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Impacts of Pollution on Ecosystem Services for the Millennium Development Goals

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FOREWORD

The Millennium Development Goals (MDGs), which grew out of the September 2000 United Nations Millennium Declaration and were agreed upon by UN member nations in 2001, represent eight time-bound goals focusing on various aspects of human development, including poverty and hunger, education, gender equality, environmental sustainability and global cooperation for development. The year 2015 was set out for achievement of all MDG targets.

In 2005, a third of the way towards the target year, SEI presented the report, "Sustainable Pathways to Attain the Millennium Development Goals: Assessing the Key Roles of Water, Energy and Sanitation". The report showed that with the appropriate investments, sustainable solutions to improve the living conditions of the world's poorest and weakest communities are not only achievable, but may in some cases be cheaper than other less sustainable and more short-term solutions to today's problems (Rockström, 2005). The study looked specifically at investment needs in the water and food, energy, and sanitation sectors. It concluded that the investment level for sustainable solutions to water, food, sanitation and energy would be approximately USD 107 billion annually between 2005 and 2015. It also outlined specific solutions for sustainable MDG attainment such as schemes for upgrading rainfed agriculture and how to accelerate energy access to the poorest.

The present report, prepared in 2010, two-thirds of the way to the target year, reviews the current situation and looks ahead towards 2015 for reaching the MDGs with a focus on two of the targets under the MDG 1, halving extreme poverty and hunger, in relation to ecosystem services that support food production and livelihoods. The review looks specifically at how air pollution, energy production and pesticides put additional pressure on ecosystems and their ability to supply services for human wellbeing. Thus, the present report seeks to contribute to an improved understanding of the conditions that influence MDG attainment in order to enable a more accurate evaluation of the range of policy responses at hand.

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Among the authors, Persson, Noel and Lannerstad were the main contributors to the introductory chapter, Morrissey to the chapter on Air pollution, Arvidson, Senyagwa, Lindskog and Nilsson to the chapter on Energy and Persson to the chapters on Pesticides and Discussion and conclusions.

CONTENTS

EXECUTIVE SUMMARY

This report has examined three stress factors that have the potential to decrease the supply of ecosystem services, thus reducing the chances of reaching the Millennium Development Goal 1 (MDG 1) in a sustainable way. Air pollution, energy generation and indiscriminate use of pesticides may affect provisioning, regulating, supporting and cultural ecosystem services. Ecosystem services like crop production, collection of wild food and biomass, climate regulation, nutrient cycling, pollination and disease and pest regulation are all vital to a sustainable MDG attainment. In view of the poor advances towards reducing poverty and hunger, it is clear that the margin for negative impacts on ecosystem service supplies is very small.

Air pollutants such as ground-level ozone (O_3), nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2) all have major impacts on ecosystem services. It is likely that these impacts will undermine the efforts to reach the MDGs, both in terms of providing sufficient crop growth to reduce hunger and maintaining diverse natural ecosystems. These impacts are seen also in developing nations, particularly in south Asia. Projections of pollution impacts to 2030 highlighted two main issues: the growing importance of air pollution impacts in south Asia and the need for effective policy measures to be implemented immediately. Reductions in crop yields caused by ozone are predicted to be substantial globally but are already high: in India the economic impact of these losses is currently estimated to be in the region of USD 4.4 billion annually and may increase 5-15 per cent by 2030.

The current energy use of the poor is neither sufficient to attain the MDGs nor is it sustainable in terms of maintaining important ecosystem services that can facilitate a transition out of poverty. Meeting the basic energy needs of the poor with minimised impacts on the ecosystem services needed for other aspects of MDG 1 attainment such as food production and livelihood support is thus vital. The additional energy required to meet basic pro-poor energy needs is small, despite the number of people that need to be served. Universal basic energy access would mean an increase of only a few per cent of global energy supply. Furthermore, achieving universal modern energy access could reduce local pressure on ecosystem services and reduce global warming. The investments needed to achieve universal modern energy access are also small in comparison to the annual investments in the global energy sector.

There are unintended negative effects from pesticide use on several ecosystem services vital to food production including pollination, natural pest control, nutrient cycling and wild food supplies. Currently, pesticides are used in an uncontrolled way in some parts of the world, for example in southeast Asia. Without careful handling, especially of the most hazardous pesticide products, the risk of severe negative effects on the health of the farmers and their families as well as on the supply of local ecosystems services is high. Products like fipronil, carbaryl and cypermethrin, which have been reported to be used in an inappropriate way in some countries have for example a high potential for reducing the supply of wild foods such as insects, frogs, crabs, fish and snails. There are important knowledge gaps, especially concerning long-term impacts of the use of multiple pesticides.

Based on the findings of the report, the following opportunities in support of the attainment of the MDG 1 targets were identified:

- Consider the various pressures on ecosystems in local and national planning for development in order to reach the MDG 1 and improve the management of ecosystems for multiple ecosystem services.
- Urgently improve the national level pro-poor energy development, air pollution emission controls and chemicals management to support attainment of the MDG 1.
- Introduce immediate air pollution emission controls in all countries in order to curb the effects on crop yields, especially in south Asia.
- Create pro-poor energy policies and regulatory frameworks at the national level to attract required investments and to build national capacity within the public and private sectors to deliver sustainable energy to the poor.
- Strengthen actors' ability at the national level to assess energy alternatives, including their impacts on ecosystem services and their implications on the most vulnerable.
- Strengthen legislation on pesticides and other chemicals and ensure its enforcement in line with the Strategic Approach to International Chemicals Management (SAICM) in order to reduce the

- the Strategic Approach to International Chemicals Management (SAICM) in order to reduce the current high risks to people and the environment from the indiscriminate use of pesticides.

- Intensify the training of farmers in Integrated Pest Management and pesticide risk reduction schemes in order to avoid decreased supplies of the local ecosystem services needed for MDG 1 attainment.

- Encourage research efforts to establish the long-term impacts of pesticide use on food production, especially regarding microbial nutrient, carbon cycling and the short and long-term cumulative impacts of different agrochemical inputs.

ECOSYSTEM SERVICES AND THE MDGS

In its 2010 annual Millennium Development Goals Report, the UN concluded that earlier advances towards reaching the Millennium Development Goals had been severely stalled and some positive trends even reversed due to the global financial crisis and economic downturn that occurred 2008-2009. Additional tens of millions of people were left in extreme poverty and the prevalence of hunger was until recently still increasing (FAO, 2010a; UN, 2010a).

Already before the latest financial crisis, it had been reported that the degradation of ecosystem services could grow significantly worse during the decades ahead, thus potentially preventing the attainment of the MDGs. The conclusions of the Millennium Ecosystem Assessment (MA, 2005a), the result of a large collaborative effort amongst numerous researchers and institutions, were made available in 2005. The results highlighted for the first time in a comprehensive way that human dependence on the services provided by ecosystems was under severe threat. The MA concluded that the last 50 years have meant an unprecedented change in ecosystems due to the pressure from human demands and concluded that approximately 60 per cent of the ecosystem services examined were being degraded or used unsustainably. These ecosystem services are crucial not only for reaching the MDG targets by deadline, but for the continued reduction of poverty and hunger in a sustainable manner beyond 2015 (MA, 2005a; TEEB, 2009; PEI, 2010; PEP, 2010).

The changing climate adds to the challenge. The regions of the world that today stand farthest away from reaching the MDGs are also the regions at greatest risk in terms of loss of ecosystem services and impact of climate change. If the vulnerability of ecosystems to impacts of climate change is not reduced, the likelihood of attaining the MDGs will be less (Galaz, 2008). The ecosystem pressures reviewed in this report - air pollution, energy generation and pesticide use - are also coupled to climate change in different ways. Climate change may interact with these pressures to give rise to unwanted effects, making MDG attainment even more challenging.

Linking MDG attainment to the ecosystem services on which we depend is thus fundamental in order to improve human wellbeing in the long-term. How can this be accomplished? The understanding that human wellbeing and development is connected to the physical environment in which we live is not a new concept. With the Brundtland Commission (formally, the World Commission on Environment and Development) report in 1987, the international community underscored the importance of making the connections between environment and development (WCED, 1987). While knowledge of the problems and opportunities has improved greatly since then, we are still struggling with the practical solutions.

With the aim of decreasing some of these knowledge gaps, current research is trying to better understand synergies and trade-offs between different ecosystem services (Bennett, 2009; Gordon, 2010; Raudsepp-Hearne, 2010b). Finding policy options that may enable us to enhance the ecosystem services that can be supplied from a certain geographic area is of interest. To make this possible, we have to understand how ecosystem services are linked to each other, both in supply and demand at different temporal and spatial scales. We also have to better understand how the supply and demand of the ecosystem services depend on economic and social drivers and how ecosystems respond to various pressures such as for example air pollution and pesticide use.

THIS REPORT

This report focuses on the ecosystem services required to meet and sustain the MDG 1 targets of halving and finally eradicating hunger and poverty. The report aims at discussing the following questions:

- How does air pollution affect the ecosystem services crucial for attaining the MDG 1?
- How does energy production and use affect the ecosystem services that are needed for MDG 1 attainment?
- How does current use of pesticides affect the ecosystem services on which food production and MDG 1 attainment depends?

Ecosystems are highly complex networks of human, animal, plant, microbial and abiotic interactions. Ecosystem services, as defined by the Millennium Ecosystem Assessment (MA, 2005a) fall into four broad categories: provisioning, regulating, cultural and supporting (see Box 1). All the services provided by the ecosystems are vital for human wellbeing and will have either a direct or indirect influence on all of the

Box 1: Examples of the four ecosystem service categories as defined by the Millennium Ecosystem Assessment (MA, 2005a).

Provisioning Services are the products obtained from ecosystem services like food, fibre, fuel, genetic resources, biochemicals, natural medicines and pharmaceuticals, ornamental resources and freshwater.

Regulating Services are the benefits obtained from the regulation of ecosystem processes such as the regulation of air quality, climate, water, erosion, disease, pests, water purification and waste treatment, natural hazards and pollination.

Cultural Services are the nonmaterial benefits people obtain from ecosystems like cultural diversity, spiritual and religious values, knowledge systems (traditional and formal), educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation and ecotourism.

Supporting Services are those that are necessary for the production of all other ecosystem services. Their impacts on people are often indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts. Supporting services include soil formation, photosynthesis, primary production, nutrient and water cycling.

MDGs; for example, changes in biodiversity may have far-reaching effects on cultural services. This report will focus on some of the provisioning and regulating ecosystem services of direct importance for reaching the MDG 1 (the poverty and hunger targets):

- crop production,
- collection of wild food and biomass fuel,
- climate regulation,
- nutrient cycling,
- pollination,
- disease and pest regulation.

The first chapter on ecosystem services and the MDGs provides background and reviews the current status of attainment of MDG 1. The Air Pollution chapter collects the most up to date information available regarding the interactions between air pollution and the ecosystem services vital for meeting the MDG 1. The pollutants covered in the chapter are ozone (O_3), nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2). The Energy chapter looks at ecosystem service impacts of the use of different energy sources. It also gives on overview of the current lack of access to modern energy by the poor and trends in improving the same. The consequences of choosing different energy sources when increasing the energy access of the poorest are also discussed. The Pesticide chapter reviews the current knowledge on the impacts of pesticide use on ecosystem services vital for food production.

MDG 1 – THE CURRENT SITUATION

The MDG 1, which has eradicating poverty and hunger as its long-term objective, is often the focus when discussing the MDGs. Two of the targets under this goal to be reached by 2015 are: *Target 1.A* halve, between 1990 and 2015, the proportion of people whose income is less than one dollar a day and *Target 1.C* halve, between 1990 and 2015, the proportion of people who suffer from hunger. This section reviews the current situation and the progress achieved towards reaching the targets.

Poverty – Target 1 A

Poverty can be defined not only from an economic and material perspective but also from the perspective of livelihoods, which involves social, political and natural qualities. Poverty also signifies a lack of choice and of power, which in turn generates a lack of opportunities and of security. From a sustainable livelihoods perspective, poverty is assessed from the range of entitlements and assets by which people secure their living. Entitlements and assets refer to available resources that are natural (land, water, common property resources, flora, fauna), social (community, family, social networks, culture), economic (jobs, savings, credit), political (participation, empowerment, enfranchisement), human (education, labour, health, nutrition), and physical (roads, markets, clinics, schools) (Arvidson, 1999).

The sustainable livelihoods approach looks beyond the ability of individuals to purchase needed commodities in a presupposed market. It acknowledges the multitude of ways in which families and communities draw upon the assets available to them as they strive to cope, adapt, and thrive in the face of external stresses and shocks (Arvidson, 1999). Indicators of poverty based on non-income dimensions of poverty are considered in the annual Human Development Report by UNDP (UNDP, 2009). However, the definition used most often is based on consumption and income-related measures.

The original World Bank indicator to measure poverty used for the MDG 1 Target 1 A (Indicator 1.1) was to halve, between 1990 and 2015, the proportion of people whose income is less than one dollar a day. Using improved price data from the 2005 round of the International Comparison Program, new poverty estimates were released by the World Bank in August 2008 (Chen and Ravallion, 2008). To better reflect reality, the World Bank changed the reference poverty line from USD 1.00 to USD 1.25 per day. Every person who has less than USD 1.25 a day (2005 Purchasing Power Parity terms, PPP) at their disposal, converted into local purchasing power parity, lives in absolute or extreme poverty.

The adjusted figures at the USD 1.25 level indicate considerable progress from 1990 to 2005 for all developing countries at the aggregated level. The total number of poor in developing countries decreased from about 1.8 to 1.4 billion and the fraction of the total population of poor decreased from 42 to 25 per cent. The developing world as a whole was thus on track to halve the proportion of extreme poverty from its 1990 levels by 2015. On a regional level, however, the picture was quite different (table 1). The main reason behind the positive global numbers is the dramatic decrease in both numbers and prevalence of the poor in east Asia and the Pacific, from around 900 million to just above 300 million and from 55 per cent to only 17 per cent. Rapid economic development over the last decades, mainly in China, has enabled millions of people to leave poverty. The situation in south Asia and sub-Saharan Africa is, on the contrary, very worrying. In both regions the total number of poor is stagnant or increasing. The highest number of poor is found in south Asia: about 600 million (40 per cent). India alone has 460 million poor and a poverty head count ratio of 42 per cent. The level of poverty in sub-Saharan Africa is as high as 51 per cent and the number of poor reaches nearly 400 million (WB, 2010a). The same trend is true for the Least Developed Countries (LDCs), with the majority being sub-Saharan countries, where the poverty level since 1990 has only decreased from 63 to 53 per cent (UN, 2010a).

The data from 2005 does not include any of the setbacks that have followed the rising food and fuel prices during the global economic turmoil, 2008-2009. According to World Bank estimates, the crisis increased extreme poverty by 50 million in 2009. This trend seemed to be curbed towards the end of 2010 (FAO, 2010a). However, as already the figures from 2005 indicated, the challenge to fight global poverty remains most difficult in south Asia and sub-Saharan Africa.

Table 1: Prevalence of poverty for all developing countries for different geographic regions 1990 and 2005, total population, number of poor, fraction poor and MDG 2015 target level (WB, 2010a).

Developing countries	1990	2005	1990	2005	1990	2005	MDG
USD 1.25 PPP per day	Population	Population	Poor	Poor	Fraction	Fraction	Target 1A
	(million)	(million)	(million)	(million)	(%)	(%)	(%)
East Asia & Pacific	1,600	1,890	870	320	55	17	27
Europe & Central Asia	470	470	9	17	2	4	1
Latin America & the Caribbean	440	550	50	45	11	8	6
Middle East & North Africa	230	310	10	11	4	4	2
South Asia	1,100	1,480	580	600	52	40	26
Sub-Saharan Africa	520	760	300	390	58	51	29
Total	4,360	5,460	1,820	1,380	42	25	21

Hunger – Target 1 C

After the Second World War, the populations of many of the newly independent developing countries increased dramatically and by the mid-1960s many countries were dependent on large-scale food aid from industrialised countries. In 1967, a report of the US President's Science Advisory Committee stated that "the scale, severity and duration of the world food problem are so great that a massive, long-range, innovative effort unprecedented in human history will be required to master it" (IFPRI, 2002). As a response to the escalating hunger situation, investments in international agricultural research systems relevant for developing countries were rapidly increased. The outcome was the "Green Revolution". With new high-yielding varieties and other improvements yields in rice and wheat increased impressively in Asia and Latin America in the late 1960s (IFPRI, 2002). Even if many countries, such as India, managed to move away from recurrent famines and dependence of food aid towards food self-sufficiency on a national level, a large number of undernourished people continue to exist across the developing world.

The global community has set several goals to reduce global hunger. At the first World Food Conference in Rome 1974, the global problem of food production and consumption was put in focus. It was declared that "every man, woman and child has the inalienable right to be free from hunger and malnutrition in order to develop their physical and mental faculties". The Rome Declaration on World Food Security from the World Food Summit in 1996 reaffirmed the right of everyone to have access to safe and nutritious food and set the goal (figure 1a) of reducing the number of undernourished people by half between 1990–92 and 2015. For MDG 1, the World Food Summit goal was reformulated from halving the number to instead aiming for halving the proportion of people who suffer from hunger between 1990 and 2015 (Target 1 C, Indicator 1.9) (figure 1b).

Undernourishment exists when caloric intake is below the minimum dietary energy requirement. This is the amount of energy needed for light activity and a minimum acceptable weight for attaining height and it varies by country and from year to year depending on the gender and age structure of the population (FAO, 2009b). Since the beginning of the 1970s until mid-2000, the absolute number of undernourished has oscillated around 850 million and, because of the global population increase, the proportion of undernourished has fallen from more than 30 per cent to just above 15 per cent.

Households with low incomes spend a high proportion of their narrow budget on food. In order to get enough to eat, the poor either have to be able to produce enough food or generate the necessary income to buy it (FAO, 2008b). In cases of increasing food prices or lost income opportunities, the poor and food insecure cope with declines in income by reducing their expenditures on food only as a last step. When nutritionally well-balanced diets are unaffordable, they bring down costs by shifting from more expensive foods rich in protein and nutrients (milk, meat, fruits and vegetables) towards calorie rich and energy dense foods (starchy roots or grains) (FAO, 2009b).

As a result of the food and economic crisis over the 2008-2009 timeframe, the earlier downward trend of the proportion and the number of undernourished was reversed. The estimates for 2008 showed for the first time in more than three decades an increase of undernourished to above 900 million. Estimates for 2009 showed a continued rapid increase to more than one billion (1,020 million) hungry in the world (FAO, 2009b). Both the number and proportion of

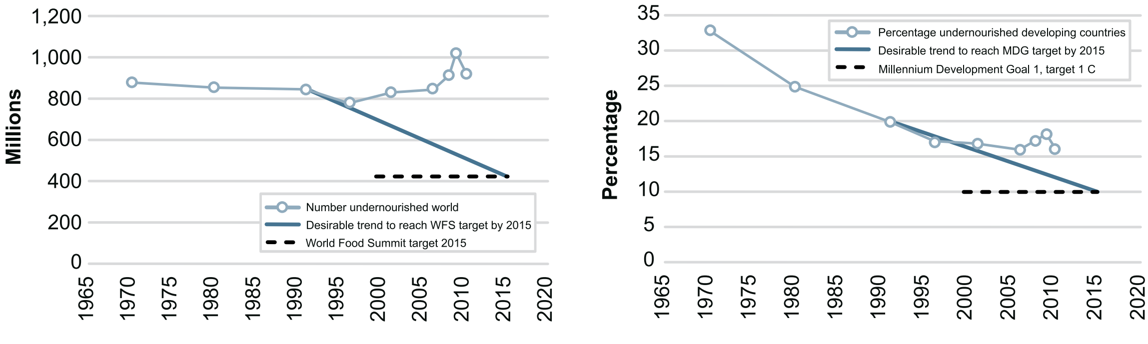

Figure 1 (a and b): Number of undernourished in the world and proportion of undernourished in developing countries, 1969–71 to 2010 (FAO, 2010b).

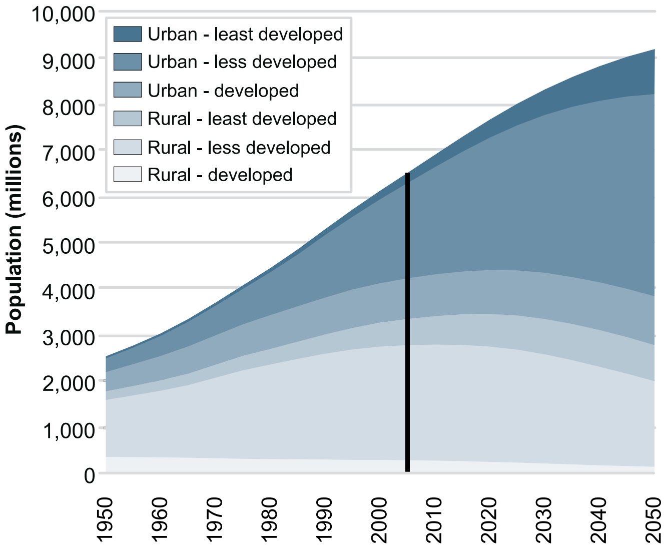

Figure 2: Global population, urban and rural, 1950-2050, for developed, less developed and least developed countries, medium projection (Data source: (UN, 2010c)).

hungry people declined in 2010 as the global economy recovered and food prices remained below their peak levels. However, hunger remains higher than before the crises, making it ever more difficult to achieve the hunger-reduction (FAO, 2010a). Regional figures available for 2005-2007 show that the highest proportion was found in sub-Saharan Africa, 26 per cent, while the highest number of undernourished was found in south Asia, 333 million and 21 per cent (FAO, 2010b). When looking only at the LDCs the proportion has decreased from 40 per cent in 1990-92 to 32 per cent in 2005-07, a reduction by only one fifth over the period (UN, 2010b).

The population growth challenge

To be able to make progress on the economic situation for the poor and to improve the food situation for the undernourished, it is necessary that development and agricultural production meet the needs of the expected population increase in the coming decades. The medium UN population projection forecasts a continued global population increase from 2010 to 2050 of another 2.25 billion, to reach a total of about 9.15 billion (figure 2) (UN, 2010c). The increase will be highest in the first decades and start to flatten out during the second half. For the first time in human history, the majority of the global population today lives in urban areas. The expected urban growth till 2050 will include the total population increase and a “migration” of more than 550 million from rural to urban areas. It is only in the LDCs that the rural population is expected to increase, by about 40 per cent to almost 800 million. By 2030, China will reach its peak population of around 1.46 billion, which will decrease to 1.41 billion by 2050. India will take over the role as the most populous country by 2050 with a population of about 1.66 billion, after an increase of more than 500 million.

HUNGER, POVERTY AND ECOSYSTEM SERVICES

The people living in hunger and poverty are like all human beings depending on ecosystem services for survival (MA, 2005a). However, the dependence on local ecosystem services may look different for these different groups, for instance urban poor and rural landless farm workers. In principle, all groups are dependent on food from the market, considering that a large part of the marginal farmers are also net food buyers. Food on the market can be both cultivated locally and in countries far away. However, the rural hungry also often have a direct dependence on local ecosystem services for food and livelihood. These can be services like crop production (either as farm workers on other people’s land or on own plots), grazing, wild food collection, forest products and fisheries. The urban poor seldom produce any food and frequently lack resources to purchase food, thus constituting a large group at risk of hunger. The global urban population is expected to grow from 3.5 billion in 2010 to 4.9 in 2030, increasing further to 6.3 in 2050 (figure 2) (UN, 2010c).

In spite of the rapid urban population growth, the absolute majority of the hungry, more than three quarters, still live in rural areas (FAO, 2004). People living in poor rural communities, mainly in Asia and Africa, that are suffering from hunger also often lack modern energy services for cooking, lighting and mechanical power to supply safe drinking water and only have access to low quality public health, education and sanitation services. The rural hungry can be divided into three major groups: pastoralists, fishing- and forest-dependent; rural landless; and smallholder farmers (FAO, 2004). The majority of the food-insecure in the world are thus often directly involved in and dependent on agriculture and work with food production. This group is often also the most dependent on the collection of goods from common property land and directly dependent on the supply of local ecosystem services. The local provisioning services of special importance for the MDG attainment are crop production, grazing for livestock, fishing, wild food and biomass energy supplies. These services are in their turn dependent on services like pollination, nutrient cycling, pest and climate regulation and primary production.

TRADE-OFFS AND SYNERGIES BETWEEN ECOSYSTEM SERVICES

There are important synergies and trade-offs between most of the ecosystem services on which we rely for food and livelihood. In the national and local settings, decisions will have to be made based on an understanding of these trade-offs and synergies, to allow for management of the resources for maintained or even increased sustainable supply of multiple ecosystem services (Bennett, 2009). From an MDG perspective, the supply of, and access to, local ecosystem services for the poor is of special concern. When for instance harvests fail, the availability of other local ecosystem services for food is of vital importance to the poorest (Enfors and Gordon, 2008). The agricultural production in itself has trade-offs with many other ecosystem services underpinning the long-term agricultural carrying capacity of the ecosystems, such as pollination, soil fertility, climate, flood and pest regulation. Raudsepp-Hearne *et al.* (Raudsepp-Hearne, 2010a) showed clear landscape scale trade-offs between agricultural provisioning services and almost all regulating and cultural services. The ongoing transformation of the agricultural sector from traditional subsistence farming to modern commercial farming with increased intensification, specialisation, and agrochemical use in developing countries (Johnstone, 2009) is likely to increase such trade-offs between crop production and other ecosystem services. However, increasing the crop yields does not necessarily mean decreased supplies of other services from a certain area. Steffan-Dewenter *et al.* (Steffan-Dewenter *et al.*, 2007), looked at optimisation of ecosystem services and income during tropical rainforest conversion and agroforestry intensification (cacao) in Indonesia. They could identify that a low-shade agroforestry system in this setting offered the best available compromise between economic forces and ecological needs. Another study looked at the trade-offs between timber production, regulation of CO_2 and pollination in western Ecuador (Olschewski *et al.*, 2010). The authors show that economic losses due to a reduction in tree density in the tree plantation could be overcompensated by the pollination service generated (habitat options for pollinators increase with lower tree density) for the close-by coffee agroforestry system.

Recent research has suggested that one way to improve our understanding of trade-offs and synergies among ecosystem services is to look at how they are linked to each other through the drivers, i.e. the human activities that influence the supply of the respective services (Bennett, 2009). Another approach is to study how ecosystem services vary at the landscape scale and learn more about how they do, or do not coexist. For instance it was shown that for certain landscape types, the provision of the fundamental regulating services are positively correlated with a greater diversity of all kinds of ecosystem services (Raudsepp-Hearne, 2010a). Thus, maintaining a certain ecosystem service diversity may be one strategy for safeguarding the provision of regulating services.

The pressures on ecosystems covered in this report are also influencing these trade-offs. Energy generation has trade-offs with food production. The use of pesticides may increase the supply of certain services while drastically reducing the supply of others. Energy production and use contributes to air pollution that has the potential to reduce food production. Agriculture itself has feedback loops to increased air pollution. These issues are discussed in more detail in the following chapters of the report.

AIR POLLUTION

Understanding the interactions between air pollution and ecosystem services is vital for meeting the MDGs. The air pollutants covered in this chapter are ozone (O_3), nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2). Although air pollution has a direct and measurable impact on human health, these direct effects, such as respiratory inflammation and toxicity will not be considered explicitly in this chapter.

IMPACTS OF AIR POLLUTION ON ECOSYSTEM SERVICES

The current state of knowledge of four air-pollutants with a range of atmospheric lifetimes and major effects on provisioning and regulating ecosystem services is evaluated in this chapter. The different lifetimes of the pollutants in the atmosphere gives differences in the scale of impact of the pollutant. Whereas the scale of impact of ammonia is mostly local, the ozone pollution is regional to hemispheric (table 2). The relatively short lifetimes of these pollutants mean that if appropriate measures are taken to reduce emissions this will immediately affect the impacts caused.

The possible effects on ecosystem services of air pollutants are summarised in table 3. Effects such as reduced plant and biomass production and altered nutrient cycling all have implications for food production and the MDG 1 targets. In the following sections these effects are described in more detail.

Ozone (O_3)

Tropospheric ozone is one of the world's most important regional-scale air pollutants carrying risks to both vegetation and human health (Royal, 2008).

Table 2: Approximate lifetimes of atmospheric pollutants in the atmospheric boundary layer and free troposphere (Adapted from (GEO4, 2007).

Pollutant	Atmospheric lifetime	Scale of impacts
O_3	Weeks to months	Regional to hemispheric
NO_x	Days	Local to regional
SO_2	Days to weeks	Local to regional
NH_3	Days to weeks	Local

Table 3: Major ecological effects of air pollution and their impacts on ecosystem service.

Pollutant	Ecological effect	Ecosystem service impact		
		Provisioning	Regulating	Supporting
O_3	Reduced plant growth Increased plant susceptibility to stress	Reduced plant and biomass production	Altered climate regulation through C sequestration	Reduced net primary productivity
NO_x	Acidification Eutrophication		Altered nutrient cycling and increased system losses	Increased net primary productivity
NH_3	Eutrophication	Reduced food provision from aquatic systems	Altered nutrient cycling and increased system losses	Increased net primary productivity
SO_2	Acidification			Loss of biodiversity

Ozone is a secondary pollutant, formed from the precursors nitrogen oxides (NO_x) and volatile organic compounds (VOCs) including methane. Biomass burning produces ozone precursors, but urban pollution sources dominate (MA, 2005b). At present ecosystems, particularly forest systems, act as a net sink of ozone. However, this effect is reduced by deforestation, which reduces canopy uptake, and replacement of forests with agriculture, which increases nitrogen oxide emissions from soil (Prather *et al*., 2001).

High atmospheric concentrations of ozone in terrestrial ecosystems can lead to substantial reductions in provisioning services. Reductions in plant growth from chronic exposures are well documented and can result in substantial yield losses of both food crops (Fuhrer, 2009; Van Dingenen *et al*., 2009) and timber and other biomass crops (Fuhrer, 2009).

Ozone is also of great importance for climate regulation. In addition to its role as a greenhouse gas, ozone may also have large effects on climate regulation services in terrestrial ecosystems. Although there are large uncertainties in the analysis, it is likely that the physiological effect of ozone on vegetation (reduced stomatal conductance) will also limit carbon sequestration by plants and thus counterbalance any increased carbon sequestration caused by CO_2 fertilisation (Sitch *et al*., 2007).

Nitrogen oxides (NO_x)

The oxides of nitrogen - nitric oxide (NO) and nitrogen dioxide (NO_2) - are emitted by tropical soils as a product of denitrification but are predominantly a product of combustion of both biomass and fossil fuels. Nitrogen dioxide is a secondary product of the reaction between nitric oxide and ozone, however, due to the rapid conversion of nitric oxide the atmospheric burden of nitrogen oxides is largely nitrogen dioxide at longer distances from sources (Emberson *et al*., 2003). Deposition of nitrogen oxides can have a fertilisation effect in N-limited ecosystems but deposition effects are largely deleterious to provisioning services. As well as directly toxic effects to plant growth, nitrogen oxide fertilisation can lead to heightened sensitivity to stress conditions (CLAG, 1996). It can also cause the reduction of biodiversity in sensitive ecosystems through acidification and eutrophication. There are also effects on aquatic ecosystems from both direct deposition and leaching from soils which can reduce water quality and the harvesting of food (NEGTAP, 2001). Although nitrogen oxide deposition will tend to increase net primary productivity (NPP) in ecosystems it is likely that the impacts on regulating services, such as biodiversity and water regulation, will be largely negative due to acidification and eutrophication. Atmospheric concentrations of nitrogen oxides are also linked to climate regulation due to its role as a precursor of ozone (Royal, 2008).

Ammonia (NH_3)

Ammonia can have significant effects on a large range of sensitive ecosystems through both increased nitrogen deposition and acidification. It also has human health impacts, acting as a precursor for secondary inorganic aerosols. The sources of ammonia are predominantly agricultural (Dentener *et al*., 2006a) and as demand for food rises it is likely that ammonia effects will become increasingly important. Emissions of ammonia affect services in both terrestrial and aquatic ecosystems (through direct deposition and leaching from surrounding areas). Large NH_x (through dry deposition as NH_3 and wet deposition as NH_4^+) inputs to ecosystems may cause a plant-fertilisation effect leading to an increase in harvestable material, e.g. of crops (arable land), timber (woodlands) and hay (grasslands). However, this nitrogen input can also cause accelerated eutrophication and acidification in aquatic habitats leading to reduced fish numbers and reduced water quality (Hicks *et al*., 2008). It is also likely that any climate benefit from increased carbon sequestration will be balanced by greater nitrous oxide production in soils (Mosier *et al*., 1998). It is unlikely, therefore, that any net benefit from increased NPP will be seen outside of fertilised agricultural areas. Furthermore, there may be adverse effects on ecosystem goods, such as increased plant susceptibility to stress (Bouwman *et al*., 2002a), close to large point sources for very sensitive systems. Globally, the highest deposition loads of ammonia are over Europe, east Asia and south Asia with 537, 705 and 1108 mg N m^{-2} y^{-1} deposited in 2000. For India, this represents a deposition load nearly ten times the global average (126 mg N m^{-2} $year^{-1}$) for the same period (Dentener *et al*., 2006a).

There may also be impacts on regulating services, particularly climate regulation. The use of nitrogen fertilisers and animal manure are recognised as the main anthropogenic sources responsible for the atmospheric increase in the greenhouse gas nitrous oxide (N_2O) (Houghton and Keller, 2001). Increased ammonia deposition generally causes higher rates of N_2O emission, an effect that becomes more pronounced as deposition rates increase (Skiba *et al*., 1998). This effect will occur to some extent in all terrestrial habitats, but it is particularly important in areas subject to direct fertilisation. N-fertilisation effects are also known to suppress methane oxidation in grasslands, forests and arable systems potentially causing increased concentrations of this potent greenhouse gas (Hutsch *et al*., 1993). There may also be effects on carbon sequestration by soils but these are dependent on numerous factors and have not yet been quantified at the landscape scale.

Sulphur dioxide (SO_2)

Although there are natural sources, production of sulphur dioxide (SO_2) is overwhelmingly anthropogenic with combustion of fossil fuels by coal-fired power stations being the most important sector (Emberson *et al*., 2003). Although sulphur deposition as SO_x (dry deposition as SO_2 and wet deposition as SO_4) can cause a reduction in both plant growth and yield it may act as a fertiliser in low sulphur ecosystems. Sulphur fertilisation can be seen in cultivated ecosystems. This effect is limited to North America and Western Europe. Acidification is another major impact of sulphur deposition in both terrestrial and aquatic ecosystems. The global average sulphur deposition in 2000 was 160 mg S m^{-2} y^{-1}, which was exceeded in several regions, notably North America, Europe (Eastern Europe in particular) and east Asia. Eastern Europe has the greatest deposition levels with 1358 mg S m^{-2} y^{-1} while east Asia had the second greatest deposition with 858 mg S m^{-2} y^{-1} (Dentener *et al*., 2006a).

AIR QUALITY IMPACTS ON FOOD PRODUCTION: CURRENT STATE AND FUTURE TRENDS

Drivers of air pollution

Emissions of air pollutants are driven by numerous social and economic factors (drivers and trends are summarised in UNEP's Global Environmental Outlook (GEO4, 2007)). Ultimately, these are the result of human consumption with the developed world still the main per capita user of fossil fuels. Often pollution effects are transferred by developed countries by purchasing goods that have been produced under lower environmental standards in developing nations. Significant downward pressure on emissions has come from increases in efficiency and implementation of new or improved technology. The main legislative control of air quality in developed countries is the Long-Range Transboundary Air Pollution (LRTAP) convention of 1979 which covers all UNECE region countries, excepting North America. Within that is the Gothenburg Protocol, 1999, which was implemented with the intention of cutting emissions of sulphur (63 per cent of 1990 levels by 2010), nitrogen oxides (41 per cent), VOCs (40 per cent) and ammonia (17 per cent). In addition to regional policy initiatives, there have been numerous national initiatives. For example, emissions of nitrogen oxides are often subject to national legislation limiting emissions from industrial and transport sources (Royal, 2008).

Table 4: Socioeconomic and legislation scenarios used to predict pollution emissions in the future.

Scenario		Description
IPPC (Nakicenovic *et al* 2001)	A1	Decreasing population Rapid economic growth Rapid change in technologies
	A2	Regional economic and population growth Slow change in technologies
	B1	Low population growth High GDP growth Rapid change to clean technologies
	B2	Intermediate between A2and B1
IIASA (Dentener *et al*. 2005; Cofala 2007)	CLE	Based on B2 including emissions legislation to 2001
	MFR	Based on B2 including maximum feasible reduction of emissions using available technology

Future scenarios

The IPCC Special Report on Emission Scenarios (SRES) (Nakicenovic *et al.*, 2000) developed four scenarios that describe different narratives of global change in population, GDP and adoption of non-fossil fuel technologies to 2100 (table 4). These were recently updated by Riahi *et al.* (Riahi *et al.*, 2007) and provide an indication of the possible range of future developments in baseline conditions without any constraints on greenhouse gas emissions. They also do not contain any assumptions about future emissions controls. An extension of these scenarios was developed by IIASA (Dentener *et al.*, 2005) (Cofala *et al.*, 2007), who have defined two scenarios based on the IPCC SRES B2 scenario adapted to include implementation of emissions legislation in place in 2001 (CLE) and the maximum reduction of emissions currently technologically feasible (MFR) (table 4). The IPCC considers each of these scenarios to be equally likely.

Most recently, the Royal Society have extended the assessment of the IIASA CLE scenario by applying it to SRES B1, B2 and A2 scenarios (Royal, 2008). These new scenarios also include air quality legislation up to 2006, which is not present in other assessments using the IIASA CLE scenario. As a result the CLE scenario used in many models does not include the limits for transport emissions that have been introduced in India since 2001. Consequently, 2030 projections shown here for Ozone, which use the updated IIASA CLE, tend to be more optimistic than for other pollutants, which do not.

Ozone

The most recent estimation of global tropospheric ozone concentrations (Royal, 2008) are based on the Atmospheric Composition Change European Network of Excellence (ACCENT) project (Dentener *et al.*, 2006b) and estimations for the year 2000 as a model baseline show considerable spatial and temporal variation in the season of maximum surface ozone with high (>50 ppb) ozone concentrations over south and east Asia during the summer/pre-monsoon period (March – May) and in southern Africa during winter (June – August).

Precursors of ozone – nitrogen oxides, carbon monoxide, methane and non-methane volatile organic compounds – are emitted from a wide range of natural and anthropogenic sources. Primary anthropogenic sources of nitrogen oxides are fossil fuel combustion for transport and power generation which account for approximately 79 per cent of the total 33 Tg y^{-1} (as nitrogen) anthropogenic emissions (Cofala *et al.*, 2007). Production of carbon monoxide is split evenly between biomass burning (both agricultural waste and deforestation) and fuel combustion by the transport and domestic sectors (Royal, 2008). Global methane emissions are dominated by energy generation (75-110 Tg C y^{-1}) and by sources in cultivated ecosystems such as rice agriculture (25-100 Tg C y^{-1}), ruminants (80-115 Tg C y^{-1}) and biomass burning (23-55 Tg C y^{-1}) (MA, 2005b). There are large uncertainties in estimations of global non-methane volatile organic compounds but production is thought to be approximately 140 Tg C y^{-1}.

There are also a wide range of natural sources of ozone precursors, however global estimates are highly uncertain and range from 10-60 Tg N y^{-1} depending on which sources are included. The most important sources are soil emissions, forest fires and lightning. The most important natural sources of NO are vegetation, oceans and wildfires although these are negligible in comparison to anthropogenic production. The single largest source of methane is wetlands with an estimated emission range of 100-230 Tg C y^{-1}. Globally, the single most important non-methane volatile organic compound is thought to be isoprene due to its very high emission rate (500-750 Tg C y^{-1}) and its reactivity (Royal, 2008).

Present day ozone levels are compared with projected concentrations for 2030 using the SRES A2, B2+CLE and B2+MFR scenarios. The A2 scenario shows an expected increase in ozone of up to 25 ppb over most of the world whilst the MFR demonstrates a potential decrease of similar magnitude. The CLE scenario, even allowing for the most recent emissions controls predicts either no change or small increases over most the globe but with large increases in ozone over India.

B2+CLE and B2+MFR represent relatively successful futures in terms of emissions control policies whereas the A2 scenario demonstrates that ozone levels will increase through the next century if precursor emissions rise and control legislation is not implemented. These scenarios represent the range of possible outcomes from most to least optimistic.

There are major uncertainties regarding the impacts of ozone on tree growth and forest cover but a meta-analysis has revealed significant reduction (10 per cent) of photosynthesis in broadleaved trees at current ozone levels but no significant reduction in coniferous species (Wittig *et al.*, 2007). However the mechanisms by which this impacts on tree growth and interactions with other factors, such as rising CO_2 levels, are still poorly understood. There is also some evidence that high ozone concentrations can substantially alter species diversity in grass and forest ecosystems.

The magnitude of change in ozone levels in the coming century is largely dependent on future methods of energy generation and controls of transport emissions. It has been demonstrated that a global maximum feasible reduction strategy may reduce ozone concentrations world-wide (Royal, 2008) but this will require a concerted effort. In contrast a "business as usual" approach to precursor control will lead to increasing ozone levels. Overall, it is likely that background and peak ozone concentrations will continue to increase in this century with the greatest increases seen over Asia, driven by biomass burning and increasing industrialisation.

Nitrogen oxides, sulphur dioxide and ammonia

To give an indication of the spatial distribution of pollutant emissions and the contribution of production sectors to global totals, the Emission Database for Global Atmospheric Research (EDGAR) project (Olivier *et al*., 2001) has disaggregated emissions of nitrogen oxides and sulphur dioxide from both biofuel and fossil fuel combustion by region and by emission sector. The largest source of nitrogen oxides is identified as biomass burning, approximately 50 per cent of which comes from Africa. The large majority (86 per cent) of sulphur dioxide emissions are generated by the industrial production and domestic energy sectors and, within these sectors, east Asia dominates as a regional source.

Within the agricultural sector the major source of ammonia emissions is volatilisation from fertilised arable and grasslands which constitute the main source of emissions. Inventory calculations by Bouwman (Bouwman *et al*., 2002a) estimate that the median loss of nitrogen from global application is 78 Tg N y^{-1} (14 per cent of total application) for synthetic fertilisers and 33 Tg N y^{-1} (23 per cent of total application) for manures. These losses come largely from synthetic fertilisers used on wetland rice cultivation and upland systems. Losses due to ammonia volatilisation are more acute in developing countries, largely due to higher temperatures.

Whilst EDGAR provides information on important regions and production sectors at current (2000) rates, further studies have been carried out comparing current emissions to possible future conditions for a range of scenarios. Cofala *et al*. (Cofala *et al*., 2007) have used the Regional Air Pollution Information and Simulation (RAINS) model to estimate anthropogenic emissions of several air pollutants including nitrogen oxides and sulphur dioxide. Current emissions have been compared to emissions under SRES, current legislation and maximum feasible reduction scenarios. These show the same spatial trends as EDGAR (i.e. high emissions in Asia). It also striking that even though total emissions for OECD90 countries are high (37 Tg y^{-1} for nitrogen oxides and 29 Tg y^{-1} for sulphur dioxide) it is expected that these will fall under current legislation (20 and 13 Tg y^{-1} respectively). The case for Asia is that emissions will rise under current legislation from 22 to 32 Tg nitrogen oxides y^{-1} and 32 to 53 Tg sulphur dioxide y^{-1}. In this region it will require a maximum feasible reduction strategy to reduce emissions of these acidifying pollutants. Globally, Cofala *et al.* (Cofala *et al*., 2007) estimate that emissions of nitrogen oxides will rise from 86 to 136-180 Tg y^{-1} and sulphur dioxide will change from 123 to 84-177 Tg y^{-1} (the range of emissions change depends on the SRES scenario used). Total emissions estimates for 2000 differ in some areas from those of the EDGAR inventory, especially for sulphur dioxide emissions, which differ by more than 10 per cent globally. Cofala *et al*. (Cofala *et al*., 2007) identify differences in accounting for emission control measures since 1990 as the source of this discrepancy.

Further investigation of key areas of simulations from 26 global models that participated in a study (Dentener *et al*., 2006a) and have been used as part of ACCENT produce global total (wet and dry) deposition estimates for NO_x, SO_x and NH_x for 2000 and 2030 using the IIASA current legation and maximum feasible reduction and SRES A2 scenarios.

These models indicate that, currently, 43 -51 per cent of all NO_x, NH_x and SO_x fall over the ocean and 50-80 per cent of terrestrial deposition falls on non-agricultural vegetation. These estimates use a critical load threshold of 1000 mg N m^{-2} y^{-1} (Bouwman *et al*., 2002b; Bobbink *et al*., 2010) to estimate risk to vegetation and show that 11 per cent of global vegetation currently receives nitrogen in excess of this. The regions of highest concern are the USA (20 per cent of vegetation), Western Europe (30 per cent), Eastern Europe (80 per cent), south Asia (60 per cent), east Asia (40 per cent), southeast Asia (30 per cent) and Japan (50 per cent). The maps also show that SO_x deposition is concentrated over China, Eastern Europe and western USA.

The ratio of total (wet and dry) deposition of nitrogen oxides for each scenario was also compared to baseline values. The intermediate current legation scenario clearly identifies India and south Asia as being at risk from increased deposition of nitrogen oxides. Similar effects are seen for NH_4 deposition under the current legation scenario with increases of 40-100 per cent in central and South America, Africa and parts of Asia, compared to a 20 per cent decrease in Europe. Under the current legation scenario, deposition of SO_x decreases in Europe, North America, Australia and Japan but strong increases (more than 50 per cent) are seen in India, Asia and South America.

The deposition of both nitrogen oxides and ammonia can lead to nitrogen driven changes in ecosystem functioning and these effects can have major implications for biodiversity in sensitive ecosystems. The best current assessment of these effects has been produced by Bobbink *et al* (Bobbink *et al.*, 2010), who carried out an analysis of regional hotspots for nitrogen risk. Using the nitrogen compound deposition estimates, they identified those ecosystems most at risk from nitrogen deposition. This analysis overlaid the nitrogen deposition estimates of Dentener (Dentener *et al.*, 2006b) with WWF G200 eco-regions to identify regional hotspots of nitrogen risk both for 2000 and 2030 using the SRES A2 and current legislation scenarios.

This study identified that the highest global nitrogen depositions are seen in Europe, North America, southern China, and south and southeast Asia and directed attention to those ecosystems in which total nitrogen deposition was predicted to exceed 15 Kg N ha^{-1} y^{-1}. These areas comprise seventeen regions representing eight eco-regions and are predominately in Asia, demonstrating that the largest nitrogen impacts on biodiversity and ecosystem functioning will be seen in Asian ecosystems.

Direct quantification of the global effects of sulphur dioxide is unavailable, however, the extent and importance of acidification as a result of both sulphur and nitrogen deposition was assessed by Bouwman (Bouwman *et al.*, 2002b). These estimates point to areas in which critical loads for acidification are exceeded in Western Europe (38 per cent of the area of natural and semi-natural vegetation affected), Eastern Europe (47 per cent), eastern USA (24 per cent) and Canada (15 per cent). In addition, considerable areas of east Asia (16 per cent) and southeast Asia (23 per cent) are subject to severe acidification risks.

The greatest current emissions of emission and deposition of acidifying compounds are presently seen in industrialised countries. However, these countries have the resources and political will to meet this challenge and it is likely that legalisation already in place will lead to reductions over the next twenty years. In contrast, south and east Asia not only have acidifying emissions that are comparable in scale to OECD countries (albeit presently lower) but are also likely to increase these substantially by 2030 unless new controls are adopted. In addition, the greatest ecosystem vulnerability to acidification is found in Asia meaning that the potential risk to biodiversity and ecosystem services is greatest in this region.

Estimated yield losses from air pollution

Tropospheric ozone has been shown to have a deleterious effect on both yield and quality of food crops. Van Dingenen *et al.* (Van Dingenen *et al.*, 2009) have published a study estimating losses of key crops (wheat, maize, soybean and rice) from ozone damage. The authors estimate that the total global loss of these crops to be as high as 12 per cent in 2000 although global losses were exceeded in India and China with losses for wheat estimated at ~15 per cent and ~20 per cent respectively compared to a mean global loss of ~10 per cent. Similarly losses for soybean crops were ~14 per cent and ~16 per cent in these two countries while the global loss was ~12 per cent. The single highest regional crop loss is soybean in Europe (~25 per cent) but it must be remembered that soybean growth is relatively unimportant in this region. When these yield losses are converted into projected economic losses at 2000 market prices it is clear that the greatest impacts fall in Asia. The top three countries predicted to have the greatest economic losses are India (estimated economic loss USD 4.4 billion), China (USD 4.3 billion) and USA (USD 2.9 billion). There are uncertainties associated with these estimates, particularly relating to appropriate exposure-response relationships for crops since this study used relationships derived from western studies and may not therefore be suitable for Asian cultivars. However there is small-scale evidence to suggest that Asian crop varieties are no less and possibly more sensitive to ozone meaning that crop impacts in Asia are potentially large.

Van Dingenen *et al* (Van Dingenen *et al.*, 2009) used the current legislation scenario to estimate future crop losses from ozone effects. The greatest yield loss in 2030 is predicted to occur in south Asia, with India, Pakistan and Bangladesh suffering the greatest increases in loss for all four crops assessed. For example, India is expected to experience losses of rice: ~4; maize: ~3 per cent; soybean: 12 per cent; wheat: 8 per cent. In comparison, losses in Europe are not expected to exceed 1 per cent and in the case of rice, maize and soybean yields may even increase. It should be noted that, unlike the Royal Society report, the current legislation scenario used in this analysis does not include emissions legislation in India which has been introduced since 2001. However, even current estimates of crop yield loss are highest in this region and tropospheric ozone is likely to remain a major barrier to maximal food production.

Although the risks to biodiversity and non-provisioning ecosystem services are difficult to assess, the provisional assessment for Europe makes it clear that the economic impacts are potentially important. Given that there is a preponderance of sensitive ecosystems in Asian countries there is a need for the losses in this region to be assessed at least provisionally. The large scale of ozone driven crop yield losses in India, Pakistan and Bangladesh that may occur over the coming twenty years mean that there is need for both a continued assessment of the air pollution impacts in Asia and consideration of the most appropriate mitigation strategies.

INTERACTIONS WITH CLIMATE CHANGE

It is expected that climate change will increase levels of tropospheric ozone over land via increase in drivers such as temperature, humidity, sunlight and drought preventing uptake by plants. Changes to other climate driven mechanisms that may influence tropospheric ozone, such as long-range transport, weather conditions and transfer from the stratosphere are also expected to increase concentrations although the mechanisms are often poorly understood (Royal, 2008).

This creates a positive feedback loop because ozone is a greenhouse gas through both direct radiative forcing and indirect routes. Although ozone is considered by the IPCC to be the third most important greenhouse gas (Forster *et al.*, 2007), recent assessments of its indirect warming effects suggest that its total radiative forcing could be increased by at least 70 per cent compared to direct warming alone (Sitch *et al.*, 2007). This recent work suggests that tropospheric ozone increases are an even more important driver of global warming than previously assumed. In addition a warming climate will increase NH_4 emissions from agriculture through volatilisation.

Air pollution mitigation can also have an effect on climate change as greenhouse gases and air pollutants often stem from the same sources (CH_4 as a precursor of ozone, for example). Moreover, because impacts on human health and ecosystems are immediate and local, the benefits of reducing air pollution are immediate, directly observable and occur where the emission reductions have taken place. A co-benefits approach, where the costs and benefits of addressing climate change and air pollution are expressed simultaneously rather than independently, can offer significant benefits; reducing greenhouse gas mitigation costs by as much as 25 per cent (Wagner, 2009).

Conversely, nitrogen oxides and sulphur dioxide both have an aerosol cooling effect on the atmosphere. Recent work has suggested that aerosol cooling may be masking the true warming effect of greenhouse gas emissions by as much as 1.6°C (global mean temperature). It is likely therefore that global reductions in nitrogen oxides and sulphur dioxide driven by air quality legislation may increase the rate of warming effects caused by anthropogenic greenhouse gases (Ramanathan and Schellnhuber, 2009). The magnitude of this effect is highly uncertain and analyses are dependent on the future scenarios used (Schellnhuber, 2008) but there is a clear indication that the reduction in cooling air pollutants already committed to by numerous mitigation policies must be matched by reductions in greenhouse gases.

Measures for reduction

Reduction of air pollutants has primarily been driven by legislation to improve air quality and reduce human health impacts in the last 25 year but it is increasingly clear that these reductions also yield economic and ecological benefits. The differing atmospheric lifetimes and deposition mechanisms of air pollutants mean that impacts occur over a very large range of distances from emission sources. At one extreme, hotspots of NH_4 deposition can occur within 1 km of large point sources such as intensive animal units (Sutton *et al.*, 1998). At the other end of the scale, nitrogen oxides and sulphur dioxide persist long enough to be subject to regional transboundary atmospheric transport. Similarly, high peak concentrations of ozone occur at local scales in urban areas and close to large point sources. In contrast, rising background ozone concentrations are driven by increasing net production of ozone in the atmosphere as well as being closely linked to rising atmospheric methane (Royal, 2008). Clearly, mitigation polices that operate at relevant geographic scales are required to effectively reduce air pollution impacts.

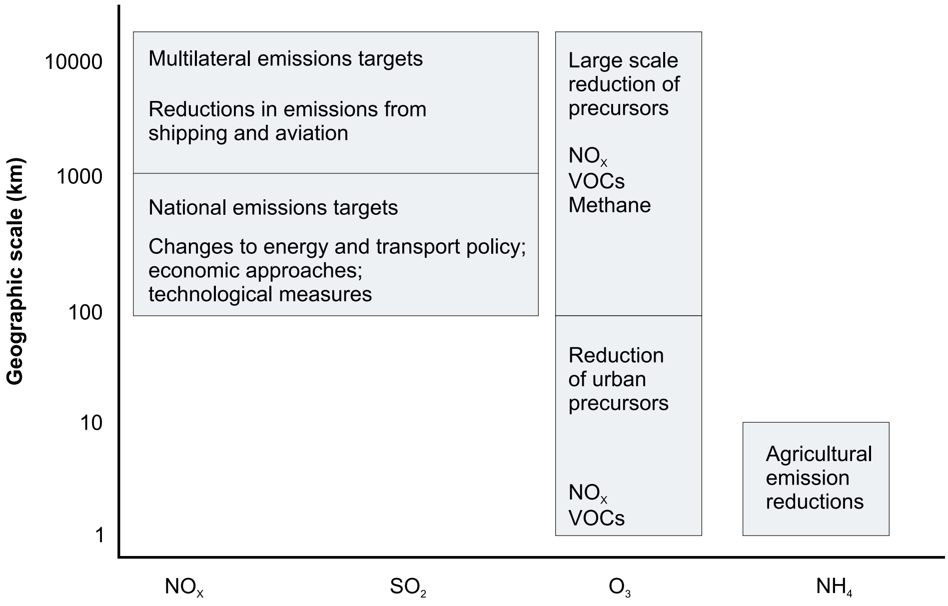

Figure 3: Measures for reducing air pollution at varying geographical scales.

Figure 3 shows an overview of the scales at which policy action to limit air pollution can be considered. At the local scale, reductions in ammonia impacts from agriculture can be achieved through measures such as emissions reductions from animal housing and slurry spreading (Misselbrook, 2007) as well as promoting low nitrogen input regimes such as organic farming. Preliminary investigations of effects of NH_4 emissions on ecosystem services show that there may be numerous benefits associated with these measures (Hicks *et al.*, 2008). Urban reductions in nitrogen oxides and sulphur dioxide concentrations can be reached by legislation to limit vehicle emissions and civic measures such as switching public transport vehicles to low emission fuels. The former approach is now used in most major Asian cities (Schwela *et al.*, 2006) while the later has been implemented with some success Delhi and Cairo (GEO4, 2007). Emissions reductions may also be achieved by traffic management such as congestion zones.

National-scale reductions can be achieved using a suite of approaches. These may be technological, focusing on single pollutants such as fitting industrial sources with flue gas desulphurisation technology or burners that produce low emissions of nitrogen oxides.

Box 2: Agricultural feedbacks with air pollution.

The effects of ozone on crop growth are potentially drastic, particularly in Asia, but are not typically included in scenarios of resource use. If yields are maintained at sub-optimal levels, producers may move towards intensification leading to increased nitrogen fertilisation or extend agricultural areas by deforestation. High levels of agricultural nitrogen use have been shown to result in increased ammonia volatilisation (Bouwman *et al.*, 2002a), especially in tropical countries, with all the attendant risks to sensitive natural ecosystems. More importantly, this will also lead to increased nitrogen oxides production (through fertiliser production and biomass burning). Because nitrogen oxides are ozone precursors, it is likely that crop losses will then be exacerbated. At present, the possible magnitude of this effect has not been considered and national agricultural policies may limit it. For example, India has made a policy commitment to optimisation of agriculture through technological advances (irrigation, improved varieties), limited land-use change and environmentally sustainable fertiliser use (IMoA, 2009). Nevertheless, these potentially significant feedbacks should be considered in future estimates of air pollution impacts on food availability.

Sectoral measures that address several pollutants at once may also be used. Energy and transport policy can be tailored to encourage the use of renewable, clean fuels. Finally, economic measures both positive (grants, subsidies etc) and negative (taxes, fees) have been used with success in Europe as an incentive to reduce pollution from industrial and transport sources (UNECE, 2006).

To fully address the long-range hemispheric transport of air pollutants, multi-lateral regional agreements are required. Within the UNECE countries, the Convention on Long-Range Transboundary Air Pollution (CLRTAP) has proved to be effective since its adoption in 1977. Outside of these countries, similar agreements are rare. However, the Malé Declaration, drafted in 1998, has been adopted by eight south Asian countries to build capacity in monitoring and assessing impacts of air pollutants (including sulphur dioxide, nitrogen oxides, ammonia and ozone) and implementing policies to reduce atmospheric concentrations (UNEP, 2008). The Acid Deposition Monitoring Network in East Asia (AENET) is an example of an agreement to monitor specific ecological impacts of air pollution and includes 13 east Asian countries.

CONCLUSIONS

The current evidence for air pollution impacts on ecosystem services suggest that developing nations with large MDG challenges, especially those in Asia, are affected, a situation that is likely to become more pronounced in the future.

It is possible that tropospheric ozone pollution may become a major barrier to achieving MDG 1 in south Asia. The likelihood of achieving MDG 1 Target 1C is already in doubt as current food shortages and subsequent rising prices are threatening the limited gains in alleviating child malnutrition. The global proportion of children under five who are underweight has fallen since 1990 but is still highest in developing regions (Africa, Asia, Latin America) with the largest proportion in south Asia. Crop yield losses caused by ozone are expected to be most severe in this region and may have severe effects on food security.

Current estimates of deforestation stand at a net loss of 7.3 million hectares per year, contributing to air pollution issues through creating emissions through biomass burning and reducing sinks. Total area of forest protected for biodiversity conservation has increased by one third (to 96 million hectares) since 1990. However, these areas are relatively small in south Asia: 5.4 per cent of terrestrial ecosystems are protected compared to an average of 6.1 per cent in developing regions and 14.5 per cent in developed regions (UN, 2007). It is likely therefore that air pollution feedbacks associated with deforestation will be more pronounced in south Asia. In addition, although protected forest areas will not be subject to deforestation, they will still be at risk from changes in ecosystem functioning driven by eutrophication and acidification as well as species loss caused by ozone toxicity. Again, the ecosystems most at likely to suffer biodiversity loss are found in Asia.

Although predictions of future emissions and impacts are highly dependent on the socioeconomic and legislative scenarios used, with all the attendant uncertainties, scenarios such as the IIASA MFR show that population increase need not be inevitably linked to environmental degradation. In agricultural terms, it is essential that future agricultural policy favours the optimisation of fertiliser use and minimises NH_4 output from livestock and fertilisation wherever possible. This will act to reduce both the direct impacts of ammonia and its effects on ecosystem regulatory services though acidification and eutrophication. Moreover, the SRES B2-CLE scenario used the Royal Society demonstrates the importance of legislation in limiting ozone concentrations. It is crucial therefore that any growth in GDP associated with poverty alleviation for meeting the MDGs should be coupled with prioritisation of emission limiting technologies to mitigate the worst air pollution effects associated with economic growth.

The co-benefits approach to air pollution and climate change shows that there are substantial financial benefits to be accrued by addressing the two issues in tandem.

ENERGY

Understanding the links between energy, poverty and ecosystem services is important for MDG attainment. First of all, increased access to energy for the poorest part of the world's population is a prerequisite for reaching the MDG1 targets. Secondly, all energy generation and use affects ecosystems and the services they provide. This chapter gives an overview of the poor and the non-poor's different dependence on ecosystem services to meet energy demands and the poor and the non-poor's impact on ecosystem services as a result of meeting energy demands. It furthermore looks at the current trends in achieving basic pro-poor energy access (electrification and alternatives to traditional biomass for cooking) that supports the attainment of the MDGs. It also illustrates and compares ecosystem impacts of traditional use of biomass relative two alternative means of meeting the energy demand for clean cooking in Tanzania and illustrates some of the trade–offs that have to be made in terms of ecosystem implications, GHG emissions, land area required, and employment consequences.

ENERGY SUPPLY - DEPENDENCE AND IMPACT ON ECOSYSTEM SERVICES

The poor are primarily dependent on traditional biomass to meet their energy needs, and are thus closely reliant on local and regional ecosystem services that provide fuel. The non-poor are less dependant on ecosystem services to meet their energy needs as the bulk of the non-poors' energy needs are met by fossil fuels[1]. At the same time the magnitude of ecosystem impacts on ecosystem services is the inverse of this. The poors' dependence on traditional biomass has an impact on primarily local but also global ecosystem services, but this impact is insignificant in comparison with the impact of the energy use of the non-energy poor. The relative magnitude of the poor and the non-poor's dependence and impact on ecosystem services to meet energy demand are illustrated in figure 4.

Ecosystems – through their provisioning, regulating and supporting services – thus underpin much of the energy that the poor use daily as a consequence of their heavy reliance on traditional biomass to meet energy needs. Biomass used in simple wood- or charcoal-burning stoves has traditionally been the most widely-used energy source and is still today the main source for cooking and heating for more than 2.5 billion people in the world (IEA, 2009).

Also renewable electricity generated from hydropower, wind and solar energy, depends on rainfall, wind and clouds and is sensitive to changes in ecosystem regulating services. Thus, provisioning and regulating ecosystem services are fundamental to ensuring that the world's growing energy demand can be fulfilled with alternatives to fossil fuels.

The energy use of the non poor (here defined as those consuming more than 500 kgoe per capita and year and for whom which the bulk of energy supply comes from fossil fuel use) are largely affecting ecosystems at global and regional scales. Currently more than 80 per cent of the worlds primary energy supply comes from fossil fuels (IEA, 2010). Table 5 gives an overview of some of the key ecosystem services impacts from energy production and use of the non-poor.

The ecosystem impacts of the energy use of the poorest, is mainly originating from the use of traditional biomass. This dependence largely has an impact on ecosystems at a local scale caused by degradation and deforestation of natural forests but also to a not insignifant degree on a global scale through global warming. Table 6 gives an overview of some of the key ecosystem services impacts from energy production and use of the poor resulting from traditional biomass use.

Not only do the poor's dependence on traditional biomass energy threaten ecosystem servies that are needed for food production and livelihoods. It also does not fulfil the energy needs sufficiently well. In the next section what can be considered as necessary basic levels of energy supply that will help the poor move out of poverty is discussed.

INCREASED ENERGY ACCESS REQUIRED FOR MDG 1 ATTAINMENT

Access to modern energy sources is a necessary, but not sufficient requirement for economic and social development (IEA, 2002). It is required in

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[1] Fossil fuels are natural resources but are not generated by the ongoing dynamics of ecosystems and are thus not regarded as ecosystem services (MA 2005).

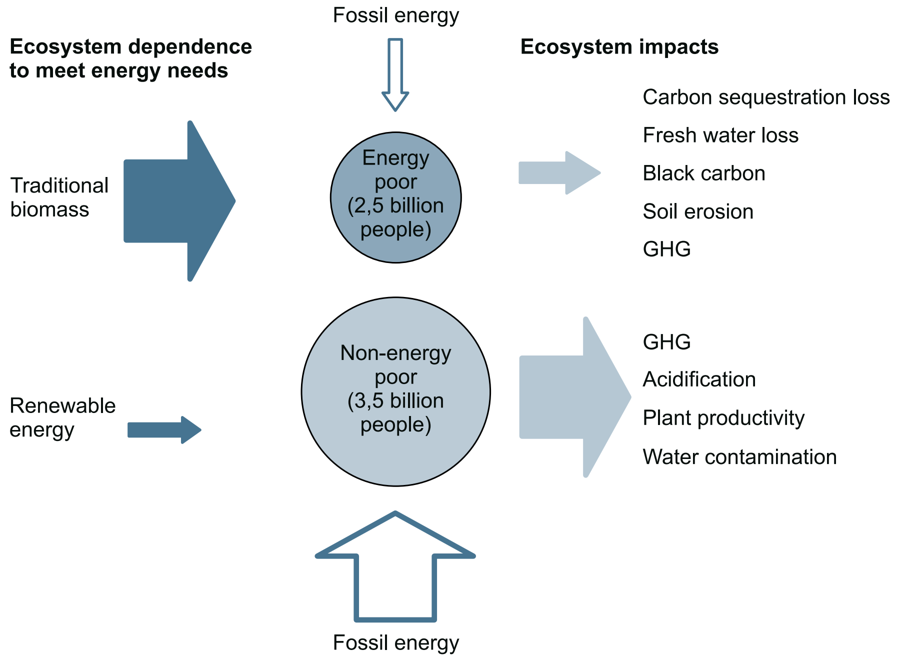

Figure 4: Energy supply - dependence and impact on ecosystem services.

industry, agriculture and the service sector, which are the engines of economic growth. Energy is also an integral part of most social and public services and therefore critical to the achievement of the MDGs (Sida, 2005). No country in modern times has substantially reduced poverty without a massive increase in its use of commercial energy (MoFA, 2009). Lack of access to energy signifies difficulties when it comes to managing needs: cooking, processing agricultural outputs, pumping and supply of water for drinking and for irrigation, and delivering health and education services.

At the household scale, access to modern energy directly contributes to MDG 1 attainment by for example providing more efficient and healthier means to undertake basic household tasks such as cooking and acquiring water; it frees up time for productive activities, enabling enterprise development, income generation activities beyond daylight hours, and increases productivity from being able to use machinery. At the village level, modern energy can improve productivity through the food chain (tilling, planting, harvesting, processing, transporting) and reduce post harvest losses through better preservation. Modern energy can power water pumping; provide drinking water and increase agricultural yields through the use of machinery and irrigation. At the town, city and national scale access to modern energy is a key ingredient to income generating, industrial, commercial and service activities (DFID, 2002; Modi, 2006).

Although there is considerable variation amongst poor countries, in terms of commercial energy use per capita and GDP, these differences are small relative

Box 3: Poverty and energy in the Johannesburg Plan of Implementation (JPOI).

In the World Summit on Sustainable Development in the Johannesburg Plan of Implementation (JPOI), the link between energy and poverty reduction was explicitly identified and the JPOI called for the international community to: *"Take joint actions and improve efforts to work together at all levels to improve access to reliable and affordable energy services for sustainable development sufficient to facilitate the achievement of the Millennium development goals, including the goal of halving the proportion of people in poverty by 2015, and as a means to generate other important services that mitigate poverty, bearing in mind that access to energy facilitates the eradication of poverty"* (UN, 2002).

Table 5: Key impacts on ecosystem services of the energy production and use of the non poor.

Energy source	Consequences	Possible ecosystem effects	Possible impacts on ecosystem services
Fossil fuels	Greenhouse gas emissions	Climate change: Temperature rises Acidification of oceans Changes in precipitation Heat stressed plants leading to reduced productivity and reduced capacity to absorb carbon dioxide	Changes in pest patterns on crops, livestock and aquacultures leading to decreased yields and catches.
Fossil fuels	Nitrogen oxides	Plant productivity Acidification of land and water	Reduced crop yields (See Air pollution chapter)
Fossil fuels	Sulphur oxides.	Acidification of water and soils	Reduced crop yields (See Air pollution chapter)
Fossil fuels	Oil leakage	Aquatic ecosystems impacts	Reduced catches of wild and cultivated fish and other coastal and marine organisms.
Fossil fuels	Particulates	Human health Acidification	Reduced yields from aquatic systems.
Fossil fuels Nuclear energy	Mining	Sulphur acid (coal) Terrestrial ecosystems Water contamination	Land use trade offs – i.e. crop production and wild food catches are smaller if mining is done on land that would otherwise deliver food related services. Water contamination may lead to lower catches of aquatic organisms.
Fossil fuels Nuclear	Thermal pollution	Aquatic ecosystems	Reduced yields from aquatic systems.
Nuclear	Nuclear contamination caused by a nuclear accident	Kills mammals Areas uninhabitable by humans	Most food related services unavailable due to contamination.
Large hydro power	Disruption in natural river cycles	Aquatic ecosystems Crop productivity	Reduced crop yields, reduced yields from aquatic systems.
All energy systems	Site preparations	Soil erosion Removal of vegetation Transformation of hydrological features	Reduced crop yields from soil erosion.
Photovoltaic	Heavy metal release	Terrestrial and aquatic ecosystem impacts	Reduced crop yields and wild food catches if release of metals over toxic thresholds.

to the energy consumption of wealthy countries. Low commercial energy use is also correlated with high rates of infant mortality, illiteracy and fertility, and with low life expectancy (UNDP, 2000). Figure 5 illustrates the large differences in average annual per capita consumption of modern energy, excluding traditional biomass and waste, between high and low income countries.

Traditional biomass and waste account for 10.6 per cent of total global primary energy supply. In low-income countries, these sources represent on average 49.4 per cent of the supply, with some countries approaching 90 per cent (REN21, 2005).

It is estimated that the minimum amount of modern energy needed annually to meet basic cooking and lighting needs is 50 kgoe per capita. However, societies also need to educate children, ensure good health and provide access to clean water, and energy for various productive uses. It is therefore estimated that a society requires at least 400 kgoe of energy per capita to stay

Table 6: Key impacts on ecosystem services from the use of traditional biomass.

Consequences	Possible ecosystem effects	Possible impacts on ecosystem services
Greenhouse gas emissions	Climate change: Temperature rises Acidification of oceans Changes in precipitation Reduced soil organic carbon sequestration Heat stressed plants leading to reduced productivity and reduced capacity to absorb carbon dioxide	Changes in pest patterns on crops, livestock and aquacultures leading to decreased yields and catches. Changes in regulating services such as flood control affecting food production and livelihoods. Soil formation and nutrient cycling changed by certain types of biomass cultivation systems.
Particulates	Human health Acidification	Reduced yields from aquatic systems.
Black carbon	Climate change	Changes in pest patterns on crops, livestock and aquacultures leading to decreased yields and catches. Changes in regulating services such as flood control affecting food production and livelihoods.
Deforestation and degradation	Soil erosion Carbon sequestration loss Fresh water loss	Reduced crop yields from soil erosion.

Box 4: MDG-compatible energy access targets.

In an attempt to evolve a vision comprising a set of energy services that could provide a way forward toward meeting the MDGs by 2015, the UN Millennium project (Modi et al., 2006) recommended the following energy targets:

- Enable the use of modern fuels for 50 per cent of those who at present use traditional biomass for cooking. In addition, support (a) efforts to develop and adopt the use of improved cook stoves, (b) measures to reduce the adverse health impacts from cooking with biomass, and (c) measures to increase sustainable biomass production.
- Ensure reliable access to electricity to all in urban and peri-urban areas.
- Provide access to modern energy services (in the form of mechanical power and electricity) at the community level for all rural communities

These targets were later adopted and incorporated into regional energy access scale up programmes to achieve the MDGs by ECOWAS and EAC (ECOWAS, 2006; EAC 2009)

In 2010, the OECD elaborated similar targets and deliberated on the costs of meeting the more ambitious target of achieving universal access to modern energy by 2030 (OECD/IEA, 2010). To achieve the target of electricity and clean cooking fuel access to eradicate extreme poverty by 2015 and for universal modern energy access to both electricity and clean cooking fuels by 2030, OECD estimated that an annual investment of approximately USD 36 billion will be required. In 2005, SEI estimated the investment needs to be about USD 45 billion per year to achieve the target of universal electricity access in urban areas, 50 per cent access to modern fuels and universal community access to modern energy by 2015 (Rockström *et al.*, 2005).

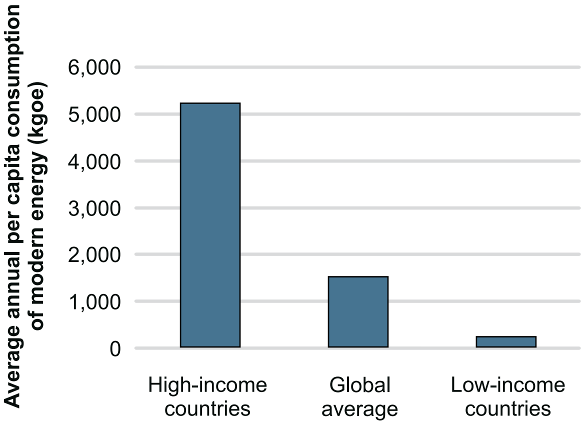

Figure 5: Average annual per capita consumption of modern energy (data source: (REN21, 2005)).

safely above the energy poverty line (REN21, 2005). There are several initiatives defining targets for MDG compatible energy access (see box 4).

Once countries have moved up the energy ladder to modern energy forms instead of traditional biomass, there is significant variation in energy consumption for different development levels. In the later stages of a nation's economic development, reductions in energy demand and a subsequent decoupling between energy consumption and economic growth are achievable (MoFA, 2009).

PRO-POOR ENERGY ACCESS TRENDS

The following section provides an overview of the current status and trends for meeting basic pro-poor modern energy access in the world, which as is about reducing traditional biomass dependence and replacing these needs with modern cooking fuels and about increasing electricity access.

Biomass use

The outlook for meeting basic pro-poor energy service needs by 2015 as defined by the UN Millennium project (see box 4) is promising for most world regions, with the exception of sub-Saharan Africa and parts of Asia (IEA, 2009; UN, 2010d).

The MDG compatible energy targets aim for a decrease in usage of traditional biomass to below 50 per cent of the population. The countries and regions furthest from this goal are India, Indonesia and sub-Saharan Africa (figure 6). Although the share of the population using traditional biomass is decreasing, progress is currently too slow to achieve the 50 per cent target by 2015 or even by 2020 (IEA, 2009; UN, 2010d). Sub-Saharan Africa is the region that will show the largest decrease in percentage terms, from 75 per cent relying on biomass today to

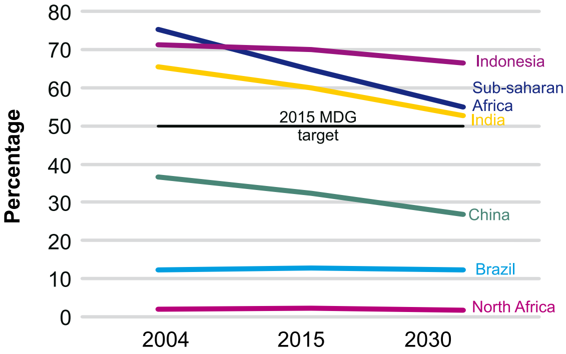

Figure 6: Percentage of population relying on traditional biomass 2004 - 2030 (IEA, 2009; UN, 2010d).

55 per cent by 2030. However, the rate of population growth in the region means an increase in the number of people using biomass, from today's 575 million to 720 million people by 2030. Today, the reliance of traditional biomass for cooking is over 95 per cent in a number of countries (*e.g.* Angola, Benin, Cameroon, Chad, Democratic Republic of Congo, Ethiopia, Ghana, Sudan and Zambia) (IEA, 2006). Current rates of progress are lagging behind in reaching the energy targets considered necessary to enable the MDGs to be met and will leave a majority of the population without access to modern cooking practices. Apart from India and Indonesia, the reliance on traditional biomass in the rest of Asia is today just below 40 per cent and the share is predicted to decrease further. Use of traditional biomass in China will decrease to approximately 10 per cent of the population over the next 20 years, a decrease of almost 100 million people (IEA, 2009; UN, 2010d).

Electrification

A prerequisite for meeting most of the MDGs is to ensure that all urban and peri-urban populations have access to electricity (Rockström, 2005; UNDP/GTZ, 2005). Significant increases in electricity access in rural areas for social service facilities such as health clinics and schools and modern energy services for agro-processing and other income generating activities are also needed to support the attainment of the MDGs. Today, the populations that are under-serviced with electricity are particularly found in sub-Saharan Africa and parts of Asia.

In East Africa, the current level of electricity access in rural schools and health clinics is about 10 per cent, including both grid connected and off-grid connected (EAC, 2009). It is estimated that, with current growth rates of new electricity connections, the situation will not change much by 2015: the connection rates are not high enough to make significant progress in access rates for a growing population. Figure 7 illustrates the extent of the necessary increase in new urban electricity connections to achieve universal electricity access in urban areas of Uganda. With the current annual urban electrification growth rate of 12 per cent, the urban connection rate will be only about 17 per cent by 2015. The growth rate needs to be accelerated to about 37 per cent to be able to meet a universal access by 2015.

In total, over 1.4 billion people - approximately one quarter of the world's population - currently lack access to electricity. Of these, 80 per cent are located in rural sub-Saharan Africa or southeast Asia. According to the International Energy Agency, the net electricity generation in the world will be 31 800 TWh in 2030, compared with today's 18 000 TWh (IEA, 2009). According to the projection, developing countries will experience the highest growth: an annual rise of 3.5 per cent. Nevertheless, the provision of access to all households in these regions will still be far from achieving the MDG energy targets by 2015 or even by 2030 (IEA, 2009; UN, 2010d).

Figure 8 illustrates the development in annual electricity consumption per capita, 1990-2030. Sub-Saharan Africa and developing Asia will continue having a low-level per capita consumption. Although the trend is increasing, the regions are likely to stay under roughly the 2,000 kWh/capita level through

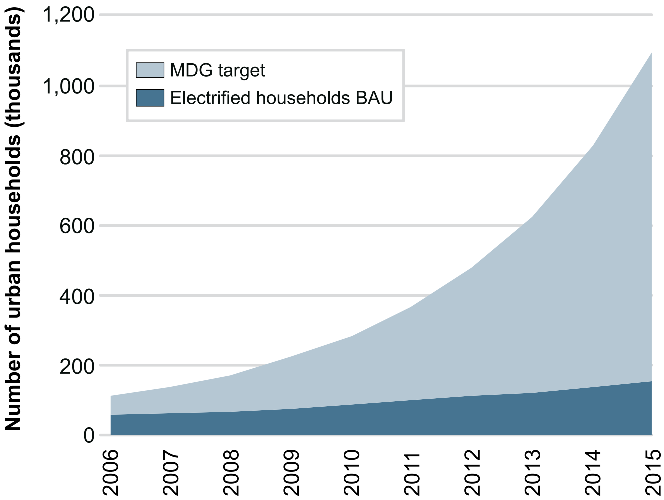

Figure 7: The urban electrification challenge: an example from Uganda (data source: (Arvidson, 2006)).

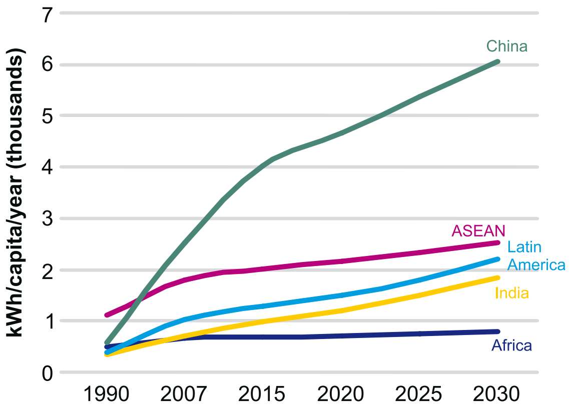

Figure 8: Electricity consumption per capita for developing country regions, 1990 – 2030 (IEA, 2009; UN, 2010d). Note: USA's per capita electricity consumption was 12 561 kWh/capita and in IEA's reference scenario increases to 14 262 kWh/capita by 2030.

2030. China stands to see the most rapid progress: it is expected to more than double its electricity per capita consumption from 2007 to 2030 (IEA, 2009; UN, 2010d).

THE COST AND GHG IMPLICATIONS OF MEETING THE PRO-POOR ENERGY DEMAND BY 2015 AND ACHIEVING UNIVERSAL ACCESS BY 2030

In 2005, SEI assessed the additional amount of energy supply that would be needed to meet the pro-poor energy targets by 2015 elaborated by the UN-Millennium project (see box 4) and came to the conclusion that in total only an additional equivalent of 900 TWh would be required; an almost insignificant amount of energy compared to today's global electricity generation of 18 000 TWh (Rockström, 2005). The additional CO_2 emissions of meeting the target by 2015 would be less than 1 per cent assuming the cooking demand is met by liquefied petroleum gas (LPG), the off-grid electricity demand with diesel generators and the urban electricity demand with the average current mix in the global energy system. This calculation did not consider the avoided global warming effects of reduced traditional biomass consumption which, as will be illustrated later, would probably result in reduced global warming from switching from traditional biomass to modern liquid or gaseous cooking fuels. An approximate annual investment of USD 45 billion would be required to achieve the MDG-compatible energy targets over a ten year period (Rockström, 2005).

In 2010 the IEA estimated the additional amount of energy needed to meet both a universal electricity access and a universal access to clean cooking facilities by 2030. To meet the electricity target, the total incremental output by 2030 is around 950 TWh (IEA, 2010). This increment represents some 2.9 per cent of the total global electricity generation in 2030 in the IEA reference scenario (IEA, 2009). Regarding the additional amount of cooking energy needed to meet universal access to modern cooking fuels, the IEA estimate this to require an additional 0.9 million barrels of oil per day (mb/d). This represents 0.9 per cent o the projected 96 mb/d of the global oil demand in 2030 (IEA, 2010). Also these figures suggest that even with universal access to basic levels of energy, the global warming effects would be minimal, or possibly reduce global warming effects, considering the reduced pressure on ecosystem services from avoided forest degradation, that this would enable. The IEA estimated the additional annual investments required to meet universal modern energy access to be USD 36 billion annually between 2010 and 2030.

Not achieving even basic levels of energy access is likely to have implications on meeting the MDG 1 targets in these regions. It is likely to impact the quality of providing social services such as education and health services. Furthermore, support for income-generating activities and increased productivity in agriculture and other sectors will be lacking. It will also threaten health objectives by forcing large shares of the population to rely on inefficient and smoky solid fuels for cooking and heating.

Table 7: Three energy alternatives for meeting the the cooking demand of the population currently using charcoal in Tanzania. (Smith Kirk R., 2000; Dovetail, 2005; Smeets, 2006; Seebaluck, 2007; Goldemberg, 2008).

Alternatives	**Charcoal**	**Ethanol**	**LPG**
CO_2 e (million tons)	18	2	5,8
Global warming potential (tonnes of CO_2 e per GJ)	0.38	0.085	0.195
Stove efficiency	25%	50%	40%
Land ha	700 000 (2 million)	110 000	n/a
Annual deforestation ha	0 (100,000)	0	0
Annual employment for production of fuel (in man years)	100,000	11,000	
End-user price per GJ in USD	16[2] (11[3])	(46[4]) 28[5]	30
Surplus electricity generation (GWh)	0	1,700	0

The calculations are based on the number of households currently using charcoal in Tanzania to meet their cooking needs which is just under two million households (GoT, 2008). The calculations are based on meeting an effective need of 6GJ of energy for cooking per year per household. To estimate charcoal production impacts, the calculations are based on annual yields of well managed eucalyptus plantations on good sites of 14-20 m^3 per hectare (FAO, 1987). This is high above the figures of current charcoal practices which are mainly produced in natural forests with mean annual incremental yields of 4.35 m^3 per hectare (Luoga *et al.*, 2002), but could be achieved if such practives were introduced and enforced. In brackets, the current practice implications of charcoal production and use are presented. The global warming potential of charcoal includes the global warming effects over 20 years of CO_2, methane, N_2O, CO, CO_2, and non-methane hydrocarbons at both charcoal kiln and when used as a cooking fuel in a stove but not greenhouse gas impacts of land use change (Bailis R., 2003). In calculating the impacts of ethanol gel fuel production and use the calculations are based on yields of 115 000 kg of sugarcane per hectare using most modern production technology in Tanzania such as drip irrigation and green harvesting and a production capacity of 80 litres of ethanol per tonne of cane, and a surplus electricity generation and capacity of 135 kWh/tonne of cane. The global warming potential for ethanol is based on the production of ethanol and the combustion of ethanol in a stove but not GHG impacts of land use change.

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[2] Price from charcoal produced in Tanzania where the costs of replanting of trees is included in the price (CAMCO, 2010)
[3] Current market price
[4] Current market price – imported ethanol gel fuel, small market
[5] Estimated market price if ethanol gel fuel is produced and sold domestically (EcoEnergy (T) Ltd, 2010)

IMPACTS FROM ALTERNATIVE WAYS OF MEETING THE ENERGY NEEDS OF THE POOREST FOR COOKING

Currently the poorest populations of the world rely almost exclusively on traditional biomass like fire wood or charcoal for meeting their energy needs. This section illustrates and compares some of the ecosystem implications of meeting the cooking demand by 2030 using three alternatives: charcoal, ethanol gel fuel or LPG, taking the case of current charcoal use in Tanzania as an example. A summary of the analysis is presented in table 7.

Land area requied and ecosystem implications

To meet the cooking fuel demand in the example by 2030, using charcoal, an equivalent of about 700 000 hectares of forest under sustainable high yielding production would be required. With current practices, the forest areas impacted by charcoal are however much larger since the wood is harvested unsustainably (and mostly illegally), without tree planting to offset the lost resources. To meet current charcoal demand, using communal lands, an estimated two million hectares are affected each year. In these forests, the outtake of wood is often larger than the mean annual increment resulting in a significant degradation of the forest land (Luoga, 2002). An estimated 100,000 – 125,000 hectares of lost forest area may be attributed to charcoal production annually (WB, 2010b). The lost forest negatively affects Tanzania's biodiversity, as indigenous fauna and flora have to move, adapt or perish. Lost tree cover can lead to soil erosion, falling water tables and shifting river flows, and the build up of silt in hydropower dams, which is believed to be contributing to reduce hydropower capacity (GNESD, 2009). Negative impacts on agricultural productivity from erosion prone landscapes and lowered water tables are also a risk when forests are degraded or removed.

If the demand is met by ethanol gel fuel, an equivalent of about 110,000 hectares under plantation will be required (Goldemberg, 2008). LPG does not require any significant amounts of land.

A smaller land area is required for the ethanol alternative compared to the charcoal alternative, but the ethanol alternative could lead to exclusion of the rural poor from ecosystems, as areas under cultivation for ethanol production become inaccessible. The livelihood impact of this however depends on the approach to feedstock cultivation. Ethanol can be produced using outgrower or block farming schemes which would incorporate local communities and provide a new livelihood opportunity. Communities may also have the option to voluntarily sell their land which would be exclusion, but should be a voluntary and remunerated one. In establishing production systems for ethanol feedstock important ecosystems may be protected and restored. As such the impacts on livelihoods and ecosystem services to a large extent depends on the security that the institutional frameworks of the country or region can provide to the communities and the environment where ethanol might be produced.

Ethanol production can have significant ecosystem services impacts depending on where and how the cultivation is done (how much carbon is removed to prepare for cultivation), the cultivation technique used such as efficiency of water and fertiliser used and the harvesting technique (burning or green harvesting). To minimise negative ecosystem services impacts from ethanol production it is particularly important to select sites that do not have a lot of standing biomass and soil carbon, to minimise periods when fields are left bare to avoid loss of soil, minimise interference with water bodies to avoid siltation from fields and to employ cultivation practices that minimise water use and fertiliser leakage by for example drip irrigation systems.

Employment

Charcoal production and distribution is currently a significant source of income for many poor people in rural areas of sub-Saharan Africa (SEI, 2002). In Tanzania the charcoal production and trade industry annually engages an estimated 1.9 million man years. Of these about 100,000 man years are related to the production of charcoal and 1,8 million man years in the transport, trade and retail part of the industry (WB, 2010b). A transition from traditional biomass to alternative modern cooking fuels, of gaseous or liquid form, can therefore have implications on employment and livelihood opportunities for a significant share of the populations in traditional biomass-dependent regions, particularly if the fuel is imported. Not to put the poor in an even more constrained situation, other livelihood alternatives for groups of people involved in the traditional biomass industry must therefore be considered seriously (SEI, 2002; Mugo, 2006). It should be noted though that also ethanol could, depending on the production approach, potentially absorb a significant amount of people in employment. Replacing the current charcoal demand with ethanol from dedicated ethanol and power industries could employ approximately 11,000 people (EcoEnergy, 2010). This does not include the transport, trade and retail part of the chain.

Greenhouse gas impacts

The charcoal alternative will have a larger impact on climate change compared to an ethanol or LPG alternative. Meeting the current charcoal demand in Tanzania contributes to about 18 million tons of CO_2 equivalent (e) emissions. Meeting the demand with ethanol will contribute about two million tons of CO_2 e. If the demand is met with a fossil fuel, such as LPG, the contribution to climate change would be about six million tons of CO_2 e.

Ethanol production can be coupled with electricity generation. The amount of surplus electricity that can be delivered to the national grid or local electricity grids when producing the volumes of ethanol in this example would be about 1 700 GWh.

CONCLUSIONS

This chapter has made the case that the current energy use of the poor is neither sufficient to attain the MDGs nor is it sustainable in terms of maintaining important ecosystem services that can facilitate a transition out of poverty. Meeting the basic energy needs of the poor with minimised effects on the ecosystem services vital for other aspects of MDG1 attainment such as food production and livelihood support is thus vital.

The progress made in the last five years towards increasing basic pro-poor energy access has been mixed. In some developing regions, including Latin America, North Africa and China, access to what is considered necessary basic energy to meet the MDGs has been or is on track to be achieved by 2015. In other regions, particularly in sub-Saharan Africa and in developing Asia, the progress towards achieving basic levels of energy access has been slow and is not projected to be met under the current increase rates in access. Looking ahead, we can conclude that the energy-poor will primarily be found in sub-Saharan Africa, India and Indonesia by 2015, and by 2030 in Sub-Saharan Africa and Indonesia.

In poorer regions, the unmet demand for basic access to modern forms of energy also poses an increasing pressure on ecosystems. As the historic trend of meeting growing energy demand in poor countries, with traditional biomass, is likely to continue unless more significant initiatives to stimulate alternative cleaner cooking practices are taken, increasing pressure will be put on ecosystem services in areas where biomass use is growing. The actual percentage of the population in developing countries relying on traditional biomass for cooking and heating will decrease from about 46 per cent in 2005 to about 38 per cent in 2030, but the absolute number of people dependent on traditional biomass will increase. The projections indicate that the number of people relying on traditional biomass will increase from about 2.5 billion people in 2005 to about 2.7 billion people by 2030.

The example of meeting cooking demand in Tanzania, illustrates some of the trade-offs that have to be made when assessing and valuing impacts of alternative means of meeting energy demands for cooking. In the example, GHG emissions, land area required, employment implications and price are included. These are just a few of the paramaters that may be relevant for policy makers to take into consideration when shaping instituional framworks to guide pro-poor energy access and protection of ecosystem services.

The additional energy required to meet basic pro-poor energy needs is small in comparison with the global energy demand, despite the number of people that need to be served. Even when considering universal basic energy access this would only mean an increase of a few percentages of global energy supply. Furthermore, the consequences on ecosystem services of universal modern energy access are positive as it would reduce local pressure on ecosystem services and reduce global warming.

Finally, the investment needs to achieve universal modern energy access are also small in comparison to the annual investments in the global energy sector. With additional investments targeted at pro-poor energy access of about USD 40 billion annually between 2010 and 2030 universal modern energy access can be achieved. This represents a significant increase from today’s levels of effort towards pro-poor energy access, but less than five per cent of the current global annual investments in energy-supply infrastructure (Rockström, 2005; IEA, 2006; IEA, 2010).

PESTICIDES

The widespread use of pesticides in modern agriculture has enabled higher food production and contributed to improved short-term food security in some areas. However, although higher yields can be achieved through such pest control, the human and environmental costs may be high. If the pesticides used hit vital ecosystem functions they may cause a reduction in the long-term supply of the ecosystem services needed for food production (MA, 2005a). There are important gaps in the current knowledge when it comes to the combined effects of diffuse pollution of mixes of pesticides in ecosystems in agricultural areas. Even less is known about the possible effects on the ecosystem services provided by these ecosystems. An improved understanding of the risks of losing ecosystem services associated with the current use of pesticides is a key component towards attaining food security for all. While the use of pesticides has been gradually regulated and risks thus minimised in developed countries, pesticide use in developing countries is often more uncontrolled, leading to widespread unintended exposure of people and pollution of ecosystems.

From the field where the pesticide is intentionally applied, there are various routes for a pesticide product to reach the surrounding environment. These include spray drift during application, run-off from the field or through the disposal of empty containers and/or pesticide rests. Proper handling of the product by the farmer is crucial in order to minimise unintended spreading, e.g. when cleaning the equipment after application of the product (Kreuger, 1998). Equally important is when and how the pesticide is applied as well as in which dose and also, not least, which product is chosen and on which grounds. Even if the agricultural sector is well developed and there is legislation in place which is effectively enforced, pesticides are reaching the environment. There are numerous reports from pesticide findings in water bodies e.g. in the USA (Barbash *et al.*, 2001; Moore *et al.*, 2007), in India (Sarkar *et al.*, 2008), in Brazil (Moraes, 2003) and in Europe (Kreuger and Törnqvist, 1998; Schriever and Liess, 2007) as well as in humans (Qin *et al.*, ; Lignell *et al.*, 2009). Many developing countries lack proper legislation and/or enforcement in the area of chemicals management, resulting in uncontrolled pesticide use with resulting serious risks for high local pesticide contamination.

This chapter reviews the available literature in order to establish how far the current knowledge can take us towards understanding the effects of pesticide applications on a selection of ecosystem services that enable food production needed for the attainment of the MDG 1 targets.

POSSIBLE PESTICIDE EFFECTS ON ECOSYSTEM SERVICES

When pesticides reach the environment, the effects on the ecosystems and their services will depend on a range of factors, such as the persistence of the pesticide and its degradation products, its mobility and the bioavailability of the compound in the ecosystem (e.g. vanLoon, 2000). For instance, the effects of a pesticide application on soil organisms will depend on the bioavailability of the applied pesticide, which in turn depends on the vegetation coverage at the time of application, the soil type and the pesticide used. Some pesticides have a general toxicity towards many groups of organisms, others are more specifically targeted at fewer species (e.g. Theiling and Croft, 1988; Soares and Busolo, 2000). Some pesticides degrade rapidly but the degradation products may be both persistent and toxic. Table 8 lists possible negative effects of pesticide use on ecosystem services. Pesticide use may also of course increase the supply of certain types of services, at least in the short-term. However, the focus of this chapter is to investigate the long-term risks of pesticide use to the overall supply of ecosystem services supporting food production, to allow for a discussion on negative versus positive effects on long-term crop yields and wild food supplies by pesticide applications. This chapter only looks at insecticides and herbicides. It should be noted that also for instance fungicides and fertilisers are added to agricultural land and that the total effect of all agrochemicals combined on ecosystems have to be considered for full risk assessments.

Based on the list above, four ecosystem services of direct importance for food production - namely pollination, pest control, supply of wild foods and nutrient/carbon cycling - were chosen for further study. This chapter will review the current knowledge concerning potential effects of pesticides on this selected set of services. It will identify the knowledge gaps in this area and discuss possible policy implications of the findings. Furthermore, specific knowledge reported in literature on three herbicides and three insecticides is outlined. The selected pesticides are commonly used in most parts of the world and they do not belong to the

Table 8: Possible negative effects of pesticide use on ecosystem services as defined by the Millennium Ecosystem Assessment (MA, 2005a).

Ecosystem services	Possible negative effects of pesticide use
1. Provisioning services	
Crops	Lower yields through indirect impact by effects on e.g. pollination, natural biological control and nutrient circulation. Direct impact on crops if pesticides are not used at correct doses and timing in the crop cycle.
Livestock	No direct impacts from pesticides used on crops.
Capture fisheries	Lower catches if pesticides with toxicity to fish reach water bodies.
Aquaculture	Lower yields if ponds are contaminated with pesticides through spray-drift or runoff or in mixed systems, e.g. cultivation of fish and other aquatic species in fields that are also used for crop production, such as rice.
Wild foods	Reduced catches, indirect if pollination services are hit, direct if wild species come into contact with pesticides e.g. by feeding on treated seeds or through spray-drift or run-off.
Timber	Lower yields if natural enemies of common pests have been reduced in numbers by pesticide applications.
Cotton, hemp, silk	Lower yields if natural enemies of common pests have been reduced by pesticide applications.
Genetic resources	Possible effects if the pesticide use in an area reduces the biodiversity.
Biochemicals, natural medicines, pharmaceuticals	Possible effects if the pesticide use in an area reduces the biodiversity.
Fresh water	Lower quality of fresh water available if pesticides enter fresh water supplies such as streams, lakes or ground water.
2. Regulating services	
Regulation of air quality, climate, water, erosion and natural hazard	No direct effects.
Water purification and waste treatment	No direct effects.
Disease and pest regulation	Increased pest populations if natural enemies of the pest species are hit by pesticide applications.
Pollination	Decreased yields of crops dependent on managed or wild pollinators that are hit by the pesticide applications.
3. Cultural services	
Spiritual and religious and aesthetic values	Reduced values if certain species are affected by pesticide use.
Recreation and ecotourism	Decreased recreational value if there is risk of spray drift of pesticides when walking along fields or forests.
4. Supporting services	
Soil formation	Possible effects through changes in the microbial community structure and total microbial activity.
Nutrient cycling	Possible effects through changes in the microbial community structure and total microbial activity.
Primary production	Possible effects through changes in the community of primary producers in aquatic ecosystems in agricultural areas.

most hazardous (all pesticides included in this study are from WHO class II and III), see table 9.

POLLINATION

Pollination of agricultural crops and wild plants is a crucial and direct ecosystem service fundamental to food production. Globally there are over 200,000 flowering plants which depend on pollination by over 100,000 different pollinators such as bees, birds and bats (Klein *et al.*, 2007). Many crops such as fruits and vegetables, as well as wild food plants, are either completely or partly dependent on pollination by wild insects, birds, bats or domesticated bees (Richards, 2001). Of the global crop production, at least 35 per cent are crops that depend on such animal pollination (Klein *et al.*, 2007). Other crops such as wheat, rice, potatoes, maize and cassava are not dependent on animal pollination since they are either wind- or self-pollinated or have vegetative propagation. It has been estimated that the agricultural demand for pollination is growing rapidly, even faster than the global stock of domesticated honeybees (Aizen *et al.*, 2009).

A recent FAO assessment (FAO, 2008a) states that there is reason for concern for the status of animal pollination service since regions on all continents (except Antarctica) have reported pollinator declines. Although there are many specific cases of well documented pollinators' decline there is still no global assessment of changes in distribution or level of pollination services (FAO, 2008a). This is partly due to methodological difficulties in monitoring insect pollinators due to the large natural variations in pollinator communities. Plant pollinator interactions are also complex. Some plants are best pollinated if visited by a number of different species. Plants may be pollinated by different species during different seasons and years depending on the between-year fluctuations of specific pollinators. Pollinators, on the other hand, often require availability of flowers for longer periods than a single crop can offer. Hence, a certain diversity of flowering plants around the fields year-round is

Table 9: Selected pesticides and their recommended classification by WHO (WHO, 2010).

	WHO classification and status under UN chemical treaties	General Formulation
Fipronil	WHO class II: moderately hazardous pesticide	Fipronil is a relatively new insecticide. Many insects, including honeybees, as well as many aquatic organisms, are highly sensitive to fipronil (Gunasekara *et al.*, 2007).
Cypermethrin	WHO class II: moderately hazardous pesticide	Cypermethrin is a pyrethroid insecticide which is widely used for a broad range of pests. It has low toxicity to mammals relative to other pesticides but like all pyrethroids it has high toxicity to fish and aquatic invertebrates (Friberg-Jensen *et al.*, 2003).
Carbaryl	WHO class II: moderately hazardous pesticide	Carbaryl is a carbamate insecticide which is also highly toxic to aquatic invertebrates, with both acute and chronic effects and it is highly toxic to bees (USEPA, 2003).
Glyphosate	WHO class III: slightly hazardous pesticide	Glyphosate is a widely used broad spectrum herbicide for weed control in agriculture and unwanted vegetation in various other types of locations. The most well known commercial product is Round-up (KEMI, 1997).
Paraquat	WHO class II: moderately hazardous pesticide	Paraquat is a widely used herbicide for weed and grass control. Apart from being toxic to many different organisms, it has a high acute toxicity to humans (CDC, 2010).
2,4-D	WHO class II: moderately hazardous pesticide	2,4-D is a widely used herbicide (phenoxy/phenoxyacetic acid type). Its uses include fields, fruit and vegetable crops, lawns and aquatic and forestry applications. It is toxic to many aquatic organisms (USEPA, 2005).

Box 5: An example at village level: pesticide use in Cambodia, Laos PDR and Vietnam.

Many small-scale farmers use pesticides in spite of high costs of purchase. In Cambodia, a recent FAO survey in Battambang and Prey Veng provinces showed that all farming households interviewed (total of 301 households in 10 villages) used pesticides on a regular basis without having adequate information about handling in order to minimise risks (Sokha, 2009). A rapid assessment carried out in the northern provinces of Lao PDR showed a similar picture with high rate of pesticide use among small-holder farmers as well as on larger plantations (Louanglath, 2008). In the Cambodian survey, over 50 per cent of the interviewed farmers reported that they had experienced symptoms of pesticide poisoning during or after spraying (Sokha, 2009), giving clear indications that safety precautions are not followed. The report also suggests that most of the pesticides are sold by untrained local dealers to farmers that cannot read the labels. Farmers often mix several different products for calendar based applications, sometimes weekly or more often yet without previous signs of pest infestations in the fields (Sokha, 2009). A survey in Vietnam interviewed 251 farmers growing melon and cabbage in 2008. It reported similar stories of indiscriminate use, improper handling and lack of safety precautions (Chung, 2008). These reports indicate that pesticides in these countries are sold, used, stored and disposed of in a way that gives rise to a high risk of pesticide poisoning for farmers and their families as well as of unwanted pesticide effects in the fields and surrounding ecosystems.

necessary to sustain wild pollinator communities (FAO, 2008a).

This section focuses on the pollination service from bees, both wild and domesticated, which accounts for 25 000 to 30 000 species (FAO, 2008a). The Honeybee (*Apis mellifera*) has been reported to have declined in the US and in several European countries. Declines are also reported for examples for bumblebees (*Bombus* spp.), Himalayan cliff bees (*Apis laboriosa*) and stingless bees (*Melipona beecheii*) (FAO, 2008a). The scientific literature points to one major reason for the decline in pollinator communities: the concurrent decline in habitat opportunities for these pollinators (Kremen *et al*., 2004; Brown and Paxton, 2009; Kuldna *et al*., 2009; Winfree *et al*., 2009). However, there are also reports of pesticides affecting pollinating species (Johansen, 1977; Stark, 1991). Effects of pesticides on pollination services may be either through direct effects on the pollinator by insecticides sprayed on crop land, grass land or forests, or indirect effects by use of herbicides that reduce the diversity of flowering plants around the fields (Kearns, 1998; Bohan *et al*., 2005). There are also fungicides with acute toxicity to bees (Anderson and Atkins, 1968; Stark, 1991). The choice of pesticide, the timing of the application and the general handling of the pesticide and application equipment are of fundamental importance for the effects on pollinators (Johansen, 1977; Stark, 1991). For instance, if small doses are used and the insecticide is applied at night, before the blooming of the crop, the cultivated bees seem to go unharmed (Stark, 1991). However, even with such precautions, recent investigations show that bees are inevitably exposed to pesticides if such products are used in the foraging area of the bees (Chauzat *et al*., 2006; Barnett, 2007; Mullin *et al*., 2010). Mullin *et al* (2010) sampled bees, bee wax, pollen and bee hives in 23 US states and one Canadian province. They found 98 different pesticides and 23 degradation products of pesticides in the 887 samples. The average number of pesticides in a single sample was seven and ranged up to 31 different pesticides in a single sample, clearly showing that honeybees across North America are extensively exposed to multiple pesticides.

Although there are large numbers of laboratory studies examining the toxicity of different pesticides to bee pollinators (e.g. Morandin *et al*., 2005; Malone *et al*., 2007; Scott-Dupree *et al*., 2009) and reports of bee kill/poisoning (e.g. Barnett, 2007), there are only few actual field studies on the effects of pesticides on the pollination service (FAO, 2008a). In the reported cases of bee poisoning by pesticides, the source of the pesticide is not always clear (Barnett, 2007) and other factors/conditions are not controlled. The lack of appropriate field studies means that the current knowledge is incomplete.

There are some studies comparing the level of pollination carried out by natural bee communities in conventional and organic farming (e.g. Kremen *et al*., 2002; Kremen *et al*., 2004). They found a strong correlation between availability of natural habitats for the native bees and the degree of pollination services carried out by these native bees. There was no correlation between other factors investigated and the pollination service, including farm type (organic or conventional) and insecticide use (Kremen *et al*., 2004). Gabriel and Tscharntke (2007) reported that insect pollinated arable weed species appeared to benefit disproportionately from organic farming. One possible explanation given is a higher bee density in organic fields which would give pollinated plant species a higher comparative advantage than in fields with lower bee density; however, the potential role of pesticides was not investigated specifically (Gabriel and Tscharntke, 2007).

Table 10 lists literature reports of effects on pollination by the selected set of pesticides. It shows that, as with the situation for pesticides in general, the state of knowledge is also weak for these specific pesticides. There are very few field studies looking at effects of pesticides on the actual pollination outcome. Until such studies are reported, the only conclusion to be drawn is that most of the pesticides used are toxic to pollinators and that the effect on the pollination service will depend on the handling and use of the pesticides in the field. It is clear that the unregulated use in some developing countries implies extra risks of effects of pesticides on the pollination service. Also worth noting is that there are several pesticides used today with higher toxicity to bees and other pollinators than the selected set in Table 10. There are, for instance, reports about serious effects on bees by the combination of a new group of pesticides, the neonicotinoids, and systematic fungicides (Mullin *et al*., 2010).

The available literature thus shows a widespread exposure of pollinating animals such as bees to multiple pesticides. Actual field experiments investigating effects of pesticide applications on the pollination service are scarce and do not give enough evidence to rule out effects on the pollination services from current pesticide use. The few existing reports from investigations in the field suggests that pesticide use, if properly managed, is not the most serious threat to pollinator communities, wild or domesticated. However, as an additional stress to already vulnerable communities, it cannot be ruled out that current pesticide use affects crop yields through impaired pollination, especially in agricultural settings where pesticide use is not properly regulated or controlled.

PEST CONTROL

Natural enemies of crop pests contribute with an ecosystem service that is widely recognised in the agricultural field (Kromp, 1999; Barrios, 2007) and the fact that pesticides may harm the natural enemies and

Table 10: Reported effects on pollination by pesticides.

	Potential effects on pollinators and the pollination service
Fipronil	Highly toxic to bees in laboratory toxicity studies (both fipronil and the metabolite called MB46136) (EFSA 2006). A limited number of studies in the field available. These have analysed fipronil residues in bees (e.g. Mullin, Frazier *et al*. 2010), but not assessed the effects of fipronil use on pollination service.
Cypermethrin	Highly toxic to bees in laboratory studies (e.g. KEMI, 1997). One study analysed cypermethrin residues in bees (Mullin, Frazier *et al*. 2010). No field studies of effects on pollination service found in literature.
Carbaryl	Highly toxic to bees in laboratory studies (e.g. USEPA, 2003). One study analysed carbaryl residues in bees (Mullin, Frazier *et al*. 2010). No field studies of effects on pollination service found.
Glyphosate	Many studies on glyphosate resistance in plants and effects on gene flow between plants. No field studies of effects on pollination service found.
Paraquat	No field studies of effects on pollination service found.
2,4-D	No field studies of effects on pollination service found.

thereby cause increased pest problems is well known (Wilson and Tisdell, 2001; Naranjo and Ellsworth, 2009). In general, insecticides are often toxic also to beneficial insects, particularly to parasitoids, but there are also reports of direct and indirect effects by herbicides (Yardım and Edwards, 2002). If the pest organism returns after spraying, there are no natural enemies left to control the population and such "pest resurgence" may thus be a serious event causing crop failure. In cases where the pest organism has developed resistance to the pesticides used, such pest resurgence events are especially destructive (Reissig *et al.*, 1982; Wilson and Tisdell, 2001; Naranjo and Ellsworth, 2009). Initial gains from pesticide use in terms of higher yields can later be reversed, leaving farmers in a situation worse than before. An example is the use of Bt-cotton in China to control the damage of the boll-worm which first reduced the needs of pesticides and increased the incomes of the farmers. Later these benefits were eroded due to an increasing use of pesticides to combat secondary pests (Wang, 2008; Lu, 2010).

There are several approaches to safe guarding the ecosystem service of pest control. Integrated Pest Management (IPM) programs aim at making optimal use of natural enemies for pest control. This is done by using as specific pesticides as possible and applying only when pest organisms reach certain thresholds (Naranjo and Ellsworth, 2009). There are also well-established techniques for releasing natural enemies in the field to combat certain pests (Bellows, 1999). Examples from large scale training programs for rice farmers in the Philippines and Indonesia have shown that it is possible to significantly reduce the pesticide use while increasing the crop yield (FAO, 2009a).

There are only few studies specifically assessing the relationship between pesticide use and the ecosystem service of pest control. An unusually well documented IPM case is described by Naranjo and Ellsworth (Naranjo and Ellsworth, 2009). It is a long-term follow up of IPM practices in the Arizona cotton system. They show that ensuring the survival of a rich fauna of beneficial arthropods gives a resilient food web with three to five insect predator species controlling the cotton pest whitefly (*Bemisia tabaci*). The authors also report on experiments where the natural enemies have been selectively reduced in the field, resulting in substantially lower cotton yields. There are some studies quantifying the yield increase due to the presence of natural enemies, or the yield loss due to the lack of such enemies (Ostman *et al.*, 2003). Table 11 exemplifies reports on effects of certain pesticides on specific natural enemies.

A meta-analysis of studies published before 2003 found that organic farming usually enhances species

Table 11: Possible pesticide effects on natural enemies to pest organisms.

	Potential effects on natural enemies to agricultural pest organisms
Fipronil	Fipronil is toxic to many organisms that are natural enemies to agricultural pests, for instance parasitoids of the Brown Plant Hopper, a wide spread rice pest (Wang *et al.*, 2008).
Cypermethrin	Being a broad spectrum insecticide Cypermethrin kills many organisms that are predators of agricultural pests, like spiders and parasitoids (NCAP, 1996).
Carbaryl	Carbaryl is highly toxic to many beneficial insects (USEPA, 2003).
Glyphosate	No effects or slightly toxic effects reported for some natural enemies (e.g. do Carmo *et al.*, 2009).
Paraquat	Harmful effects on arthropods have been reported (e.g. Carmo *et al.*, 2009; Yardım and Edwards, 2002; Carmo *et al.*, 2010).
2,4-D	No effects of 2,4-D reported in one study on one organism (Carmo *et al.*, 2010).

richness, most notably of plants, birds and insects. The authors propose that the effects of organic farming on species richness will be larger in intensively managed agricultural landscapes than in small-scale diverse landscapes with many non-crop biotopes (Bengtsson *et al*., 2005). Another review (Hole *et al*., 2005) points at the knowledge gaps that persist when it comes to the effects of organic farming on biodiversity. They also identify a number of taxa including mammals, birds, invertebrates and arable plants that benefit from organic farming practices (including reduced or prohibited use of pesticides) through increases in abundance and/or species richness (Hole *et al*., 2005). Norton *et al* (2009) carried out a large sampling of conventional and organic farms in the UK and analysed habitat and management differences on 161 farms. The results point at the importance of organic farming to field and farm complexity with benefits for biodiversity. However, this study does not allow for conclusions to be drawn as to the effect of pesticides on the biodiversity since the organic farms also varied in other management aspects (Norton *et al*., 2009). Geiger *et al* found that the use of insecticides and fungicides in European agricultural landscapes has consistent negative effects on biodiversity in the eight European countries included in the study (Geiger *et al*., 2010). It should be noted that the general diversity of species is not necessarily the most important for the ecosystem service of pest control. The functional diversity may be more crucial (Elmqvist *et al*., 2003).

There are many laboratory studies showing toxicity of various insecticides and herbicides to natural enemies, but there are only few systematic field experimentsassessing the services provided by these organisms. However, the current knowledge is complete enough to suggest the importance of pesticide reduction schemes, with the purpose of allowing natural enemies to contribute to the pest regulation. This knowledge is far from being implemented in all agricultural settings. The risks of reducing the number of natural enemies in a way that may have implications for crop yields, especially in the case of pest resurgence, are especially high in areas where pesticides are used in an uncontrolled way.

NUTRIENT AND CARBON CYCLING

Nutrient and carbon cycling is an essential ecosystem service not only for food production but also for many supporting and regulating ecosystem services (Barrios, 2007). These processes include for instance the capture of nitrogen by nitrification bacteria and the decomposition of the organic matter. The nutrient cycling is governed both by abiotic and biotic processes. For the biotic component, soil microorganisms constitute an important part of the process. Soil microorganisms not only degrade plant and animal matter, but also pesticides if they are available. Some studies of specific organisms show substantial effects of pesticide applications on the soil micro fauna, see table 12. For example, paraquat treatment of bean plants (in pots) almost completely removed heterotrophic soil bacteria from the system (Ampofo, 2009). The average agricultural field will contain large numbers of different microorganisms with different functions in degradation and nutrient cycling. Guidelines for the approval of pesticides include determining potential side-effects on microorganisms by studying functional parameters such as carbon or nitrogen mineralisation. These parameters will however not give information on changes in microbial diversity or changes in the species composition due to the pesticide application. Some microbial groups may be able to use an applied pesticide as a source of energy and nutrients, while the pesticide may be toxic to others. Such changes in species composition may have implications in the soil ecosystem and thereby for food production (Johnsen *et al*., 2001).

The methodological difficulties in assessing the effects of pesticides on microorganisms are substantial. Soil is a heterogeneous media and the microorganism community is complex in species and functions. While there are large numbers of studies on pesticide effects on certain groups of bacteria or organisms, there is still little knowledge on effects of pesticides on long-term changes of microbial diversity at the community scale (Johnsen *et al*., 2001). For example, Eisenhauer *et al* (2009) reported that of the three pesticides in their study, two increased and one decreased the activity and biomass of soil organisms. This is one of many studies showing that pesticides are affecting the soil microorganisms when applied under normal field conditions. However, it does not reveal changes in intra-species relations or the long-term effects on the microbial community structure in these fields with subsequent implications for soil fertility and crop yield.

To conclude, also for the important ecosystem services of nutrient and carbon cycling, the evidence of pesticide effects on crop yields is incomplete. The soil fauna is clearly affected by pesticide applications with resulting short-term changes in number and in species composition. The long-term consequences for the soil ecosystem, the soil fertility and the crop

Table 12: Possible effects of pesticides on nutrient and carbon cycling.

	Microbial activity/Nutrient cycling
Fipronil	Low risk to soil macro and micro organisms although there are still some open questions in the risk assessment (EFSA, 2006).
Cypermethrin	Cypermethrin has been reported to decrease nitrogen fixation in soybean root noodles (NCAP, 1996).
Carbaryl	Significant reduction of arthropods including springtails and mites reported from field trials in citrus orchards in Australia (Liang *et al.*, 2007).
Glyphosate	Soil fungi reported to be significantly reduced by commercial products based on Glyphosate (Freemark and Boutin, 1995). However, the toxic effects reported seem to be related to the surfactant added to the product and not to Glyphosate itself (Mann, 2009).
Paraquat	Paraquat treatments of plants reduced the total number heterotrophic soil bacteria and the Rizobium population number by 93% (Ampofo, 2009).
2,4-D	The number and diversity of Springtails (Collembola) were reduced by 2,4-D applications in field trials with Winter wheat, Barley and Oats in Germany (Prasse, 1985).

production remain unknown. The academic field covering these issues is not a homogenous single community – studies of soil fauna and pesticide effects require multidisciplinary approaches and various different competencies. The results that have been produced so far suggest that the pesticide effects on soil fauna are serious enough to call for further research. This is especially true since the soil fauna is not only crucial for soil fertility and sustained crop production, but is also part of larger regulating and supporting ecosystem services, including carbon cycling and climate control.

SUPPLY OF FISH AND OTHER AQUATIC SPECIES/WILD FOODS

Pesticide applications that infiltrate and reach the ground water, or runoff water that contains pesticide rests, spray drift at the application and secondary airborne spread of pesticides are all transport routes that may take pesticides to water bodies such as rivers, lakes, ponds and marine coastal areas. Pesticides in these water bodies may affect the supply of fish and other aquatic species collected for food. This concerns both the quantity of the catches, but also the quality, e.g. fish with high concentrations of pesticides in their bodies may affect the health of the consumer (e.g. EFSA, 2005; Moon *et al.*, 2009).

Pesticides are commonly found in most surface waters with agricultural activities within the catchment area (Schriever and Liess, 2007; Sarkar *et al.*, 2008). The total amount of pesticides used in the field has been reported to be the single most important predictor of the concentrations in the nearby water bodies (Krueger, 1998) and the most important route is through surface water runoff (Schriever and Liess, 2007). However, the amount of pesticides reaching the aquatic environment surrounding the fields also depends on the intrinsic properties of the pesticide (Krueger, 1998) as well as the handling of the pesticide by the farmer (Krueger, 1998). Daily average concentrations in receiving streams may vary over orders of magnitude from one day to another due to run-off conditions. Field trials showed that when cypermethrin was sprayed at the agricultural field, the macro invertebrates in the adjacent stream showed reduced survival. However, if the spraying was not carried out all the way to the stream but instead left a buffer zone, no effects on the invertebrates were recorded (Maltby and Hills, 2008). Still, current agricultural practices do result in pesticides reaching the aquatic ecosystems. Mize *et al* (2008) measured the fipronil concentration in streams in rice cultivation areas in south-western Louisiana and found stream concentrations at an order of magnitude above the lethal concentration (LC50) for the macro invertebrates included in the study. In Sweden a project measuring pesticide concentrations in receiving streams in agricultural areas reported concentrations at or above the concentration levels demonstrated as having an impact on the aquatic fauna and flora (Krueger, 1998).

In some cases, pesticides are added directly to the water, like in oyster production[2]. In Washington State in the USA there was a case reported where oyster producers added carbaryl to their mud banks to protect the oysters from shrimps. The carbaryl also killed fish and crabs that were cultivated in the same area giving raise to conflict over the local water resource (Feldman *et al.*, 2000).

The effects on an aquatic ecosystem of a certain concentration of pesticides are not straightforward to analyse. Most methods developed for assessing ecological risks by contaminants look at one chemical at a time, and often with simplified ecosystem models. The consequences for the real ecosystem of mixtures of contaminants combined with other stressors may be different from those indicated by such models. Also low levels of pesticides in receiving water bodies may, for instance, alter the food web by killing microorganisms and algae and leaving others to proliferate (De Laender *et al.*, 2010).

A meta-analysis carried out by Johnston and Roberts (2009) showed that across all types of habitats, marine pollution was associated with marine communities containing fewer species than their pristine counterparts. The contaminants in this study included sewage, sold waste, metals, effluents and nutrients and did not specifically look at pesticides. A review by Sarkar (2008) looked at organochlorine pesticide residues in abiotic and biotic compartments in coastal regions in India and reported findings of several different types of pesticides in the marine environment such as DDT, HCH, HCB, aldrin, dieldrin, eldrin, methoxyxchlor, and endosulfan sulphate. The levels of DDT were reported to exceed the effects range-low (ER-L) in sediments at some locations (Sarkar *et al.*, 2008).

As is commonly the case, short-term effects are more easily measured and there are few studies on long-term effects by pesticides in the aquatic environment. A mesocosm experiment of pulsed pesticide application showed that even 40 days after the pesticide application, and after the pesticide degraded, differences in the microbial, phytoplankton and zooplankton communities remained (Downing *et al.*, 2008). In Swedish field measurements, some pesticides remained in the stream water for several months up to years after the pesticide application (Krueger, 1998).

The effects of pesticides when they reach surrounding aquatic environments are diverse as seen in table 13. It should be noted that also in countries with enforced legislation and control of pesticide use like the USA, current use of 2,4-D may pose a threat to aquatic species, recently forcing the authorities to lower the allowed application rates (USEPA, 2005). 2,4-D is also applied directly to water bodies for weed control, which makes the risks of damage to aquatic species higher.

Summarising this section, again it has to be concluded that knowledge is incomplete, especially concerning long-term effects. There are many examples of short-term effects and the risks of having negative effects on local wild food supplies associated with uncontrolled pesticide use has to be considered high. Of special concern is the indiscriminate use of pesticides in field settings were wild food is collected in, or just adjacent to the field that is treated with pesticides. This concerns, for example, rice paddy fields where wild food such as insects, fish, crabs and snails are collected. Using substances such as fipronil, cypermethirin or carbaryl in such fields means high risks of seriously reducing the supply of wild foods. For all three pesticides, long-term effects have been reported where a dose of pesticide could have effects on wild food yields up to six months after the pesticide application. The glyphosate containing products, if containing also the surfactant POEA, will be of concern to many aquatic species when used in an uncontrolled way (Mann, 2009).

The short-term and long-term effects of pesticides in agricultural settings where a more precautionary and regulated use is being practiced poses a much lower risk to the aquatic ecosystem; however, it is still not always negligible (Geiger *et al.*, 2010). More research is needed for the long-term effects of pesticides when used in a regulated and precautionary way. Immediate measures are needed to improve the situation in countries were pesticides are used as reported for instance from southeast Asia (Chung, 2008; Louanglath, 2008; Sokha, 2009).

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[2] It should be noted that pesticides are also sometimes added directly to ponds or rivers as a fishing technique: the intoxicated fish float to the surface and are easily collected.

Table 13: Possible effects of pesticides on fish and aquatic organisms.

	Examples of pesticide effects on fish and other aquatic species
Fipronil	One of the degradation products of fipronil (MB 46136) poses a long-term risk to aquatic invertebrates (from the assessment of representative use of fipronil in Maize). The risk of bioaccumulation of metabolites in fish is not fully assessed (EFSA, 2006). Fipronil is toxic to non-target arthropods and other aquatic species (EFSA, 2006). A study from Louisiana showed effects on the crawfish industry after application of fipronil to combat rice weevils in rotational cropping. The effect persisted several years after the pesticide application (Bedient *et al*., 2005).
Cypermethrin	Cypermethrin has high acute toxicity to fish and to crustaceans, but strong binding to soil and sediments quickly reduces the bioavailable concentrations to fish and insects. However, for some arthropods, effects have been recorded up to six months after exposure (NCAP, 1996; KEMI, 1997). Crabs, shrimps, crayfish and lobsters are reported to be highly sensitive to cypermethrin (NCAP, 1996). Field experiments have shown clear effects on species abundance and community structure in the aquatic ecosystem from a dose of cypermethrin that can occur from current practice and use within the EU (Friberg-Jensen *et al*., 2003; Wendt-Rasch *et al*., 2003). Cypermethrin has been reported to impact growth of green algae at low concentrations (NCAP, 1996) and alter food web carbon flows (De Laender *et al*., 2010).
Carbaryl	Carbaryl poses a high acute and long-term risk to aquatic organisms (USEPA, 2003; EC, 2006). It is highly toxic to freshwater fish. Chronic reproductive and growth effects on freshwater invertebrates have been reported (USEPA, 2003). The situation for marine/estuarine fish is so far unclear, especially considering the potentially higher persistence of carbaryl in anaerobic conditions (USEPA, 2003). Controlled studies have not shown phytotoxic effects, but there have been field indications to the contrary. The largest number of field incident reports in the US for carbaryl use have been associated with plant toxicity (USEPA, 2003).
Glyphosate	Glyphosate has low to moderate toxic effects on fish and studied algae and invertebrates (KEMI, 1997). Most commercial glyphosate based products include a surfactant called polyoxyethylenetallowamine (POEA) which has been shown to have a relatively high toxicity to for instance amphibian larvae (Mann, 2009).
Paraquat	Paraquat is toxic to green water algae (*Chlamydomonas moewussi*) in laboratory tests (Prado *et al*., 2009).
2,4-D	2,4-D is toxic to fish and aquatic invertebrates (USEPA, 2005). It has also been shown to have long-term effects on the macroinvertebrate communities in artificial ponds (Stephenson and Mackie, 1986).

CONCLUSIONS

There are effects of pesticide use reported on all four ecosystem services included in this chapter; pollination, natural pest control, nutrient cycling and wild food supplies. The available literature shows a widespread exposure of pollinating animals such as bees to multiple pesticides. The few existing reports from investigations in the field suggests that pesticide use, if properly managed, is not the most serious threat to pollinator communities, wild or domesticated. However, as an additional stress to already vulnerable communities, it cannot be ruled out that current pesticide use affects crop yields through impaired pollination, especially in agricultural settings where pesticide use is not properly regulated or controlled.

The importance of protecting the natural enemies of agricultural pests is well established. This knowledge is far from being implemented in all agricultural settings. The risks of reducing the number of natural enemies in a way that have implications for crop yields, especially in the case of pest resurgence, are especially high in areas where pesticides are used in an uncontrolled way.

For the ecosystem services of nutrient and carbon cycling, the current knowledge of pesticide effects on crop yields is incomplete. The soil fauna is clearly affected by pesticide applications with resulting short-term changes in number and in species composition. The long-term consequences for the soil ecosystem, the soil fertility and the crop production remain unknown. The results that have been produced so far suggest that the pesticide effects on soil fauna are serious enough to call for further research. This is especially important since the soil fauna is not only crucial for soil fertility and sustained crop production, but is also part of other regulating and supporting ecosystem services, including climate regulation.

The risks of having negative effects on local wild food supplies from uncontrolled pesticide use have to be considered high. Products like fipronil, carbaryl and cypermethrin that are reported to be used in an inappropriate way by farmers in e.g. Laos, Cambodia and Vietnam (Chung, 2008; Louanglath, 2008; Sokha, 2009) have a very high potential for reducing the supply of wild foods collected in or nearby the rice paddies such as insects, frogs, crabs, fish and snails. Immediate measures are needed to improve the situation in countries were pesticides are used as reported for instance from southeast Asia. The short and long-term effects of pesticides in agricultural settings where a more precautionary and regulated use is being practiced poses a much lower risk to the aquatic ecosystem; however, it is still not always negligible (Geiger *et al.*, 2010). More research is needed to esatblish the long-term effects of pesticides when used in a regulated and precautionary way.

For all four services covered, there are reports of unintended negative effects on ecosystems. However, no studies were found in the literature search that try to capture long-term effects (10 years and longer) of the pesticide use on the ecosystem services needed for agriculture. Also, there are very few studies looking at more than one pesticide at a time, thus any cumulative effects are not captured. More research is needed especially on the long-term supply of ecosystem services when exposed to mixtures of pesticides over long periods of time. The potential risk of pesticide use for the ecosystem services has of course to be seen in relation to the potential yield gain of the pesticide use. But the yield gain in the short-term perspective has to be seen in relation to potential long-term effects by pesticides on the supporting ecosystem services. The pressure from pesticide use on ecosystem services vital to food production and MDG 1 attainment also has to be evaluated as one of many pressures on ecosystems - air pollution and energy consumption that are covered in the other chapters in this report are some examples of such pressures.

DISCUSSION AND CONCLUSIONS

This report has examined three stress factors that have the potential to decrease the supply of ecosystem services, thus reducing the chances of reaching the MDG 1 in a sustainable way. Air pollution, energy generation, and the indiscriminate use of pesticides affect provisioning, regulating, supporting and cultural ecosystem services from local to global scale. The 2008-2009 economic downturn increased the number of people living in poverty and hunger, especially in the rural areas in south Asia and Africa. Increasing the food production by the magnitudes needed for MDG achievement in these areas depends heavily on the availability of both local and global ecosystem services.

The **Air pollution chapter** showed that air pollutants such as ozone (O_3), nitrogen oxides (NO_x), ammonia (NH_3) and sulphur dioxide (SO_2) all have major effects on ecosystem services. These range from substantial reductions in food provisioning due to crop yield impacts (O_3) to changes in ecosystem functioning driven by eutrophication and acidification (NO_x, NH_3 and SO_2). It is highly likely that these impacts represent a barrier to attaining the MDGs both in terms of providing sufficient crop growth to reduce hunger and maintaining diverse natural ecosystems.

Projections of pollution impacts to 2030 highlighted two main issues: 1) The growing importance of air pollution effects in south Asia and 2) That effective policy measures taken now are vital for avoiding the worst impacts. Reductions in crop yields caused by ozone are predicted to be substantial globally but in India the economic impacts of these losses are estimated to be in the region of USD 4.4 billion and may increase by 5-15 per cent by 2030. In addition, it is likely that the greatest effects of acidification and eutrophication in 2030 will be seen in natural ecosystems in Asia. However, a comparison of different socio-economic and legislative scenarios demonstrates that a range of future outcomes are possible. An IPCC "business as usual" scenario shows large increases in ozone concentrations whilst a maximum feasible reduction in emissions scenario gives a reduction. This highlights the importance of effective policy measures to control emissions and protect natural ecosystems. Current research also suggests that a set of co-benefits can be gained since addressing air pollution also has positive impacts for the climate change mitigation efforts.

The **Energy chapter** concluded that the current energy use of the poor is neither sufficient to attain the MDGs nor is it sustainable in terms of maintaining important ecosystem services that can facilitate a transition out of poverty. Meeting the basic energy needs of the poor with minimised impacts on the ecosystem services needed for other aspects of MDG1 attainment such as food production and livelihood support is thus vital.

The energy-poor will primarily be found in sub-Saharan Africa and in India and Indonesia by 2015 and by 2030 in Sub-Saharan Africa and Indonesia. Not achieving even basic levels of energy access is likely to have implications on meeting the MDG targets in these regions. The actual percentage of the population in developing countries relying on traditional biomass for cooking and heating will decrease from about 46 per cent in 2005 to about 38 per cent in 2030, but the absolute number of people dependent on traditional biomass will increase. The projections indicate that the number of people relying on traditional biomass will increase from about 2.5 billion people in 2005 to about 2.7 billion people by 2030. This will mean increasing pressure on ecosystem services in areas where biomass use is growing.

The additional energy required to meet basic pro-poor energy needs is small in comparison with the global

Box 6: How does the air pollution affect the ecosystem services crucial for attaining the MDG 1?

- Air pollutants have major negative impacts on ecosystem services. These include substantial reductions in food production. It is likely that these impacts represent a barrier to attaining the MDG 1.
- Projections of pollution impacts to 2030 highlighted two main issues: 1) The growing importance of air pollution effects in south Asia and 2) That effective policy measures taken now could help avoiding the worst impacts.
- An IPCC "business as usual" scenario shows large increases in ozone concentrations whilst a scenario with maximum feasible reduction in emissions gives a reduction.

energy demand, despite the number of people that need to be served. Even when considering universal basic energy access this would only mean an increase of a few percentages of global energy supply. Furthermore, the consequences on ecosystem services of universal modern energy access are positive as it could reduce local pressure on ecosystem services and reduce global warming.

Finally, the investments needed to achieve universal modern energy access are also small in comparison to the annual investments in the global energy sector. With additional investments targeted at pro-poor energy access of about USD 40 billion annually between 2010 and 2030 universal modern energy access can be achieved. This represents a significant increase from today's levels of effort towards pro-poor energy access, but less than five per cent of the current global annual investments in energy-supply infrastructure (Rockström, 2005, IEA, 2010; IEA 2006).

The **pesticides chapter** concluded that there are reports of unintended negative effects from pesticide use on all four ecosystem services covered (pollination, natural pest control, nutrient cycling and wild food supplies). With the sometimes uncontrolled handling of the most hazardous pesticide products, the resulting risks of severe negative effects on the health of the farmers and their families as well as on the supply of local ecosystems services are high.

The available literature shows a widespread exposure of pollinating animals such as bees to multiple pesticides. As an additional stress to already vulnerable pollinating communities, it cannot be ruled out that current pesticide use affects crop yields through impaired

Box 7: How does the energy production and use affect the ecosystem services that are needed for MDG 1 attainment?

- The current energy use of the poor is neither sufficient to attain the MDGs nor is it sustainable in terms of maintaining important ecosystem services that can facilitate a transition out of poverty.
- Meeting the basic energy needs of the poor with minimised impacts on the ecosystem services needed for other aspects of MDG1 attainment such as food production and livelihood support is vital.
- The projections indicate that the number of people relying on traditional biomass will increase from about 2.5 billion people in 2005 to about 2.7 billion people by 2030.
- Unless ambitious efforts are taken to increase pro-poor energy access, there will still be significant numbers of energy-poor in sub-Saharan Africa, India and Indonesia by 2015. This will further reduce the chances of MDG attainment in these areas.

Box 8: How does the current use of pesticides affect the ecosystem services on which food production and MDG 1 attainment depends?

- There is a widespread exposure of pollinating animals such as bees to multiple pesticides. The literature suggests that pesticide use, if properly managed, is not the most serious threat to pollinator communities, wild or domesticated. However, as an additional stress to already vulnerable communities, it cannot be ruled out that current pesticide use affects crop yields through impaired pollination, especially in agricultural settings where pesticide use is not properly regulated or controlled.
- Natural enemies of agricultural pests can be severely hit by pesticide use, especially if precautionary measures are not followed, which leads to crop yield reductions.
- Aquatic organisms collected for food are at high risk of being affected if pesticides are used without safety precautions. Also in regulated agricultural settings the risks posed to aquatic fauna may not always be negligible.
- The soil fauna that performs a regulating ecosystem service through nutrient and carbon cycling may be at risk by the current pesticide use in some countries. There are however serious knowledge gaps in this field, hindering a full assessment and calling for further research.

Table 14: Summary table of possible negative impacts on ecosystem services. An X signifies that the negative impact may be caused.

Ecosystem services	Possible negative impacts	Air pollution	Energy generation	Pesticides
Provisioning services				
Crops	Lower yields	X	X	X
Livestock				
Capture fisheries	Lower catches	X	X	X
Aquaculture	Lower catches	X	X	X
Wild foods	Lower catches	X	X	X
Timber	Lower yields	X	X	X
Cotton, hemp, silk, and other fibre crops	Lower yields	X	X	X
Genetic resources	Reduced diversity	X	X	X
Biochemicals, natural medicines, etc	Reduced diversity	X	X	X
Fresh water	Lower quality/volumes		X	X
Regulating services				
Regulation of air quality, climate, water, erosion and natural hazard	Altered climate regulation	X	X	
Water purification and waste treatment			X	
Disease and pest regulation	Increased pest populations and number of pests		X	X
Pollination	Decreased yields			X
Cultural services				
Spiritual and religious and aesthetic values	Reduced values		X	X
Recreation and ecotourism	Decreased recreational value	X	X	X
Supporting services				
Soil formation	Altered nutrient cycling	X	X	X
Nutrient cycling	Altered nutrient cycling	X		X
Primary production	Reduced or increased primary production	X	X	X

pollination, especially in agricultural settings where pesticide use is not properly regulated or controlled. Furthermore, the current knowledge on the contribution to crop yields by natural enemies to agricultural pests clearly indicates the importance of pesticide risk reduction schemes and Integrated Pest Management training, with the purpose of allowing natural enemies to contribute to the pest regulation. This knowledge is far from being implemented in all agricultural settings. The risks of reducing the number of natural enemies in a way that may have implications for crop yields, especially in the case of pest resurgence, are high in areas where pesticides are used in an uncontrolled way.

The long-term consequences of pesticide use for soil microorganisms remain largely unknown. The results so far suggest that pesticide impacts on soil fauna are serious enough to call for further research. This is especially true since the soil fauna is not only crucial for soil fertility and sustained crop production, but is also part of larger regulating and supporting ecosystem services, including carbon cycling and climate control. The risks to aquatic organisms from the uncontrolled pesticide use are high. The short-term and long-term effects of pesticides in agricultural settings where a more precautionary and regulated use is being practiced poses a much lower risk to the aquatic ecosystem; however, it is still not always negligible. More research is needed for the long-term impacts of pesticides when used in a regulated and precautionary way. Immediate measures are needed to improve the situation in countries were pesticides are used as reported for instance from southeast Asia.

Air pollution, energy generation and pesticides affect ecosystem services vital for reaching the MDGs. Table 14 summarises the findings in the earlier chapters. It shows that for many ecosystem services of different categories, air pollution, energy generation and pesticides have common impacts such as reduced crop yields and altered nutrient cycling. This is serious considering that these pressures constitute only a small selection of the drivers influencing the supply of ecosystem services. Considering the close link between ecosystem degradation and the persistence of poverty (TEEB, 2009), these findings have implications for the MDG attainment efforts. Pollution reduction and pro-poor access to modern energy thus have to be part of the MDG attainment strategy.

The synergies and trade-offs between different ecosystem services at both spatial and temporal scales complicate the picture. Agricultural production sustains human communities but is at the same time one of the most important drivers of tropical deforestation, biodiversity loss, fragmentation and loss of habitats – factors that all reduce the supply of provisioning and regulating ecosystem services needed for sustained food production. Agricultural production needs expansion but also modifications in order not to undermine the underlying conditions for sustained production. Using pesticides to increase the production of certain crops can reduce the supply of other services such as fish and other wild foods. The production of biomass has important trade-offs with agricultural crops for food. Production of charcoal has trade-offs with other services derived from forests such as collection of wild foods and climate regulation. Finding the right balance for each geographic area is not always straight forward even if clear priorities have been identified among the ecosystem services in the area. The complexity of the linkages between services and between services and drivers may cause surprises. Improved tools to assist decision makers and other stakeholders deal with these synergies and trade-offs are urgently needed.

ISSUES FOR POLICY CONSIDERATION

- Consider the various pressures on ecosystems in local and national planning for development in order to reach the MDG 1 and improve the management of ecosystems for multiple ecosystem services.
- Urgently improve the national level pro-poor energy development, air pollution emission controls and chemicals management to support attainment of the MDG 1.
- Introduce immediate air pollution emission controls in all countries in order to curb the effects on crop yields, especially in south Asia.
- Create pro-poor energy policies and regulatory frameworks at the national level to attract required investments and to build national capacity within the public and private sectors to deliver sustainable energy to the poor.
- Strengthen actors' ability at the national level to assess energy alternatives, including their impacts on ecosystem services and their implications for the most vulnerable.
- Strengthen legislation on pesticides and other chemicals and ensure its enforcement in line with the Strategic Approach to International Chemicals Management (SAICM) in order to reduce the current high risks to people and the environment from the indiscriminate use of pesticides.
- Intensify the training of farmers in Integrated Pest Management and pesticide risk reduction schemes in order to avoid decreased supplies of the local ecosystem services needed for MDG 1 attainment.
- Encourage research efforts to establish the long-term impacts of pesticide use on food production, especially regarding microbial nutrient and carbon cycling and the short and long-term cumulative impacts of different agrochemical inputs.

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