to understand the consequences of declining natural resources, highlighted above, the MA examined trends in ecosystem services over the past half century. Of the ecosystem services presented in Box 7.2, 24 provisioning, regulating and cultural services could be assessed with respect to how human activity has changed them. Supporting services are not directly used by people, rather they underpin the other kinds of services, so they are not included in this analysis. Of these 24 services, 15 (60 %) are undergoing degradation or are being used unsustainably. Those that have been particularly degraded over the past 50 years include: capture fisheries; water supply; waste treatment and detoxification; water purification; natural hazard protection; regulation of air quality; regulation of regional and local climate; regulation of erosion; spiritual fulfilment and aesthetic enjoyment. Two of these services, fresh water and capture fisheries, are being exploited at such levels that they cannot be sustained under current demand, much less the demand of a growing population. Only four services: food production; livestock; crops and aquaculture, have been enhanced in the past 50 years.

The MA makes a point of showing how services are inter-linked. For example, increasing services to agriculture by converting forests to crop land may contribute to reducing local poverty but at the same time this will degrade other services provided by forest watersheds and biodiversity, and make these improvements less sustainable.

The MA has provided an environmental baseline for progress against MDG 7 and has identified priority areas for attention. Perhaps more importantly, it has developed the concept of ecosystem services and their measurement for human development. While MDG 7 sets out admirable targets to reduce the loss of natural resources and biodiversity, efforts to achieve these targets will compete poorly for attention against other MDGs that have a more obvious human benefit unless these efforts can be expressed in terms of *benefits to human welfare*. This is where the concept of ecosystem services is so useful.

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Figure 7.5 – A river snakes through the land in Bhutan

Recent scientific advances in natural resource management

While the specified environmental targets of MDG 7, forests, fish, water and biodiversity constitute very different kinds of natural resources, their restoration and sustainable use pose more or less the same challenge: *how to understand and manage the self-renewing nature of these resources so that we can utilize them without destroying them or the ecosystems which provide them?* This requires that we have scientific tools to:

- Measure and monitor changes in natural resources over time;
- Model and predict what affects that change;
- Place a value on the resources in terms of human well-being.

These tools have a direct relevance to environmental policy development and implementation. To develop successful policies we need to understand the state of the natural resource and the risk to it, the likely consequences of our policy on its supply, and the benefits that it will bring to society. Once developed and implemented, these same three tools continue to be important in monitoring the performance of the policy and predicting whether the resource's new trajectory will realize the policy goal and demonstrate value to people.

In some cases, we have had these scientific tools for policy development for some time. Predictive, mathematical models have underpinned fisheries management for many decades. But some of the tools are new or rapidly improving, such as methods for valuing ecosystem services, and technologies for environmental monitoring. Further, scientific tools for; monitoring, modelling and valuing the environment, are coming together today with the help of advances in information technology, to generate a powerful integrated platform for developing and managing environmental policy.

Measuring and monitoring changes in natural resources

MDG 7 targets focus on measuring changes in the proportion of a resource conserved, e.g. the proportion of land which is forested or the proportion of total water resource used. But natural resources like these are often extensive and their use is therefore difficult to measure at a national, much less a global level. Some resources, because of their accessibility, are not easy to measure –

much of the water on which we rely lies below the surface of the earth, out of easy measurement. Finally, the complexity of ecological processes may make it difficult to find simple indicators that give us a measure of how complex ecosystems are changing.

A major advance in the way we measure and monitor natural resources is underway through progress in earth observation and remote sensing.[13] Satellite imagery has long provided a means of observing changes in land cover and land use. Since 1972 land cover has been routinely monitored by Landsat and similar satellites, and with higher temporal but poorer spatial resolution by sensors mounted on weather satellites. These generally measure solar reflectance at a set of narrow visible and near infrared wavebands. Reflectances can be used to distinguish vegetation types, such as agricultural and forested land. Countries such as Brazil and India have been using satellite imagery since the 1990s to measure the changes in forest cover, and these now provide a baseline for measuring change.

However, broad patterns of forest cover may not be a good indicator of forest health and degradation, as significant changes can occur underneath a forest canopy. Gathering more information from remote sensing requires greater image resolution. This can then reveal forest gaps caused by tree-felling, and evidence of logging or other activities in forested areas. The widely used SPOT and Landsat imagery has a resolution of 10-60m. Newer systems like IKONOS and QuickBird can now resolve images down to less than 5m, but are still very expensive.

Imaging radars mounted on airplanes have been used to supplement optical sensors, and have the potential to measure forest structure below the canopy. One advantage of radar is that there is no interference from clouds or smoke, and thus it is useful for mapping tropical forests where there is persistent cloud cover. Another emerging remote sensing technology is Lidar (Box 7.3).

© NASA – Visable Earth

Figure 7.6 – A Landsat image taken of the Zambezi river in April 2003, after flooding turned the normal thin blue line into a vast swamp of standing water. Tens of thousands of people were displaced

Box 7.3 The LIDAR – Light Detection and Ranging System

Lidar is an optical remote sensing technology that measures properties of scattered light to find a distant target. It relies on laser pulses and therefore uses shorter wavelengths of the electromagnetic spectrum than radar and most optical methods, making it possible to distinguish smaller objects on a landscape. Because Lidar is highly sensitive to aerosols and cloud particles it has particular environmental value in monitoring changes in atmospheric chemistry and pollution.

Figure 7.7 illustrates how Lidar, mounted in an airplane, scans a landscape. A laser scanner on the aircraft sends up to 100,000 pulses of light per second to the ground and measures how long it takes each pulse to reflect back to the unit. These times are used to compute the distance each pulse travelled from scanner to ground. The Global Positioning System (GPS) and Inertia Monitoring Unit (IMU) determine the precise location and attitude of the laser scanner as the pulses are emitted, and an exact coordinate is calculated for each point. Large areas are surveyed with a series of parallel flight lines.

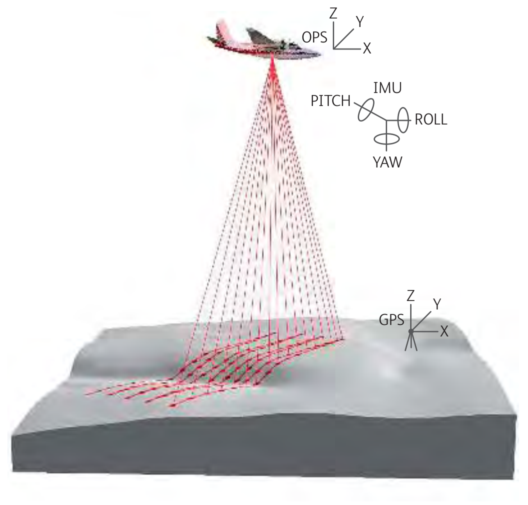

Figure 7.7 – A Lidar system scans a landscape[14]

Operating in this way, Lidar can be used to assess canopy height, biomass and leaf area, or to detect the land surface beneath a forest. In disaster situations it can detect earth movements or other landscape changes, relative to baseline scans.

Earth observation is an extremely valuable tool in monitoring, not only forest exploitation, but also the pattern and change of exploitation of other natural resources. In most cases, satellite images are "ground truthed", that is, matched to observations made on the ground, to ensure that the particular spectral image is consistently indicative of a particular ecosystem feature. This allows the calibration of spectral reflectances with the objects or activities to be measured, e.g. a certain kind of logging activity, water pollution or land degradation.

Earth observation is also of potential value in monitoring of natural disasters.[15,16] Satellites fitted with sensors, which operate over a range of wavelengths, can be used to detect recent and ongoing disasters like fire (infrared), flooding (near infrared, microwave), earthquakes (microwave), typhoons (visible, microwave).

Under the geographical knowledge provided by earth observation, we can overlay other information on this to generate an understanding of the environmental change observed and its causes. We can use successive images to provide a time series of images and identify "hot spots" where change is most rapid. To illustrate this we present two recent studies which have used earth observation to monitor changes: in the use of water resources for irrigation worldwide, and the degradation of land in Africa.

Many parts of the world, particularly arid regions, face water shortages, and it is likely that climate change will exacerbate this (see Chapter 9). Irrigation accounts for about 70 % of the water that we currently use. This enables us to produce about 40 % of the world's food from 17 % of the cultivated area. Given our need to increase food production, there will be future pressures to increase levels of irrigation, but can we afford to do this?

An accurate measure of current global irrigation and how it could change in the future will provide important evidence for future water policy. Until recently our understanding of the extent and distribution of irrigation worldwide came from surveys. However, the accuracy of these surveys was only as good as the infrastructure which collected the data, and this was weak in many poorer countries. In 2006, scientists at the International Water Management Institute (IWMI) in Sri Lanka developed an analysis which used satellite imagery to construct an improved, global map of irrigated lands. (Box 7.4).

Box 7.4 Monitoring global trends in irrigation[17]

Production of a global map of irrigated lands was not a simple task. Areas where irrigation was unlikely to occur were masked out of the global map on the basis of remotely sensed information on altitude, temperature, rainfall and forest cover. Remaining areas were then studied using 159 layers of data, including spectral images from different satellite systems comprising reflectances at different wavelengths and different times. With the help of ground-truthing (either on the ground itself or by using high resolution pictures from Google Earth), spectra associated with different kinds of irrigation in particular regions were identified. Seasonal patterns of greening were particularly useful in identifying irrigated crops from other vegetation.

Ground truth testing showed this approach was about 90 % accurate. This was better than current methods based on national surveys, and had the added benefit of providing more precise geographical information on irrigated areas.

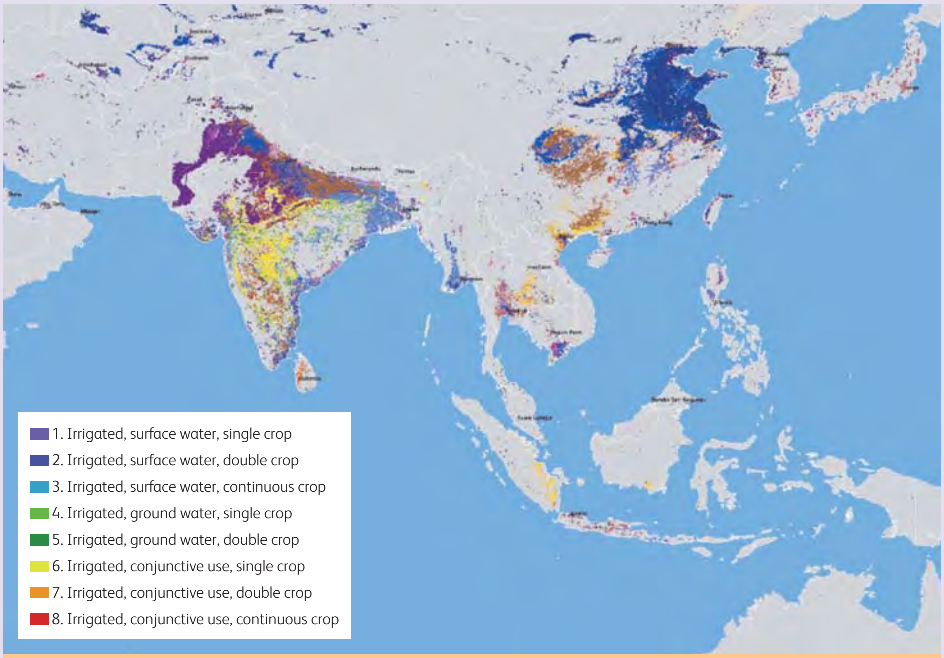

Figure 7.8 – Satellite sensor based global irrigation map showing the concentration in China and South Asia[17]

The final map revealed the global distribution of irrigation. It is composed of images of very high resolution, in some cases down to 500m. It reveals that the total annualized irrigated areas of the world cover 480 million ha ("annualised" takes into consideration irrigated areas during different seasons). Of this irrigated land 75 % occurs in Asia, indeed 60 % occurs in just two countries, China and India, where it supports largely double cropped agriculture.

There is considerable local evidence that land degradation is a serious problem in Africa. Deforestation, overgrazing, inappropriate agriculture (particularly on poor soils) and desertification all appear to be contributing to this process. Degradation is eroding Africa's capacity to increase its food production to meet the demands of a rapidly growing population. Understanding where and why this degradation is occurring, and its extent and rate, is extremely difficult, particularly in remote areas. Yet, it is precisely this information that is needed to develop strategies and policies for land restoration. Box 7.5 illustrates how such mapping has been done using a combination of satellite-based remote sensing data and ground-based weather data.

Box 7.5 Mapping land degradation in Africa[18]

A project to map land degradation in Africa began with the assembly of a time series of satellite images and the application of these to derive the Normalized Differenced Vegetation Index (NDVI) – an algorithm for correlating spectral reflectance with vegetation cover. Annual observations over 20 years were used to identify sites in Africa where the vegetation index had changed. Then, using separate data on patterns of rainfall over that period, the study removed sites where changes in vegetation were strongly correlated with changes in rainfall. These included, for instance, large areas of the Sahel, which have recently been "greening" due to increased precipitation. In the areas that remained, vegetation cover had declined independent of changing rainfall implicating human activity as a cause. The distribution was then compared to another satellite-generated map of land cover and land use in Africa. This identified regions that were under agriculture, grassland, different

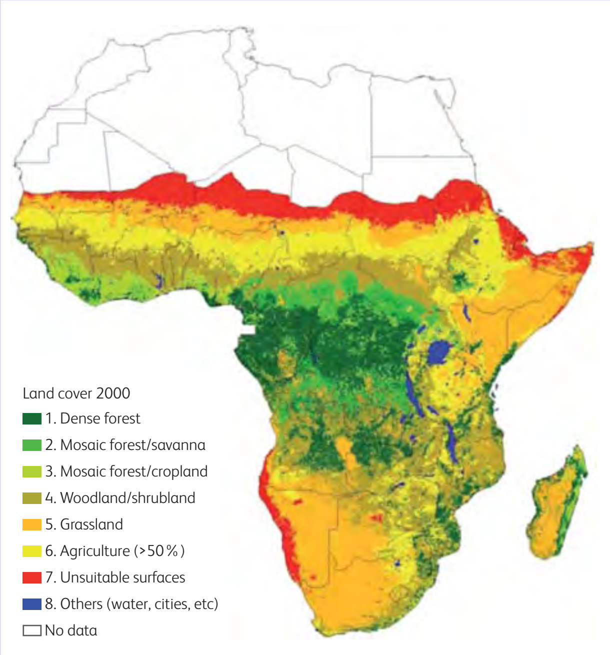

Figure 7.9 – Major land cover classes in 2000 extracted from GLC2000 data[18]

kinds of forest and desert as seen in Figure 7.9. Figure 7.10 shows areas of declining vegetation index, presumed to be degraded. Matching these areas to the vegetation map (Figure 7.9), we can identify different kinds of degradation. These are colour coded in Figure 7.10 as follows:

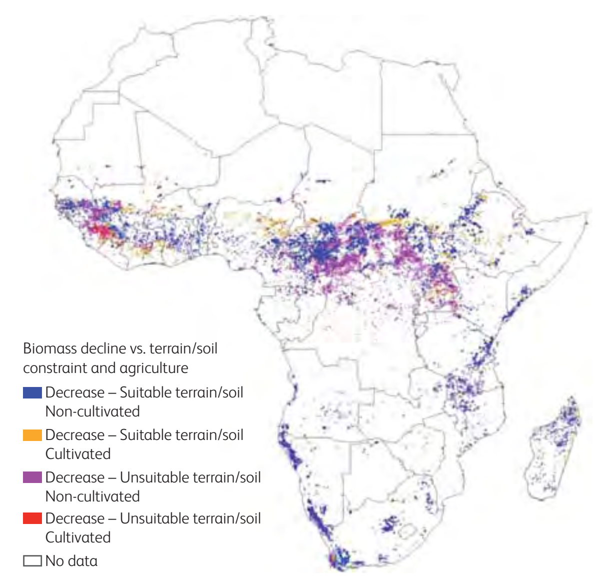

Figure 7.10 – Areas with biomass decline as function of soil/terrain constraints and their agricultural use[18]

- Yellow indicates areas which are suitable for agriculture and cultivated, about 0.3 million km^2, where degradation of agricultural land is probably occurring due to poor management;
- Blue indicates a decline in agriculturally suitable areas not in cultivation, about 1.46 million km^2, which are likely to include drier grasslands being degraded by over-grazing, woodland and grassland mixtures and dense forests being degraded by deforestation;
- Red indicates regions that are considered unsuitable for agriculture but are, in fact, being cultivated and degraded. Totalling about 0.1 million km^2, these areas are found, for instance, on the eastern borders of Sierra Leone and Liberia as well as in Uganda.

This study is a first attempt at characterizing and mapping African land degradation, and further research needs to be done in order to make this more accurate. However it does show how technologies based on satellite-based, remote sensing systems, Geographical Information System (GIS) and Information and Communication Technologies (ICT) can be integrated to generate a better understanding of the distribution of environmental problems and how they are likely to change over time. This will be important in measuring the impact of efforts that are being made on behalf of the MDGs and other initiatives.

Future demand for improved remote sensing technology in environmental monitoring is likely to be driven by a need to monitor policy implementation and agreements. For instance, delegates at the UN Climate Change Conference in Bali in 2007 agreed to explore voluntary schemes for Reducing Emissions from Deforestation and Forest Degradation (REDD), which could involve a market-based approach whereby developing countries received carbon credits for reducing or reversing deforestation. A monitoring system would need to be established for REDD that could measure, on an annual basis, the national change in carbon stocks associated with forest management. While it was agreed that, in principle, the basic technology exists for such an accounting system, at least in developed countries, REDD raises a number of scientific challenges. For instance, forest cover is not a precise measure of forest carbon. The carbon content of forests is a function of the size of trees and other vegetation which can be difficult to measure remotely. One possibility would be to build carbon maps using a combination of remote sensing tools and field measurements to calibrate satellite images with biomass on the ground and with indicators of its change.

Earth observation by a wide range of scientific methods, from satellites to land-based surveys, provides new opportunities to constantly monitor the state of the earth and its resources. The global potential for such a system was captured in 2005 by the establishment of a plan for a Global Earth Observation System of Systems (GEOSS) to link existing earth observation systems across a wide range of regions and resources, in order to, *"increase understanding of dynamic Earth processes, to enhance prediction of the Earth system, and to further implement our international environmental treaty obligations"*. Creating GEOSS was the aim of the Group for Earth Observation (GEO),[19] a voluntary partnership of 79 governments and various international organisations. GEO is actively bringing together different earth observation systems around common formats to build this global capability.

Modelling natural resources dynamics

Because we harvest renewable resources, we are faced with the question – how much can we take and still have the resource there to use in the future? Efforts to answer this question began in the early part of the last century, when biologists began to study, in a quantitative manner, the dynamics of plant and animal populations. Many were motivated by the paradox that, while the many millions of species on earth each experience high rates of birth and death, their abundance and numbers seem strikingly constant. To understand this dynamic equilibrium, biologists turned to mathematics to understand what might regulate the numbers of single species.[20] Mathematical models of populations combined variables for birth, death, immigration and emigration to reveal, and subsequently validate, the processes which cause such systems to be stable. These single species population models, in turn, informed applied research on harvested populations and allowed prediction of the inter-generational consequences of removing individuals at different rates.

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Figure 7.11 – One fisherman's daily catch in Indonesia

The key role that such modelling has played in natural resource management, and its value to realizing MDG 7, is perhaps most clearly seen with fisheries. Fish play an important part in the diets of people in developing countries, who produce and consume more fish per capita than people in developed countries. Not only do they offer a great source of protein but they also provide important micronutrients. They constitute two distinct natural resources, wild fish stocks which are harvested, and cultivated fish stocks which are farmed.

MDG 7 focuses on restoring wild fish stocks that have been overexploited. At least one quarter of important commercial fish stocks are currently over-harvested. The management of commercial fisheries needs a good scientific understanding of the dynamics of fish populations.

Population models developed for single fish species populations over 50 years ago still underpin sustainable harvesting schemes around the world. Harvesting represents an additional mortality acting on a wild fish population which, above a certain rate, will cause the population to decline until no fish can be harvested. Modelling allows prediction of the maximum sustainable yield – the rate at which fish can be harvested while keeping the number of available fish constant. In practical terms, fisheries models help to identify, for any fishery, the levels of fish abundance (from the record of catches) which correspond to this optimal harvesting rate. Typically, management involves establishing levels of fish abundance which indicate sustainable supply and those lower levels which indicate that the fish population will not replace itself and will go into decline. With the help of monitoring from fish catch data, harvesting is done to approach the first level and avoid the second.

Modelling of this kind has underpinned longstanding investment by DFID to support sustainable fisheries in developing countries. From a policy perspective, models help to show that a growing number of fishers, each acting to maximize their individual catch, will drive fish populations below the optimal harvesting rate, and may cause the fishery to collapse. The solution is to regulate fishing, for instance around a total allowable catch per season. Such regulation may be achieved by shutting the fishery once this catch is realized, or moderating the catches by imposing restrictions on the number of fishers or the duration of the fishing season. Recently, the use of "individual transferable annual catch quotas" has shown advantages over traditional regulatory approaches because it allows fishers to trade quotas, reducing the number of fishers and ensuring that those remaining have a catch sufficient to maintain their livelihood.[21] Optimal regulatory strategies depend on understanding how fishing communities respond to restrictions and incentives, as well as on the modelled dynamics of fish populations. Hence, successful, sustainable fisheries depend critically on understanding the behaviour of both fish and human populations, and a scientific approach requires both natural and social science elements.[22]

Fish are, of course, not the only harvested natural resource where modelling has a value to sustainable policies. Box 7.6 gives an example of how the same approach can be used in the management of woodlands by the rural poor.

Box 7.6 Harvesting non-timber forest products[23,24]

From 2003 to 2006 the DFID Forest Research Programme funded a study to assess the sustainable harvesting of bark widely used as traditional medicine in southern Africa. The project covered miombo woodland in Malawi and Zambia and afromontane forest in South Africa and Malawi.

Bark is usually harvested by removing strips at regular intervals to allow for bark healing. Clearly, removing too much bark could kill the tree, but it is difficult to know exactly how much can be removed, and over what period of time. Researchers collected experimental data over a three year period, and developed detailed mathematical bark growth and volume models for the species in the study.

The results of this work gave the team a better understanding of optimal harvesting rates, and led to some novel recommendations. For some tree species wood exposed by bark removal is susceptible to insect attack that carries in fungal infections which can rapidly kill the tree.

It was found that for these species strip harvesting is unsustainable at any rate and a better method is to fell the tree and harvest all the bark at once and achieve sustainability by growing a new tree.

In order to clearly present results to policy makers in the region, the models were incorporated into decision-support structures like the one in Table 7.2. This table allows users to examine any species being considered for harvesting, and based on observed wound closure and pest attack, choose an appropriate harvesting method.

Figure 7.12 – A roadside seller of herbal medicines outside a clinic in Zomba, Malawi. Most of the medicines are derived from miombo trees

Wound closure	Fungal and/or insect attack: 1 Major	2 Minor	3 None or neglible
None	Full tree harvesting	Full tree harvesting	Full tree harvesting
1 Poor	Full tree harvesting	Full tree harvesting	Marginal scope for strip harvesting[23]
2 Fair	Full tree harvesting	Marginal scope for strip harvesting[23]	Strip harvesting
3 Good	Marginal scope for strip harvesting[23]	Strip harvesting	Strip harvesting

Table 7.2 – Harvest method recommendations for tree species with different characteristics

Bark growth models were also used to make recommendations for the specific size and frequency of strip harvesting to use on species where this was determined sustainable (Table 7.3).

Wound closure	Fungal and/or insect attack: 1 Major	2 Minor	3 None or neglible
1 Poor			5cm strip 33 % of population
2 Fair		5cm strip 33 % of population	5-10cm strip 50 % of population
3 Good	5cm strip 33 % of population	5-10cm strip 50 % of population	10 cm strip 66 % of population

Table 7.3 – Strip harvesting recommendations for various tree conditions

Scientifically driven guidelines like these are now being used by the governments and NGOs in Malawi, Zambia and South Africa.

Modelling individual species, as is done for most natural resource models, is a relatively crude approach. We know that there are important interactions between species in ecosystems which are not captured in single species models. But modelling multi-species ecosystems is enormously complex. Recent advances in capturing and processing large amounts of environmental data will make this possible in the future. Scientific modellers also predict that improved modelling and computing technologies will allow us to add a more detailed, spatial dimension to modelling, and to model in "real time": measuring very recent environmental changes, feeding these data into models and generating predictions that allow us to take corrective measures immediately.

Finally, tomorrow's models will better integrate biological with economic elements, to provide powerful bio-economic tools for policy making, and to link the dynamics of resources with the economic value of the ecosystem services they deliver.

Putting a value on natural resources

A key contribution of the MA was to promote the concept of ecosystem services as a basis for putting a value on the sustainable management of natural resources. Valuing ecosystem services requires an integration of natural science and economics, and usually generates economic returns on different natural resource management options, from which the most appropriate policy can be derived. An example of this is shown in Box 7.7, for a tropical ecosystem in the Philippines.

Box 7.7 Valuing ecosystem services for forestry and fisheries[25]

On the Philippine island of Palawan in the 1980s, local communities of Bacuit Bay generated income from fishing and also tourism – as the Bay's coral reefs were popular with scuba divers. But increased erosion, and the flow of sediment into the bay from commercial logging in the surrounding highlands threatened fisheries and tourism income. Suspended sediment in the bay's water had a negative effect on the fish populations and on the survival of coral reefs. In effect, the processes which generated different ecosystem services to the community were closely inter-linked.

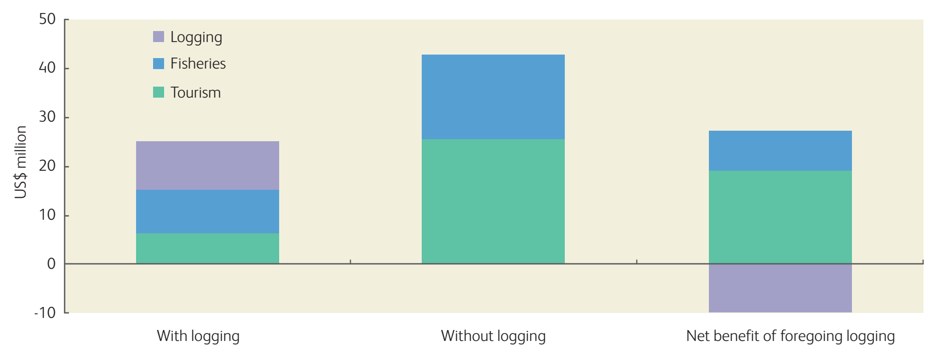

Figure 7.13 – Gross revenues over 10 years showing the benefits of foregoing logging in El Nido, Philippines[25]

As shown in Figure 7.13, an economic analysis of the value of the three ecosystem services: forestry, fisheries and tourism, estimated that the ten-year value of forestry was actually less than that of the other services combined, and that the value of fisheries and tourism without logging would be even greater. Hence the net benefits of foregoing logging (third column) outweighed the benefits of logging. This analysis led the government to ban logging in the area and to declare Bacuit Bay a marine nature reserve.

It is unlikely this decision to conserve the biodiversity of Bacuit Bay would have been made without an economic analysis of ecosystem services. Fisheries recovered, but ironically their rapid growth led to over-fishing and a decline in coral reef fish, which impacted on the tourism industry. So the need to understand the ecological interactions in this ecosystem and to measure the economic value of its services has continued.

Synthesis – new platforms for policy development

The last decade has seen a dramatic increase in research on ecosystem services and the development of a range of practical tools. It has involved a convergence and synthesis of scientific approaches. The use of remote sensing has enabled geographical representations of natural resources and their monitoring in real time. This information has been incorporated into a sophisticated GIS, which can also incorporate spatial information on human populations and economic processes. As a result natural resources and their dynamics can now be mapped onto demand for the services they provide. Hot spots can be identified, where demand for ecosystem services is exceeding supply, requiring policies that reduce resource use and restore sustainable, self-renewing supply. Modelling methods can be applied to these spatially detailed data sets to predict the consequences of policies into the future for sustainable development and well-being.

So far, efforts to take this synthetic, geographical approach have been restricted largely to developed countries. One developing country example relates to an important ecosystem in Eastern Africa, comprising an arc of mountains stretching from Kenya across Tanzania, described in Box 7.8. Natural Capital Project is mapping the ecosystem services provided by these mountain ecosystems, estimating their value, and using the information to inform and finance investments in conservation and restoration of natural resources. This new approach seeks to answer previously intractable questions such as: which parts of a watershed should be preserved to provide the greatest collective benefit to carbon sequestration, biodiversity, and tourism? or where would reforestation or protection achieve the greatest downstream water quality benefits? Geographic systems for evaluating ecosystem services have policy value to both developed and developing countries. However, the need for their use is more urgent in developing countries where resource loss is most rapid and where populations are more dependent on ecosystem services for their livelihoods.

Box 7.8 “Valuing the Arc” – ecosystem service management in Tanzania[26-28]

One part of the Natural Capital Project focuses on valuing ecosystem services for the Eastern Arc Mountains in Tanzania. These mountains have an unique biology; resulting from millions of years of isolation from other African mountain systems, as well as a global conservation value. But they also constitute a development challenge. After decades of steady logging, fires and farmland conversion, the forested area on these mountains has been reduced by almost 70 % . Forests are now fragmented across 13 mountain blocks. The forests support local

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Figure 7.14 – African violets, *Saintpaulia* spp, one of the most popular house plants in the world, are restricted in nature to the Eastern Usumbara Mountains of Tanzania where, like many other unique species, they are threatened by deforestation

Figure 7.15 – The Eastern Arc Mountains stretch from Kenya to Western Tanzania[26]

villagers, supplying firewood, medicinal plants, lumber and meat, but they also serve as the watershed for half a dozen rivers flowing into populated regions of Tanzania. Not only do they maintain a fresh-water supply for more than three million people but they also provide more than 50 % of Tanzania's electricity through hydroelectric power.

The research project concentrates on mapping and providing economic values for a range of ecosystem services across the mountains, including: hydrological services; carbon sequestration; timber products; non-timber forest productions; ecotourism; pollination services; governance and biodiversity. Integrated in a GIS format, it will be possible to determine how future decisions, such as the creation of roads or changes in forest or water management, will affect all ecosystem services and the economic benefits to local livelihoods and other stakeholders.

Reducing biodiversity loss – a development issue?

It is relatively easy to put a value on ecosystem services that directly support human well-being by supplying essential resources like water, fuel and food, or generate income, like forestry or farming. But what about that parts of ecosystems, where there are literally millions of species that have no apparent direct benefit to human well-being? Does their conservation – by reducing biodiversity loss and species extinction – serve a development purpose or only an environmental one? Does "saving the tiger" really help to reduce poverty, hunger and disease?

MDG 7 includes reducing biodiversity loss, with specific indicators relating to increasing protected terrestrial and marine areas and reducing extinction rates, for two good reasons.

Firstly, the provision of valuable ecosystem services is closely linked to the activity of animals, plants and microbes in the ecosystem. This does not mean that every plant or bird or insect species is important to human livelihoods. The past few decades of ecological research have helped us to understand that most ecosystems contain some degree of redundancy, or overlap, between the functions of species in ecosystems that would allow a species to drop out without affecting ecosystem processes and, hence, services. But among the many thousands of species in any ecosystem, there will be some which are particularly important, often called 'keystone species', whose disappearance will change ecosystem function and services.

Box 7.9 The ecologist, Paul Ehrlich, described the phenomenon of species redundancy in ecosystems in 1981 with a now famous analogy:

"Ecosystems, like well-made airplanes, tend to have redundant subsystems and other 'design' features that permit them to continue functioning after absorbing a certain amount of abuse. A dozen rivets, or a dozen species, might never be missed. On the other hand, a thirteenth rivet popped from a wing flap, or the extinction of a key species involved in the cycling of nitrogen, could lead to a serious accident."[29]

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Figure 7.16 – A wolf spider, one of the keystone predators in Asian rice systems, devouring a brown plant hopper.

However, we have still a poor understanding of which are the keystone species in different ecosystems. Indeed, we often discover this only after a species is eliminated and we suddenly lose an important ecosystem service, at which point a scientific 'hunting expedition' begins to discover the cause. For instance, in the 1980s when pesticide use in rice fields was initiated to protect the new, high-yielding rices of the Green Revolution, there was a region-wide outbreak of a previously little known pest, the rice brown planthopper. Scientists had no idea why a pest control chemical had removed natural pest control as an ecosystem service, with such devastating results. After some years of ecological research it became apparent that the chemical pesticides were eliminating general predators in rice paddies, like spiders – keystone species in reducing pests on rice. Integrated pest management measures were then introduced which resolved this problem (see Box 5.5), but it was not until 1999 that it was fully understood why these predators were keystone species in rice, but not in other local crops.[30]

Biodiversity as a source of future innovation

Another reason why biodiversity conservation is an important influence in reducing poverty is that biodiversity has an inherent value as a source of future technologies – particularly for agriculture and health. Much of this valuable, but poorly understood, biodiversity is found in poorer regions of the world, particularly the subtropics and tropics. Understanding such useful biodiversity may benefit the poor by providing new, inexpensive and renewable crops and medicines.

Of course, the value of local species of plants and animals has often been long recognized by the indigenous population, who have fashioned them into traditional technologies such as herbal medicines. But modern science has the potential to greatly improve and extend the benefits of this biodiversity to the well-being of communities that have discovered its value and to people worldwide.

All of our crop plants and domestic animals are derived from wild species. Local races, or related wild relatives, still contain genes which have potential value to agricultural production in the future. But this biodiversity is at risk. As agricultural production intensifies, production systems select and rely on fewer and fewer species and varieties. This results in a loss of important genetic diversity that could be used to improve the nutritional value of food crops, protect them from unexpected new pests or help them adapt to changing environmental conditions.

For instance in 2007, there were a reported 7,616 breeds of livestock. Of these 20 % were classified as at risk of extinction, and since 2001, 640 breeds have become extinct.[31] For plants, we have seen over 90 % reduction in the number of different varieties of some crop species in the past century.[32] Protecting agricultural biodiversity in order to give us a variety of resources to address yet-unknown future needs is a most urgent priority. Box 7.10 illustrates an important recent response: establishing and maintaining a living collection of the world's key crop plants and their genetic diversity.

Box 7.10 The Global Crop Biodiversity Trust

In response to the disturbing trend of crop variety loss, the Global Crop Diversity Trust was established in 2004, "to ensure the conservation and availability of crop diversity for food security worldwide."[33] It supports germplasm collections around the world and established, in 2008, the Svalbard Global Seed Vault, which provides a permanent storage facility for crop biodiversity below the permafrost on Spitzbergen, an island in the Norwegian territory of Svalbard, in the Arctic Ocean. The seed collections are duplicates of national collections which can be replaced if lost.

Figure 7.17 – The Svalbard Global Seed Vault

It is encouraging that between the 1996 and 2009 editions of the State of the World's Plant Genetic Resources reports, *ex situ* collections (e.g. those preserved as seeds in storage rather than as *in situ* living plants in the field) have increased by 20 % worldwide to reach 7.4 million accessions.

The Svalbard Global Seed Vault is a landmark undertaking in preserving future crop diversity. However, specialists agree that it is also crucial that crops, and their close relatives, which may carry beneficial traits for future breeding, are preserved *in situ*, that is, in the natural and agricultural habitats in which they have evolved and developed. The wild relatives of crops are often grown in areas that are particularly threatened by human activity. It has recently been estimated that 6 % of wild relatives of cereal crops (wheat, maize, rice, sorghum etc.) are under threat of extinction, as are 18 % of legume species (the wild relatives of beans, peas and lentils) and 13 % of species within the plant family that includes potato, tomato, eggplant, and pepper.[34]

What has just been said about the value of conserving natural biodiversity for future agricultural development applies equally to future improvements in health. Many wild plants contain chemicals of medicinal value. In many cases, their value is known locally, but is under-developed compared to their global potential for health improvement. For instance, *Artemisia annua*, a relative of the daisy found worldwide, has been used in China for over 2,000 years as a traditional herbal treatment for malaria. It was only in the 1970s that one of its chemical constituents, artemisinin, was developed as a modern drug and is now a key element of Artemisinin-based Combination Therapies (ACT) which underpin a new campaign for malaria control worldwide (see Chapter 6).

As with wild relatives of crop plants, much of this wild biodiversity of medical value is now threatened. *Catharanthus roseus* is a species of periwinkle, native to Madagascar, where habitat destruction has driven it to near extinction. Fortunately, it has been widely cultivated in other countries as an ornamental, and it is also used by some local communities for the treatment of diabetes. Some decades ago, the pharmaceutical company, Eli Lilly – while researching its medicinal properties – discovered the value of the periwinkle's constituent alkaloids, vincristine and vinblastine, in treating childhood leukemia and Hodgkin's Lymphoma. Today these are important, globally available cancer drugs.

The study of wild biodiversity and its potential global value to agriculture and medicine has involved many public and private sector organisations. Much of this work has been undertaken in developing countries, with their rich biodiversity. All too often, exploitation of this biodiversity has proceeded without benefit to the local communities where that biodiversity was found and conserved – communities which have often done much to recognise and develop its value through traditional technologies, such as herbal medicine. Exploitation of biodiversity in this way, without fair and equitable benefit sharing, is often called biopiracy. The inter-governmental Convention on Biological Diversity (CBD) came into force in 1993 with the aim of allowing developing countries to benefit from their biodiversity resources and traditional knowledge, by giving them more control over access to their local biodiversity and establishing agreed procedures for sharing benefits of its development, e.g. into new wonder drugs or super crops. However, the CBD and its member governments have made slow progress towards this goal, and "biopiracy" is still a concern.

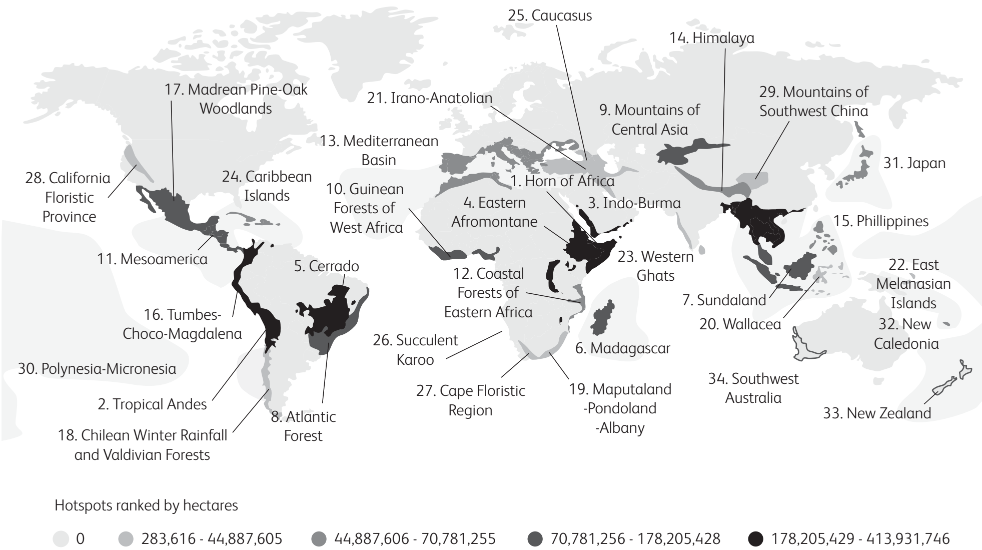
Threats to biodiversity

The major threat to biodiversity conservation worldwide is habitat destruction. A major contributor is the extension of agriculture and commercial forestry into terrestrial natural habitats, while pollution from terrestrial habitats has a major impact on aquatic biodiversity. Habitat destruction is often associated with poverty, due to pressure that large, poor populations put on the environment, and particularly natural environments which are marginal for production. This problem is exacerbated by the strong geographical association that areas of particularly high biodiversity have with regions of high poverty. Over the past decade, scientists have identified biodiversity "hot spots", specific areas of the earth's surface which are particularly rich in biodiversity.[35]

Figure 7.18 – Pollution of a riverbed in Morocco

The majority of the earth's terrestrial biodiversity is found in 34 biodiversity hot spots, comprising less than 2 % of the earth's land surface. The complete protection of these hot spots would preserve about 44 % of all plant species and about 35 % of vertebrate animal species. Figure 7.19 maps these global biodiversity hotspots. Each one is shaded according to its overlap with areas of high poverty. Darker shading means more hectares within the hotspot have high levels of undernourishment, economic poverty, poor access to clean water and high population pressure.[36,37] From this it is clear that many biodiversity hotspots are also areas of high poverty, where conservation of their rich biodiversity may bring local and global benefits.

Figure 7.19 – The 34 world biodiversity hot spots identified by Conservation International, shaded according to the area of these hotspots characterized as being under socio-economic poverty[37]



The second greatest threat to biodiversity loss, particularly in developing countries, arises paradoxically from the addition of species, not their removal. Alien plant and animal species, introduced by human activity into local ecosystems from ecosystems on other continents, will sometimes become invasive, dominating ecosystems and affecting biodiversity and ecosystem services.[38] In the Cape region of South Africa, for instance, a number of tree species, introduced for forestry, have invaded the highly sensitive native shrub vegetation, the fynbos. This highly localised flora comprises one of the world's six floristic kingdoms, comprising over 9,000 plant species, 6,400 of which are found nowhere else. In addition to threatening this unique biodiversity, invasive alien trees are drawing up water, reducing water supply for rural communities and threatening the water catchment area supplying Cape Town.

Managing alien species requires an understanding of their ecology, in order to find the best way of eliminating or containing their populations. Substantial success has been achieved, with benefits for both biodiversity conservation and poverty reduction. In South Africa, for instance, the Working for Water project has, since 1995, cleared more than one million hectares of invasive alien plants whilst at the same time providing jobs and training to approximately 20,000 people annually, from among the most marginalized sectors of society, of whom over 50 % are women.[39] Control of alien plants restores watersheds for these rural populations and nearby urban communities. Control methods range from traditional physical and chemical technologies, to innovative biological control methods that use specific natural enemies, parasites and pathogens of these plants to reduce their growth and spread.

4. Climate change mitigation

Perhaps the greatest contribution of science to the future of contemporary society has been the discovery and elucidation of the process of anthropogenic (human induced) climate change. The scientific method has been essential in establishing the convincing evidence base, without which, policy initiatives like the Kyoto Protocol would not have made progress. The scientific toolkits mentioned above for environmental measurement, monitoring, modelling and valuation, have been precisely those required to understand the problem of climate change and to evaluate measures to reduce its impact.

When the MDGs were created this scientific and policy process was only just underway. As a result climate change figures in only a handful of indicators under one target of MDG 7. Because of its importance, and particularly its relevance for international development, the next two chapters are devoted to the scientific evidence for climate change, its impacts on the poor and how developing countries can adapt.

In MDG 7 the indicator for climate change is carbon dioxide (CO_2) emissions – total, per capita, and per US$1GDP.

Over the past hundred years the bulk of emissions have been produced as a result of industrialisation and urbanisation. The developed countries have been mostly responsible for this along with, in recent decades, a growing contribution from newly emerging countries such as China and India who are undergoing rapid industrialisation. The less developed countries, on a country by country basis, have contributed relatively small amounts of GHGs to total global emissions. However, collectively they are a significant contributor, for instance through the processes of forest clearance and agricultural development.

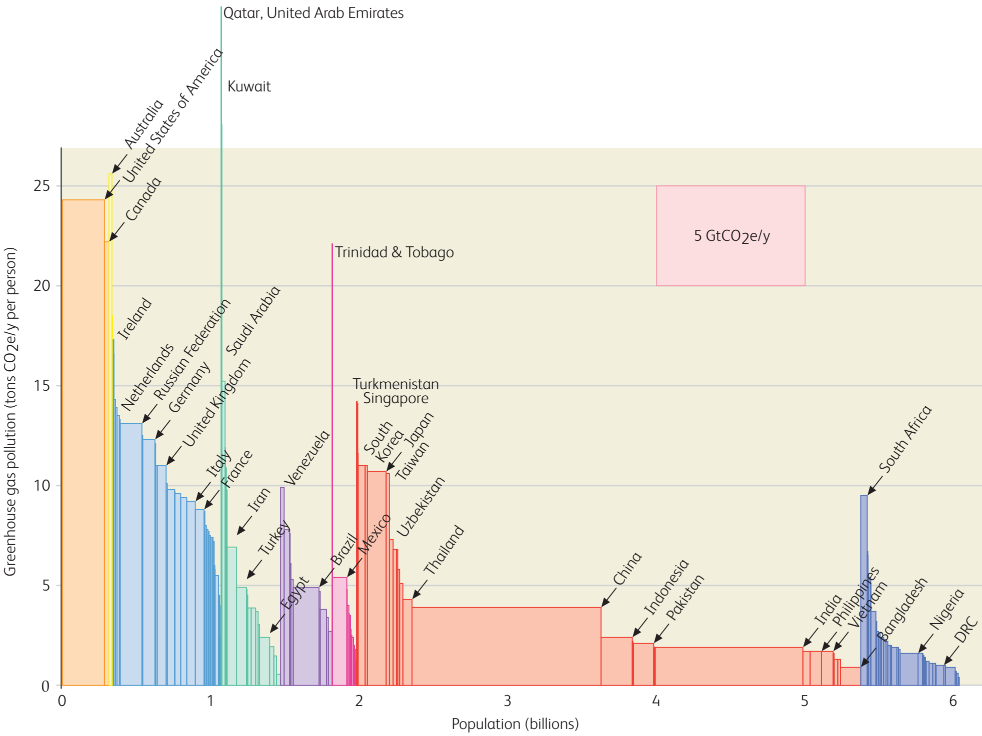
It could be argued that mitigation measures, therefore, should be principally the responsibility of wealthy countries. Indeed, most initiatives on climate change and international development have focused on assisting less wealthy countries with adaptation to, rather than mitigation of, climate change as this is the significant challenge for poverty reduction.

© Tran Thi Hoa – World Bank

Figure 7.20 – Traffic in Ho Chi Minh City

However, mitigation will increasingly become an issue for developing countries as they industrialize. Figure 7.21 compares the per capita production of GHGs for different countries and relates this to their population size. In this figure a country's contribution is the size of its box. Therefore countries with low per capita production and large populations, such as China and India, make substantial contributions compared to highly industrialized countries with lower populations and high per capita consumption.

Figure 7.21 – Per capita production of greenhouse gases[40]



Emerging economies, such as China and India, are now responding rapidly to the challenge of climate change. The Chinese government announced in 2007 the 'Middle and Long-term Development Plan of Renewable Energies', promising to derive 10 % of national energy supply from renewables by 2010, and 15 % by 2020. While this is a large goal, they are on track to do so. For example, by doubling wind power capacity for the fifth year in a row in 2008, they have surpassed the 12GW wind target for 2010 two years early.[41]

India is also looking to increase its renewable energy capacity, under its national action plan on climate change. In August 2009 the government announced plans to boost solar energy production from the current 51 MW to 20,000 MW by 2020.[42] In both of these rapidly emerging nations, investment in this area not only helps to mitigate future environmental and climate damages, but also offers uniquely practical and efficient ways to supply electricity both to a growing number of businesses and urban consumers, and to the millions of households in remote rural areas.

For the billions of people in developing countries with no, or expensive and unreliable, electric grid connections, advances in renewable energy technologies can provide appropriate and flexible alternatives to conventional energy supplies. Scientific advances have the potential to, not only contribute to mitigating climate change and reducing fossil fuel dependence and pollution, but also to bring economic, health and broader development benefits.

Here, we look at examples of work being done on low-carbon energy production in the private, public and partnership realms, both in highly industrialized countries such as the US, Germany and Japan, as well as in China and India. We focus on science innovations which have the dual benefit of addressing greenhouse gas mitigation and potentially delivering cost effective energy alternatives to the poor. We draw on examples from solar and wind energy production, where scientists are looking at ways to harness more energy from these natural sources, and on energy production from biomass products such as wood, agricultural residues and plants where the challenge is to use the resource more effectively.

Harnessing the sun's energy

The sun is the most sustainable, plentiful and fundamental of all our energy sources. It makes sense to utilise it as an alternative to oil-based power and as a way for developing countries to 'leapfrog' existing energy options. Solar energy can be a cleaner, healthier, more flexible and cheaper technology.

Energy from the sun can be harnessed in two ways. The first is to concentrate the sun's energy using lenses or mirrors, heat up a liquid, and use the heat source to power an engine. The second, and more widely known method, is to use photovoltaic cells which directly convert solar energy to electricity. Both these applications have the potential to become important components in the global energy supply mix and new efforts to combine these two technologies are yielding even more efficient systems. Solar energy technology is now at the point where wind energy was a decade ago – poised to make big improvements.[43]

Concentrating solar thermal systems

Energy from the sun was first used to power a steam engine as early as 1866. Since then a wide variety of 'concentrating solar thermal' (CST) methods have been developed to capture and concentrate the sun's rays and use the resulting heat source to power irrigation, refrigeration, locomotion or even conventional power plants. The basic components of CST systems include: a receiving device, such as parabolic trough, dish or chimney, a tracking system to follow the sun, and a power generation system. Advances in all three areas are continually making these systems more efficient and practical (Box 7.11).

Box 7.11 New ways of concentrating the sun's energy

At the Sandia National Laboratories in New Mexico, more than a decade of steady improvements have yielded a highly productive receiver-engine configuration. Eighty two mirrors on 38 foot wide parabolic Stirling dish 'suncatchers' concentrate light onto a receiver at the dish's focal point, heating liquid which is used by a simple Stirling engine to generate power. The suncatchers produce a heat at the foci equivalent to 13,000 suns. Engineers are now looking at new ways to store the energy, incorporating thermal storage tanks to keep engines running after the sun has set.[44]

Designers have also found a way to expand mirror surface area and reduce cost, by using a series of long thin mirrors moving on a single axis instead of the more expensive parabolic shape. This type of collector, known as a Concentrating Linear Fresnel Reflector (CLFR), was used in the first large-scale CLFR plant which began commercial operations in Spain in 2009.[45,46]

Most CST systems are quite large, but the technology is modular and scalable, and can be used in a variety of situations. Groups such as Raw Solar[47] and STG International[48] have developed smaller, simple receiving systems, with the latter expanding into developing countries such as Lesotho.

© STG International

Figure 7.22 – A woman collects water next to a protype CST system installed by STG International, in Ha Teboho, Lesotho, which generates hot water from a second tap

Photovoltaics

Since the invention of the first 'solar cell' in the 1880s, made with selenium, it has been possible to directly convert solar energy to electricity, without the use of an intermediate engine. The sun's visible and UV radiation is powerful enough to knock electrons free from the atoms of particular materials, called semiconductors. This creates a useful direct electrical current, known as the photovoltaic effect. In 1954 Bell Labs in the US discovered that silicon was particularly sensitive to light, and developed the first practical solar cell, which was soon being used to power satellites in space.

© US Air Force

Figure 7.23 – 70,000 PV panels on the Nellis Air Force Base in Nevada, US generate 15MW of power

Photovoltaics (PV) are currently the fastest growing source of renewable energy, with capacity increasing at around 50 % per year.[43] The first solar cells were able to convert about 6 % of the sun's energy; new crystalline silicon cells now average around 18 % efficiency. The price of producing energy with PV has fallen but, until recently, was still a long way off from the target of 5 cents/kWh needed to compete with coal. With advances in established silicon technology, as well as the development of 'thin film' cells which use new materials, PV is set to become a viable competitor.[49] As stated in a 2008 issue of *Nature*, *'In the future, new manufacturing methods that use alternative materials should make the capture of sunlight at least an order of magnitude cheaper than it is now.'*[50]

Solar cells made from purified crystalline silicon have been the mainstay of PV technology since the 1950s, and while expensive, partly due to the competition from the high-value silicon-chip market, they have become highly efficient through years of development. SunPower in California, for example, has introduced a number of small innovations to make their single-crystal silicon cells the most efficient on the market, at about 22 %.[51] New entrants into the purified silicon production market, such as China, could also bring the price down considerably, making this established technology more competitive.[52]

Recently, a new type of photovoltaic technology has emerged in the form of *thin-film* solar cells (Box 7.12).

Box 7.12 Thin-film solar cells

Rather than using solid wafers which are generally around two tenths of a millimetre across, thin-film cells are only nanometres to a few micrometers thick, and are produced using cheaper, more flexible, although less efficient and shorter-lasting materials.

The first thin-film cells were produced by depositing vaporized silicon directly onto a glass or stainless steel substrate. New, slightly more efficient cells are now coming onto the market using materials such as cadmium telluride (CdTe), and combinations such as copper indium gallium diselenide (CIGS). New dye-sensitized and organic solar cells are also being researched, which could allow for even greater breakthroughs in customization, flexibility and cost. First Solar, currently the largest producer of thin-film cells in the US, is already producing CdTe cells on a large-scale, and there appear to be great opportunities for the new thin-film CIGS.[49]

Finally, promising work is being done in combining CST receivers with PV cells – using magnifiers to concentrate the sun's energy and focus it directly onto high-efficiency solar cells, in order to further enhance efficiency. The company SUNGRI, also based in California, has produced *'Extreme Concentrated Photovoltaic'* (XCPV) units. These systems can magnify the sun's rays 2,000 times, which when focused on a solar cell, achieve 37 % efficiency, and lower production costs to around the 5 cents/kWh target. In order to deal with the extremely high temperatures generated by the focused light, SUNGRI has incorporated a new cooling system to keep the panels operating safely. Although still in the early stages of development, advances like these are likely to succeed as research and development increase to keep up with demand.[43]

All of these new developments are making solar technologies an increasingly practical solution to providing energy to consumers in developing countries. The use of solar technologies, particularly

PV panels, has risen dramatically in the last few years, with production and use in China, for example, expanding rapidly. Many businesses and households across Africa are beginning to buy and sell PV panels and other small solar products. A number of non-profit groups are also working in this area, with the aim of fighting poverty and climate change simultaneously. The Solar Electric Light Fund (SELF)[53] began in 1990 in the US, the UK group SolarAid, was founded in 2006[54] and Lighting Africa, a joint International Finance Corporation and World Bank programme, works to support the private sector in developing off-grid lighting technologies tailored for African consumers.[55] Box 7.13 below looks at some of the projects being pursued by SolarAid.

Box 7.13 Bringing the solar business to the poor[54,56]

When the UK Solar Energy company Solarcentury was founded in 1998, the owner decided to donate 5% of its net profits to help the poorest communities access solar energy. When Solarcentury eventually netted profits in 2006, the charity SolarAid was formed.

© Andy Bodycombe

Figure 7.24 – 'Sunnymoney' franchisee Moses Owiti demonstrates the panel he is selling in Kenya which can power a radio or LED light or charge a mobile phone

SolarAid works by helping developing countries by-pass dirty and expensive fossil-fuelled energy options, and benefit from specially tailored solar powered technologies. The group brings the professional commercial sector knowledge from Solarcentury, emphasizing entrepreneurialism and innovation, to both its 'micro' and 'macro' solar approaches.

First, at the micro-level, SolarAid works with individuals to train them as entrepreneurs, teaching them about technical and business skills so that they can sell and repair products such as solar LED lights and solar chargers for radios and mobile phones. The technologies are simple – the light bulbs and chargers are powered through monocrystalline PV panels – and the products are mass produced cheaply and efficiently in China for the African market. The merchants make money, and the consumers save money which they would have spent on kerosene, disposable batteries, and travelling to access phone charging stations.

SolarAid also works at the more traditional macro-scale, working with communities to install PV panels on schools, health clinics, and community centres. By bringing electricity to these buildings many new opportunities emerge, including teaching at night and running televisions and computers, safe storage of vaccines and medicines in refrigerators, and the option for communities to run adult training classes, or just get-together in the evenings.

Energy from the wind

Humans have been harnessing the energy from wind for over 2,000 years, constructing simple windmills to grind grain and pump water. The first wind turbines built to directly convert the wind's kinetic energy into electricity were constructed as early as the late 1880's. These were used to charge batteries and run electric generators, mainly on farms and in other areas without access to

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Figure 7.25 – A wind farm in Xinjiang, western China. The phrase on the tower reads "Xinjiang wind power company welcomes you"

grid power. In the last few decades, however, with a growing interest in finding alternative sources of energy, there has been renewed effort in improving turbine technology.

These efforts have resulted in great progress being made. Turbines have been developed which can achieve up to 50 % conversion efficiency, very close to the 59 % theoretical maximum.[57] Costs have been reduced to around eight cents per kilowatt-hour (kWh)[58], world wind power capacity is growing at around 30 % a year, and is predicted to reach around 3 % of world generation by 2012.[40,57] Engineers are continuously working to make turbines cheaper, more efficient, longer-lasting, more reliable and easier to produce and transport. They are tapping into new composite materials and looking at innovative designs which allow for larger, smarter blades which can flex with the wind. Advances are also being made in turbine placement – so that the wind can be used to its maximum.[57,58]

Today wind turbines are commonly built using tall steel towers (200-300ft), with three large (20-40m), light blades, made from glass-reinforced plastics, pointed into the wind by computer-controlled motors. The blades capture the wind energy and convert it to low-speed rotational energy – which is then fed into a gearbox and converted into high speed energy which can be used to power an electric generator. Average turbine capacity is now around 2MW and turbines are often grouped together on wind farms in suitable areas.

Wind power has a number of advantages. It is clean and renewable. It can also be added to on a piecemeal basis. One turbine, of any size, can be used for a small project, whilst for larger projects, turbines can be added one-by-one as time and funding allows. Designers are also developing increasingly diverse and tailored machines, using both horizontal and vertical axis turbines, and ranging from the very small (50W), to the very large (a 10MW off-shore turbine). With new technologies wind power is now becoming cheaper and more efficient – turbines can now be effective with wind speeds as low as four metres per second, making them a practical proposition in many more areas.[59]

Currently, wind turbine production is focused in a select group of countries (the top five producing countries are Denmark, the US, Germany, Spain and India). China is also rapidly developing capacity in this area, with 45 % of China's 3.4GW of wind installation in 2007 being supplied by domestic producers.[60] The biggest challenge to other countries wishing to take advantage of this technology is the transportation of the large amounts of material needed to construct the turbines. Nevertheless, many developing countries are making the investment, with significant installations in India, Egypt, Morocco and Kenya – where the wind turbines help to power homes, schools, and businesses.[61]

The development of smaller turbines is also proving very promising. These are used to perform tasks such as pumping water for drinking or irrigation, or charging car batteries for use as household electric supplies. A number of small non-profit groups have started working in this area. These include the Clean Energy Initiative working in Mozambique, the German group Green Step installing turbines in Cameroon, the group Blue Energy working on solar-wind hybrid systems on the Caribbean coast of Nicaragua and Wind Aid in Peru. Practical Action, a UK charity which focuses on developing appropriate technologies, is also working on micro-turbines in both Asia and South America as one of its many energy-related programmes (Box 7.14).

Box 7.14 Small-scale wind power in developing countries[59,62,63]

Rural families in developing countries all face a similar challenge – powering their homes without access to the grid. Many use car batteries, which they pay to have charged at businesses in nearby towns or cities, to run lights, televisions and radios. Kerosene lamps are also very popular, and solar panels are slowly being introduced to the mix.

In the late 1990s the non-profit group Practical Action started working in two countries, Peru and Sri Lanka, where many households use car batteries for electricity. Here they typically spend around 8 % of their income, travelling from one to two hours to reach a charging station. For those even farther away from a town, this was not even an option. With funding from DFID, Practical Action has worked with communities to design, test and pilot small-scale wind generators, which villages can use to power batteries – without the need to travel.

Figure 7.26 – One of 32 100W small wind turbines being installed in 'El Alumbre' in the north Andes of Peru. Three of the individuals shown were trained to install, operate and maintain the systems.

The turbines are small, with eight to ten metre tall steel towers, and three 0.7 metre-long fibreglass blades. Outfitted with permanent magnet generators the turbines average around 100W of generating capacity which, under the five metres per second average winds of Sri Lanka, is enough to keep around ten households regularly charged. The machines have been designed so that local small enterprise groups can construct them, and they are installed and maintained by the users themselves.

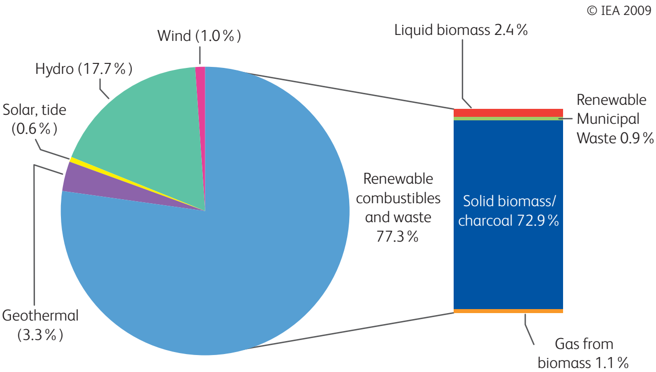
The machines currently cost around US$700, about one third of the cost of an equivalent machine constructed in an industrialised country, and are estimated to last for about 20 years. They are competitive with other alternatives, with the cost per kWh being the same or cheaper than diesel or solar. They also have the added benefits of saving time on travelling, encouraging local ownership and enterprise, and of course, acting as a clean and safe source of off-grid energy.

Over the years the technology has caught on, with over 100 units installed in different parts of Peru, including 34 solar-wind hybrid systems installed by the government. The idea has also spread to both Bolivia and Ecuador, and in Asia from Sri Lanka to Nepal.

Using biomass for fuel

Biomass, or any organic material which can be used for energy production, was the first source of energy used by humans, in the form of wood for heat and cooking, and it remains an important component of global energy production today. Green plant material is a valuable source of stored chemical energy, converted by the plants from the sun, through the process of photosynthesis.

Figure 7.27 – Biomass dominates world renewable energy supply



Biomass fuels include: woodfuels such as wood, charcoal and forestry residues, which are the most common, energy crops such as sugar and cereals, oil crops such as soya and *jatropha*, and agricultural and livestock by-products, such as stalks, straw and manure. These fuels may be produced as solids (e.g, charcoal), liquids (e.g. alcohol, biodiesel) or gases (e.g. methane). Bioenergy, then, is defined as any energy produced directly from biomass, and is considered a renewable energy source – as long as the materials are harvested sustainably, replaced, or grown for the specific purpose of energy production.

Since the industrial revolution most developed countries have used less and less biomass for energy production. However in recent years, with an increasing move to lower carbon alternatives, bioenergy – especially the growing of crops for the production of fuel for transport – has gained in popularity. Currently, bioenergy accounts for about 9 % of global primary energy supply, although there is a large variation between regions. As of 2001 developed countries obtained only about 5 % of their energy from biomass, while developing countries averaged around 22 %, with Asia at 19 % and Sub-Saharan Africa at 60 %.[64] In rural areas of developing countries, the figure is often as high as 90 % to 95 %.[65,66] This is the largest used source of renewable energy both globally and in developing countries, dwarfing the still growing hydroelectric (2.2 % of global supply), wind (0.125 %), solar and tide (0.075 %), and other renewable industries (Figure 7.27).[67]

Using more biomass for energy holds potential for billions of people without access to electricity or improved cooking fuels. The challenge, however, is to make energy production from biomass sources more sustainable and efficient: causing less GHG emissions and ideally acting as an additional source of income and enterprise. And, where crops are grown specifically for energy production, it is necessary to ensure that they do not compete with food production or distort food prices in ways which harm the poor.

A number of groups have recently formed to work towards this goal, some with a specific emphasis on developing country needs. The FAO, for example, works to support countries in strengthening their capacity to implement bioenergy programmes through assessing project potentials and reviewing policy options.[68] FAO is leading both the recently formed Bioenergy and Food Security (BEFS) project, which evaluates food security concerns relating to bioenergy,[69] and the International Bioenergy Platform (IBEP) – an attempt to bring together partners to address technical, policy and institutional questions.[70] The UN also launched the Global Bioenergy Partnership (GBEP) in 2005 to unite public, private and civil society stakeholders in promoting '*wider, cost effective, biomass and biofuels deployment, particularly in developing countries where biomass is prevalent.*'[71]

Below the issue is broken down into two areas – the household use of biomass for cooking and heating, and the larger-scale production of bioenergy for electricity or transport.

Household use of biomass

About three billion people rely on solid biomass fuels such as wood, coal and dung for cooking. Harvesting wood for stoves and for charcoal production degrades surrounding forests if it is not done sustainably. This leads not only to a decline in environmental health and an increase in soil erosion, but it also increases the time that women must spend searching for fuel.

In addition, the smoke released by these fuels, when burnt inside homes, more than doubles the risk of respiratory illnesses, such as bronchitis and pneumonia, leading to around 1.6 million deaths per year.[72] Rural women and children are the most at risk.

© Sara Delaney

Figure 7.28 – A woman cooks dinner in her smoky kitchen in rural Mali

There are a number of interventions that can be effective in reducing indoor air pollution, including improving fuels, reducing the time needed for heating food and technologies which improve the cooking devices themselves. Studies have shown that the health and productivity gains from these types of improvements are a good economic value.[73]

Switching from biomass to more efficient fuels, such as kerosene, Liquefied Petroleum Gas (LPG) and biogas, provides the greatest reduction in indoor smoke. While kerosene and LPG are usually expensive, biogas can be produced from cow dung mixed with water. Simple biogas units can anaerobically ferment the mixture and produce a gas which is 65 % methane, this can then be used directly for cooking or energy production.[74]

Improvements can also be made on cooking tools and stoves themselves, through simple modifications such as adding insulation, or more radical attempts to use advances in technology to create new ways of cooking altogether (Box 7.15).

Box 7.15 Improved stove designs

In many rural communities there is still limited access to alternative fuels. In these places, better stoves can reduce indoor smoke levels considerably.[72] On a simple level, cooking over open fires can be improved by constructing better insulated, mud stove structures around the pots. Practical Action in the UK has also developed a solution called the "fireless cooker." After cooking food on a traditional stove, the food is transferred to a simple basket, that is insulated with local resources such as banana leaves or old clothes and covered with dry heat-resistant polythene. The food then continues to cook over a long period of time using stored heat. This can reduce fuel use by 40 %, and save time in collecting fuel.[75]

Figure 7.29 – A woman uses an adapted SCORE stove in Nepal

A more ambitious attempt to improve stove design is the SCORE (Stove for Cooking, Refrigeration and Electricity) project. This project uses thermoacoustic technology, to convert biomass into electrical energy to power a stove, refrigerator and generator. Heated air from the burning biomass is sent through a resonating pipe, producing sound as it cools, which can then be converted to electricity using a device similar to a 'loudspeaker working backwards'. The amount of wood or dung that is needed to cook is halved when compared with an open fire, fewer pollutants are produced, and waste energy can be used for lighting or charging batteries. The work builds on research by Los Alamos, NASA and the US military to develop engines and refrigerators for a range of applications including the cooling of satellite systems. The SCORE research team, which comprises representatives from a number of universities in London and the charity Practical Action, aims to develop stoves that are acceptable technologically, economically and socially. They also want to ensure that there is scope for communities to set up businesses around the development of the SCORE stoves. Stoves are currently being developed and tested in Kenya and Nepal.[76]

Biomass for energy production

While communities in the developing world are already using biomass for household energy, new technologies are being developed which will open up opportunities for larger-scale and more sustainable energy production. Biomass can be used as a substitute for fossil fuels to generate heat, power, or transport fuel, either for an individual village, or an entire region. While fossil fuels are expensive and difficult to transport to rural areas, biomass materials, such as non-crop plants and agricultural residues are generally readily available in communities. Both non-crop and crop plants can also be grown specifically for energy production. In addition, bioenergy projects can lead to increased opportunities for employment and income-generation within communities.

There are a large variety of established technologies for converting various sources of biomass feedstock to energy. Depending on the feedstock source available, either thermal or biochemical processes can be used and the number of options are continuously growing. For example, wood or other solid fuels, such as agricultural residues, can be converted using simple combustion to produce heat which can be captured, or through gasification, where the fuel is partially burned at a high temperature to produce a synthetic gas. Manure and other animal or vegetable waste, can be converted using the biochemical process of anaerobic digestion, where the organic materials are broken down by microbial activity in the absence of air and at slightly elevated temperatures. This produces biogas (60% methane and 40% CO_2), which can be used for cooking or lighting, fuel or electricity generation using modified gas engines or turbines.

Of growing popularity is the use of sugar and starch crops for the production of fuel called bioethanol. Sugar crops, such as sugar cane, sugar beet and sweet sorghum, and starch crops, such as maize and cassava can be grown and converted using fermentation methods. The feedstock is ground, the sugar is dissolved out and then fed to yeast in a closed, anaerobic chamber. The yeast ferments the sugar to produce ethanol which is then distilled to produce bioethanol. This can be used on its own in specialised combustion engines, or mixed with petrol. There are however drawbacks to this method, including the competition it places on land which could otherwise be used to grow food-crops, and the inefficiency of the conversion process.

Finally, oils such as animal fats, waste cooking oil, or those derived from rapeseed, sunflower, soya, palm, or coconut can all be converted through a process called transesterification. The oil is reacted with an alcohol and a base catalyst splits the oil into glycerine and methyl esters forming biodiesel. The biodiesel can then be used as fuel in a diesel engine. Engines can also be modified to run on less purified forms of oil, such as straight vegetable oil (SVO) or the oil from the seeds of plants such as *Jatropha curcas*, described in Box 7.16 below.

Box 7.16 Jatropha powered rural electrication in Mali[77]

In the Garalo commune in southern Mali, 33 villages have successfully united in a local energy production project. The area is using oil from the seeds of the shrub *Jatropha curcas* to power a hybrid power plant, which has the capacity to serve a 13km wide network of households.

Jatropha, known as *bagani* in Mali, is an inedible perennial shrub which grows widely across the country, thriving in poor soils with little water. The small tree is often planted as a 'natural fence' around crop fields, because its smell and taste repels grazing animals. The Royal Tropical Institute estimates that there are currently more than 22,000 linear kilometres of the bush in Mali.[78] Jatropha is a long-term investment – while seed production starts within six to nine months, the plant does not reach maturity for five years, and will remain in constant production for up to 25 years, and can live for up to 50 years.[79]

The seeds of jatropha can be pressed to yield a high-quality oil, due to their 32% oil content, 3kg of seed will yield about 1 litre of oil. The seeds are pressed using a locally manufactured machine, which itself is powered by jatropha oil – the energy used to press the nuts amounts to less than 10% of the oil obtained. The residues from the seeds are higher in nitrogen and phosphorous than cow dung, and so act as an excellent organic fertiliser that can be used on other food crops or sold.

Experimenters discovered in the early 1990s that jatropha oil could be used to power diesel engines, but at the time diesel prices were low, and switching over did not make economic sense. Now, with oil prices rising, and a commitment by the Malian government to increase

Figure 7.30 – *Jatropha curcas*

renewable energy use, jatropha-powered energy production is gaining in popularity. The oil is being used to power small-scale generators for a wide-variety of uses, as shown in the *Energiebau* example in Chapter 3. In Garalo, however, project leaders are scaling-up this idea quite dramatically.

Initiated by the Mali Folke Centre (MFC)[80] in 2006, the Garalo project in rural electrification is funded by the FACT Foundation,[81] a Dutch group that promotes the use of biofuels for local development, and *Stichting het Groene Woudt* (SHGW), another Dutch NGO. A government-supported grant from AMADER, a parastatal company in charge of rural electrification, is also used to reduce household tariffs.

The team has worked with the local community to increase jatropha production in the region. Farmers are intercropping jatropha with their normal crops and on land previously used for increasingly less profitable cotton production. As of 2008 they had 600 hectares under production, but they are eventually hoping to be working on up to 10,000 hectares. The jatropha nuts are harvested by the farmers, processed by the local cooperative using the oil press, and the oil is then sold to the local power company ACCESS at an agreed price.

ACCESS is running a 300kW capacity vegetable oil-diesel hybrid power plant. The group is starting with a 5 % jatropha oil blend and plans to slowly scale-up to 100 % by 2013 as jatropha production increases. The power is then sold back to connected households in the area. As of April 2009, 283 connections had been set up, which puts the plant at about 23 % capacity. Around ten new connections are being added each month, with 90 % recovery of bills reported.[82] While the project is still in the beginning stages, all of the necessary institutional connections and agreements are in place for a project which will not only bring electricity, but will also generate income for the community.

Figure 7.31 – Extracting oil from jatropha seeds using a press

A number of challenges need to be addressed in order to move to successful and sustainable use of biomass for large-scale production. These include: competition with food production, the need for stable land ownership due to the long-term commitment needed, and technical and market support for the production process. Some of these needs are being addressed through new conversion technologies, including second-generation bioethanol and biodiesel which will enable synthesis of previously unusable plant products. This will make processing cheaper and easier. Lessons are also being learned and documented as current projects progress, which will help in the development of more appropriate institutional and policy support.

5. Water supply and sanitation

Despite its critical importance to international development, and its scarcity in many poor countries, there is no headline MDG for water. In MDG 7, the subject is split between water resource conservation, as one of a number of natural resources for conservation and restoration, and the specific target of sustainable access to safe drinking water and basic sanitation. This division reflects a long-standing split of research in this area between ecologists and hydrologists, who address the generation and distribution of water resources arising from catchments, and engineers and health specialists who have a specific interest in the supply of clean, safe water and sanitation to communities.

Needless to say, this historical division of effort on water issues is rather artificial. Watersheds must be managed to supply water sustainably to a wide range of stakeholders, not just households with their needs for safe water for drinking, washing and cooking, but to agriculture and industry as well. This challenge of sharing a limited resource across a range of societal needs cannot be achieved without good water governance, at the local, national and international level. As with other elements of MDG 7, improvements in policy are key to making progress, and science innovation can support this process by providing tools for monitoring, measuring and valuing, and in some cases by developing new enabling technologies. However, many of the technologies required for addressing the water needs of the poor, from pumps to filters, are already available and only need deployment.

Bearing in mind the overriding need for good water governance, the specific demand for clean water for drinking and sanitation enjoys a high profile because of its implications for human health. Water and sanitation are intimately linked. Poor sanitation, and particularly the spread of disease from person to person by contact with excrement, is mediated by the availability and sources of water for drinking and washing in many communities. The available data suggests that 884 million people currently lack access to safe water and 2.5 billion to basic sanitation.[83] About 1.5 million children die each year due to diarrhoea, primarily caused by unsafe drinking water and inadequate hygiene and sanitation. This is equivalent to 170 child deaths from diarrhoea per hour.[84]

Indeed, it will be virtually impossible to achieve the infant and maternal mortality targets of the MDGs without improving poor people's access to safe water and sanitation facilities. In addition, the need to collect water, and the absence of toilet and sanitary towel disposal facilities have negative impacts on girls' attendance at school, thus hampering progress towards the universal primary education and gender equality targets. Water supply and sanitation therefore represent an important point of leverage for several of the MDGs.

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Figure 7.32 – A young woman pulls water from a well in Mali

In order to achieve the water and sanitation targets, as of 2005, about 175,000 people needed to gain access to safe water and 350,000 people to basic sanitation every day until 2015.[85] However, it is now clear that at current rates of progress, this water target will not be achieved in many countries in Sub-Saharan Africa and the sanitation target will be missed in both Africa and Asia by 700 million people.[83]

The reasons for this are diverse and many relate to governance and institutions. Water and sanitation are generally not given a high priority in government. Demand for sanitation is not always clearly expressed and its implementation involves infrastructure and service, as well as hygiene promotion programmes. Responsibilities for different parts of the problem may lie in different ministries, which makes progress slow, while different donors and development agencies frequently take an individual approach within a given country.[86]

Donor assistance for water and sanitation has been steadily increasing since 2001,[87] as has political support for the sector. The UN's Water Supply and Sanitation Collaborative Council (WSSCC) launched the Global Wash Campaign in 2004,[88] 2008 was designated the International Year of Sanitation[89] and the Global Sanitation Fund was opened the same year. However, aid in this sector is often poorly targeted, with only about 24 % going to Sub-Saharan Africa.[90]

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Figure 7.33 – Water from a community tap in Sri Lanka

Supply of clean water

Infrastructure is a key constraint to water supply, particularly in rural areas, where 70 % of the people live without clean water and 70 % have inadequate sanitation. Extensive research in recent decades has led to a range of intermediate technologies which are relatively low cost, easy to maintain and appropriate to local, social, financial and geographical conditions in the developing world.

Institutions like Water Aid promote a portfolio of technologies for water sourcing and provide guidance to help communities select and build the most appropriate technology for their needs, whilst encouraging and supporting the development of new technologies (Figure 7.34).[91]

Figure 7.34 – The wide range of proven technologies to increase the supply and quality of water for the rural poor. They represent largely intermediate technologies, developed by integrating innovative science and an understanding of local conditions and resources[92]

Water source	Capital cost	Running cost	Yield	Bacteriological water quality	Situation in which technology is most applicable
Spring protection	Low or medium if piped to community	Low	High	Good if spring catchment is adequately protected	Reliable spring flow required throughout the year
Sand dams	Low – local labour and materials used	Low	Medium/High – depending on method used to abstract water. Water can be abstracted from the sand and gravel upstream of the sand dam via a well or tubewell	Good if area upstream of dam is protected	Can be constructed across seasonal river beds on impermeable bedrock
Sub surface dams	Low – local labour and materials used	Low	Medium/High – depending on method used to abstract water. Water can be abstracted from the sand, gravel or soil upstream of the sub-surface dam via a well or tubewell	Good if area upstream of dam is protected	Can be constructed in sediments across seasonal river beds on impermeable bedrock
Infiltration galleries	Low – a basic infiltration gallery can be constructed using local labour and materials	Low	Medium/High – depending on method used to abstract water	Good if filtration medium is well maintained	Should be constructed next to lake or river
Rainwater harvesting	Low – low cost materials can be used to build storage tanks and catchment surfaces	Low	Medium – dependent on size of collection surface and frequency of rainfall	Good if collection surfaces are kept clean and storage containers are well maintained	In areas where there are one or two wet seasons per year
Hand-dug well capped with a rope pump	Low	Medium – spare parts required for pump	Medium	Good if rope and pump mechanisms are sealed and protected from dust. Area around well must be protected	Where the water table is not lower than six metres – although certain rope pumps can lift water from depths of up to 40 metres
Hand-dug well capped with a hand pump	Medium	Medium – spare parts required for pump	Medium	Good if area around well is protected	Where the water table is not lower than six metres
Tube well or borehole capped with a hand pump	Medium – well drilling equipment needed. Borehole must be lined	Medium – hand pumps need spare parts	Medium	Good if area around borehole/tubewell is protected	Where a deep aquifer must be accessed
Gravity supply	High – pipelines and storage/flow balance tanks required	Low	High	Good if protected spring used as source	Stream or spring at higher elevation – communities served via tap stands close to the home
Borehole capped with electrical/diesel/solar pump	High – pump and storage expensive	High – fuel or power required to run pump. Fragile solar cells need to be replaced if damaged	High	Good if source is protected	In a small town with a large enough population to pay for running costs
Direct river/lake abstraction with treatment	High – intake must be designed and constructed	High – treatment and pumping often required. Power required for operation	High	Good following treatment	Where large urban population must be served
Reverse osmosis	High – sophisticated plant and membranes required	High – power required for operation. Replacement membranes required	High	Good	Where large urban population must be served
Household filters	High – certain filters can be expensive to purchase/produce	Filters can be fragile. Replacement filters can be expensive or difficult to source	Low	Good as long as regular maintainance is assured	In situations where inorganic contaminants are present in groundwater sources or protected sources are not available
SODIS (solar disinfection)	Low – although clear bottles can be difficult to source in remote areas.	Low	Low	Good	In areas where there is adequate sunlight – water needs to be filtered to remove particulate matter that may harbour pathogens before SODIS can be carried out effectively. SODIS is not appropriate for use with turbid water

= most preferable = preferable = least preferable

While most appropriate technology for supplying clean water to poor populations is based on conventional and intermediate technologies, advances in nanotechnology may provide dramatic breakthroughs in clean water supply in the future. As discussed in Chapter 2, this new platform technology is finding application in the design of filters to remove disease causing agents and toxic chemicals from water. The technology relies on the unique properties that materials have at the extremely small, nano (one millionth of a millimetre) level. For polluted water, there are a number of approaches. Nanomembranes are manufactured with holes that allow water through, but not larger molecules of toxic chemicals, or much larger viruses or bacteria. Carbon nanotubes provide a similar barrier, trapping all but the small molecules that can pass through the tubes. Some natural attapulgite clays and zeolites have nano properties and can be used in nanofilters. Another approach is to produce nanoparticles which can be placed in water, where they bind with chemical pollutants and can then be removed. Magnetized nanoparticles, for instance, can be removed from water with a magnet, once they have bound target pollutants. Finally, nanocatalysts are materials that facilitate the breakdown of toxic substances in water. Their nano size makes them particularly active.[93]

Nanotechnology has many potential applications in water purification, from removing micro-organisms, to removing chemicals such as arsenic, which is a major problem in groundwater in South Asia and other regions, and pesticides and other chemicals from waters used in industry. A similar approach can be used to desalinate sea water for human consumption. South Africa, India and China have all invested heavily in nanotechnology research for water purification, as have many companies in wealthy countries. The cost of nanomaterials is a limiting factor in the application of these technologies but further research may reduce these.

Sanitation

While there are many challenges to realizing MDG 7 targets for water supply, the current situation for sanitation is worse because the challenge has attracted less attention than water provision. Here again, the appropriate technologies exist to build latrines which will reduce open defecation and thereby address one of the major sources of diarrhoeal diseases and other illnesses. In rural areas, various designs of pit latrine can remove both faeces, and the fly vectors of faeces-borne pathogens, from communities. In urban areas, the technical challenge is to provide latrines capable of managing high volumes of faeces, which would normally require a capacity for sewage removal where sewers are not available. Like water sourcing, sanitation technologies have substantial up-front costs for poor communities, to which governments in developing countries have generally not been directing sufficient resources.

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Figure 7.35 – Toilet facilities like these do not inspire use

While there has been more effort in recent years to improve global sanitation by increasing the number of households who have access to an adequate toilet or latrine, this is only part of the equation. People will decide where they defecate based on a wide range of factors, including distance, privacy, comfort, smell, cultural norms, and often lastly, perceived benefits to individual and community health. Having access to a latrine – particularly if it is not private or clean – does not guarantee use. In rural areas, many people find it more pleasant, and culturally acceptable, to defecate outside. In urban areas however, the problem is often lack of effective facilities.

The challenges here are broad. On the technical side it is important to ensure that facilities are being designed which not only provide the necessary health benefits, but also respond to the desires of consumers.

For millions of urban households worldwide one of the challenges of using a pit latrine which is not connected to a sewer network, is emptying the latrine. For years, families in both rural and urban areas have done this task manually – either doing it themselves or hiring others – and usually dumping the excreta in uninhabited areas or using it as compost for fields. In the developing world as a whole, around 90 % of sewage is discharged, untreated, into rivers, causing pollution, contaminating drinking water and harming aquatic life.[94]

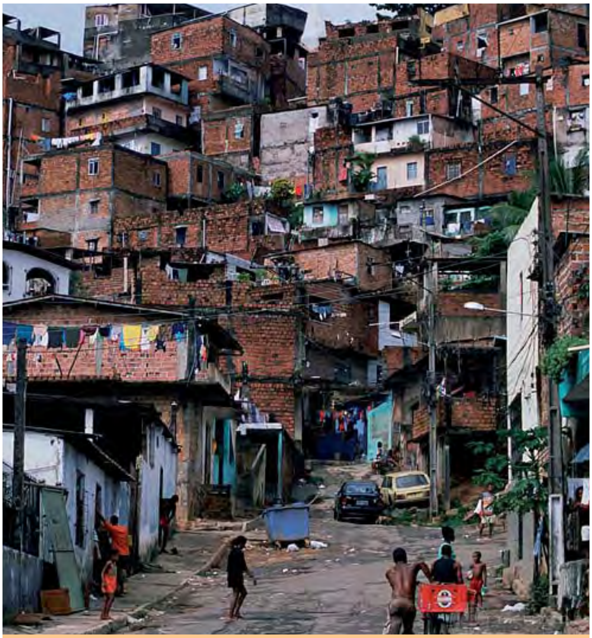

Figure 7.36 – The slum area of 'Favela' on the outskirts of Salvador de Bahia in Brazil

Growing urbanisation is now confounding this problem, with millions migrating to cities, often in unplanned urban settlements, or slums, each year. They are all constructing houses and latrines which are not connected to any waste treatment facility. And, in such crowded areas, manual emptying becomes not only hygienically dangerous to those doing the job, but to all those around, and finding a place to dump the waste becomes increasingly difficult. As population density increases, it also becomes less feasible to cover a pit, dig a new one and construct a new structure, notwithstanding the cost of doing so. Urban inhabitants are therefore forced to either resort to open defecation, or use increasingly crowded shared facilities.

All of this adds up to a huge environmental and health problem. While some work has gone into the development of toilets, very little has been done to address the problems of pit emptying and waste disposal. Conventional vacuum tankers, which are used for this purpose, cannot operate in the narrow and crowded slum settlements, and thus attempts have been made to modify their design. In 1988 the Dutch NGO, WASTE, piloted a miniaturized, manually operated version of a tanker called MAPET in Dar es Salaam, Tanzania. However, it never really took-off because of the cost (£950) and a number of organisational problems. In 1995 an Irish engineer, Manus Coffey, working with UN-Habitat, developed a similar product powered by a gasoline engine, called the Vacutug. This had some success in the slums of Kibera in Kenya. However, the tanker is expensive (~£4,500) to both construct and operate, and while it has been moderately successful, the team has encountered problems with cost-recovery and manoeuvring the tanker in crowded areas.[95,96]

A researcher at the London School of Hygiene and Tropical Medicine (LSHTM), Steven Sugden, saw the need for a simple technology to fill the gap between tankers (of any size) and manual diggers. Box 7.17 describes the inexpensive hand-pump he helped to develop and pilot in Dar es Salaam, and how this has spurred further innovation in the field.

Box 7.17 The Gulper – filling a gap in urban sanitation[95,96]

© Steven Sugden

Figure 7.37 – The Gulper in use in Dar es Salaam

Looking to introduce a new technology into the limited range of latrine-emptying machines, Sugden approached Steven Ogden, an agricultural engineer and farmer in Yorkshire. They came up with the 'Gulper,' a direct action hand pump adapted from water pump principles. The Gulper fits into the hole in the latrine slab, and with one or two operators it brings the sludge out through an outlet pipe and into a container. Importantly, the Gulper is relatively cheap (~£55 manufacturing price in Dar es Salaam), durable, small, portable, and can be constructed with local materials.

Trialling of the product began in Dar Es Salaam in 2007, a city with a population of 2.8 million, only 10 % of which is served by sewers. This causes wide-spread health problems. In 2006, 60 to 80 % of the city's hospital cases, and 97 % of out-patients at health centres, were suffering from sanitation related diseases. In an attempt to reduce this huge problem, a group from WaterAid and LSHTM set up local, small-scale entrepreneurs with Gulpers, which they can use to empty customer's latrines, and then transport full containers, on the back of motorcycle based tractors, to the city's waste treatment plant.

Results have been positive, with local people saying they like using the services of the Gulper operators. And although the cost is still relatively high, (around £2 to remove 50 litres), it is cheaper than building a new latrine, and it is 'quick and clean.' The biggest limitation is the inability of the Gulper to cope with the denser, compacted sludge at the bottom of pits – as this requires more power to lift. Thus, at the moment, the Gulpers are only dealing with the top 70cm of waste.

Continued innovation is required, and Sugden and Ogden have recently developed a new model called the 'Nimbler'. This is based on the rope and washer pulling method used in the 'Elephant' water pumps.[97] The pump is able to draw up thicker sludge and is also constructed entirely from locally available materials such as bicycle parts.

Sugden says that while neither the Gulper nor the Nimbler may be the final product needed to address the issues in Dar es Salaam, or other cities, he thinks that this work may have helped to 'catalyse' work in an area which had been static for decades. International meetings on the subject are beginning to take place, with UN-Habitat, OXFAM and other NGOs increasingly recognising the importance of addressing the full cycle of sanitation management and supporting the development of the technology needed.

The final target of MDG 7 is to reduce the number of people living in urban slums. We will not discuss this target in detail here, but would note that the four key challenges for improving the lives of slum dwellers are to improve water, sanitation, living space and building tenure and durability. So far, science innovation has found particular application with the first two, water and sanitation, as discussed above.

6. Conclusion

The relationship between the environment and development has a complex and sometimes strained history, particularly with respect to economic growth. Scientific and technological advances in agricultural production, public health, and other areas, have often had negative environmental consequences. The incorporation in the MDGs of environmental targets is therefore significant. While some targets of MDG 7 lack the clarity needed to focus effective action, they make an important first step in integrating environmental targets into a framework for development.

For agriculture and health, as we have seen, recent scientific innovation has focused largely on the development of new technologies which will directly benefit the poor. For MDG 7, the contribution of science innovation is rather different. The importance of policy to environmental sustainability, and the need for environmental mainstreaming, has stimulated the development of scientific tools for policy making, specifically earth observation, modelling and GIS technologies. Perhaps most importantly, through the concept of ecosystem services, science has given policy making the tools it needs to value the environment so that it can be explicitly incorporated in development goals and programmes.

The importance of science and innovation to policy is nowhere more clear than in the understanding it has given us of the environmental and societal consequences of climate change. Written today, MDG 7 would place much more emphasis on climate change and on adaptation as a major development challenge. We devote the next two chapters to this issue. As it was written, MDG 7 focused on mitigation of climate change. While the science of climate change mitigation has its principle application in those developed and emerging economies which are contributing most to greenhouse gas generation, it has been remarkable to see how the rapid development of science for low carbon energy production has generated appropriate technology for low cost energy production for the poor.

The opportunity to better link MDG 7 with targets in other MDGs emerges clearly in opportunities to improve health through improved cooking stoves and, particularly, improved water supply and sanitation. While many of the technological tools to achieve these aims exist already, there is enormous scope to enhance these intermediate technologies through engineering innovation in materials and processes, for instance in the application of nanotechnology to water filtration systems in poor communities. This link between environment and health illustrates the kind of integration of environmental thinking into development that needs to be developed in future across the MDG portfolio.

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