OECD INSIGHTS

TRACEY STRANGE ANNE BAYLEY

SUSTAINABLE DEVELOPMENT

Linking economy, society, environment

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Sustainable Development

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By Tracey Strange and Anne Bayley

OECD

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 30 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

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Foreword

Since the Brundtland Commission published its landmark report in 1987, we have come a long way in our reflections on sustainable development. Few would dispute its fundamental principles: that our actions must take into account effects on the environment, economy and society, and that what we do today should not compromise the well-being of future generations.

In the last 20 years, significant progress has been made. Most national governments have begun to incorporate sustainable development into their planning and policy. Pro-active businesses across the globe have brought sustainability to their products and processes. Local initiatives have had success in informing citizens of the importance of participating in reducing waste, renewing urban spaces and other programs.

In spite of these efforts, though, putting the principles of sustainable development into practice has proven to be anything but simple or straightforward. After all, both people and institutions have their habits, and changing them, even when the need is obvious, can be daunting. A key question remains whether we have made enough progress, or taken the warnings seriously enough to allow us to grasp and confront our biggest, most pressing problems.

We have solid evidence of climate change, with projections pointing to an increase in extreme environmental events with potentially devastating consequences for the systems that support human life and society. About half the world still lives on less than $2.50 dollars a day, lacks access to clean water, sanitation, adequate health care and education – an unacceptably stark contrast to the much higher standards of living in developed countries. Some emerging economies, such as China and India, are undergoing rapid growth, resulting in more wealth, but also an increased demand for energy and greater pollution problems. Finding sustainable solutions for growth holds the potential to help reduce poverty, foster development and preserve the environment. Implementing them requires political will and co-operation on a global scale.

The OECD has been at the forefront of the effort to advance sustainable development. We have supported extensive research on the challenges of sustainability and been active in efforts to develop best practices in areas such as sustainable production and consumption and measuring sustainable development. One of the significant challenges lies in policy coherence – ensuring that different policies and practices support each other in reaching a goal. Achieving this coherence in our policies and institutions is essential to achieving real and lasting progress. With a long record of research, analysis and international co-operation, the OECD can offer policy options for addressing these challenges.

The aim of the *Insights* series is to generate an informed debate on some of the key issues that affect our societies and economies today. For a truly meaningful dialogue, we need to go beyond exchanging opinions – no matter how fiercely they are held – and look at the facts and figures. We also need to move beyond jargon. After all, it is this kind of inclusive and broad-based dialogue that will produce the most widely-supported decisions and strongest results.

Angel Gurría
Secretary-General of the OECD

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Currency Note

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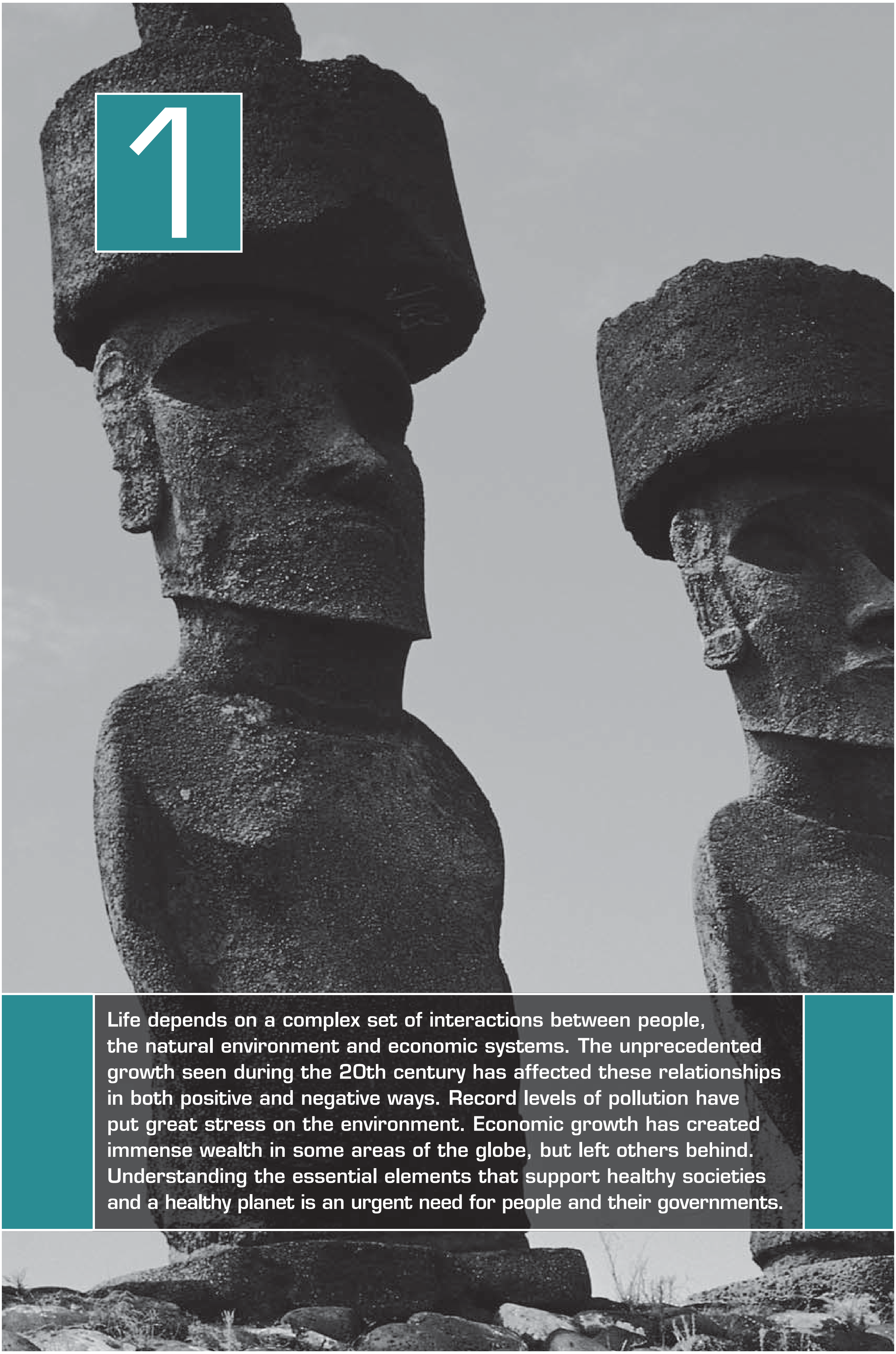
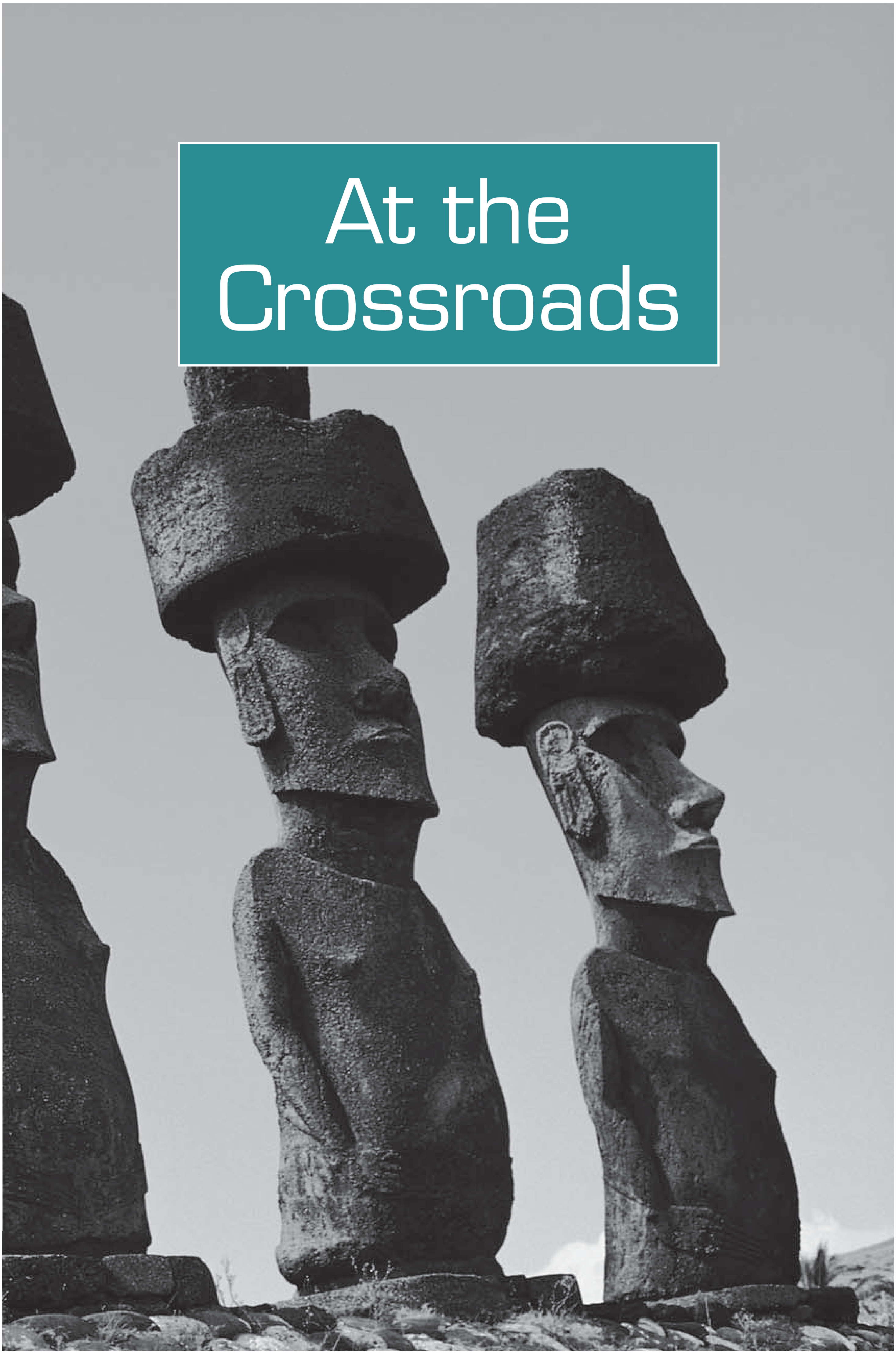


Life depends on a complex set of interactions between people, the natural environment and economic systems. The unprecedented growth seen during the 20th century has affected these relationships in both positive and negative ways. Record levels of pollution have put great stress on the environment. Economic growth has created immense wealth in some areas of the globe, but left others behind. Understanding the essential elements that support healthy societies and a healthy planet is an urgent need for people and their governments.

At the Crossroads



By way of introduction…

Two thousand three hundred miles to the west of Chile and 1 300 miles to the east of Polynesia's Pitcairn Islands lies an island that has inspired intense interest for centuries, not for its perfect climate or its untouched beauty, but because it holds a secret, a mystery. Rapa Nui, or Easter Island as it was named by 18th century Dutch explorers, attracts scientists from around the world who come to study its stone statues, called moai.

The moai, like the pyramids of ancient Egypt, intrigue and confound us with their sheer size: weighing up to 270 tonnes and as much as 70 feet tall, these massive monolithic figures form an imposing presence: outsized human faces looking out over this remote island and the thousands of miles of ocean that lie beyond it. We marvel at the engineering and wonder at how stone-age Polynesians managed to erect such immense structures without the use of cranes, metal tools, or large animals. The creation of statuary of this size and sophistication speaks to the existence of a populous, creative and complex society – one that was well-off enough to support an artisan class. They could afford to allocate time and resources to the various activities involved in making, transporting and erecting hundreds of statues.

Or could they? European explorers who visited the island in the 18th and 19th centuries found a population of only a few thousand, a mere remnant of the statue-building society that came before. Something had significantly altered life on Rapa Nui.

What had at one time been a sub-tropical forest was now a completely deforested island, with at least 22 species of trees and plants extinct. Most wild sources of food were gone – overhunting had left Easter with almost no wild bird species. Without trees to make canoes, large fish were inaccessible, leaving only fish that could be caught close to shore. Evidence shows that these stocks too were depleted. What happened to bring Easter's civilisation to near extinction, driving its population almost to zero and ending its period of cultural flourishing and creative production? In his book *Collapse*, Jared Diamond suggests a scenario in which the population continued to exploit resources available to them beyond their limits, in an environment whose ecological fragility made it vulnerable to permanent destruction. The exact cause of the deforestation is still being debated. The trees were cut to supply wood for rollers and beams to transport the statues. Forest was cleared for agriculture. Trees were also burned to obtain charcoal.

Another possibility is that rats brought to the island by the first settlers fed off the seeds of the trees. Easter's collapse has inspired thousands of pages of study and analysis – in part because islands make interesting cases studies, providing a kind of closed Petri dish in which we can study cause and effect. But Easter also intrigues us because of the extent of its devastation, what Diamond calls "the most extreme example of forest destruction in the Pacific, and among the most extreme in the world." Is there a lesson in this experience for the world of today? What can we learn from Easter's cautionary tale?

The relationship of humans to the environment has always been one of give and take. Easter Islanders made use of their surroundings for their physical and cultural needs in the same way that all human societies do – but they either did not see or did not heed the requirement of keeping their "systems" in balance, of ensuring that new trees were growing when old trees were cut, for example. When the rate of use overtakes the rate at which a resource can be replenished, then that resource will be drawn down and eventually disappear, affecting all of the people, animals and plants that depend on it.

The question of equilibrium – balancing use with renewal, pollution with its impact on ecosystems – is key to understanding the challenges of our world. Even CO_2 emissions that we all worry about these days serve a beneficial purpose, being absorbed by plants for increased growth, as long as the proportions remain right: the carbon dioxide put into the atmosphere should not exceed what can be absorbed through photosynthesis. Problems arise when proportions get out of balance, such as with excessive CO_2 emissions that cannot be absorbed by the ocean, plants and other so-called carbon sinks, and thus contribute to climate change.

Keeping systems in balance is an important idea that reaches beyond environmental concerns. Think of the demographic balances in a given society, the interplay between births, deaths, emigration and immigration. For our economies, we must have enough young workers to replace retirees, and to fund their pensions. Finally, can societies remain stable when resources are concentrated in the hands of a few, while others go without?

> **"World population is projected to increase [by around 2 billion] by 2050. Practically all that growth will be in the developing countries of Asia and Africa. This will put increased strain on resources and systems that are already insufficient in many cases."**
>
> *Emerging Risks in the 21st Century: An Agenda for Action*

This chapter starts by looking at the state of the world today. It describes the material progress the industrial era has brought and what this means for our daily lives. It then describes the downside – the social and economic inequalities and negative environmental impacts. Finally, it looks at where we are heading and the questions we should be asking about the sustainability of our societies.

How are we doing?

To look at the statistics, the world today is, on average, a prosperous place. Growth in the second half of the 20th century was greater than at any previous historical period. Average incomes have increased eightfold since 1820, while population is five times higher.

> **"The world economy performed better in the last half century than at any time in the past. World GDP increased six-fold from 1950 to 1998 with an average growth of 3.9 per cent a year compared with 1.6 from 1820 to 1950, and 0.3 per cent from 1500 to 1820."**
>
> *The World Economy: A Millennial Perspective*

Global life expectancy at birth in 1800 was about 30 years, compared with 67 in 2000 and 75 in the rich countries. In countries with well-developed health care systems, infant mortality has been brought to very low levels and vaccines have virtually eliminated life-threatening childhood diseases.

We also live in a period of intense cultural production and technical ability. The so-called information age has put virtually limitless amounts of data at our fingertips – provided that we have access to the technology that links us to it. Films, plays, books, music, scientific studies, analysis and opinion on everything from politics to sport are all readily available, creating the possibilities for a society that is better informed and more aware than in any previous historical epoch.

And we are not just learning or consuming all of this content as individuals – we are discussing it, interacting with it and refining it collaboratively. Blogs, wikis, website discussion threads: these have created a new nexus of information between "official" and "unofficial" communications. Some bloggers become authorities on their topics and influence trends. Wiki contributors become widely read. The lines of communication have essentially opened up, giving us the opportunity and the responsibility of understanding what is going on around us – provided that we learn to use all of this information in a meaningful way.

Indeed, our choices have multiplied in nearly every domain: educational, professional and personal. As students we can choose from hundreds of subjects of study and among an increasing number of educational institutions offering diplomas. Programmes like the EU's Erasmus exchange scheme encourage students from one country to study in another – to learn another language, another culture, or simply to have access to a particular type of education not available in their home country.

The globalisation of business, science and culture has also opened up our professional choices: following a job far from one's home town, working as an expatriate in another country, travelling regularly to offices around the world. On the whole, we are a wealthier, longer living, more educated and more mobile population. But can this continue? Will it be true for future generations? In all parts of the world?

Clouds on the horizon?

> **"If everyone used energy and resources the same way we do in the Western World, we would need three more earths at least. And we have only one."**
>
> Mona Sahlin, former Minister for Sustainable Development, Sweden, *Institutionalising Sustainable Development*

Still, in spite of the advanced state of many contemporary societies, we see some troubling contradictions. Notably, there is a stark inequality between those with access to the fruits of advanced development, and those living in contexts where that advancement is impeded by lack of access to what others take for granted.

Stark differences divide the world in terms of access to water and sanitation, energy, health care and education. For example, it is estimated that 1.1 billion people in the world lack clean water. The question is not one of comfort: water-related illnesses are the second biggest killer of children in the world – approximately 1.8 million children die each year from diseases caused by dirty water and poor sanitation. Illness from poor water and sanitation keeps children out of school and adults out of work, while the search for water in areas where access is poor takes up a large portion of time in the daily lives of women and girls, time that they cannot spend working for economic improvement or going to school.

According to the United Nations Human Development report and to water specialists like Professor A.K. Biswas, the problem is not one of scarcity, but mismanagement. Leaking taps in the developed world waste more water than is available to the billion people in the developing world who need it. Fixing those leaking taps won't magically solve water access problems, but an approach to water management that includes sharing successful techniques for making the best use of available water supplies can improve things dramatically.

While people living in the least developed nations often lack the necessary elements to fulfil basic needs and have access to a life of health and quality, the developed world suffers from having too much. Poorer countries face the terrible consequences of largely preventable diseases like malaria or AIDS, while the richer ones battles epidemics of excess, such as adult-onset (or Type II) diabetes and heart disease caused by obesity. There is a level of international co-operation never before seen in history bilaterally, or between governments, and multilaterally through institutions like the United Nations, OECD, World Bank and others. And yet there are still violent conflicts that place those caught in them in conditions of extreme insecurity and vulnerability. The human population continues to grow. Predictions have the current population of 6.5 billion increasing to over 8 billion by 2050. More and more of those people are living in cities, and everyone who has the means is using more resources. Our lives are full of more and more things. The proliferation of markets, products, and the ease of trade means that both our choices for consumption and the consequences of that increased activity are greater than ever.

Economic development has allowed for advances that have fundamentally changed the ways humans live from previous centuries, but these activities have also brought about problems with potentially dramatic consequences. Climate change is the most visible, most talked about at the moment, especially after the recent (2007) Intergovernmental Panel on Climate Change report confirmed that the climate is almost certainly undergoing significant change as a result of human activity. But economic development has also brought social challenges: countries are advancing at different speeds, and people within countries are living with vastly different quality of life. In many countries the gap between the rich and the poor is increasing rather than shrinking with economic growth.

Climate change is symbolic of the larger problem – one that is both practical and philosophical – of the dangers inherent in pushing our ecosystems out of balance. Are we pushing our societies and environment too far, too fast? Are we outrunning the regenerative possibilities inherent to our ecosystems? Are we creating social imbalances that cannot be corrected? Could we be on some kind of crash course, like the Easter Islanders, without even realising it?

> **"The loss of key elements of an ecosystem can alter the balance between its components and lead to long-term or permanent changes."**
>
> *Preserving Biodiversity and Promoting Biosafety* (an OECD Policy Brief)

When systems work, when they are in equilibrium, they tend to continually produce possibilities for renewal: if land is well-managed, given time to lie fallow and regenerate nutrients, then it continues to be fertile indefinitely. If not, then the quality of soil degrades and in some cases becomes useless. Wild species naturally replace themselves. But populations will crash, possibly to extinction, if they are overharvested.

We can even extend this notion to humans and their interactions. Children who are well-nourished, educated and cared for tend to flourish, carrying with them a lifelong capacity to contribute to their community. Deprive them of those things and the outcome is likely to be quite different. The same is true at the societal and governmental level. Abuse, conflict or deprivation can cause entire communities to collapse.

This can be applied to economic systems or markets. Imbalances in supply and demand, in savings and spending, in loans and investment can lead to economic crashes, recessions and depressions. The most talented economists are still unable to predict reliably when and why these events might occur, due to the extreme complexity of the world's economy. What we do know is that economic, environmental and social systems must all be kept in relative equilibrium, and also balanced with each other, to be sustainable.

One problem is that we do not know when the "critical threshold" of these systems will be reached and exceeded. To continue moving towards, even beyond these thresholds, is to take a great risk: are we creating a future that will experience failures of Earth's life-sustaining systems with increasing frequency and unpredictability? Are we living in a present where economic and social developments benefit some and leave others mired in need and conflict?

Where are we headed?

In the last 200 years, the world's economy has grown sixfold, and almost tenfold in the regions that were first to industrialise. Standards of living, health and education have improved considerably. At the same time, burning coal for energy led to deadly smog in England and the US, water pollution left entire lakes "dead", irrigation for cotton brought the Aral Sea to a fraction of its historical area, and now fossil fuel use is causing changes to our climate. In addition, economic and technological development has left huge gaps in prosperity, opportunity and standards of living. The question is: can we do a better job with development, starting now?

What are the principles driving these phenomena? What kind of future are they spelling out for our descendents? As we develop economically and socially, whether as individuals, governments or businesses, we need guiding principles that will help us make the right choices.

> **"Unsustainable development has degraded and polluted the environment in such a way that it acts now as the major constraint followed by social inequity that limits the implementation of perpetual growth."**
>
> Emil Salim, *Institutionalising Sustainable Development*

But do we really have to choose between progress and sound management of the systems that support us? Every day, we hear about new technologies that can benefit people, economy *and* the environment: public health programmes that improve health outcomes for more people, energy efficient alternatives for many of the products and processes we have come to rely on, and new non-toxic and durable materials.

If the Easter Islanders were aware of their dwindling resource base, history shows that they didn't take the necessary steps to prevent passing the critical threshold. Many people today realise that our world also shows signs of stress – and at the very least presents some core problems to which we need to find solutions. Evidence suggests that we need better ways of managing our natural resources; better ways of securing what people need to develop; better ways of co-ordinating our actions to take care of all the things we rely on to survive, thrive and prosper.

It is time to learn how to develop without these negative social and environmental side effects, and in a way that benefits more of us. Easter Island was isolated from trade and limited in its ecological resources; perhaps the only way its human residents could have prevented tragedy was through careful planning. We are living on a much larger scale, but could the same be true of us?

What this book is about…

No one knows what the future will look like. Good or bad, clean or dirty, peaceful or war-torn – what will we be able to achieve with the tools at our disposal? Technological progress has made many things possible, but there are signs that we are reaching some thresholds at which negative consequences can become more than just an inconvenience.

Growing awareness of the fragility of our world has caused us to look more seriously for solutions, not just to one-time problems, but to faulty approaches to development that are short-sighted and self-destructive. Scientists, politicians and citizens from every walk of life have informed this discussion, seeking ways of balancing the benefits of growth with the drawbacks it can produce if not done carefully and intelligently.

"The future of mankind is being shaped by issues that no one nation can address alone. Multilateral co-operation is instrumental in meeting the key challenges of this new world." – Angel Gurría, "Making the Most of Globalisation: The OECD and the MENA countries".

We do actually have the tools and information to plan our development *sustainably* – in a way that takes all aspects of development into account and prefers choices that maintain a maximum level of well-being over the long term. Identifying the most significant issues and making the necessary changes is anything but simple. **Sustainable development** provides a way of doing this: assessing our current situation, setting goals that will produce better results and making the right choices about the direction we want to take.

Chapter 2 explores the concept of sustainable development, its history and what it means to us today.

Chapter 3 looks at the global dimension of sustainable development and how we can put rich, poor and rapidly emerging economies on a sustainable path.

Chapter 4 explains the importance of planning for the future, managing our economic, human and natural resources so that we can continue improving our societies without leaving a messy legacy for years to come.

Chapter 5 looks at how we behave as producers and consumers and the critical role this plays in achieving sustainable development goals.

Chapter 6 shows us how we can measure the different aspects of sustainable development and why this is important.

Chapter 7 examines how governments and civil society work together in creating the incentives, rules and regulations that make sustainable development possible.

What is OECD?

The Organisation for Economic Co-operation and Development, or OECD, brings together the governments of countries committed to democracy and the market economy to tackle key economic, social and governance challenges in the globalised world economy. It has 30 member countries, the economies of which account for 68% of the world's trade and 78% of the world's Gross National Income, or GNI (a measure of countries' economic performance).

The OECD traces its roots back to the Marshall Plan that rebuilt Europe after World War II. The mission then was to work towards sustainable economic growth and employment and to raise people's living standards. These remain core goals of the OECD. The organisation also works to build sound economic growth, both for member countries and those in the developing world, and seeks to help the development of non-discriminatory global trade. With that in mind, the OECD has forged links with many of the world's emerging economies and shares expertise and exchanges views with more than 100 other countries and economies around the world.

In recent years, OECD has also begun a process of enlargement, inviting five other countries (Chile, Estonia, Israel, Russia and Slovenia) to open talks on joining the organisation, and offering enhanced engagement to five emerging economies (Brazil, China, India, Indonesia and South Africa).

Numbers are at the heart of the OECD's work. It is one of the world's leading sources for comparable data on subjects ranging from economic indicators to education and health. This data plays a key role in helping member governments to compare their policy experiences.

The OECD also produces guidelines, recommendations and templates for international co-operation on areas such as taxation and technical issues that are essential for countries to make progress in the globalising economy. *www.oecd.org.*

OECD and sustainable development

OECD Ministers recognise that sustainable development is an overarching goal for their governments and the Organisation itself, and member countries bear a special responsibility in achieving sustainable development worldwide. Activities linked to sustainable development are overseen by the Annual Meeting of Sustainable Development Experts (AMSDE), government delegates from capitals who co-ordinate special projects as well as review progress in mainstreaming sustainable development concepts into the overall work of the OECD.

Many activities relate to sustainable development, from climate change analysis to development co-operation to corporate social responsibility. On this website, there are links to a wealth of projects and information which shed light on certain dimensions of the issues: *www.oecd.org/sustainabledevelopment.*

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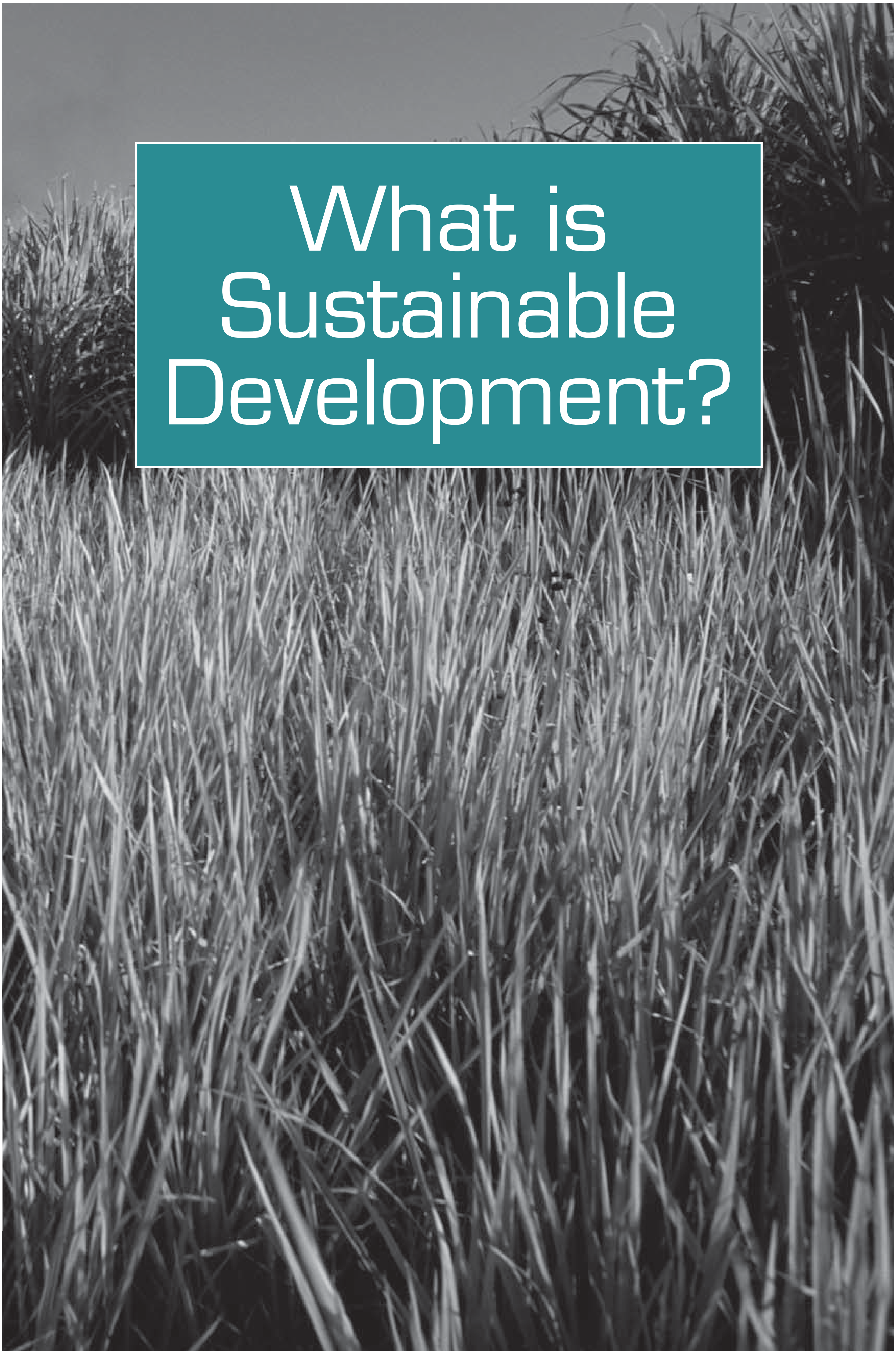
It is impossible to know precisely what the consequences of unchecked or badly managed development will be, but we have enough information to understand that they are potentially negative, costly and irreversible. Sustainable development gives us a new way of thinking through and managing human impact on the world – one that can generate long-lasting positive results for the greater benefit of human societies.

What is Sustainable Development?



By way of introduction…

Monique Huteau, a recently retired nurse, is up to her elbows in soil as she tends to her lush garden. Strawberries, lettuce, squash, potatoes and more, she grows enough to cover a large portion of her family's needs in produce, buying what she lacks at the local hypermart. She also cooks, cleans, cares for her grandchildren and paints watercolours at her home in the countryside a few minutes outside Poitiers, France.

During their working years, she and most of her nine siblings earned considerably more than their parents had, poor farmers from the Anjou region. They live in well-maintained houses, drive nice cars, and take yearly vacations to distant places. A lot of hard work and astute savings and investments have allowed Monique and her husband, a retired teacher, to achieve these things – with the help of French social benefits which have kept their health care and education costs low and ensured them an adequate retirement income. For Monique there is no question: her generation had opportunities not available to their parents and consequently live very different lives materially and socially.

Monique's experience is a common one in OECD countries: generations that had endured scarcity and hardship growing up have achieved, even on relatively modest incomes, the satisfaction of basic needs plus enough discretionary income to indulge in a few luxuries. With this have also come certain social benefits. Education levels have increased. More people have access to health care. Leisure time is guaranteed through paid vacations and retirement plans. There is more geographic and social mobility.

Indeed, the so-called developed world has seen average improvements in many areas that are important to "the good life". Along with these improvements, however, have come worrying indications that this growth has costs which we cannot continue to ignore.

All the economic prosperity in the world cannot alone solve a problem like climate change on its own. On the contrary, unchecked growth – in the number of people driving cars and taking planes, for example – is making the situation worse. Also, average economic growth says nothing about income inequality: if wealth is growing for only a few, then the majority may not experience any tangible gains or improvements.

These problems are compounded when added to the challenges facing the developing world – encompassing countries such as China and India who are undergoing rapid growth, as well as those like many Sub-Saharan African countries which are still far from having what the richer countries take for granted: peace, basic health care access, education, a relatively safe water supply, and so on.

Finally, do the resources exist to enable this kind of lifestyle for all of Earth's 6.5 billion residents? It is estimated that in 2002 humans extracted over 50 billion tons of natural resources from the planet's ecosystems, up a third in just 20 years. Projected economic growth rates put our extraction needs at 80 billion tons in 2020. Would using the Earth's resources at this rate be advisable? Can we and should we continue with the traditional model of development?

These problems are not new. Indeed, the accumulation of a number of bad habits and "unsustainable" practices seems to have led to critical stresses on societies and the environment. In spite of unprecedented economic growth, the world has been on a course leading to resource depletion and serious social crises, and old ways of problem-solving have proven inadequate. Something has to be done to change development – its philosophy and methods – if societies wanted to reverse those negative trends. As Albert Einstein wrote, "Today's problems cannot be solved if we still think the way we thought when we created them."

We hear the term "sustainable development" in high-level discussions; we see it in political platforms and on corporate websites. More and more universities have programmes covering the field. Indeed, sustainable development has become a kind of conceptual touchstone, one of the defining ideas of contemporary society. This chapter reviews the debate on what exactly the concept of sustainable development means. It looks at where the term came from and what it now includes. And it asks how we can make use of the concept in our daily lives and our systems of governance.

Defining sustainable development

Development: **the act or process of developing; growth; progress.**

Sustainable development: **development that meets the needs of the present without compromising the ability of future generations to meet their own needs.**

The term sustainable development began to gain wide acceptance in the late 1980s, after its appearance in *Our Common Future*, also known as *The Brundtland Report*. The result of a UN-convened commission created to propose "a global agenda for change" in the concept and practices of development, the Brundtland report signalled the urgency of re-thinking our ways of living and governing. To "responsibly meet humanity's goals and aspirations" would require new ways of considering old problems as well as international co-operation and co-ordination.

The World Commission on Environment and Development, as it was formally called, sought to draw the world's attention to "the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development." In establishing the commission, the UN General Assembly explicitly called attention to two important ideas:

- The well-being of the environment, of economies and of people is inextricably linked.
- Sustainable development involves co-operation on a global scale.

Sustainable development is about integration: developing in a way that benefits the widest possible range of sectors, across borders and even between generations. In other words, our decisions should take into consideration potential impact on society, the environment and the economy, while keeping in mind that: our actions will have impacts elsewhere and our actions will have an impact on the future.

We tend to arrange things compartmentally, by divisions and departments, governments and communities; even households are rarely set up as holistic systems. Ministries of agriculture, finance, the interior and foreign affairs handle the issues that come under their domain. We divide up the tasks of our daily lives: work, rest, errands and holidays. It is not that we *can't* see business, government or home life as a "whole" – making a household budget or a corporate strategy are examples of just this type of exercise – but in the bustle of our complex lives it can be difficult to take the time to see beyond the most immediate or obvious concerns. Often, as the old saying goes, we can't see the forest for the trees.

The concept of sustainable development has been used to articulate several essential shifts of perspective in how we relate to the world around us and, consequently, how we expect governments to make policies that support that world view.

> **"Governments face the complex challenge of finding the right balance between the competing demands on natural and social resources, without sacrificing economic progress."**
>
> *Sustainable Development: Critical Issues*

First, there is the realisation that economic growth alone is not enough: the economic, social and environmental aspects of any action are *interconnected*. Considering only one of these at a time leads to errors in judgment and "unsustainable" outcomes. Focusing only on profit margins, for example, has historically led to social and environmental damages that cost society in the long run. By the same token, taking care of the environment and providing the services that people need depends at least in part on economic resources.

Will I know it when I see it?

In the first years of the 21st century the term sustainable development has entered the public sphere. No longer restricted to academic and policy debates, the concept has made its way into everyday language and into community activities the world over. When we say the words "sustainable development", what exactly do we mean?

Sustainable development can be:

- spreading the benefits of economic growth to all citizens;
- turning brownfields into ecologically sound urban housing projects;
- increasing educational opportunities for both girls and boys;
- innovating industrial processes to be more energy-efficient and less polluting;
- including citizens and stakeholders in policy-making processes.

Next, the interconnected, or interdependent, nature of sustainable development also calls for going beyond borders – whether they be geographical or institutional – in order to co-ordinate strategies and make good decisions. Problems are rarely easily contained within predefined jurisdictions such as one government agency or a single neighbourhood, and intelligent solutions require co-operation as part of the decision-making process.

Take genetically modified crops, for example. Making decisions on the production, consumption and development of GMOs requires the participation of agriculture, environment, trade, health and research ministries. It requires that these ministries compare evidence and agree on a position within national government so that they can enact workable policies – policies that have the greatest benefit for the least cost. But the need for co-ordination doesn't stop at the national level. Apart from anything else, seeds from genetically modified plants can cross borders, carried by wind or birds, adding an international dimension to the issue. Differing policies between import and export countries leads to confusion and inefficiency in trade, as processed foods containing just one genetically modified ingredient require special labelling and are even banned by some countries.

Finally, thinking about human actions has had to undergo a temporal shift: put simply, we should consider the impact of a given choice beyond the short term. If poorly-managed logging leads to the depletion of a forest in the interest of immediate profit, then the overall result is actually a substantial loss: loss of income over the long term, loss of biodiversity, loss of capacity to absorb carbon dioxide, among other things.

An "honest" approach to timelines is also essential to questions of intergenerational equity: the idea that resources, whether economic, environmental or social, should be utilised and distributed fairly across generations. No single generation should bear an undue burden. This is not only a problem of leaving a clean, healthy planet for future generations, but also concerns pressing problems like meeting the medical, financial and social needs of an ageing population.

The three pillars of sustainable development

At the core of sustainable development is the need to consider "three pillars" *together*: society, the economy and the environment. No matter the context, the basic idea remains the same – people, habitats and economic systems are inter-related. We may be able to ignore that interdependence for a few years or decades, but history has shown that before long we are reminded of it by some type of alarm or crisis.

The fact of the matter is that we depend on ecosystems and the services they provide in order to do what we do: run businesses, build communities, feed our populations and much more. Whether we consider the more obvious, immediately vital examples – the need for soil that can grow food or for clean water to drink – or the less obvious but equally significant things like oxygen production during photosynthesis or waste processing by bacterial decomposers, we cannot avoid the conclusion that we depend on the environment for our existence. If we damage or destroy the capacity of the environment to provide these services we may face consequences for which we are completely unprepared.

> **"As a group, women – and their potential contributions to economic advances, social progress and environmental protection – have been marginalised."**
>
> *Gender and Sustainable Development*

In the same way, the long-term stability and success of societies rely on a healthy and productive population. A society (or communities within a larger society) that faces unrest, poverty and disease will not develop in the long term: social well-being and economic well-being feed off each other, and the whole game depends on a healthy biosphere in which to exist.

Understanding the complex connections and interdependence of the three pillars requires some effort, and the effort has to be constant. Whether we're talking about the duration of political cycles or the length of time the media focuses on a particular issue, the question of our collective attention span is an important one for sustainable development.

The Rio Earth Summit and Agenda 21

In June, 1992, in Rio de Janeiro, representatives from 179 countries came together for the United Nations Conference on Environment and Development, popularly known as the *Rio Earth Summit*. One of the major agreements signed during this meeting was a programme of action called Agenda 21.The 900-page document describes first steps towards initiating Sustainable Development across local, national and international levels as the world moved into the 21st century. Signatories promised to pursue action in four domains:

- Social and Economic Dimension, such as combating poverty and promoting sustainable urban planning;
- Conservation and Management of Resources, such as safeguarding the oceans' fisheries and combating deforestation;
- Strengthening the Role of Major Groups, such as women, local governments and NGO's; and
- Means of Implementation, such as transfer of environmentally-sound technology.

For example, Chapter 28, *Local authorities' initiatives in support of Agenda 21*, calls for the participation of local and regional governments and civil society in the development of Local Agenda 21. Co-ordination in the sustainable development effort from the international level down to local municipalities will ideally make every action more effective. Cities across the world – from Surabaya, Indonesia to Seattle, United States – have implemented such a plan to promote sustainable development at the local level.

Trade-offs

With tens of millions of inhabitants concentrated in a limited space, today's mega-cities struggle to balance the needs of the population with the capacity of the existing infrastructures. Juggling the complex web of activities in urban environments is an ideal place to start thinking through the trade-offs that sustainable development can imply. For instance, everybody might agree that traffic is a nightmare, but making changes to improve the situation inevitably affects many people in a variety of ways, not all positive. Should the city discourage car travel but risk overloading public transport? Should it introduce measures to make traffic move more quickly and risk attracting more vehicles onto the roads? Calculating the financial costs of transport policies is relatively straightforward, but predicting the personal choices and behaviours of those using the urban space is much less so. What will city dwellers and commuters actually decide to do? For example, if the bus service improves, will it attract car drivers or people who might otherwise have walked?

The lesson here is not that it's impossible to improve things, but that improvement means thinking through the links among a number of factors. Less traffic equals shorter travel times and easier movement. Better air quality means a healthier population. The trade-offs, such as taxes or tolls, in exchange for overall improvement of the urban space are being tested in London, Singapore and other cities. The debate as to the success or failure of such schemes shows in a concrete fashion what's at stake. The environmental impacts may seem clear, but what about social equity – the rich can afford to pay a congestion charge that poorer people can't – or the economic impact on shops and other businesses?

On a personal level, the choices may not be so clear-cut either. Imagine you want to avoid supporting the use of pesticides so you choose to buy only organic produce. However, the only organic grocery store in your city is too far to walk or cycle to. Fossil fuels have to be burned to get you there and back. Likewise, you may want to support local producers and avoid the damage air transport causes. But flying flowers to the UK from Africa for instance may cause less harm than importing flowers from nearby Holland that needed heated greenhouses and intensive fertilizer use. And horticulture may benefit more people in Africa than in the Netherlands. In a perfect world, making good choices would be an easier, more coherent task; in the meantime, the concept of sustainable development is helpful for balancing out the vast number of variables and optimising our decisions.

Sustainable development: process or end result?

So, is sustainable development a kind of guiding principle, as many of its supporters would argue? Or rather a concrete goal or set of goals that can be measured, evaluated and deemed "achieved"? Looking at the massive body of literature on the subject reveals plenty of support for both these points of view and several other possibilities. Really, though, there is no obligation to choose among these options. Whether we are talking about the abolition of slavery, universal education, democracy or any of the "sea changes" that previous generations have undergone, we are always in a constant process of translating big ideas into concrete practices. And this always involves multiple experiments, learning, failures, mistakes and a constant effort at adapting and refining our methods.

Sustainable development is also a means for considering the relationships of things to each other in order to propose viable solutions. As the Brundtland report puts it, "sustainable development is not a fixed state of harmony but rather a process of change…" It is a way of forcing ourselves to look at factors we might rather ignore in favour of short-term benefit, as in the case of a polluting industry that worries primarily about this year's profits, or a pension plan that doesn't account for the increase in the number of retirees relative to the number of subscribers.

Brice Lalonde, former Minister of the Environment in France, offers the following definition: *"To me, it refers to how the economy should enable us to live better lives while improving our environment and our societies, from now on and within a globalised world."* In this view, sustainable development frames the possibilities for progress: the economy is a vehicle that helps us reach the overall, collective, goal of improving quality of life *globally*. Success comes through putting all three pillars on the same progressive trajectory, or path.

It might be useful, then, to see the advent of sustainable development as a significant change in how people and governments perceive their activities, their roles and responsibilities: from primary emphasis on increasing material wealth to a more complex, interconnected model of the human development process.

Sustainable development is therefore:

- a conceptual framework: a way of changing the predominant world view to one that is more holistic and balanced;
- a process: a way of applying the principles of integration – across space and time – to all decisions; and
- an end goal: identifying and fixing the specific problems of resource depletion, health care, social exclusion, poverty, unemployment, etc.

Easier said than done?

Society, the environment and the economy – doesn't that cover just about everything? One of the first things we notice when trying to understand sustainable development is the vastness of the topic. Taking into account the economic, social and environmental

Low-tech high-impact: insecticide-treated mosquito nets

Sustainable development means using all the tools at our disposal to promote well-being. As the following example shows, technologies don't have to be high-tech to achieve significant change.

Malaria kills a child every 30 seconds and over a million people every year. Apart from children its main victims are pregnant women. Most of those who die are in Africa. Poor people and communities with limited access to health care are the worst affected.

Malaria is responsible for a "growth penalty" of 1.3% a year in some countries and contributes to the substantial differences in GDP between countries with and without the disease. It can affect the tourist industry since travellers prefer to avoid badly affected areas. Traders' unwillingness to travel to and invest in malaria areas can leave markets underdeveloped. Farmers cannot take the risk of planting labour-intensive crops because of malaria's impact on labour during the harvest season.

In some countries, malaria may account for as much as 40% of public health expenditure, 30 to 50% of inpatient admissions and up to 60% of outpatient visits. It stops children from going to school and can cause permanent neurological damage. It hits the earnings of sick workers and can ruin families who have to pay for drugs, other health care and transport to hospital.

The parasite that causes the disease is becoming more resistant to antimalarial drugs, and no new treatments are expected soon. Likewise, the mosquitoes that transmit the disease are becoming more resistant to insecticides.

A simple technology to prevent deaths and the spread of the disease exists: insecticide treated mosquito nets. The nets generate a chemical halo that extends beyond the fabric itself to repel or deter mosquitoes from biting or shortens the mosquito's life span so it can't transmit malaria.
They also reduce the quantity of insecticide that needs to be sprayed in homes and elsewhere. But while the technology is simple, using it effectively depends on getting a number of things right:

- People need to be convinced of the utility of the nets and shown how to use them through education and social marketing campaigns.
- Taxes and tariffs on mosquito nets, netting materials and insecticides should be waived.
- Encouraging local manufacturers and suppliers can help reduce costs so that nets are affordable.
- Nets that can last for years without having to be retreated with insecticide need to become widespread.

In Kenya, from 2004 to 2006, the number of young children sleeping under insecticide-treated nets increased tenfold thanks to a programme of free mass distribution. There were 44% fewer deaths than among children not protected by nets. Kenya's success suggests three ingredients which all need to be present for malaria control to succeed:
high political commitment from the government, strong technical assistance from the WHO and adequate funding from international donors.

To find out more, visit the website of the Roll Back Malaria Partnership launched in 1998 by the WHO, UNICEF, the United Nations Development Programme and the World Bank: *www.rollbackmalaria.org.*

aspects of development can ultimately include a wide variety of concepts, policies and projects. So wide, some would say, that it loses its usefulness as a concept.

This could in part explain why, in spite of its popularity and rapid acceptance by some members of government, civil society, countless companies and many cities, the concept of sustainable development has not yet translated into widespread changes in either behaviours or policy, and this after more than a decade of efforts. Early supporters of the concept had hoped for rapid progress, but the complexity of the problems at hand, their

Women and Sustainable Development

> **"At present, the female half of the world's human capital is undervalued and underutilised the world over... Better use of the world's female population could increase economic growth, reduce poverty, enhance societal well-being, and help ensure sustainable development in all countries."**
>
> *Gender and Sustainable Development: Maximising the Economic, Social and Environmental Role of Women*

When it comes to improving economies, societies and preserving the environment, women have a central role. Across the globe, per capita income is lowest in countries where women are significantly less educated than men, suggesting that investing in women is a first step to raising everyone's well-being. In Africa, studies show that giving women equal access to capital could increase crop yields by up to 20%. But developed countries would benefit from fuller use of women's potential too, for instance the UK's GDP could rise by 2% by better harnessing women's skills. Improving education for girls and women also has social benefits, including lower fertility rates, reduced infant and mother mortality, and improved nutrition for all members of the family. Data from developing countries indicate that one to three years of maternal schooling reduces child mortality by 15% while an equivalent level of paternal schooling achieves only a 6% reduction.

Women are also on the environmental "frontlines". Wangari Maathai won the 2004 Nobel Peace Prize for her work with the Green Belt Project, reforesting vast areas of Kenya. The 30 million trees women have planted through the Project provide firewood and shelter, and improve local climate and soil. As Maathai said in her acceptance speech, "throughout Africa, women are the primary caretakers, holding significant responsibility for tilling the land and feeding their families. As a result, they are often the first to become aware of environmental damage as resources become scarce and incapable of sustaining their families." As Maathi proves, women often hold the solutions, too.

Clearly, improving the situation of women worldwide is a critical first step for sustainable development – indeed this was one of the conclusions of Agenda 21.

reach across cities, regions and beyond national borders, and the difficulties inherent in changing people's perceptions and actions have all contributed to frustrating those hopes.

Adding this level of complexity to decision-making processes most probably necessitates changes in previous patterns of behaviour – whether at the level of individual consumption or international law. And change is almost never easy, even when it is obviously necessary. It is particularly difficult when it might involve real or perceived sacrifices on the part of one "pillar", industry, country or generation in favour of another.

It is still quite common to hear that sustainable development is primarily about the environment. And while it is true that the concept grew out of thinking about the dangers of environmentally unsustainable practices such as the damage done to ozone layer by CFCs or the damage to soils and water supplies due to pesticides, sustainable development has also always included the social dimension.

In any case, to get caught up in an argument over whether sustainable development is more about the environment or about people is to miss the point: it is the connection of humans, their economies and societies to the ecosystems that support them which defines sustainable development. "Environmental problems are really social problems anyway," said Sir Edmund Hilary, the first man to conquer Mount Everest. "They begin with people as the cause and end with people as the victims."

So really we can see sustainable development as a big theory, a process, or as practical guidelines for making solid development decisions that do not blindly seek growth in one area only to cause damage in another. We can choose to support any or all of these positions, provided that we have the information we need to make honest assessments about our activities and their impact – and make some of the "tough" decisions that good management often requires.

Applying the principles of sustainable development is really nothing more than applying the principles of sound management to all our resources, like we would if we wanted to create a prosperous business or build a new house. Rather than overlook potential conflicts, we can plan ahead, integrating considerations of what counts from the beginning. Of course this is easier said than done:

spending money now to prevent something that "might" happen in the future is a challenge for us. Just as spending money to fix a bad situation "elsewhere" is also tough. Really, though, the future is right around the corner, and in our globalised world what seems far can become very suddenly close. By following the example of the ever-increasing number of individuals, businesses and governments who make planning decisions within a sustainable development framework, we ensure ourselves and our children a brighter future.

Find Out More

... FROM OECD

On the Internet

For a general introduction to OECD work on sustainable development, visit *www.oecd.org/sustainabledevelopment.*

Publications

Sustainable Development: Critical Issues (2001):
Following a mandate from OECD Ministers in 1998, this report stresses the urgency to address some of the most pressing challenges for sustainable development. It reviews the conceptual foundations of sustainable development, its measurement, and the institutional reforms needed to make it operational. It then discusses how international trade and investment, as well as development co-operation, can contribute to sustainable development on a global basis, and reviews the experience of OECD countries in using market-based, regulatory and technology policies to reach sustainability goals in a cost-effective way.

Also of interest

OECD Contribution to the United Nations Commission on Sustainable Development 15: Energy for Sustainable Development (2007):
Under the theme of "Energy for Sustainable Development", this brochure presents policy findings from OECD, IEA and NEA reports relating to energy, climate change and sustainable development.
It focuses on four main topics:
I) widening energy access in developing countries,
II) increasing energy research and development and dissemination,
III) promoting energy efficiency and diversity, and IV) benefiting from energy-related climate change policies.

Gender and Sustainable Development: Maximising the Economic, Social and Environmental Role of Women (2008):
As a group, women – and their potential contributions to economic advances, social progress and environmental protection – have been marginalised. Better use of the world's female population could increase economic growth, reduce poverty, enhance societal well-being, and help ensure sustainable development in all countries. Closing the gender gap depends on enlightened government policies which take gender dimensions into account.

This report is a contribution by the OECD to the UNCSD and its cross-cutting work on gender. It aims to increase understanding of the role of women in maintaining the three pillars – economic, social and environmental – of sustainable development.

Advancing Sustainable Development, an *OECD Policy Brief* (2006):
This Policy Brief looks at progress towards sustainable development in the OECD and its member countries, and at what more can be done to advance sustainable development in the Organisation's work and policy discussions.

All titles are available at *www.oecd.org/sustainabledevelopment.*

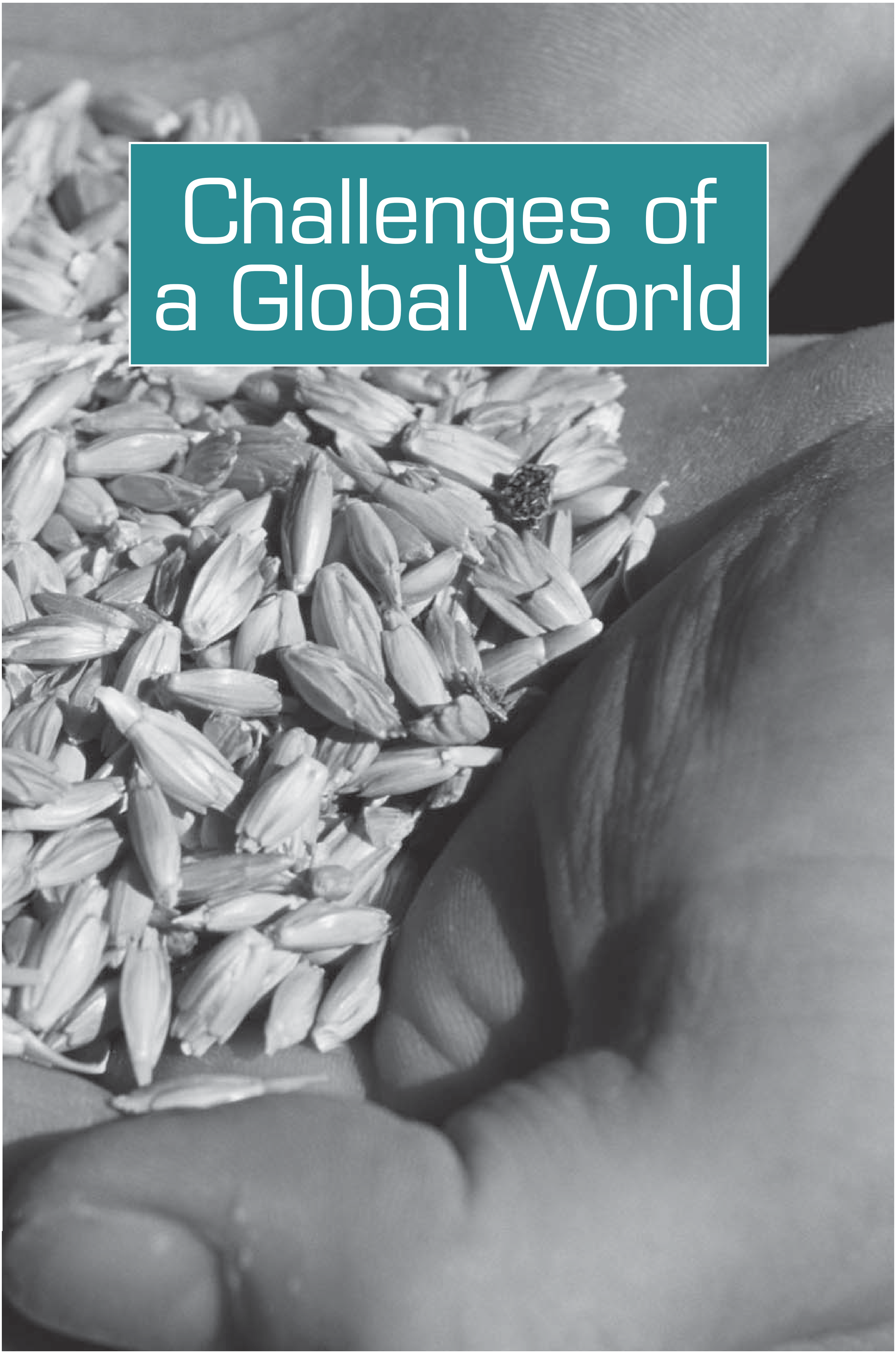
... AND OTHER SOURCES

Our Common Future ("The Brundtland Report") (*www.un-documents.net/wced-ocf.htm*):
This 1987 report from the United Nations World Commission on Environment and Development placed environmental concerns on the political agenda and laid the foundation for the 1992 Earth Summit and the adoption of Agenda 21, the Rio Declaration and the Commission on Sustainable Development.

3

In today's interdependent world, economic trends that start in one country affect many others, and national economies are affected by the internationalisation of production and international trade. Resource management, pollution control and climate phenomena are all issues that by their nature reach beyond geographic borders, making the challenges of sustainability a priority shared by countries and communities everywhere.

Challenges of a Global World



By way of introduction…

Life in Ahoto in the state of Jigawa, Nigeria has followed the same rhythm for centuries. In this village of thatched mud huts, farmers eke out a subsistence income from the difficult lands to the south of the Sahara desert. But things have begun to change recently: solar power has come to Ahoto and brought with it substantial improvements people's lives.

Garba Bello, head of the village, is very happy about these changes. As a recipient of one of the household lighting systems (costing about four dollars per month), he enjoys what solar lighting has done for his household, and most of all for his village. "The difference is great," he says. "People now go out at night and chat. Before, you could not even see your neighbour's house in the night."

The solar power project has brought more than just light to Ahoto and the two other villages participating in the region. A new shopping area is driving business development and creating much needed economic activity. Educational opportunities are also on the rise: women now attend classes at night and children can do their homework.

A collaborative effort by NGOs, the state government and foreign aid, the Jigawa State project takes a promising use of alternative energy a step further than previous projects that focused on only one use, such as pumping water. By attempting to address *all* of a village's energy needs, from education and commerce to security and women's advancement – the project gives participants the means to move forward simultaneously in all areas of their development.

The benefits extend beyond the social and economic to questions of health. Villagers now have access to clean water from more efficient solar pumps that draw water from deeper non-polluted sources and distribute it to household and communal taps. Easier access to relatively low-cost potable water also frees up considerable amounts of time that used to go to collecting water by bucket or hand pumping from wells. Activities that had to end at sunset can now continue, and in healthier circumstances. Dangerous and dirty kerosene lamps are now rarely lit. This has significant implications for health. About 1.5 million people die prematurely each year from the effects of indoor pollution from burning wood, charcoal and waste, more than from malaria, almost as many as from tuberculosis and almost half as many as from HIV/AIDS.

It is a solution that is elegant in its simplicity – bypassing, or "leapfrogging", traditional technology to move directly to one that is cleaner and far more sustainable. Yet projects like Ahoto's are still too few compared to the vast energy needs of the developing world, where, on present trends 1.4 billion will still be without access to mains electricity in 2030.

In Chapters 1 and 2, we saw how massive growth can create as many problems as it solves, some of them serious and potentially very destructive. Equally significant is the fact that growth may benefit some groups and leave others behind, a fact that is masked by indicators such as rates of increase in a country's GDP. And finally, if a short-term increase in wealth comes at the expense of long-term well-being and or survival, then it is not really "good" growth in any meaningful sense.

In this chapter we turn to sustainable development to formulate the central question that ties together our contemporary globalised society: how can we grow in a way that maintains the achievements in health and living standards in the developed world and continues to raise living standards for those who still lag behind without permanently damaging the world we depend on? Can we see more development in the style that has benefited Ahoto in recent years?

Going global: an old process on a new scale

The phenomenon of globalisation has received a considerable amount of attention in recent years as social scientists, political pundits and cultural critics have tried to explain how it has transformed our world. Is it really new, though? For as long as explorers have had the means to cover great distances, people have sought to know, understand and profit from what lay beyond the familiarity of their own communities.

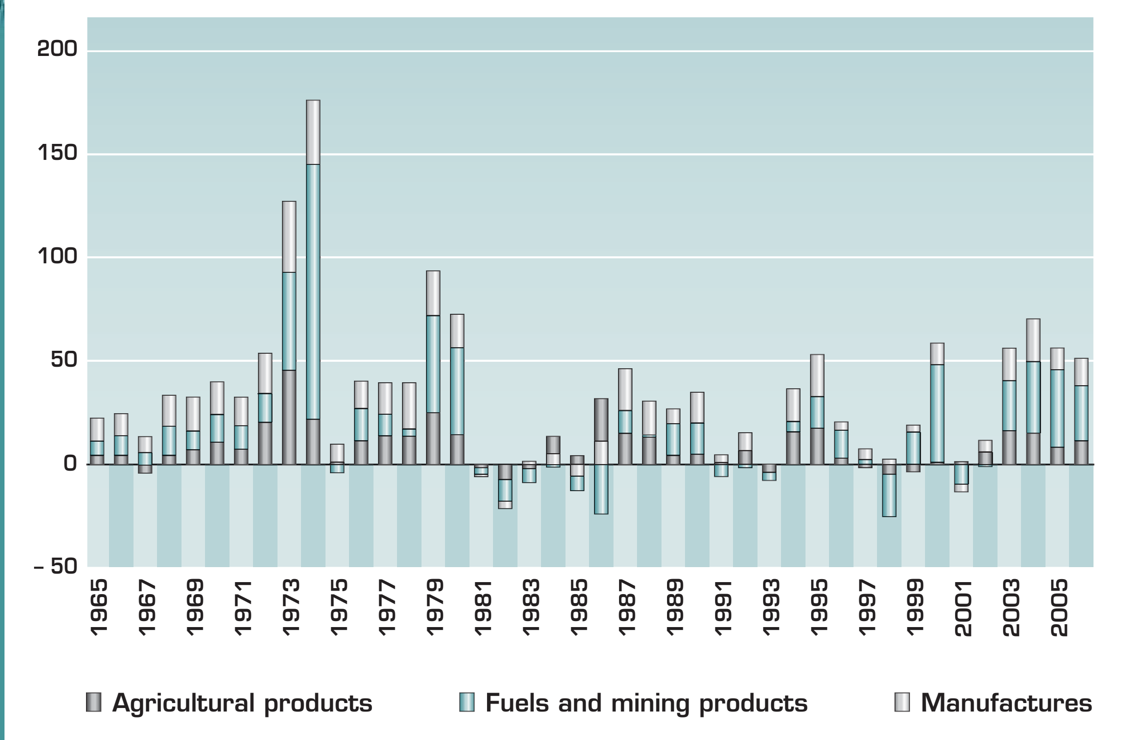
The great periods of exploration and colonisation attest to this desire, one that combines many different motivations. To learn about the world, to seek out better means of survival when local methods had failed, to seek fame and fortune, to trade for what one lacked, to bring glory to the state – these various driving forces interacted and pushed human societies forward to a world that became more and more connected over time.

Nowadays, globalisation is not about a few rich countries trading with far-off lands. Geopolitics, technology and finance have transformed consumption and production patterns across the globe. Over the past decade alone, around a billion workers have joined the global marketplace. Better communication tools and falling transport costs have expanded the range of goods and services in national markets. The combination of a greater supply of cheap labour alongside technologies that facilitate trade means that "value chains" – the numerous steps involved in transforming materials, knowledge and labour into saleable products – are spread across the globe. What is new about the globalisation of the last 30 years or so is that we are nearing a point where connection is not the *exception* but the *rule*.

According to the World Trade Organization, international trade has consistently increased with yearly growth rates of around 6% over the last decade. China is a leader here, with merchandising

WORLD MERCHANDISE EXPORTS

Annual percentage change in export value, 1965-2006



Source: UNCTAD (2008), *Development and Globalization: Facts and Figures.*

export increases of 27%, while developing countries' share of world merchandise exports reached an all time record of 36%. It is a fact that our economies are now dependent on international exchanges for their continued progress.

Whether we are talking about trade and investment, politics or culture, examples of linkages and interdependence surround us. We need only think of the food on our plates, the clothes on our backs or a website like YouTube: the sources of what fills our daily lives are multiple and geographically diverse. We sample the world's offerings every day, rarely realising how all of those connections have come to be, or how they interact.

These changes in our daily lives are related to international developments with a substantially increased movement of money and things: trade rules have been "liberalised" or modified to encourage international competition; corporations have expanded beyond their country of origin to new markets around the globe. All this moving and mixing has opened up possibilities for exchange, commercial expansion and overall growth, making the world, on average, a richer place.

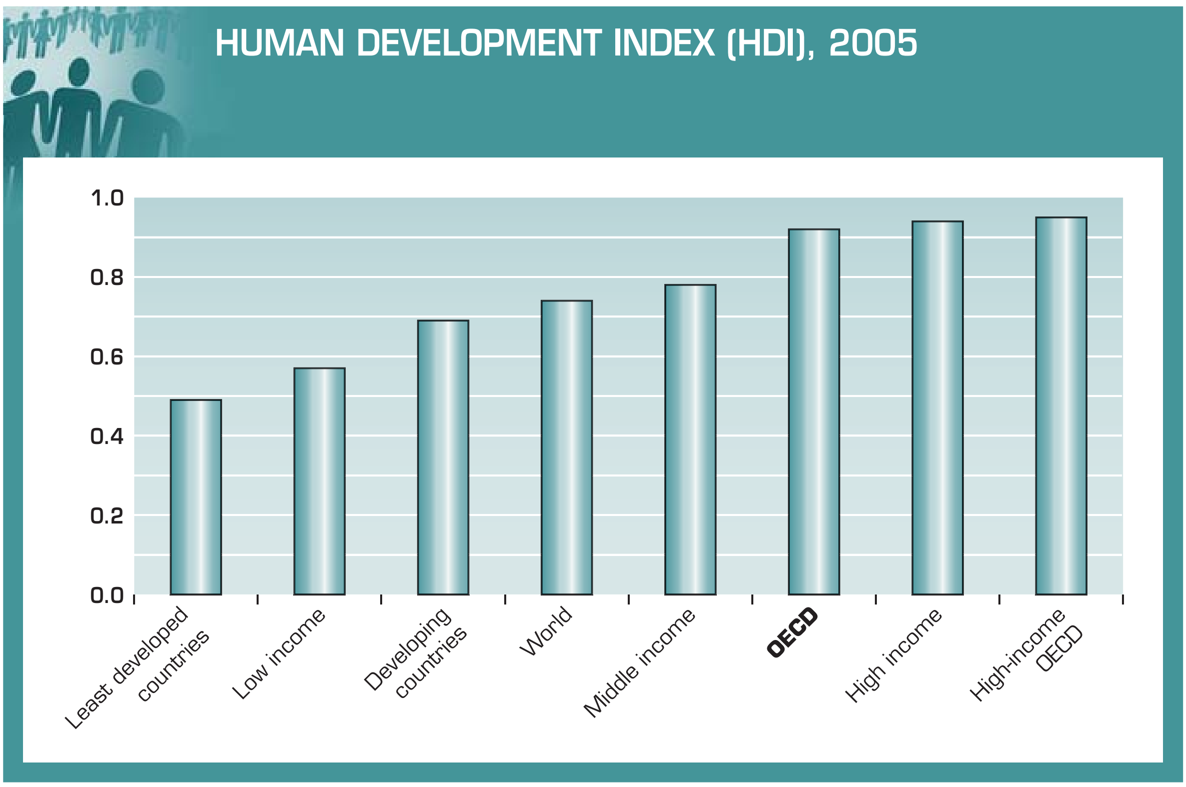
> **"Recent years have indeed witnessed striking changes in the global economic landscape, confirming the role of trade as a driving force in economic development and providing an indication of the potential for further trade liberalisation, under the right conditions, to benefit the global economy broadly."**
>
> Douglas Lippoldt, *Trading Up: Economic Perspectives on Development Issues in the Multilateral Trading System*

This "new" global dimension – economic, political and social – offers seemingly endless opportunities. But these opportunities are not equally available to all, and means to restore the balance have to be found. Nobel Prize economist Joseph Stiglitz has written recently about one of these, the fact that economic globalisation has left politics trying to play catch up. He points out that globalisation has in some ways changed the role of the nation-state since so many important issues now reach beyond the country level. In spite of this shift, Stiglitz notes, "there has yet to be created at the international level the kinds of democratic global institutions that can deal effectively with the problems globalization has created."

A two-tier world

Globalisation has increased our ties across geographical boundaries and perhaps transformed the way we think of «the world». Yet for all our increased connections, we obviously don't share the same circumstances, lifestyles or opportunities. As long as we have lived in large communities, the "haves" and the "have nots" have existed side by side. In today's media-rich culture, it is hard not to be aware of the glaring disparities in living standards in different parts of the world, even as we all participate in the same global economy.

Where we are born, grow up and live makes a big difference. An average child growing up today in Europe has vaccinations, dental care and educational opportunities, not to mention a more than adequate diet. He or she can look forward to higher education, travel, employment and retirement provided, at least in part, by a stable government. Economic growth in such OECD countries hovers around 2.5%, enough to maintain and hopefully continue improving quality of life provided that resources are managed wisely.



Source: UNDP (2007), *Human Development Report 2007/2008.*

> **"Despite progress, huge challenges remain. Gross inequality is still prevalent in the world and global problems – such as climate change – continue to grow."**
>
> Richard Manning, *Development Co-operation Report 2007*

Some other countries have, after long periods of no or slow growth, recently gained speed – at least in terms of increases in their Gross Domestic Product (GDP). Still, many of their citizens are living "in another world". In India, where growth has averaged 8.5% for the last 4 years, 300 million people still live on less than the equivalent of a dollar per day. Africa has shown encouraging growth too – averaging above 5% per year for the continent as a whole in 2007, the fourth successive year of record growth – yet life expectancy in many African countries remains shockingly low. In Swaziland, people live on average 39.6 years – less than half the average lifespan in Japan, the country with the highest average.

Indeed, the different speeds at which countries are meeting basic development goals leaves us asking: Will economic growth translate into equal opportunities for citizens in the near future? What else can be done to make sure that more of the world's underdeveloped communities gain ground in as fast and efficient a way as possible?

North and South, High and Low

For a long time, when speaking about the differences in wealth and equality, we have used common shorthand references such as "developed and developing countries" or "North and South", the latter having grown out of a geographical reference, comparing the US and Canada with Latin and South America; Europe with Africa.

Today its meaning has evolved into an economic one, referring to the differences between high income countries and poorer countries that are behind in various areas of development: income, education levels and access to health care, among others. With rapidly growing economies like India, China, Brazil and Russia that do not easily fit into either category, the picture is less and less clear. What is evident is that some countries (the "North") are able to provide an advanced level of social services, income and environmental quality to their citizens, a level that by almost all statistical measures improves year by year, while many others (the "South") have not reached the basic level.

For some commentators, this sort of division is the natural order of things. But for more and more of today's citizens this two-tiered system is not only unfair, it will also be detrimental in the long term, even to those of us living in the top tier.

National growth has global consequences

For China, India and the other emerging economies, growth is happening rapidly, bringing with it both the positive and negative consequences of intensified production and increased economic activity. Because of their sheer size, the choices these countries make as to how to direct their growth have a huge impact worldwide. Media everywhere noted with gravity a symbolic passage in 2007: China is now the world's largest producer of CO_2 emissions. But we cannot forget that its emissions per capita are still a fraction of those of OECD countries. The principle of "shared but differentiated responsibility" between developed and developing countries tries to take this into account. Outlined at the 2002 Johannesburg Summit on Sustainable Development, the principle recognises historical differences in the contributions of developed and developing states to global environmental problems, and differences in their respective economic and technical capacity to tackle these problems.

> **"The global importance of rapidly emerging economies is growing as they become major economic and trade partners, competitors, resource users and polluters on a level that compares to the largest of OECD countries."**
>
> *OECD Environmental Outlook to 2030*

Environmental consequences such as climate change respect no borders, driving home the necessity for a global perspective on pollution. To reach their current sizes of about $14 trillion and $16 trillion annual GDP respectively, the United States and European economies drew heavily on natural resources and depended almost entirely on fossil fuels. Today's changing climate is largely due to the rich countries' historical emissions. The economic model that drove this development had serious consequences for the environment, such as the permanent destruction of species and ecosystems and an increase in atmospheric carbon dioxide that most scientists believe is already changing our climate. Now the model, and its consequences, are being replicated by other countries at an accelerated pace.

The global nature of our economy means that we are increasingly linked to other countries. Disruptions half-way across the world come home in a dramatic way when they drive up the price of food or petrol at home, or result in a deployment of armed forces.

People living in regions where economic prospects are dim may choose, by whatever means possible, to emigrate to wealthier destinations. While the positive impacts of immigration in OECD countries are well-established – providing much-needed labour for example – humanitarian and economic emigration can put a burden on countries' social systems of both the country people leave and the one they go to, especially in situations of crisis and when the "host" country is a developing country.

By 2030, the world population is expected to reach 8.2 billion people from 6.5 billion today. Such projections from the most recent OECD Environmental Outlook can seem like daunting increases when we consider that the world's resources are already stretched to capacity in many respects. Where will that growth take place? A large part of it will be in the fast-developing economies of Brazil, Russia, India, Indonesia, China and South Africa – known as the BRIICS. What form will that growth take? How can we all shift to more sustainable models of growth?

A level playing field

Those who criticise the environmental record of rapidly developing countries run into an interesting debate regarding the "right" of developing countries to pollute or to have access to more advanced, less damaging technologies. Europe and the United States spent several hundred years practicing rampant deforestation and industrial pollution before putting in place tight regulation. Why should China and Indonesia have to play the game by different rules from those followed by developed countries in the past?

> **"There can be no moral grounds for expecting China and India selectively to curb their economic growth simply because world energy demand is rising unacceptably, with associated risks of supply interruptions, high prices and damage to the environment. These are global problems to be tackled on a global basis."**
>
> *World Energy Outlook 2007: China and India Insights*

Indeed it is often perceived as unfair for rich countries to lecture poor countries on resource use when the developed world is responsible, by its size, history and volume of activity, for the majority of resource consumption and the problems that ensue from irresponsible development. While all major emitters must act, the developed countries need to take the lead in addressing climate change. With global issues such as ozone depletion, climate change and biodiversity loss, everyone feels the effects of development when it is unsustainable; everyone should also feel the benefits when it is sustainable. Whether we are talking about people's quality of life or sound natural resource management, success depends on the participation of countries, regions and localities at all stages of development.

So then the question becomes one of *how* to fairly share the burdens of achieving well-managed growth. Developing countries have to cope with climate change and other problems they did not create, and do not have the same means as developed countries in tackling them. The developed countries can help by providing technologies, finance and know-how to tackle these issues, over and above regular development assistance.

The international community has engaged in various forms of development aid for over half a century; billions of dollars have been spent on different types of projects designed to spur growth and improve living standards in the poorer countries. The current international consensus is that each OECD country spends 0.7% of gross national income (GNI) on foreign aid versus 0.3% at present in order to reach global development targets such as the Millennium Development Goals. Aid to Africa alone is expected to reach $51 billion by 2010 from $40 billion in 2006. But making sure that aid is directed to sustainable projects adds another layer of complication.

Closing the development gap sustainably

Meeting the needs of today without diminishing the capacity of future generations to meet their needs: sometimes discussions on sustainable development have tended to focus more on the second half of this of this phrase – the effect of our actions on the future – than on the first half. Yet meeting the needs of today is anything but obvious, easy or conflict-free. If sustainable development is to do this, then tackling the "development gap" – the vast difference in income, access to health care, sanitation and education that exists between the wealthier and poorer countries – must figure among its most pressing projects.

> **"Addressing the challenges of the globalizing economy means addressing the needs of those people and countries that remain on the fringes, as well as those which are emerging into the mainstream."**
>
> Robert Zoellick, World Bank President, OECD/World Bank Conference on Sustainable and Inclusive Development: Going for Growth

"It is not easy for men to rise whose qualities are thwarted by poverty," observed the 1st century Roman poet Juvenal. The question of what causes poverty and what can reduce or eradicate it has long been a source of much debate, one of the fundamental questions facing the human community. We all have some idea or image in our heads of what constitutes poverty. It's not just a question of possessions – poor people in rich countries own more things than most people elsewhere. Research on the topic points to a more complex combination of the material, social and political aspects of poverty, where lack of access to information, political participation, health care and education among other things contributes to blocking the dynamic that would make lasting development possible. Being ill, hungry, or having to flee violence forces people to redirect their energy to the act of survival, without the luxury of long-term considerations. Addressing the basic needs of the world's poorest people would go a long way in fostering development in today's global economy, but it would obviously require a global approach.

Early promoters of sustainable development realised that to make the substantial changes required to produce meaningful results would require a global effort. No person, municipality, region or even country could alone transform the ideas and practices driving development. The increasingly important role of international agreements on the common concerns of the global community – trade, multinationals, poverty reduction to name only a few – attest to the need for international arena to solve problems of global significance.

The UN, OECD and other international organisations are struggling to bring sustainable development to the forefront. Other organisations including the World Bank, International Monetary Fund and World Trade Organisation are seeking means to incorporate sustainability as a basic principle in their economic operations. These institutions have brought national governments with a diverse range of views and means together to the same table to hash out their differences in the interest of improving development practices. At the same time, local and regional governments are joining forces to compare

The Millennium Development Goals

Officially established in 2000 at the UN Millennium Summit, the Millennium Development Goals identify 8 development goals and under these 18 concrete targets to be reached by 2015.
Agreed by 192 UN Member states, they represent a global agreement to achieve results in the most critical areas of human progress.

1. Eradicate extreme poverty and hunger

Reduce by half the proportion of people living on less than a dollar a day.

Reduce by half the proportion of people who suffer from hunger.

2. Achieve universal primary education

Ensure that all boys and girls complete a full course of primary schooling.

3. Promote gender equality and empower women

Eliminate gender disparity in primary and secondary education preferably by 2005, and in all levels by 2015.

4. Reduce child mortality

Reduce by two-thirds the mortality rate among children under five.

5. Improve maternal health

Reduce, by three-quarters the maternal mortality ratio.

6. Combat HIV/AIDS, malaria and other diseases

Halt and begin to reverse the spread of HIV/AIDS.

Halt and begin to reverse the incidence of malaria and other major diseases.

7. Ensure environmental sustainability

Integrate the principles of sustainable development into country policies and programmes; reverse loss of environmental resources.

Reduce by half the proportion of people without sustainable access to safe drinking water.

Achieve significant improvement in lives of at least 100 million slum dwellers, by 2020.

8. Develop a global partnership for development

Develop further an open, rule-based, predictable, non-discriminatory trading and financial system.

Address the least developed countries' special needs.

Address the special needs of landlocked countries and small island developing states.

Deal comprehensively with developing countries' debt problems.

In cooperation with the developing countries, develop decent and productive work for youth.

In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries.

In cooperation with the private sector, make available the benefits of new technologies – especially information and communications technologies.

The MDG Monitor tracks the progress towards achieving these goals. It gives an overview of the principle targets that come under each goal, indicators for measuring progress and examples of success stories.

www.mdgmonitor.org/goal1.cfm

their experiences and work together, often across great geographical distance. All in all, governments are starting to realise that they need to undertake a more collaborative, open approach to problems that are more crosscutting.

The idea of being able to improve the lives of the poorest through global action has taken hold over the course of this century, culminating with the Millennium Development Goals – an effort to attack the problem in a co-ordinated way and on a global scale. Originating in the OECD guidelines for development, the MDGs, as they are known, represent a concerted effort on the part of the world community to address the persistent problems of underdevelopment.

Tools for sustainable growth

With the exception of a few rapidly growing economies, growth in the developing countries has on the whole been inconsistent and insufficient to bridge the huge differences in living standards within these countries and compared to the developed countries. Recent indicators show that Sub-Saharan Africa has begun to see the rates of growth comparable to the rest of the world, albeit from a low starting point, but this has not yet translated into great gains in a number of critical areas. For example, the number of people in Sub-Saharan Africa with access to drinking water increased by 10 million per year over 1990-2004. However, population sizes have grown even faster, so the number of people without access has increased by about 60 million.

Each country's historical, economic, social and political context is unique, but the basic principles of sustainable development apply to all. Economic growth is essential, but growth alone, without understanding all the factors that contribute to well-being including social, environmental, institutional and cultural considerations, does not produce sustainable poverty reduction. While it is true that economic growth generally correlates with overall improvements in quality of life, higher levels of education and life expectancy at the country level, this does not tell us:

- how this growth is achieved
- whether or not it is lasting
- who benefits and who might be left behind.

Countries with highly valued natural resources such as diamonds, metals or oil have the means to increase overall economic development by selling these resources on world markets. Still, this may result in no improvement in people's lives if this income remains in the hands of very few and is not used in any way that benefits the population. If these resources are non-renewable, or poorly-managed, then the income they produce will at some point cease to be a source of growth – unless profits from them are reinvested in other projects or funds that are sustainable over time. Finally, activities that are profitable today may be degrading the environment for tomorrow. In sum, short-term growth may mean nothing in terms of long-term stability, and it can produce net environmental and social loss if the stocks and the capital generated from them are not managed *sustainably*.

Pro-poor growth

So the question is how to create growth that allows the poor to achieve real, lasting advances. Economists and development theorists call this *pro-poor growth*. According to this way of thinking, it is not enough to achieve average growth rates of a certain percentage. Growth should specifically benefit poor women and men and allow them to reap the benefits of increases in economic activity and income so that they can access a path of consistent improvement in their living conditions.

Aid for Trade

Trade offers real potential to boost growth and meet development goals. Yet developing countries often lack some of the elements necessary to reaping these benefits: such things as reliable banking systems, functioning telecommunications or good roads and ports for transport.
Aid for Trade is development assistance specifically dedicated to helping countries eliminate these barriers and take advantage of trade opportunities.

It includes assistance in:

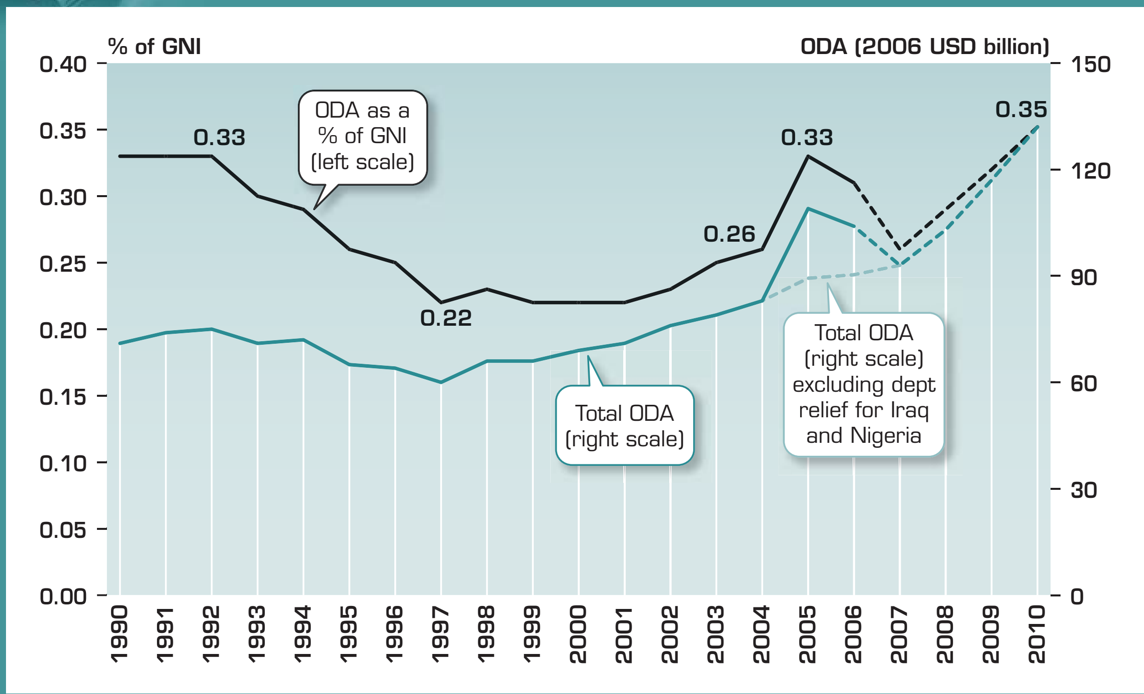
- negotiating trade agreements
- capacity building (creating the conditions to enable policies and projects to succeed)
- marketing
- meeting international standards for quality

The global trade organisation, WTO, and the OECD work together on assessing the effectiveness of Aid for Trade measures in contributing to international development.

What exactly are the means of meeting development goals? We all know some of the basic elements such as capital, health, education, technology. Approaches to providing aid and fostering growth are diverse. Development specialists describe three major avenues: official development assistance or ODA, foreign direct investment (FDI), and trade. Though these are distinct categories in a definitional sense, they work together in practical terms. For example, ODA funds might be directed to measures intended to attract FDI or develop trade, as in the case of Aid for Trade.

NET ODA 1990-2006 AND SIMULATIONS OF NET ODA TO 2007 AND 2010

Percentage of Gross National Income (GNI)



Source: Development Co-operation Report 2007. **StatLink** *: http://dx.doi.org/10.1787/470848625256*

New forms of aid have also begun to play an important part in helping achieve development targets. Large private foundations such as the Bill and Melinda Gates foundation and public-private partnerships like the Global Fund to fight AIDS, Malaria and Tuberculosis and the Global Alliance for Vaccines and Immunization (GAVI) have had a significant impact on how aid programmes are conceptualised and implemented, even though they represent a relatively small percentage of the funding pie.

Donor countries and agencies have certainly become aware of the importance of sustainability issues and are working to ensure that environmental considerations are integrated into the Poverty Reduction Strategies of recipient countries. The United Nations Environment Programme (UNEP) and the UN Development Programme (UNDP) oversee many of these efforts as part of the Poverty-Environment Initiative. In turn, the OECD's Development Assistance Committee (DAC) keeps track of these projects, in accordance with the Paris Declaration on Aid Effectiveness. The objective is to ensure that environmental concerns are integrated into development strategies, although for the time being progress is uneven.

Another example of the international effort to ensure that environmental considerations are included in development initiatives is Strategic Environmental Assessment (SEA). While Environmental Impact Statements have long been required by donor countries, they often represent a last item on a checklist for a project, an approach that leads to conflict of interest and missed opportunities. Since 2001, both donor and recipient countries have been passing legislation to undertake SEA for development programmes likely to have an impact on the environment. With SEAs, environmental considerations are integrated from the conception of national or regional Poverty Reduction Strategies. But we still have a long way to go before sustainability assessments of all three pillars are routinely conducted and Poverty Reduction Strategies are transformed into Sustainable Development Strategies.

Achieving positive revision to forest policies in Ghana

Issue
An examination of the Ghana Poverty Reduction Strategy (GPRS) identified potential conflicts between the forest policy (aimed at broadening the resource base of the wood industry) and environmental protection of river system bank-side ecosystems. As a result, Ghana's forest policy was modified. In less than six months, the government had set up nurseries to raise bamboo and rattan plants to increase the supply of raw materials for the industry, thereby helping protect riverbanks from uncontrolled harvesting of wild bamboo and rattan.

Key benefits
- Reduced pressure on primary forests and fragile river ecosystems.
- Creation of new timber resources.
- Employment.

Source: IMF (2006), "Ghana: Poverty Reduction Strategy Paper Annual Progress Report", *IMF Country Report,* No. 06/226, IMF, Washington, D.C.

Making aid count

There is a need to ensure that the development objectives of countries giving aid and those receiving it are co-ordinated and mutually reinforcing. In March 2005, representatives from non-governmental agencies and over 100 countries – both donors and recipients of aid – came together to sign an international agreement in this direction: The Paris Declaration on Aid Effectiveness.

> **"We… resolve to take far-reaching and monitorable actions to reform the ways we deliver and manage aid … we recognise that while the volumes of aid and other development resources must increase to achieve these goals, aid effectiveness must increase significantly as well to support partner country efforts to strengthen governance and improve development performance."**
>
> *Paris Declaration on Aid Effectiveness*

Co-ordinating the efforts of different donor and recipient governments is challenge enough – but add to that all the other actors involved in the development process such as NGOs, the media, or financial institutions, and we soon see why the infusion of capital is simply not sufficient. Donors must be organised and coherent in their approach – what is called "harmonisation." They should base their efforts on the needs expressed by recipient governments' national strategies.

Donors, recipients and professionals working in project implementation realise that without better co-ordination, local engagement and accountability, aid is likely to fall short of its targets. The Paris Declaration on Aid Effectiveness of 2005, an agreement signed by donors and recipient governments as well as multilateral aid organisations, reflects this commitment to a more coherent, realistic approach to meeting development goals.

Realising and articulating the need for better, more focused co-ordination is an important step, but it is only a beginning. Closing the development gap depends on building sustainable, healthy societies – removing the barriers that impede progress and bringing into the discussion such things as human rights, gender equality, peace and security. These more complex and diffuse elements pose a challenge for monitoring, but the need for policy coherence on these items is included in the reviews (know as "peer reviews") the OECD carries out of its member countries' development assistance efforts.

Going forward

In spite of the amount of aid, investment and trade-related growth, the development gap remains. One reason for this is a lack of co-ordination. Sometimes policy aims conflict, as when donor countries provide aid for health systems and at the same time try to attract doctors and nurses from the developing world.

Countries are starting to address what has to happen to make aid, trade, investment and other economic policies perform better in order to achieve lasting development results. In specialist language, this is called "policy coherence for development" which means making sure that the economic objectives of donor countries are coherent and do not undermine each other. For example, subsidies to domestic farmers or fishers do not negate gains in opening world markets, export credits or investment incentives do not conflict with the goals of development assistance policies do not interfere with building human and social capital, and so on.

> **"Providing aid to improve a country's ability to engage in agricultural trade while maintaining trade barriers or measures that keep the developing country's goods out renders aid inefficient and hampers growth."**
>
> *Agriculture: Improving Policy Coherence for Development* (an OECD Policy Brief)

According to a much-quoted saying, "Give a man a fish and you feed him for a day. Teach him how to fish and you feed him for a lifetime." But is this true? What if he overfishes? Or more efficient boats from elsewhere take all the accessible stocks? Or pesticides are washed into the breeding grounds and drive the fish away? Teaching "how to fish" involves much more than knowing how to cast a net. We have to understand the critical nature of linkages – how things relate to each other. And it is here that applying the principles of sustainability throughout the development process takes on its full meaning. The goal is not for the developing world to "catch up" with the bad habits of the industrialised countries, but rather for the developing and developed countries to co-operate in instituting sustainable growth across the board. If we are to put both richer and poorer countries on a path to development that lasts, we all have to start fishing sustainably.

Find Out More

... FROM OECD

On the Internet

For an introduction to OECD work on sustainable development and development in general, visit *www.oecd.org/sustainabledevelopment* and *www.oecd.org/development*.

Publications

Trading up: Economic Perspectives on Development Issues in the Multilateral Trading System (2006):
Trade liberalisation is a hotly debated issue, especially concerning developing countries. This book considers trade and development from an economic perspective to examine these emotive issues using empirical approaches and dispassionate analysis.

Applying Strategic Environmental Assessment (2006):
Strategic Environmental Assessment (SEA) is a tool for integrating the principles of sustainable development into country programmes and policies. This volume explains the key steps for its application based on recent experiences. Twelve points are identified for the practical application of SEA in development co-operation, along with a checklist of questions and hands-on case studies. Evaluation and capacity development for SEA processes are also addressed.

Trade that Benefits the Environment and Development: Opening Markets for Environmental Goods and Services (2005):
This collection of studies is a practical tool to help negotiators navigate the numerous, complex issues in international discussions over liberalising trade in environmental goods and services.

Also of interest

Toward Sustainable Agriculture (2008):
This OECD contribution to the UN Commission on Sustainable Development promotes policy coherence in terms of agricultural subsidy reform and social dimensions (foood security).
www.oecd.org.substainabledevelopment

Agriculture: Improving Policy Coherence for Development, OECD Policy Brief (2008):
This Policy Brief explains the importance of agriculture for development and looks at how the OECD is using its multidisciplinary policy expertise and direct contacts in national ministries and authorities to help governments promote policy coherence for development in agriculture.
www.oecd.org/publications/policybriefs

Aid for Trade at a Glance (2007):
This joint OECD/WTO report provides the first comprehensive global picture of aid for trade and will enable the international community to assess what is being achieved, what is not, and where improvements are needed.

Paris Declaration on Aid Effectiveness (2005):
The Paris Declaration is an international agreement to which over 100 Ministers, Heads of Agencies and other Senior Officials committed their countries and organisations to continue to increase efforts in harmonisation, alignment and managing aid for results with a set of monitorable actions and indicators.
www.oecd/org/dac/effectiveness/parisdeclaration

In April 2006, OECD Environment and Development ministers met to discuss ways of helping developing countries to strengthen their economies without harming the environment. The outcomes of the meeting were a **Framework for Common Action around Shared Goals** and a **Declaration on Integrating Climate Change Adaptation into Development Co-operation**.
www.oecd.org/epocdacmin2006

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Our world is showing signs of reaching critical thresholds in all of its major systems. Striking a balance between the needs and resources of today and tomorrow poses tough choices. What tools can help us decide how best to manage our systems for the long term?

The Future Is Now

By way of introduction…

Straddling the border of Poland and Belarus is a magical place, seemingly untouched for thousands of years. In the spring, wildflowers bloom under majestic oaks, and animals give birth to their young in the last remaining fragment of a primeval forest that once covered almost all of western Europe. The preservation of this particular region began centuries ago, when tsars and princes reserved the land as a private hunting ground for the elusive and increasingly rare wisent, the European bison. During the First World War, the forest and its inhabitants were again in serious danger: logging mills were built, and the last wild wisent was killed by a poacher in 1919. It seemed this last corner would go the way of wild areas on the rest of the European continent, with the virgin forest and its large mammals lost forever.

As soon as peace returned, however, determined conservationists went to work, and in 1932 the Bialowieza National Park was established. In the decades since, this unique ecosystem has been recognised as a UNESCO World Heritage Site and Biosphere Reserve. The wisent were reintroduced in 1952 from the small population surviving in zoos. Today, the bison population is healthy at about 250 individuals, in addition to other large mammals such as elk, deer, wolves, wild horses and over 100 species of birds. Each year, 100 000 tourists visit the small area of the forest open to the public, for a glimpse at this rare and wonderful ecosystem.

At the end of 19th century, the primeval forests of western Europe had been gone for generations, and in the United States the last borders of virgin forests were being logged. Species like the American bison had been hunted down to the last few hundred; others like aurochs and the great auk were gone forever. But a movement to protect the last wild places swept across Europe and the Americas, and over the 20th century thousands of square kilometres were set aside, protected in one way or another, for future generations.

By establishing national parks we narrowly escaped the permanent loss of many species and ecosystems. Now we turn to our future and wonder – what is it that we need to protect, or risk losing forever? With economic development and urbanisation racing ahead, how do we ensure that we're giving future generations a fair chance for the kind of lifestyle we've enjoyed? As the pace of human activity and impact increases, today's adults might even worry for the stability of our own future.

A century ago it seemed enough to set aside areas of special habitat. Today, we know that not only have we used up certain resources, accumulated national debt and released long-lasting pollution into water, air and soil, we're even changing the climate on which our lives depend. Clearly, it is time for another type of conservation movement: one that helps us manage what is important to our well-being and that of future generations, responsibly and sustainably.

This chapter looks at the need for forward-looking thinking to achieve sustainable development and the tools available to help this thinking. But it also stresses the need to act now, since many of the issues future generations will have to deal with are already present today, and the more we wait the more difficult it will be to tackle them.

A fair share between generations

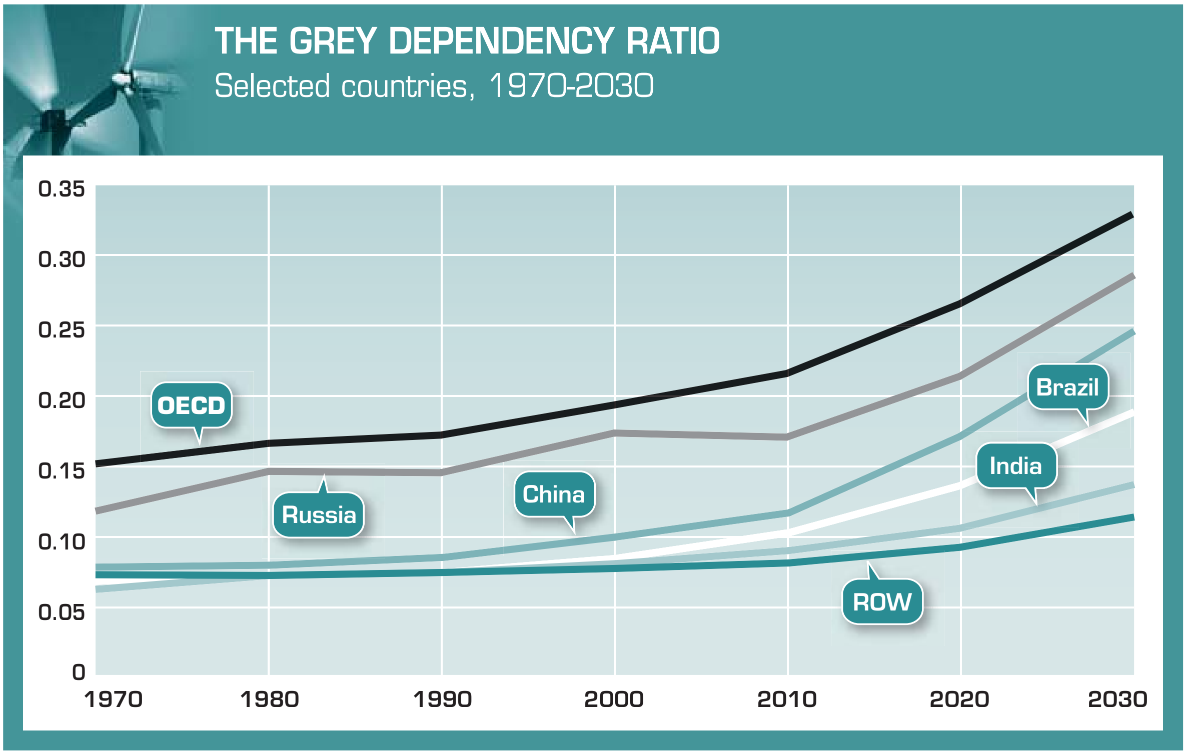
> **"In addition to balancing economic, environmental and social objectives, a basic tenet of sustainable development is the need to balance the needs of current and future generations."**
>
> *Good Practices in the National Sustainable Development Strategies of OECD Countries*

When the concept of sustainable development was first articulated in the Brundtland Report, fairness to future generations was a central tenet. This concept is sometimes called *intergenerational equity*. While relations between nations are regulated with laws and agreements, people who will live in the future can't defend their rights, even though their well-being is affected by our actions. We therefore have a duty to protect their interests, even at the cost of potential short-term gains to us.

The problem is not only one for generations at some far off time disconnected from the present: in reality, the future is as early as the child born five minutes from now. Managing systems for the long term is not an altruistic notion. Our interest is in the future because we are going to spend the rest of our lives there, to paraphrase American inventor Charles Kettering.

This is obviously a huge challenge, involving choices that we as citizens have to inform ourselves about. Take some of the most hotly debated topics such as health, pensions or public debt. You often hear that health expenditures will rise because of population ageing – the "grey dependency ratio" shown in the graph. But analyses carried out by the OECD present a more complicated picture. Although health costs rise with age, the average cost per individual in older age groups should fall over time in part because people are not only living longer, they're staying healthier longer. And they'll be getting pensions longer, too. Should it be up to individuals to make sure they have enough to live on at retirement, or should we tackle this issue as a community? Or what about public debt? Is it merely a burden we're passing on to our children or are the infrastructures, education or other services it pays for an investment in their future?

And what about our stewardship of the earth's land and resources? Outside of those lands set aside for protection, we have a history of exploiting resources through intensive activity. Can we manage most or all our forests, wetlands and oceans so that they continue to provide the riches we rely on? Are the habitat changes caused by our development endangering species that our descendents might value for aesthetic and philosophical reasons, or even practical uses like medicine and agriculture?



Source: *OECD Environmental Outlook to 2030.*

StatLink : http://dx.doi.org/10.1787/470855417842

It is as if suddenly, after tens of thousands of years of human progress and all the activity that goes with it, we have finally grown into our planet: we can reach its most remote corner; we circle it in a day; we can re-direct its rivers and climb its highest peaks. It also seems that we could soon grow out of it if we do not proceed carefully.

Indeed, the planet is showing signs of reaching critical thresholds in all of its major systems. Climate change, species loss and pollution are evidence that the world's capacity to handle what humans generate is close to full. Lest this sound like a purely "environmental" problem, keep the following in mind: the changes that occur as a result of higher temperatures, natural disasters or losing an important insect in the food chain all have profound effects on individual human beings and society as a whole. If there is one realisation that seems to have taken hold since the advent of sustainable development, it is that the environment, the people who inhabit it, and the economies and cultures they thrive on depend on each other.

> **"The remaining environmental challenges are of an increasingly complex or global nature, and their impacts may only become apparent over long timeframes. Among the most urgent of these challenges for both OECD and non-OECD countries are climate change, biodiversity loss, the unsustainable management of water resources and the health impacts of pollution and hazardous chemicals. We are not managing our environment in a sustainable manner."**
>
> *OECD Environmental Outlook to 2030*

Learning to be sustainable: what tools do we have?

For over a hundred years, forestry schools have been teaching how to manage forest resources. Knowing how fast a certain species of tree will grow in a given climate, it is possible to calculate the sustainable yield. In a tree plantation, the trees can even be treated as an 80-year agricultural crop with the same species covering thousands of hectares, and they can be harvested indefinitely if the soil is fertilised and climate conditions don't change.

This type of forest, with trees of one age and one species, is not a useful habitat for very many other species, but even tree plantations can be managed for maximum biodiversity.

A bigger challenge today is managing fisheries resources: the main way we have of tracking these populations is based on catch. How can we know whether we're overharvesting the resource? Improvements in equipment and methods engineered over the last half century allow for greater catch – giving the impression at a given point in time that the population is healthier than ever – until it crashes. This is precisely what has happened in some of the world's best fisheries, such as the Grand Banks off the coast of Newfoundland in Canada.

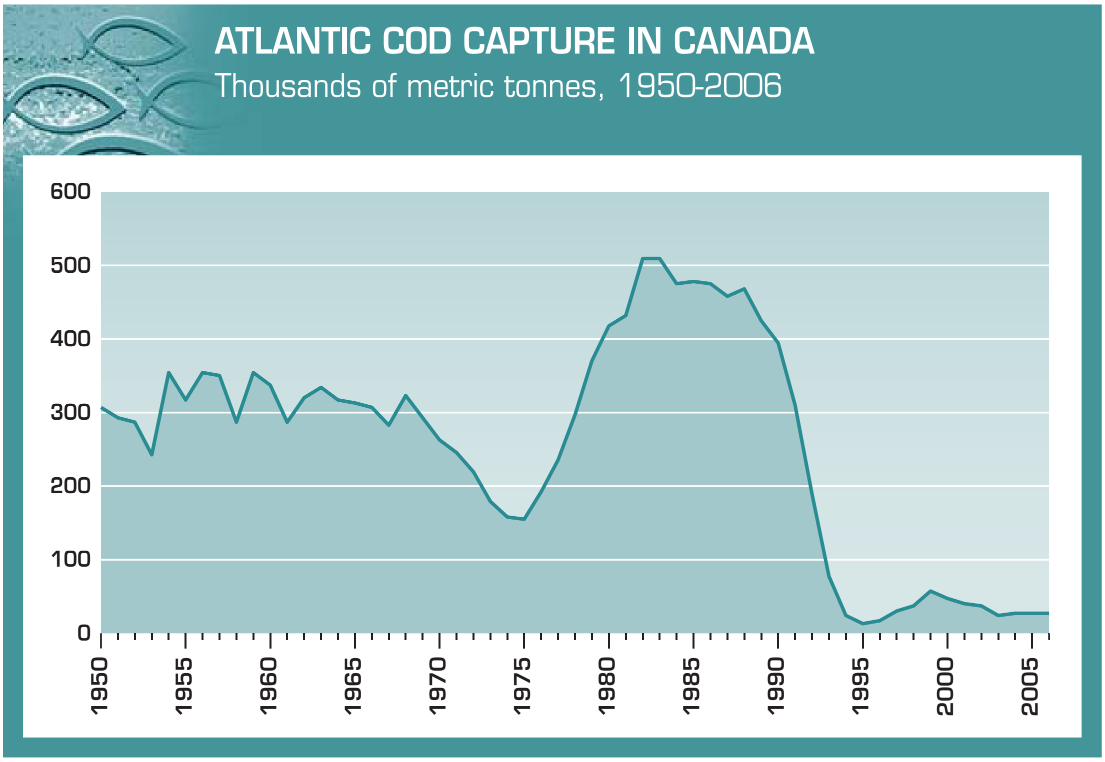
At least one-quarter of marine fish stocks are overharvested. The quantity of fish caught increased until the 1980s but is now declining because of the shortage of stocks. In many sea areas, the total weight of fish available to be captured is less than a tenth of that available before the onset of industrial fishing. Inland fisheries, especially important for providing high-quality diets for the poor, have also declined due to overfishing, changes to habitats and withdrawal of fresh water.

What can be done to conserve these valuable aquatic resources for future generations? Marine biologists, fishermen and policy experts have proposed several possible solutions to make sure that fish stocks will be available well into the future: quotas are imposed for each species, in hopes that enough are left in the waters to reproduce; Marine Protection Areas are established, with strictly no fishing, as a base from which populations can grow. Naturally, these policies are only effective when they are fully enforced. For the fishers themselves, government programmes buy back boats, offer professional reconversion programmes and try generally to support communities where there are simply too many fishers for the resource.

Finally, we can replace wild fish with a more easily-managed resource: fish from aquaculture. Aquaculture currently provides almost 40% of the fish and shellfish we eat, but it has its limits as well. Raising so many fish in such small quarters makes the risk of infection so high that antibiotics have to be used. Escaped fish interbreed with wild populations, endangering their genetic diversity, and pollution from the fish food and wastes flows

The Collapse of the Grand Banks cod fishery

The rich fishing grounds off the southeast coast of Canada have been exploited for hundreds of years, from the 17th century when Basque fisherman ventured north to the late 20th when an estimated 40000 people worked in the fishing industry of Newfoundland, catching and processing cod. During the 1990's the harvest reached a very profitable maximum, before crashing in 1992, for reasons that still aren't fully understood. What we do know is that the collapse is still costing upwards of 250 million Canadian dollars per year in lost income. For local residents in towns like Bonavista (population 4000), other occupations need desperately to be found: the cod population still shows no sign of recovery despite a moratorium on cod fishing enacted in 1994.



Source: UN FAO Fishstat database.

With the end of the cod harvest, people started fishing for skates, which were formerly considered "by-catch". Now evidence shows that the skates too are overfished. Clearly, this is not a sustainable solution, and the local communities are paying the price in lost income and tradition: Bonavista has lost one-tenth of its population over the last decade, turning to tourism as its fishers hope for a miracle.

In the meantime, they have a warning for other fisheries where the catch is still high, "It would be better for them to take drastic measures now, bite the bullet for a little while and then hopefully their stock will rebuild" says Larry Tremblett, a Bonavista fisherman, "Not like what happened to us, just letting it go until there was nothing left. As far as Newfoundland is concerned now, our fishery has gone – wiped out, and all because of greed and stupidity."

easily into surrounding waters. All of these problems will require continued attention and investment in order for aquaculture to become a truly sustainable solution.

With hindsight, the tragedy of Grand Banks seems avoidable. Yet other fisheries are likely in the same situation today as Grand Banks was in 1991, with a catch that seems stable or declining only slowly, but is really nearing or already past its critical threshold. Globally, we still have a very hard time following Larry Tremblett's advice. Even if we know that a crisis may be just around the corner, we all find it difficult to step back and make major changes.

Now is the time to act

One major barrier to making changes is the degree of uncertainty that comes with planning for the future: there is no experiment to "prove" what the exact consequences of unsustainable choices will be. In the case of climate change, we don't know for certain what amount of CO_2 in our atmosphere will trigger serious and possibly irreversible damage – our Earth is our only laboratory on this one. The same is true for biodiversity loss or any of the other resource-management issues that we face. This uncertainty is sometimes taken as an excuse not to make investments in better, cleaner sustainable practices: why pay all that money if we're not *sure* we have to?

And yet that kind of reasoning leaves us vulnerable to a big surprise once there is overwhelming evidence that a systems failure of some type will be devastating, it is likely to be too late to muster the means to avoid it. Sure, some miracle solution might come along, but do we really want to take that risk? What sustainable development argues for is to mitigate those risks now, in ways that enhance our present, as well as preserve our future.

When faced with the prospect of major changes to our environment, a common response is to say "human beings are so resourceful; we'll find a way to deal with that problem when the time comes." Indeed, new methods and technologies can lead to decreased reliance on natural resources, allowing us to give the planet a break, but they can also increase pressure on natural ecosystems or create new worries of their own, as in the fisheries example.

Those technological wonders that we hope will appear in time to save us take years to develop, and there is really no break between a "now" in which we can procrastinate and a "future" when we can start thinking about solutions. Waiting until a problem presents serious consequences is clearly not the best way of managing things.

> **"If no new policy actions are taken, within the next few decades we risk altering the environmental basis for sustained economic prosperity."**
>
> *OECD Environmental Outlook to 2030*

Even if we can avoid the most drastic outcomes, emergency solutions tend to be very expensive. And often we can only mitigate the negative effects of a problem, rather than erase them. Whether the crisis is starvation, pollution or flooding, those who are affected at the moment of crisis suffer the consequences of a lack of long-term planning. And in the case of species loss, there is no possible solution what is gone is gone forever.

Planning for the future

We want to guarantee that our actions today won't leave behind unsolvable problems and a planet whose capacity to meet the needs of its inhabitants has been depleted. And yet we don't have a crystal ball to look into to see who the people of the future are, how many they are and what resources they require to lead fulfilled lives.

What we *can* do is project into the future using computer models that build on today's situation to try to predict future conditions. Such models can be used to forecast the availability of various social and natural resources, from health care and pensions to fossil fuels and fish. They also forecast the demand for these resources, based on several factors: population growth, economic growth and technology choices. They can give us essential information on what could happen if we do not make the necessary changes.

Imagine possible scenarios for the year 2050: in one, the human population has grown to 9 billion and our societies have continued with fossil fuel-intensive development. As natural gas resources have dwindled coal's share in electricity generation has grown. Increased production has led to increased electricity demand, and more people are driving cars. As a result, annual global greenhouse gas emissions have increased by over 50%, going nearly 47 Gigatonnes – that is, billion tonnes – in 2005 to over 70 Gigatonnes in 2050. The concentration of CO_2 in the atmosphere is above 500 ppm and is still rising.

Another possibility: the same population growth has occurred, but economies have shifted from materials-intensive production to service and information activities. Government policies to mitigate climate change, such as taxing greenhouse gas emissions, have been in place for 40 years. Clean and efficient technologies for generating energy and managing emissions have been rapidly developed and shared worldwide, and non-fossil sources of energy have a far bigger share in the energy mix. Global greenhouse gas emissions peaked around 2015 and the atmospheric concentration of CO_2 is just stabilising at 450 ppm.

These are the kinds of scenarios that policy makers are considering as they try to balance today's needs with tomorrow's: what the world will look like if we change little or nothing, and what we can achieve if we undertake concerted, co-ordinated actions.

Mathematical equations that take into account population, economic growth and energy consumption are used to project future greenhouse gas emissions. This data is then plugged into an even more complex climate model, revealing, with the best current knowledge we have, the impacts. If we're heading towards the first scenario, we could expect a temperature increase of 4-6°C or more in the long term. In the second scenario, the models indicate a more moderate 2-3°C in the long term. Remember that for humans, a heat wave that is just a few degrees warmer than usual can cause thousands more deaths, as Europe experienced in the summer of 2003. Not to mention the more complex effects that warmer temperatures are already having on glaciers and ice caps and sea level.

Such models do not tell us what as yet unforeseen solutions might appear on the horizon, but they can help us understand the possible consequences of decisions we make now. And these days they are sending a clear message: our current path of development is hurtling us towards major changes, changes that will affect almost every aspect of our lives.

Mobile banking: developing countries show the way

Efficient financial services are central to economic development, yet most people in the world don't have a bank account. Even in the US, 10 million households do not have accounts at banks and other mainstream financial institutions. Access to financial services is becoming more important even for the very poor as digitised financial transactions become widespread. In the developing countries, the problem is worse in areas where people might have the means to open an account, but where the banks don't find it worthwhile to build a branch.

The result is that the "unbanked", as they are called, have to pay high fees to intermediaries to send or receive money. This can represent a significant "tax" on the wages of workers who send remittances to their families, especially if they are in another country. People may have to spend hours going to the nearest bank to deposit or withdraw funds. Or they may have to trust their cash to someone going to their home area.

But many if not most people who lack access to a bank do have access to a mobile phone, even if it's not their own. And they are never far from a shop selling top-up cards for the phones. This is the basis for mobile banking. Money can be transferred to the phone and cash picked up from the retailer selling the top-up cards. In more advanced applications, becoming common in South Africa, customers can pay for services using their phones. The next stage being planned is a system as practical as cash machines. In other words, it will allow transactions between people using different telephone operators and different banks if they have an account.

There are plans to link this to microfinance schemes. Until now microfinance operations have been run by organisations dedicated to this purpose. But with the spread of mobile banking, large financial institutions are exploring ways to extend their services to the vast numbers of potential customers usually thought of as unprofitable. In an interview to the *Guardian* newspaper, Alastair Lukies, chief executive of one of the companies promoting the plan, explained their thinking: «One of the things the banks are waking up to now is micro-finance and 'the unbanked' has gone from being a thing you talk about in the corporate and social responsibility paragraph at the end of the annual report to being a fantastically viable market.»

Telecoms analysts Juniper Research back this up, forecasting that mobile banking transactions will soar from 2.7 billion in 2007 to 37 billion by 2011, for a value close to $600 billion, driven by users in developing countries who don't have a bank account or credit card. Other forecasts put the total number of transactions at 62 billion.

Source:

Jupiter Research (2008), "The 'great unbanked' to drive mobile finance market", Juniper Research, 17 June 2008, *www.juniperresearch.com*.

Wray, R. (2008), "Cash in hand: why Africans are banking on the mobile phone", *The Guardian*, 17 June 2008, *www.guardian.co.uk*.

Tackling the 'superstar' issue: climate change and our future

> **"Scientific evidence shows unequivocal warming of the climate system, and the rate of change is accelerating."**
>
> *Climate Change: Meeting the Challenge to 2050* (an OECD Policy Brief)

Our species, *Homo sapiens*, has established agriculture, cities, writing and an impressive array of technology during the relatively stable climate of the last 10 000 years, since the end of the last ice age. Now evidence shows that we are changing the very climate we depend on, largely because of our dependence on the fossil fuels (first coal, then oil and natural gas) that made the industrial revolution possible. Energy needs will increase in the foreseeable future, as developed countries continue their economic growth and developing countries race to catch up. If governments around the world stick with current policies, the world's energy needs will be well over 50% higher in 2030 than today, with China and India together accounting for almost half the increase in demand.

We are already paying for historic emissions from developed countries with more frequent heat waves and stronger hurricanes. At the current rate, the Arctic waters will be completely ice free in summer by the middle of this century, possibly within ten years. Seas will continue to rise as the warmer water expands and is joined by melt-water from glaciers and ice caps.

For the last two decades the debate about the seriousness of this threat has raged mounting evidence of substantial alteration to the climate on one side and scepticism on the other, with some people dismissing human-caused climate change altogether. Yet the latest scientific evidence overwhelmingly supports the hypothesis of a climate that is already undergoing change due to human activity.

All of these changes have potentially huge financial and social costs that make inaction seem illogical, short-sighted and even immoral. For example, the Intergovernmental Panel on Climate Change (IPCC) warns that agricultural production in many African countries and regions could be severely compromised by climate variability and change. The area suitable for agriculture, the length of growing seasons and yield potential, particularly along the margins of semi-arid and arid areas, are expected to decrease. This would further adversely affect food security and exacerbate malnutrition in the continent. In some countries, yields from rain-fed agriculture could be reduced by up to 50% by 2020.

On the other hand, recent projections show that costs of reducing carbon emissions will have a minimal effect on global growth. World GDP is projected to double by 2030 and triple by 2050. Stabilising greenhouse gases in the atmosphere at about 450 ppm CO_2 is by all calculations affordable compared to expected economic growth and to the estimates of cost of inaction. The OECD estinated that this stabilisation would cost a small fraction of accumulated wealth worldwide in the comming decades, possibly less than one tenth of a percent of world GDP growth. It is not cheap, but manageable.

Melting glaciers are more than just a change of scenery

Hardly a day goes by that that we don't hear or read something about climate change. Most recently, a report by the United Nations Environment Programme has announced the appearance of a rather significant trend: the earth's glaciers are melting much faster than at any time in the past. Of thirty reference glaciers from which scientists have taken regular measurements since 1980, only one has slightly increased. All the others experienced loss, at an average rate more than double the previous year.

What does the loss of major glaciers mean? For some, it's the change in a familiar landscape or the disappearance of species dependent on the integrity of that landscape that seems unfortunate. Footage of polar bears struggling to move across patchy ice are particularly affecting because we are spectators to the effects of the bears' habitat loss, in real time.

But you don't have to be a naturalist or animal lover to be concerned about glacier melt: the effects on people and economies are multiple. For example, scientists have serious concerns about how much water is being added to already-rising oceans and the impact on currents such as the Gulf Stream that play a large role in global climate. Another impact that only the people downstream from a glacier appreciate fully is their role in providing freshwater: snow at the top freezes and is stored for future use while melting releases fresh water into rivers. In the Himalayas, farmers have started building "artificial glaciers", networks of pipes to capture and channel water from melting snow. In temperate zones, this means that water will be available all through a dry summer. As long as the system functions, what is lost is replaced by what is deposited.

At current rates, that kind of replacement is impossible. Scientists at the World Glacier Monitoring Service describe a dramatic scenario: too much melting will initially cause floods. And if the glaciers shrink too much or disappear, they will no longer be able to serve as natural water storage, resulting in a serious lack of freshwater during dryer seasons. For the millions of people who depend on rivers for water to drink, to grow food and to produce energy, this represents a vital threat.

> **"A window of opportunity to act is now open, but it will not be open for long. We need forward-looking policies today to avoid the high costs of inaction or delayed action over the longer-term."**
>
> *OECD Environmental Outlook to 2030*

When put in those terms, paying the price to reduce carbon emissions now sounds like a smart choice. Also, the more co-operation there is on a global scale, the lower the costs will be.

Calculating the costs of inaction

The cost of making changes has often been cited as the reason why we have not managed to take more comprehensive action to eliminate bad habits. One difficulty arises in trying to calculate and compare these costs. We are quite used to calculating the cost of something new. Say a factory is contemplating changing to a cleaner production process, adding a filter that will reduce emissions of nitrogen oxides (NO_x): first there is the cost of the new equipment itself. To this must be added the costs of stopping production while the modifications are made and the cost of disposing of the old materials.

Determining the cost of inaction, however, requires bringing together a number of previously separate issues, some of might not be easy to put a price tag on, such as health and quality of life. Particulate matter produced by fires, diesel engines and incinerators, among other sources, is known to cause heart and lung disease, cancer and respiratory ailments: 960 000 premature deaths and 9.6 million "years of life lost" worldwide was the estimated figure for the year 2000. Photochemical smog, a result of several emissions present in dense urban areas (NO_x, CO_2, SO_x, and ground level ozone, O_3) also causes respiratory illness, cardiovascular problems and increased mortality.

So how much is this extra pollution costing society? Missed work days for adults and increased asthma treatment for children both cost money to the local and wider economies. Smog also affects the value of real estate, and the growth of plants. These are complex calculations at the local level. At a national level it is estimated that damages from air pollution in the US range between $71 and $277 billion per year.

MITIGATING CO_2'S EFFECT ON CLIMATE

Changes in CO_2 concentrations over time, 2000 to 2050

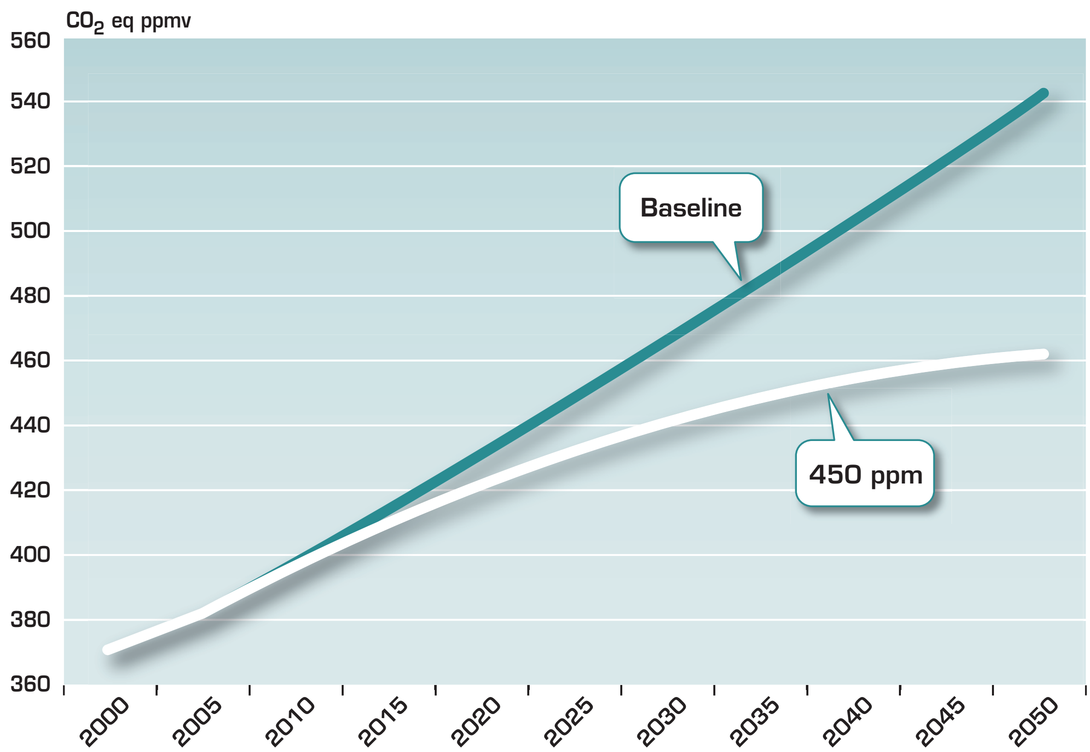
CO_2 is a "trace gas", making up less than 1% of the Earth's atmosphere by volume, compared to O_2 and N_2 (21% and 78% of our atmosphere respectively), but as a greenhouse gas it retains heat close to Earth's surface, leading to climate change.

In the past 150 years, humans have increased the concentration of carbon dioxide in the atmosphere from about 280 parts per million to 385 ppm today, principally through the burning of fossil fuels.

Since there is a lag time between when we emit a molecule of CO_2 and when its full effects are felt by our very complex climate, there really is no way to "stop global warming". Instead, experts talk about *mitigation*.

It will be many years before we can even imagine reducing atmospheric CO_2 back to historic levels, but we can limit its rise.

The graph below shows where CO_2 will be in 2050 for a baseline scenario of action (scenario 1 in this text) compared with an aggressive global effort to keep CO_2 below 450 ppm (scenario 2).



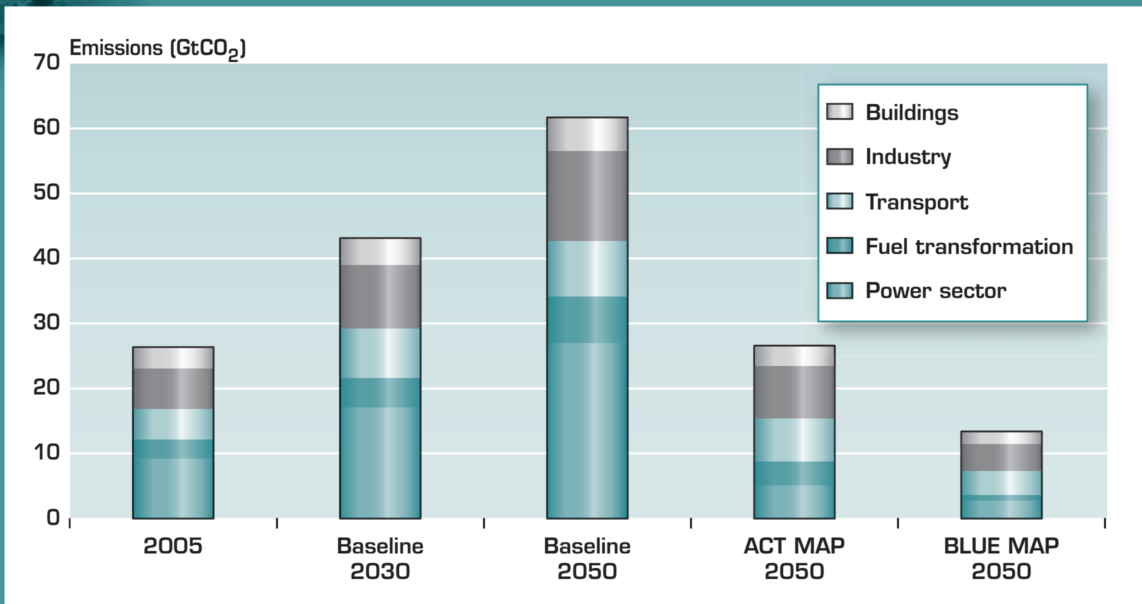
Source: Based on *OECD Environmental Outlook to 2030.* StatLink: *http://dx.doi.org/10.1787/470886725475*

Reducing our emissions of greenhouse gases will cost even more than retrofitting factories to control local air pollutants like NO_x. But the potential costs of inaction on climate change are higher, too.

> **"We will act with resolve and urgency now to meet our shared and multiple objectives of reducing greenhouse gas emissions, improving the global environment, enhancing energy security and cutting air pollution in conjunction with our vigorous efforts to reduce poverty."**
>
> G8 Communiqué, Gleneagles Summit 2005

In response to the political will expressed by leaders of industrialised nations at the G8 Summit at Gleneagles in 2005, the International Energy Agency (IEA) has published a series of scenarios and strategies aimed at meeting environmental goals. The so-called ACT scenarios show that, with the right decisions taken early enough, it is possible to move the energy system onto a more sustainable basis over the next half century, using technologies that are available today or that could become commercially available in the next decade or two. The ACT scenarios only stabilise emissions at 2005 levels.

GLOBAL CO_2 EMISSIONS IN THE BASELINE, ACT AND BLUE SCENARIOS



Source: OECD/IEA (2008), Energy Technology Perspectives 2008: Scenarios and Strategies to 2050.

StatLink : http://dx.doi.org/10.1787/470887573126

But returning emissions to 2005 levels may not be enough. The IPCC has concluded that emissions must be reduced by 50% to 85% by 2050 if global warming is to be confined to between 2°C and 2.4°C. The BLUE scenarios look at how this could be done, including the use of technologies that still have to be developed, such as hydrogen fuel cell vehicles.

Here again, our choices are many: will we combine the forces of governments, the business community and our own personal choices to make the necessary changes? What the scenarios show is that we *are* capable of reducing our emissions, shifting away from activities that affect the climate and still grow our economies *if* we make a concerted international effort to manage the climate change question sustainably.

Educating ourselves for a sustainable future

Finally, we have to take a close look at what got us into our current situation and think seriously about how to change our habits and methods in a way that will last. Now that we know so much more about the relationship between development and the well-being of people and natural systems, we need to find ways to transmit that knowledge.

For future generations to avoid some of the problems we are struggling to solve today, they must continue making better and more sustainable choices. This message is passed on from parents, through the media and increasingly at school: UNESCO declared 2005-2014 the "Decade of Education for Sustainable Development". Nations from Australia to France, from Chile to China, have included environmental concepts in their national curricula and are building eco-schools to ensure that younger generations meet the future with some of the tools they need to carry these ideas forward. But teaching children the complex concepts of sustainable development – interdependency, interdisciplinary thinking, intergenerational needs – is proving far more difficult. Curricula approaches for teaching sustainable development are still at an early stage.

We owe it to future generations to put mechanisms in place to achieve sustainability: nations can start enforcing emissions quotas and trading, to make each ton of CO_2 more expensive to emit, while at the same time developing and sharing alternatives for energy. It is important not to forget that we also owe it to ourselves: many of the consequences may seem like they are in the indefinite future, but that may be much sooner than we would like. Ageing populations, increasing poverty, stronger hurricanes, more frequent heat waves, increased flooding… the evidence suggests that these are no longer projections: the future is now.

Find Out More

... FROM OECD

On the Internet

For a general introduction to OECD work on sustainable development, visit *www.oecd.org/sustainabledevelopment*.

Publications

OECD Environmental Outlook to 2030 (2008):

The *OECD Environmental Outlook to 2030* provides analyses of economic and environmental trends to 2030, and simulations of policy actions to address the key challenges. The Outlook shows that tackling the key environmental problems we face today – including climate change, biodiversity loss, water scarcity and the health impacts of pollution – is both achievable and affordable. It highlights a mix of policies that can address these challenges in a cost-effective way. The Outlook reflects developments in both OECD countries and Brazil, Russia, India, Indonesia, China, South Africa, and how they might better co-operate on global and local environmental problem-solving.

Energy Technology Perspectives 2008: Scenarios and Strategies to 2050
IEA, 2008:

This publication responds to the G8 call on the IEA to provide guidance for decision makers on how to bridge the gap between what is happening and what needs to be done in order to build a clean, clever and competitive energy future. The analysis demonstrates that a more sustainable energy future is within our reach, and that technology is the key.

Also of interest

Teaching Sustainable Development (forthcoming 2008):

This report summarises the outcomes of the September 2008 workshop on education and sustainable development and proposes teaching and curricula approaches as an OECD contribution to the UN Decade of Education for Sustainable Development (2005-2014).
www.oecd.org/sustainabledevelopment

Climate Change: Meeting the Challenge to 2050, OECD Policy Brief (2008):

Over the past decade, governments have developed an international framework for action on climate change, and many countries have implemented policies to address it. While this experience will be invaluable as a base for developing future climate policies and a post-2012 framework for tackling climate change internationally, the current actions are insufficient to significantly slow the progress of climate change.
This Policy Brief highlights the OECD's work on the likely impact of various courses of action to mitigate climate change.
www.oecd.org/publications/policybriefs

"The Economics of Climate Change: The Fierce Urgency of Now", Speech by Angel Gurría, OECD Secretary-General, at the UN Climate Change Conference in Bali, Indonesia on 12 December 2007
In his speech, Mr. Gurría presented the climate change policies that should be put into place to limit further deterioration. Answering the crucial question "who pays for it", he noted that the countries who provoked climate change have a greater capacity to pay than those who joined the group of large emitters more recently.
www.oecd.org/secretarygeneral

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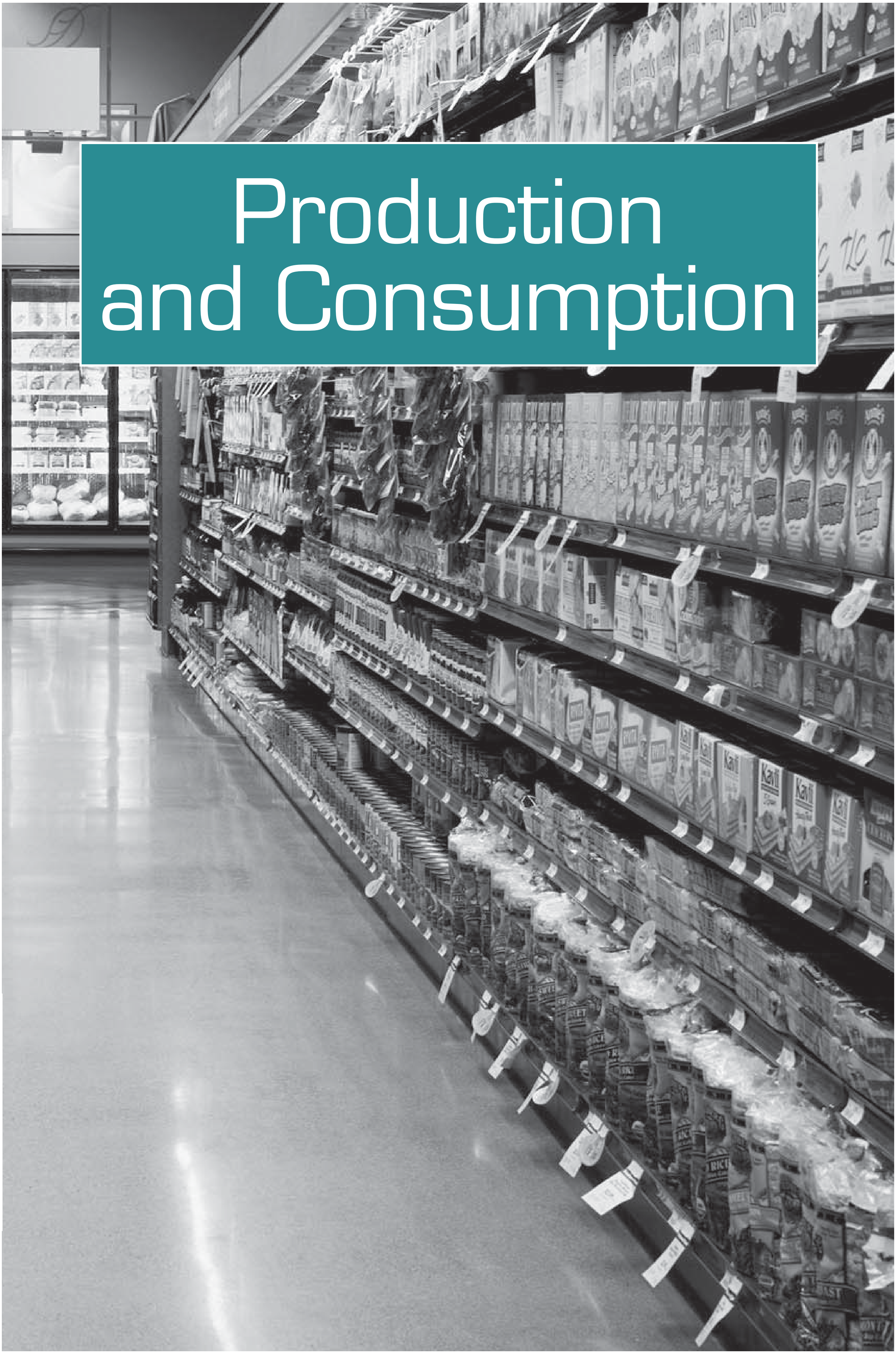
Sustainable development is about making better choices as producers and consumers – choices that do not use up our resources or create consequences that we literally can't live with. To make good choices we have to know something about the products and processes we use on a daily basis. Governments and businesses must work together to make sustainable choices available and more visible to consumers. People need incentives including information and education to begin consuming sustainably.

Production and Consumption



By way of introduction…

In Samuel Beckett's novel *Malone Dies*, the main character decides to make a list. Taken literally, Malone's idea may seem like a typical example of the absurd. Yet so often with Beckett, an everyday occurrence can suddenly reveal unexpected depths, complexity and connections among what we are, what we do and, in this case, what we have. Imagine trying to write down everything you possess – every single thing. It might take a while, right? Yet go back a few generations and the problem would probably have been a lot easier for most members of your family – food, working clothes, maybe a set of formal clothes that lasted a lifetime, some household utensils and perhaps a few other goods. And that's all.

Even now, the 40% of the world's population living on less than two dollars a day wouldn't need much time to draw up their list of possessions. In OECD countries however, the economic expansion and social reforms of the past few decades have made the material conditions of most people's lives unimaginably superior to those at any other time in history. Rapidly developing economies such as China, India and Brazil are catching up and their consumption patterns are converging with those of OECD countries. Worldwide, more and more people possess more and more things.

This has obvious implications for sustainable development. The billions of goods and components humans now own all have to be manufactured, transported and, sooner or later, disposed of. Consumption and production touch virtually every aspect of our lives: international trade, agriculture, energy, working conditions, social life and well-being. In fact, all the areas considered important to sustainable development actually have something to do with what producers bring to the market and what consumers – whether individuals, groups or governments – take from it.

▶ In this chapter, we'll look at how consumption patterns are changing thanks to more goods being available at prices more of us can afford. We'll also examine the "hidden" costs of production and consumption. And we'll discuss what they mean to the people who have to pay. Finally, we look at what consumers, producers and governments can do to promote more sustainable always of doing things.

The material society

We live in a "productivist" society, where growth and economic activity have long been the central focus of the activities we undertake as individuals and communities. World GDP has grown from around $16 trillion in the mid 1970s to over $40 trillion today. Companies are churning out more of everything and inventing new products all the time.

To take a simple example, let's go back to Malone for minute. He doesn't get very far with his list, overwhelmed as he is by a pencil and a notebook. Even such small and seemingly innocuous objects can give us pause for thought once we begin to add up the totality of their "weight" in the world. Every year, the Faber-Castell company alone produces 2 billion pencils, enough to reach from here to the Moon if laid end to end. An ordinary graphite pencil can write around 45 000 words, that's around 70 closely-written pages, or a line almost 60 km long. So Faber-Castell could probably meet the world's pencil needs for some time to come with a year's output. A quick look at any stationery store tells a different story. The modern marketplace offers an enormous range and quantity of even the simplest products. And manufacturers are continually trying to produce the next big thing, the next hot item that everyone will want. Workers, research, raw materials, machines, components, marketing and distribution, and numerous other services are mobilised to meet our demand as consumers for new and better products.

Although poverty and deprivation still exist, most people in OECD countries enjoy a standard of living that allows them to spend a significant share of their income on goods and services other than food, shelter, clothing or other basics. Even for the basics many of us can spend much more than is necessary for our physical well-being. Consuming is a pervasive fact of life and begins even before babies are born, when the parents' friends and relatives celebrate the big event with a gift. Babies themselves begin to consume, or to influence purchasing decisions, as soon as they can point at a toy or cereal box. In the US for example, discretionary spending by children aged 3 to 11 is expected to grow from $18 billion in 2005 to over $21 billion by 2010, while families will spend over $140 billion on consumer goods for their kids by 2010.

What happened to the paperless office?

Indeed, consumption often seems to be the major criterion in defining activities or social groups. As the chairman of the IFPI, trade association for the recording industry, explained to a trade show in 2005: "A new generation has defined new ways of consuming music". Not "listening to" or "enjoying", but "consuming". In the past few decades, the technology for "consuming" music has undergone several major transformations: records, tapes, CDs and now the immaterial and intangible digital file.

Production has a far greater impact on sustainability than consumption, so taken in isolation, the fact that goods can now be obtained in a digital format is a good thing for sustainability. Selling a million copies of a song via Internet downloads saves tons of plastic, tons of packaging materials and tons of fuel to get the CDs to the shelves and the fans to the store. But, once again, we have to keep in mind that sustainability is not about taking things in isolation, but instead about examining the trends and interactions that make up the whole cycle of production and consumption. In this case, it means remembering that the virtual economy has physical foundations and that the digital product uses resources and creates waste. Over 7 million tons of phones, computers and TVs were sold in 2006, and this is expected to rise to almost 10 million tons a year by 2016. The servers that store all this information are using significant amounts of electricity – over 1% of the world's total.

> **Our overriding challenge is to dramatically decouple economic growth from the use of natural resources and degradation of the environment.**
>
> Connie Hedegaard, Danish Minister for the Environment,
> *Measuring Subtainable Production*

The digital revolution has added hundreds of new objects to the market and often without the savings in resources that it was assumed the innovations would generate. People have been predicting for the past 30 years that the PC and other advances in electronic equipment would reduce the amount of paper used, leading to the "paperless office". In reality, consumption of paper products has almost tripled since the mid-1970s. Of course not all of this is due to office applications, but the introduction of e-mail into organisations for instance increased paper use by 40%. Other office technologies also have significant sustainability impacts, as in the 3.3 litres of oil it takes to produce a laser printer cartridge. And in spite of the possibilities for savings in travel through telecommuting, the vast majority of people still work in an office, with fewer than 2% of workers working more than eight hours a week at home.

Why has technological progress and the so-called information society not produced the resource (and time) savings that should be possible? Well, for a start, goods have become cheaper – you can now buy a laser printer for the price you would have paid for the cheapest inkjet printers five years ago – and world living standards are rising, increasing the number of buyers of every kind of object. The answer to this question also has to account for how people use the technologies, favouring throw-away objects rather than reusable ones for example. Making production and consumption sustainable means considering the whole life cycle of a product, from the raw materials needed for production to labour costs and conditions, to the costs of transport, retail distribution, use and waste disposal.

Two sides of the same coin

Production and consumption together form the backbone of the economy. They also help to determine social status and shape the natural environment. We can better understand some of these issues by looking at an everyday object, the mobile phone.

Thirty years ago, the idea of a tiny radiotelephone capable of calling practically anywhere in the world was the stuff of futurist fancy. Today, not to have a mobile is to pass for an oddball, or a technophobe. Even in countries where income is very low and poverty a major concern, mobile technology is relatively common, having leapfrogged traditional telecoms in many cases. There are only about 14 fixed-line telephone subscriptions for every 100 people in developing countries, but over 33 mobile subscribers. And the trend for mobiles is moving sharply upward, while that for fixed is actually declining in the developed countries according to the International Telecommunications Union.

What does this mean for sustainable development? It means that more people than ever have access to modern communications networks and the benefits they bring. As Internet via mobile phone expands, it will mean that people who can't afford a computer can access the Web. It means that banking services can be made available without having to build banks. But since we are looking at all that goes into (and comes out of) a product, we have to examine the physical impact of all these phones, too. Worldwide mobile subscriptions had reached 3.3 billion by the end of 2007, and a billion mobile phones are sold each year. An average user changes phones every 18 months to two years and very few of the old ones are recycled. Although one phone may not make much difference, the life cycle of billions of phones is a major issue.

Out of sight, out of mind?

What really happens to all that waste at the end of a product life? What does it mean exactly to "store or reuse" it? Where does it really go when "exported"? In 2006, the tanker *Probo Koala* offloaded a cargo of toxic wastes onto trucks in Abidjan, the Ivory Coast capital. The trucks then dumped the waste at 14 municipal dumps around the city. The resulting pollution killed at least 7 people and poisoned 9 000 others, provoking vomiting, nosebleeds, headache and rashes. The story starts in Amsterdam, where the cost for treatment would have been €500 000. The ship sailed on to Estonia, which refused to let the waste enter its territory. It was then sent it to Africa, and a newly registered company was paid $18 500 to dispose of the

Electronic waste

- Nokia looked at how much CO_2 a typical 3G phone generates in a year: 12.3 kg for manufacturing, 33 kg for equipment operating, and 9.6 kg for operator activities, giving a total of almost 55 kg of CO_2 per phone. The study also describes a number of substances that are harmless while the phone is intact, but that could be dangerous if recycling is not carried out correctly (*http://ec.europa.eu/environment*).

- According to the UN, 20 to 50 million tons of waste from electrical and electronic equipment, WEEE, are generated each year from the products we throw away. (In 2005, visitors to London could see the Weee man, a 7 metre high giant composed of the estimated electrical and electronic waste one UK citizen will discard in a lifetime.) Greenpeace estimates that only 25% of WEEE generated in the EU27 each year is collected and treated. No precise data are available on whether the rest is stored, disposed of otherwise within the EU, or exported to developing countries. Part of the 25% collected may also be exported, and hazardous waste exports are taking place despite an EU ban on such exports to non-OECD countries. Figures for the US are similar, with 80% of this waste incinerated, sent to landfill, put into "storage or reuse", or exported (*www.greenpeace.org*).

waste. The *Probo Koala* case is only one example of the "grey areas" involved in disposing of material waste. Like similar cases, it reveals some of the many governance, regulatory and even geopolitical factors that can impede or hinder sustainability.

The raw materials side of a product's life cycle can also have a significant influence on people's quality of life, their health and safety. This can even inadvertently contribute to conflict, as in the case of the capacitors found in phones, laptops and other electronic devices, which use a substance called tantalum, valued for its good thermal conductivity and energy efficiency. Although Australia is the world's biggest producer, the increased demand has made other sources attractive, too. A UN report revealed that the civil war in the Democratic Republic of Congo was being partly financed by illegal mining and trading of coltan, the African abbreviation for columbo-tantalite, a source of tantalum. Phone manufacturers do not buy coltan directly, and knowing which components suppliers are using illegal materials is extremely difficult, the more so given the sheer number of components that go into a phone – 500 to 1 000 depending on the model.

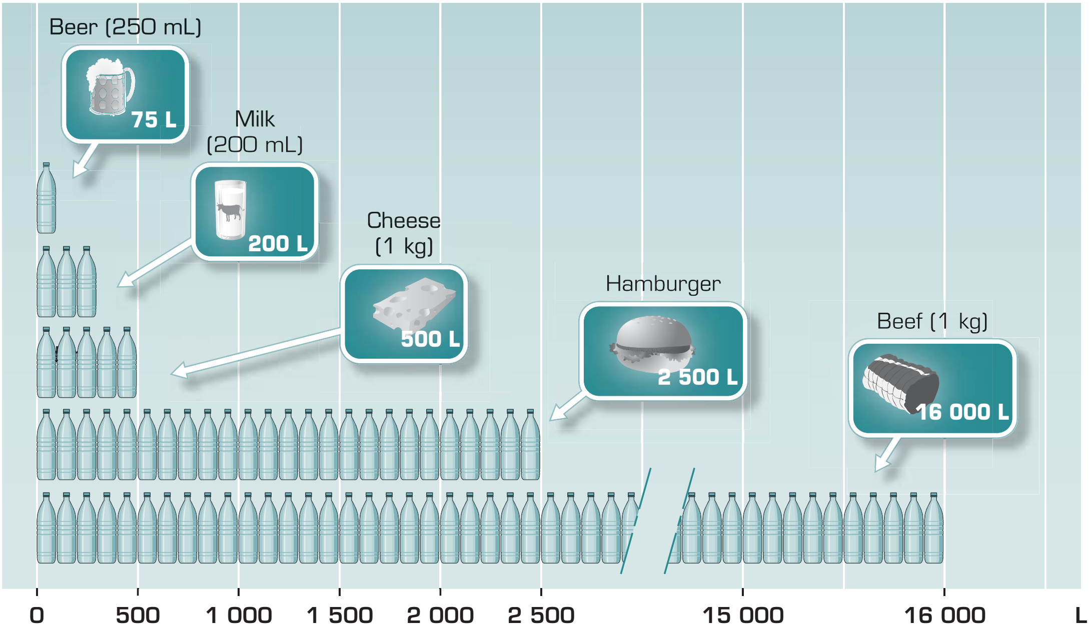
Getting the price right

If asked to describe how the price of goods is fixed, most of us could describe the various factors taken into account, such as raw materials, labour, profit margins and so on. But these economic parameters do not tell the whole story. The *Economist* magazine has devised an amusing and instructive index it calls the Big Mac index to compare prices around the world. For example, an average American would have to work for around ten minutes to buy a hamburger, while a Kenyan would have to work for three hours. We can use this novel way of looking at things to think about production and consumption.

Most of us wouldn't mind working 10 or 15 minutes to buy a hamburger. But what if you had to find the 2 400 litres of water needed to make it? You are probably familiar with the idea of carbon footprints – the amount of CO_2 generated by various activities such as travel. The water footprint is a similar figure calculated for the use of fresh water. It is based on the idea of "virtual water". A tee-shirt for example contains no water, but it takes 11 000 litres on average to produce a kilogram of the cotton it's made of, once you include irrigation, bleaching, dyeing and all the other steps in

DRINK MORE BEER?

Water footprint (L)



The water footprint of an individual is the total water used for the production of the goods and services he or she consumes.

Some products you might think are similar to each other show surprising variations. A cup of tea "costs" 30 litres of water for instance, while coffee costs 140 and fruit juice 190.

You could argue that drinking beer is the righteous path for the concerned citizen since a 250 ml glass will only set the planet back 75 litres of water. But as pointed out above, the water footprint includes the whole production chain, and the can, bottle or barrel has to be included, too. The global average water footprint of industrial products is 80 litres per dollar of value added, but this varies widely, *e.g.* 10 to 15 litres for Japan, Australia and Canada; 20 to 25 for India and China; and 50 for Germany and the Netherlands.

The water footprint of a nation includes that part of the footprint that falls inside the country (internal footprint) and the part due to using water in other countries (external footprint). The global average per person is about 1 250 m^3 a year, half the value of the biggest per capita consumer, the US. For China, it is 700 m^3 of which only about 7% is outside the country. Japan, with a footprint of 1 150 m^3, has about 65% of its total water footprint abroad.

the production chain. Virtual water is therefore the total amount used to make a product, adding up to 2 700 litres for a shirt. Unlike the fuel that produces CO_2 though, water is rarely sold at a price to the main users that takes into account all the costs incurred. Often the costs of providing infrastructure, purification, waste treatment and distribution are subsidised, so there is less incentive to use water sustainably.

What's the real price and who pays?

Economists use the term externalities to describe the positive and negative aspects not accounted for directly in prices. Bees are often cited as a typical positive externality. The beekeeper raises them to be able to sell honey, but they pollinate all the plants in the area, providing a benefit to farmers and gardeners. Pollution from factories is a typical negative externality where the cost to public health is not included in the productions costs the polluters pay. Getting the price right means getting closer to the "real" price – and this requires factoring in what the production and the consumption of something will generate in terms of externalities.

Assigning a value to things that previously fell outside systems of accounting, budgeting and measurement is a major challenge. It is not easy, for example, to assign a value to natural resources. For some, such as forests, we can calculate the value of what is produced because it is bought and sold and therefore has a monetary value. Still, knowing the price of wood – and therefore knowing something about what a forest is worth monetarily – doesn't tell us anything about its value in offsetting CO_2 emissions, its role in preserving biodiversity or its spiritual and cultural value to people whose way of life depends on it. Assigning a value to clean air is harder still. Air pollution generates costs in the form of increased rates of disease, lower real estate values in "dirty" areas, and current and future damages related to climate change. Clean air is worth something to us, but can we say how much exactly? The "ecological services" concept sees that putting a price on these services is a useful way for them to be valued – getting the "real cost" of resource consumption into the equation.

In the meantime, nearly two-thirds of the services provided by nature to humankind were found to be in decline worldwide by the UN's Millennium Ecosystem Assessment. The UN points out that the costs may be borne by people far away from those enjoying the benefits, as when shrimp eaten in Europe is farmed in a South Asian pond built in place of mangrove swamps – weakening a natural barrier to the sea and making coastal communities more vulnerable.

Current trends in global production and consumption patterns are unlikely to change significantly, meaning that externalities will increase. Goods are becoming cheaper and are being transported in ever-bigger amounts from one side of the world to the other. Even a simple pot of yoghurt may have travelled over 3 000 km by the time it reaches the table and require inputs from several countries for its ingredients, production and packaging. We replace goods much more quickly than in the past. Few people still use an MP3 player they bought five years ago, for instance, but an old gramophone would have lasted for decades. And unlike our grandparents' generation, we throw out rather than repair everything from vacuum cleaners to socks.

Corporate social responsibility

The idea behind corporate social responsibility – that corporations have an obligation to consider the impact of their activities on the environment, economy and society – is not exactly new. How companies treat their employees and what kinds of products they submit to their customers has been the topic of debate for centuries.

In its contemporary version, corporate social responsibility can encompass everything from service to shareholders, community, governance, diversity, employees, environment, and human rights. A big part is reporting – letting the public and shareholders know about what the companies are doing to fulfil their role as corporate citizens. This is also a way for corporations to communicate their "good deeds" for public relations purposes. Third-party organisations also produce "report cards" rating corporations on the different aspects of social responsibility.

The benefits of increased corporate responsibility are clear, but there may also be more ambiguous issues.
Corporate power may also increase along with responsibility. Corporate social responsibility allows companies to publicise their good actions but can also obscure unsustainable practices in other areas, especially in the case of multinationals with complex supply chains and subcontractors that may or may not be following company guidelines. The problem with corporate social responsibility, as promoted in the OECD Guidelines for Multinational Enterprises, is that it is voluntary. In some cases, corporations are out in front of governments in terms of addressing climate change and other problems. But the time is coming when companies will be required by governments to fulfil their environmental and social obligations both at home and abroad in the interest of sustainable development.
www.oecd.org/daf/investment/cr.

Technology might reduce some of the negative impacts on sustainability of production and consumption but it will create others, and technological improvements are often outpaced by growth in consumption. Cars are now much more fuel-efficient than before, for instance, but air pollution is getting worse because so many more people have cars.

While market-related transactions have grown ever more efficient and many private goods such as food, cars, air-conditioning and designer clothes can, in principle, be afforded by anyone who would like them, the growing externalities of these transactions has made many "public" goods increasingly scarce: clean air, silence, clear space, clean water, splendid views, and wildlife diversity are highly valued and sought after. Nearly every transaction of private goods carries an invisible cost, paid by everyone through degraded public goods. Achieving "decoupling" between continued economic growth and prosperity and the negative externalities created by such development is therefore a major challenge for achieving "development that lasts".

What do cheap clothes really cost?

The way products are produced and consumed affects not just the environment, but also living and working conditions. Once again, looking at an everyday object can help us understand the issues. Fred Pearce, *New Scientist's* senior environment correspondent, set out to discover where the cheap pair of jeans he bought in London came from. His investigation took him to Dhaka, the capital of Bangladesh, where hundreds of thousands of women make clothes for the big brands of Europe and North America – for just under one dollar for a ten-hour day. On his blog and in the book he wrote afterwards, Pearce reports that the companies behind these brands say they insist on decent conditions for the workers. But the women point out that the sociologists who conduct the regular "social audits" of factory conditions do not learn the truth: before they come, "the managers instruct us what to say about working hours and holidays and conditions".

> **"Advancing on sustainability concerns fuller attention to the role of the workforce in helping attain the triple bottom line – maximising profits, people and the planet."**
>
> Roland Schneider, Trade Union Advisory Committee to the OECD, *Measuring Subtainable Production*

Does this sound unfair? It might come as a surprise to learn that none of the women Pearce spoke to supported boycotts of the goods they make. As he points out, they are the first women in conservative, rural Bangladesh to have any sort of freedoms beyond those allowed by their husbands in the villages. "The garments industry has created a revolution in women's economic empowerment," says Mashuda Khatun Shefali, who runs an NGO that supports women garment workers and tries to improve their conditions. Another campaigner, Nazma Akter, notes that, poor as most were, "women are becoming an economic force here. This is the first time they have had jobs. They are independent now. They can come and go; nobody stops them. Don't take that away from them."

What these women ask from consumers in the rich countries is to pay a fair price for the goods they make and not to ask them to sacrifice their health and well-being for a marginal improvement in our standard of living. Women's status, workers' rights and fairer trade are as much a part of sustainable development as protecting the environment. Making production and consumption sustainable implies recognising the true costs of what we make and what we buy, across the entire supply chain, from sourcing to retail distribution to waste disposal.

Connecting the dots

What can be done concretely to promote sustainable production and consumption? Even quite small actions can have a large cumulative impact. According to the US Environmental Protection Agency, if every home in America replaced just one incandescent light bulb with a compact fluorescent one, in one year enough energy would be saved to light more than 3 million homes and prevent greenhouse gas emissions equivalent to those of more than 800 000 cars.

Or, as the European Lamp Companies Federation calculated, if Europeans switched to the more efficient bulbs, the continent would need 27 fewer power plants. This trade association has launched an effort to encourage European consumers to switch to the energy-saving bulb. Australia, Japan and the state of California plan to implement bans on incandescents, seeing the need for government to step in and make the switch more rapid and definitive. The European Commission is talking about a phase-out, too.

Most successful efforts at influencing markets involve co-ordinated efforts – where producers, consumers and governments each have a role to play. Only through the combination of these efforts can old behaviours and processes be transformed on a large enough scale to make sustainable development the rule rather than the exception.

Co-ordinating our efforts

How can producers integrate sustainability into product design, manufacture and distribution without sacrificing traditional factors such as profit or brand image? We can't really be sustainable consumers without sustainable product choices.

Design is arguably the most influential single stage in the process, since it determines the rest. First of all, the design has to consider the product as part of a product system and consumer lifestyle. If a phone integrates a camera and an MP3 player, will users then buy only the phone, saving the environmental and other costs of manufacturing three separate products? Or will they also buy the others, adding

Read this and save over €500 year!

An argument commonly heard against sustainable development is that whatever benefits it brings, it costs too much and would somehow reduce our standard of living. In fact, the opposite can be true.

Energy-saving technologies can save you money, although the savings tend to be in the long run and require the initial investment such as in a fuel pump, improved windows or a hybrid car. On the other hand, unsustainable consumption can cost an astonishing amount, although we may not be aware of just how much. For example, people living in Britain throw away around a third of the food they buy. Most of it (4.1 million tons a year) could have been eaten. The most common reason for food being wasted is that it's simply isn't eaten – 61% of the avoidable food waste or 2.5 million tons. Of this, almost 1 million tons isn't even touched, and at least a tenth – 340000 tonnes – hasn't passed its "use by" date. Cooking and preparing too much results in an additional 1.6 million tons of food waste a year.

It costs UK local authorities £1 billion (around €1.3 billion) to collect and send most of this wasted food to landfill. Stopping the waste of good food could avoid 18 million tons of CO_2 being emitted each year, the equivalent of taking one in five cars off the road.

And the 500+ we said you'd save? Uneaten food costs people in the UK £10 billion every year, that's an average of £420 per household, or over €500 you could save by better planning, storage and management.

See "The food we waste" at *www.wrap.org.uk*.

to the burden? Design also means choosing the materials from which the product will be made. Can the product be designed in such a way as to maintain the required physical properties while using fewer materials? Could it be made of renewable, recyclable materials? Design also influences manufacturing by determining the number of steps in the production process.

> **"In order to incorporate sustainability management, companies need to work in partnership with other organizations and groups, which have an interest in the company's activities and their economic, social and environmental impacts."**
> Rajesh Kumar Singh, Bhilai Steel, India, *Measuring Subtainable Production*

Questions specific to manufacturing can involve how to reduce energy consumption or pollution, or how to improve worker safety. Once the product is made, what is the most sustainable way to package it for shipping and sale? Should it be transported by air, sea or land, by rail or truck?

Design and manufacturing play a big part in determining how long something will last, how many other products it will need to work (*e.g.* batteries) and if it can be repaired or maintained. And finally, producers also have to think about what happens to the product at the end of its cycle. Once again, good design can make a difference. Are the materials used easy and safe to recycle for example? Can parts of the product be refurbished and reused?

Is the customer always right?

Think of your first major purchase – maybe your first bike or a car. Think of all the factors that went into that decision. Cost was probably one of them but so were colour, texture, brand, and a whole host of aesthetic and emotional associations that attract us to the objects we buy. Businesses spend a lot of money on market research and advertising (over $650 billion a year worldwide on marketing alone), trying to understand those associations, to be able to predict and influence people's tastes and preferences.

At first glance, the pervasive influence of marketing and the push to consume seems to be at odds with sustainable consumption after all, unchecked consumption has played a big part in creating many of the problems we currently face. And yet, if we don't know of a less-polluting product for cleaning the kitchen sink or the difference in energy use for an appliance, then we can't make a better decision. Including a sustainability dimension in marketing and distribution allows us to add another, very important criterion to purchasing decisions. It provides information to consumers and is of course a means to influence them in a "sustainable" direction.

Experience of the past decades has shown that providing sustainable products to the niche market of "green" or "fairtrade" consumers is not enough to change patterns on a larger scale, although it has been a significant factor in pushing both producers and consumers in a new direction. The proliferation of eco and fairtrade labels in the last ten years is evidence of that evolution. For a long time, products such as organics and fairtrade suffered from their reputation as "specialty" items, attractive only to a small category of consumers willing to pay extra to consume according to their beliefs. But this trend has started to change, for several reasons.

For one, more people are aware of the impact that their choices have on the world around them. Problems related to unsustainable consumption – the cost of petrol, for example – have become more "real" and have begun to touch the average consumer in more concrete ways. As a result, a growing number of consumers are beginning to ask important questions about what they buy; how much waste is created by the product and its packaging; how much water, energy and other resources go into its production (and into

Fairtrade

In 2008, the OECD staff canteen announced that all its hot beverages would come exclusively from Fairtrade sources. The Fairtrade Labelling Organisations (FLO) are seeking sustainable development through trade, giving small farmers and workers in poor countries a "living wage" for their products. The question is why consumers – rather than governments or large firms – are driving the movement to sustainable trade. Consumers are demanding that imported goods are produced in a way that is environmentally and socially sustainable.

The Fairtrade network now reaches 58 developing countries and 1.4 million famers, who are guaranteed a minimum price, a long-term contract and premiums to put towards community development projects. Production must follow certain social standards (worker rights) and environmental standards. In some European countries, Fairtrade now has 20% of the coffee market and over 50% of banana sales. According to its founders, "*Fairtrade is not only about social and environmentally friendly production methods, but about the empowerment and development of producers.*"

its disposal); and what are the living and working conditions of the people who produce the goods.

Second, the products themselves have become more mainstream. A wide range of companies are using the tools of marketing to give products and services considered sustainable a cool or sexy identity. Manufacturers are designing more products that are appealing for their aesthetic qualities or their ease of use *as well as* for their environmental and social sustainability – a look at the latest fuel-efficient car designs provides a good example. Most major retail grocery chains now offer a selection of certified "environmentally friendly" products whose market shares are increasing: for instance organic coffee imports to North America grew by 29% over 2006-2007 compared with 2% for conventional coffee.

The changes in consumer awareness and the proliferation of more sustainable products and services seen over the past few years are encouraging. Some critics and consumer advocates rightly point out that some of this is "fluff" or "greenwashing". Products that claim to be environmentally friendly can look much less so once you take a hard look at the list of ingredients or analyse the entire product life cycle. Buying fairtrade coffee cannot alone solve the problem of poverty. While this may be true, it doesn't detract from the fact that sustainable consumption and production are critical to the success of any kind of sustainable development. The fact that more people and businesses recognise and even wish to capitalise on this realisation can be seen as testament to the growing mass appeal of sustainability. Efforts at making the consumer society sustainable are gaining momentum.

What's the government doing about it?

Finding the right policy tools to encourage good production and consumption practices and avoid overlap and inconsistency is one of the biggest challenges that governments face. Elected officials are under pressure from constituents and special interest groups to respond to issues perceived as important and follow a given line of action. For one, decisions must be based on thorough research and sound evidence, or they risk not solving the problems at all and often create additional ones. Governments have the enormous advantage however of being able to make laws and impose regulations. One solution at their disposal is simply to outlaw products and behaviours that are seen to be doing more harm than good. This is what happened to CFCs (gases used in refrigerators and aerosol sprays) that were damaging the ozone layer. The *Montreal Protocol on Substances that Deplete the Ozone Layer* came into force in 1989, and 191 countries have now signed it. Since then, atmospheric concentrations of the most important CFCs and other related gases have either levelled off or decreased. The plastic shopping bag is another example. Bangladesh banned them in 2002 following a movement that began in the 1980s in Dhaka. Discarded bags were blocking drains during the monsoon, causing flooding.

Critics of such plans point out that packaging is a much bigger source of waste than plastic bags. Retailers should be using their buying power to influence packaging choices from their suppliers and governments should be using their regulatory powers, rather than passing off the responsibility for reducing waste to consumers alone. This kind of argument is heard often in discussions around sustainable development: who is primarily responsible for changing bad practices? Where is the best place to focus our efforts? One might counter that, in the above case, why not do it all? Encourage customers to reduce needless use of plastic bags by charging for them, a measure that has shown consistent results. At the same time, encourage retailers to use their influence to reduce packaging and to implement any other measures to curb resource use and waste. And develop government standards for sustainable and recyclable packaging. The town of Modbury in England shows what could be done. The town became the first in Europe to ban plastic bags after shopkeepers agreed to the move following a few weeks campaigning initiated by Rebecca Hosking in the pub one evening. And as she explained to the *Guardian* newspaper, Modbury is a town "… that's always been very conservative. If we've done it, it proves you don't have to be one of those 'green' towns to change over."

The fact is that often, although we might see what would help, changing things is a different story. As former UK Environment minister Margaret Beckett points out, "*Many unsustainable behaviours are locked-in and made 'normal', not just by the way that we produce and consume, but by the absence of easy alternatives*". Creating those alternatives is thus a priority, one that can benefit from the force of government intervention. The European Union launched an Integrated Product Policy pilot project involving mobile phone producers, component manufacturers, telecoms operators, consumer groups, recyclers, NGOs, government representatives and researchers. A number of governments are making efforts to promote recycling through initiatives such as France's "éco-participation", a surcharge on electronics goods of €0.52 per kilo that goes towards paying recycling costs.

As the CFC example suggests, persuading producers and consumers to change is not always the most efficient way to tackle the issues, nor is it enough to produce a big enough change on a large enough scale. The individual producer or consumer generally has little power to change things or interest in doing so. A manufacturer who decided to go it alone and implement stricter environmental standards or much better pay and working conditions than competitors would be at a considerable disadvantage. People have a hard time reducing their consumption even of products they know are damaging their own health or adopting behaviours that would improve it. Although consciousness about sustainability is improving, waiting for a change of attitude is not the best policy.

Powerful persuaders

Governments have powerful persuaders at their disposal: regulations and taxes. These have long been applied to economic and social policy. Can they work for sustainable development? The answer is yes. Governments originally tried persuasion and communications campaigns to get consumers to use less energy in their homes. They worked with producers to put labels on appliances indicating their relative energy consumption. In the end, they enacted minimum energy efficiency standards, which forced companies to change the design of their products. Although consumers can have some influence, regulating processes and products is the fastest way to sustainable production.

Experience also shows that environmentally related taxes ("green" or "ecotaxes") and emissions trading can be efficient instruments. They can force polluters (whether producers or consumers) to take into account the costs of pollution and can help to reduce the demand for harmful products. Ireland's 2002 "plastax" led to a 90% reduction in the use of plastic bags.

The 1990 the United States Clean Air Act pioneered emissions trading. It included a requirement for a major reduction in sulphur dioxide (SO_2) and nitrogen oxides by 2010. Each polluter had the “right” to emit a certain quantity of SO_2. If they managed to emit less they could keep their permit or sell it; if they emitted more they had to buy quotas from another polluter (or pay a fine greater than the cost of the quota). By controlling the number of quotas allotted, the Environmental Protection Agency has already brought emissions down 50%. Other countries have since started emissions trading schemes.

All OECD member countries now apply several environmentally related taxes (375 in all plus around 250 environmentally related fees and charges). The taxes raise revenues of about 2% to 2.5% of GDP, with 90% of this revenue from taxes on motor vehicle fuels and motor vehicles.

The environmental effectiveness and economic efficiency of green taxes could be improved if existing exemptions and other special provisions were scaled back or if the rates were made highly dissuasive. The rise in fuel prices shows that cost can be a big factor in changing behaviour, but the level of carbon taxes is generally too low to make it worthwhile for manufacturers to change production methods. Moreover, higher tax rates can face political opposition for two reasons. First is the fear of reduced international competitiveness in the most polluting sectors of the economy. This is why the taxes are levied almost exclusively on households and the transport sector, leaving energy-intensive industries totally or partially exempt. Second, exemptions create inefficiencies in pollution abatement and are contrary to the OECD’s “polluter pays” principle.

Another point to bear in mind is that, in practice, environmentally related taxes are seldom used in complete isolation. A labelling system for instance can help increase the effectiveness of a tax by providing better information to the users. Combining a tax on energy use with subsidies or government standards for better isolation of buildings can be a good way to encourage energy savings. The combination of a tax and a voluntary approach can increase the political acceptability of the tax, although this may reduce environmental effectiveness or increase the economic burdens placed on other groups.

What's next?

Seeing, calculating and understanding exactly what we buy, use and waste is just a beginning. It's an important first step in gaining awareness, but it would be unfortunate and ineffective if tools like the footprint are used only as gadgets. Realising that it takes x amount of water or oil to make a given thing has to lead us to at least two questions:

- How could we develop more efficient processes that are implemented on a large scale – in order to significantly reduce resource use and the negative impacts of production?
- How should we use the role of "informed consumers" to make sustainable consumption decisions on a scale that produces real results?

As we said at the beginning of this chapter, production and consumption are at the heart of sustainability. From a material point of view, life today is far better than it was a century ago for most people. If the improvement is to continue and benefit the world's population as a whole, the economic, social and environmental pillars of sustainability will have to be reconciled. This will not be easy. Sometimes what might favour one pillar will damage another. Different social groups will have different priorities and projects. But debating these differences and finding solutions is not beyond us, in fact it's what democracy does. This will be discussed in the final chapter which looks at how governments, civil society and business could work together in creating the incentives, rules and regulations that make sustainable development possible.

Find Out More

... FROM OECD

On the Internet

For a general introduction to OECD work on sustainable production and consumption, visit *www.oecd.org/sustainabledevelopment* and *www.oecd.org/env/cpe*.

Publications

Measuring Sustainable Production (2008): Most people support sustainable development without knowing what it is. What exactly are sustainable consumption and sustainable production, and how are these practices identified? This book reviews the state-of-the-art in measuring sustainable production processes in industry. It includes types of measurement developed by business, trade unions, academics and NGOs, as well as by the OECD and International Energy Agency.

The Political Economy of Environmentally Related Taxes (2006): Environmentally related taxes are increasingly used in OECD countries, and there is ample and increasing evidence of their effectiveness. However, there is a high potential for wider use, provided that they are well designed and that their potential impact on international competitiveness and income distribution are properly addressed. Based on experience in OECD countries, this book provides a comprehensive discussion of the issues and of research on the environmental and economic impacts of applying environmentally related taxes.

OECD Guidelines for Multinational Enterprises, Revision 2000
The *OECD Guidelines for Multinational Enterprises* were adopted by OECD member governments plus Argentina, Brazil and Chile in June 2000. This booklet comprises the revised text and commentary, implementation procedures and the Declaration on International Investment and Multinational Enterprises.

Also of interest

Promoting Sustainable Consumption: Good Practices in OECD Countries (2008): This report highlights OECD government initiatives to promote sustainable consumption, with an emphasis on individual policy tools and instruments and their effective combination. *www.oecd.org/sustainabledevelopment.*

... OTHER SOURCES

UN Millennium Ecosystem Assessment (*www.millenniumassessment.org*): This report assesses the consequences of ecosystem change for human well-being. It provides a scientific appraisal of the condition and trends in the world's ecosystems as well as the basis for action to conserve and use them sustainably.

Toxic Tech: Not in Our backyard, Greenpeace 2008: (*www.greenpeace.org*): This report investigates the global sales of electrical and electronic products and assesses the amount of resulting waste.

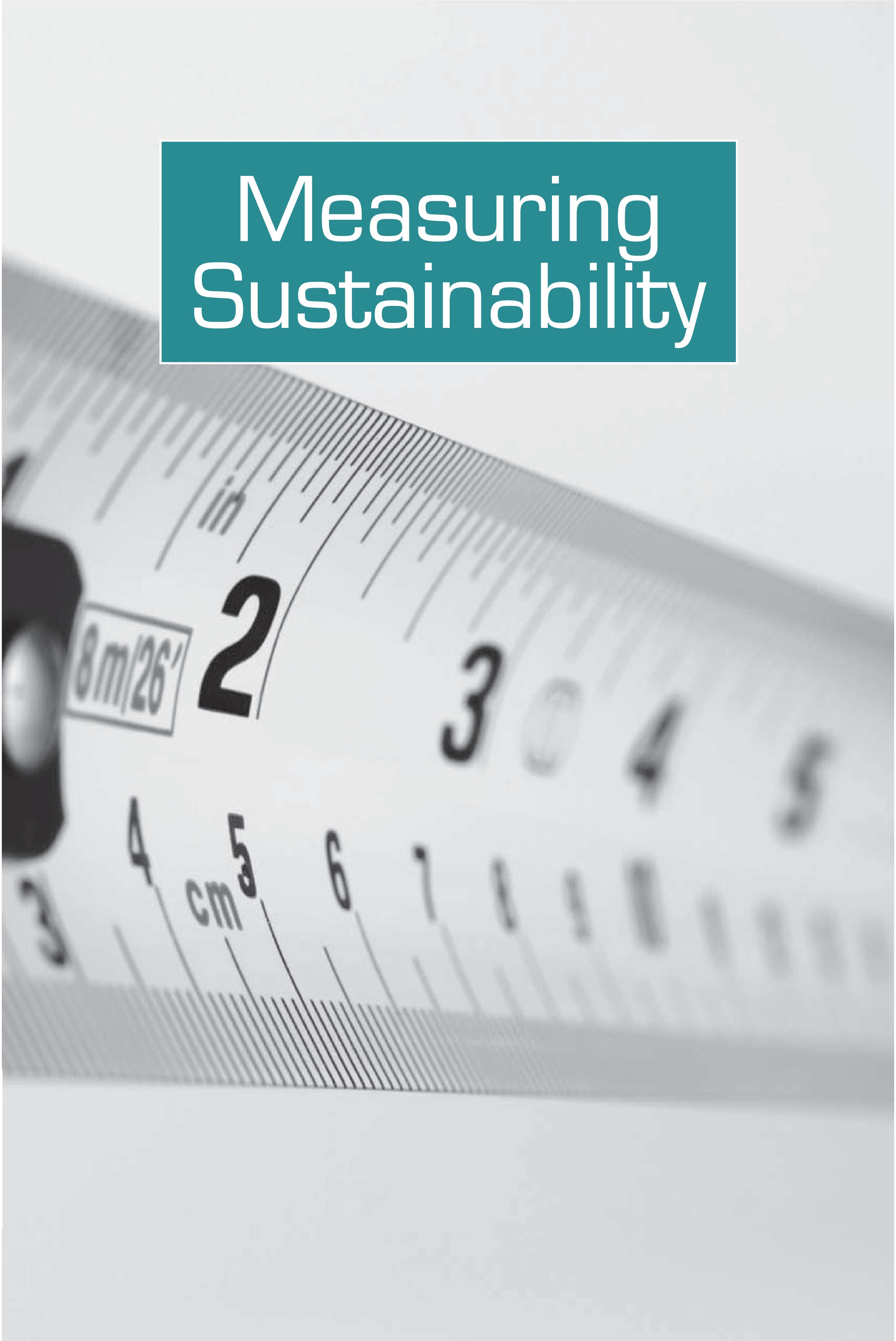
The Water Footprint (*www.waterfootprint.org*): This website is maintained by the University of Twente in collaboration with the UNESCO-IHE Institute for Water Education, the Netherlands.

The Food we Waste (*www.wrap.org.uk*): The Waste & Resources Action Programme is working to ensure that the UK reduces waste and recycles as much as possible at minimum net cost.

6

Meeting today's and tomorrow's needs requires knowing what we have, what we consume, what will remain and what can be regenerated or replaced. Accurate measurements and accounting of our natural, social and economic capital are essential to moving forward on a sustainable path.

Measuring Sustainability



By way of introduction…

The previous pages explored what sustainable development means and how contemporary societies are trying to implement it. But how do we know if what we're doing is helping or hurting, or having no effect at all? How do we know that one way of doing or making things is more sustainable than another? That a city, region or country is doing well in terms of sustainable development? How do we calculate today's needs and measure our progress in meeting them? And how can we get some idea of how our decisions will affect the future our own and our children's? To be able to answer these questions, we have to decide first on the basics. What is important to us? What resources do we need to keep track of? What are the different factors that contribute to our quality of life and well-being?

We often have to do this kind of calculation in our daily lives. We know how much money we have and how much we need to buy food and pay the bills. We know, albeit imperfectly, what expenses we'll have to meet later, and we know that there will probably be some unexpected ones, too. We know what we'd like to do and if there is something left over we can spend it on dinner and a movie, clothes or maybe even a holiday. All this depends on counting, planning and reasonable guesses. It is based on measuring our "resources" and following what happens to them, establishing priorities among all the things we have to do and those we'd like to do, sometimes leading to difficult choices. To put it another way, we all have an information system (however informal) to let us see how we're doing just now, make predictions about what we will be able to do in the future, and monitor whether or not we are living within our means.

What makes a good and sustainable society and how can we judge our progress towards creating one? It's more than money, to be sure. The answer lies in a range of factors that make significant, often essential contributions to our "success" from access to education, health care and functioning ecosystems to freedom, justice and cultural expression. Developing and refining accurate measures of these things will allow us to build a more sophisticated and stronger knowledge base, and potentially to speed up progress towards achieving them.

What problems can we not afford to ignore? Like the inhabitants of Rapa Nui mentioned in the first chapter, we depend on systems that are vulnerable to natural and human pressures and linked by a complex web of interactions. Ignorance of the facts critical to our progress, well-being and survival puts us too at risk of encountering undesirable changes that could prove irreversible. The debate continues on the best way of measuring sustainable development in order to provide more precise accounting of whether or not our policies and practices are assuring our longer-term well-being.

▶ This chapter looks at the different tools and criteria used to assess sustainability and how they are combined to provide information on the issues, trends and interactions that determine whether a given situation meets our expectations and what can be done to improve it. It explores which indicators to use to measure sustainable development and how to combine and present them.

Measuring sustainability: what should we count and when?

Agreeing on the best indicators to measure sustainability or progress towards sustainable development is a challenge. An indicator is a summary measure that provides information on the state of, or change in, a system. Indicators give us a snapshot of how we are doing at a given point in time relative to what we've decided is important. Indicators also provide feedback on the effects of our actions and government policies. And indicators have to be able to adapt to the changing conditions and the content of policy.

At first sight, measuring sustainable development seems impossible, the subject is so vast and the influences so many – climate change and child care, business ethics, government policy and consumer trends to name but a few. We know that sustainable development involves economic, social and environmental variables – all of which must be measured to some extent. As shown in the annual *OECD Factbook*, there exist a wealth of indicators from traditional macroeconomic measures, such as gross national product (GNP) and productivity, to environmental indicators, such as water consumption and polluting emissions, and social statistics, such as life expectancy and educational attainment. But which indicators are the most important to sustainable development?

The issue is made even more difficult by the fact that as well as being multidimensional, sustainable development is a dynamic concept. Quantifying it requires juggling a number of parameters including time horizons. Economic, social and environmental phenomena operate at different rhythms to each other (and even within any one of these, several time scales may be operating simultaneously). For instance, the legal systems of most countries are still strongly marked by codes dating from the time of Augustus and the Roman Empire, and their basic principles change slowly. Some technologies, on the other hand, change at a rapid pace your new computer is probably out of date before it's out of the box.

Consider the economy: if you're planning a major energy project, you have to think at least 50 years ahead, but if you're trading on financial markets, the nanoseconds it takes price data to go from one exchange to another can mean substantial gains or losses. For its part, the environment shows how the pace of change can suddenly accelerate, as when fish stocks rapidly disappear after declining slowly for years.

Moreover, we have to bear in mind that sustainable development is a process linking what happened in the past to what we're doing now, which in turn influences the options and outcomes of the future. In a sense, it's like walking along a path backwards – you can see where you've come from, you can see more or less where you are, and you can get a rough idea of where you're heading. But you can't tell if the other paths branching off from your route are dead ends, short cuts or ultimately heading in a completely new direction. Likewise, it's difficult, if not impossible, to say if any given point along the development path is sustainable, it may be more or less so depending on how far we've come, what happens next, which new perspectives open up, and how attitudes and other influences change.

These uncertainties complicate sustainable development measurement. And developing measures is not a purely statistical or technical exercise. It touches on two very sensitive areas for all societies: government accountability and social participation. Measuring progress on sustainable development (or any other important area of policy) with reliable information is a key ingredient of the democratic process. It makes governments more accountable and gives people a tool to participate more actively in defining and assessing policy goals.

Measuring progress

> **"By measuring progress, we foster progress."**
> Enrico Giovannini, OECD Chief Statistician

Progress has long been defined and measured in purely economic terms. A country's overall performance or well-being is often expressed in a kind of shorthand fashion through one "superstar" measure: gross domestic product. GDP calculates in monetary terms the value of what counts as production. You may also be familiar with GDP per capita, how much each person in the country would have if everybody got an equal share of GDP. While these measurements may sound fairly straightforward, they omit important factors and include others that we would probably rather live without.

For instance, software that is sold goes into the calculation, but freeware does not. On the other hand, spending on cleaning up an oil spill is included in GDP. In this case, not only is something negative being counted as contribution to "production", but substantial costs to well-being are left out of the equation and remain invisible. Housework, caring for one's children and volunteer work are not counted, though they contribute value to the economy and our daily lives. Per capita GDP is a fairly crude measure, too. As an average, it does not address issues of distribution benefits of economic productivity may go disproportionately to only a small percentage of a population, even though the average looks good.

Such indicators are useful for giving a rough idea of what's happening in the economy and comparing national performance. But there is a large and growing gap between what official statistics, like GDP, tell us about "progress" and what people experience and care about in their daily lives purchasing power, public services, quality of life and so on. The notion that the three pillars of sustainable development should be considered equally important, interconnected and interdependent reflects the idea that economic progress alone is not enough to guarantee that a society is "headed in the right direction". Other factors, such as access to good health care and education, can be equally or more important to creating well-being, life satisfaction and health over the long term, both for the current and the future generations.

> **"We cannot face the challenges of the future with the tools of the past."**
>
> José Manuel Barroso, European Commission President
> at the international conference on Beyond GDP:
> Measuring progress, true wealth and the well-being of nations,
> 19-20 November 2007

Individual calculations can help us gain awareness of the progress we are making in terms of income or health for example. But if these calculations don't fit within some kind of framework that structures the analysis, we can't get any sense of how we are doing or where we are headed. We need something that allows us to understand the big picture emerging from the data and use it as the basis for policy and action. A conceptual framework can help us select those indicators which best measure what we want to assess in a coherent and consistent manner. It will also help compare sustainability across different societal levels.

Finding ways to make comparisons between countries or regions who may not share the same history, culture, level of economic and social development or physical conditions is a challenge. Reaching this goal requires an ongoing dialogue on needs, resources and how they are evolving, as well as a flexible approach to building sets of indicators that can supply the most useful evidence and information. Individual indicators are the basic building blocks of this process.

The task is complicated further by the fact that what is considered important to sustainability varies to some degree from place to place the quality of water, land or air; people's income or access to energy; life expectancy or any number of other indicators. How then do we develop methods for measurement that reflect a particular context or geography and also allow us to work across institutions and geographical boundaries to advance sustainability worldwide?

A range of indicators can be used to compare the relative situations of countries, assess their strengths and weaknesses and identify domains where policy intervention is required. It would be much easier to have one list of indicators for everyone, allowing quick comparisons among different places and across time, but this is not so simple: what matters in California is not an exact match to what matters in Helsinki or Bangalore.

And yet, common indicators are needed if countries or localities want to compare their progress on sustainable development with others. From this, they can learn what works and what doesn't work. This is why, as measurement of sustainable development has evolved, many local, national and supra-national bodies such as the United Nations and the European Union have developed and refined sets of indicators. Along with international organisations and NGOs, they have put considerable effort into discussing and tuning their indicator sets to improve measurement of sustainable development and allow comparisons among countries or other levels of administration.

The Capital Approach

The key idea of sustainable development is the linkage between the well-being of the current generation and the well-being of future generations. To make this connection we can use the concept of capital. In economic terms, capital is a stock that is used in production over several years: think of a machine or a factory. Capital can be created by investment, and it is consumed over years and eventually wears out. The concept of capital can also be applied to sustainability, allowing us to measure all types of wealth that contribute to well-being more comprehensively. Economists use the concept of *national wealth* to indicate this broader measure.

The "Capital Approach" is a framework for measuring sustainable development which operates on the principle that sustaining well-being over time requires ensuring that we replace or conserve wealth in its different components. It emphasises the need to focus on the long-term determinants of development not to the exclusion of current needs, but rather according to a principle of sustainability: development that can be continued into the future. This approach allows us to discuss and evaluate how what we do now will work in the very near, medium and long-term, and how to talk about whether or not there is "progress", "regression" or "stagnation".

With this model, a society's total capital base encompasses five individual types:

- *financial capital* like stocks, bonds and currency deposits;
- *produced capital* like machinery, buildings, telecommunications and other types of infrastructure;

- *natural capital* in the form of natural resources, land and ecosystems providing services like waste absorption;
- *human capital* in the form of an educated and healthy workforce;
- *social capital* in the form of social networks and institutions.

Conceiving these different forms of capital as inputs into the production of well-being allows us to calculate national wealth as the sum of the different kinds of capital.

Sustainable development requires making sure that national wealth per capita does not decline over time and, when possible, that it increases. For example, if we consume all our natural capital and do nothing to preserve or increase it, this source of well-being will dry up, leading to unsustainable outcomes. The capital approach allows monitoring that capital stocks are not "drawn down" too low. Norway's management of its petroleum stocks provides a good example. With some of the world's largest petroleum reserves, Norway could spend the profits from the sale of its petroleum on any number of programmes. Instead, Norway invests these profits to be sure that when the oil reserves are depleted, other sources of income will be in place. To put it another way, just as financiers seek to maximise their capital base and the dividends it produces, we should maximise the financial, produced, human, social and natural capital base of our welfare and make sure it continues to pay dividends in terms of well-being over time.

This sounds very straightforward, but "maximising" capital involves making important decisions about what can be used up and what must be preserved. One important question: can the different types of capital be "substituted" for each other, as long as the total sum is maintained, or does each type have to be maintained at a certain minimum level? The practical answer to this question is that it depends on circumstances. In most circumstances, some specific categories of "critical capital" will be essential to the proper functioning of the world and our societies, things which perform essential functions and can be replaced at the margin only at huge costs.

A liveable climate is perhaps the most striking example it doesn't much matter what our national wealth adds up to, if climate change makes life on Earth or in certain parts of it impossible. Although environmental types of essential natural capital are the

Using technology to make architecture more sustainable

As we try to follow the model of sustainable development, among the first targets are the spaces in which we live and work. After all, what indicates human "development" more than the buildings and cities we construct? The 20th century saw several revolutions in architecture, with focuses ranging from aesthetic to productive to ecological. The role of technology has not been entirely positive, as the use of asbestos insulation shows.

In recent years, the movement towards more environmentally-friendly architecture, popularly called "Green Building", has grown significantly. In the US, this effort has been spearheaded by the Leadership in Energy and Environmental Design, or LEED, programme. LEED certifies new and renovated building projects on a scale up to "platinum", depending how many environmental "points" the project earns. Up to 70 points are awarded for aspects ranging from use of renewable energy and recycled materials to how close the site is to public transportation.

Experience now shows that prioritising the environment carries over to the social and economic pillars: the benefits of natural lighting on worker satisfaction and productivity are well-established; avoiding paints and glues with aggressive solvents improves worker health, thereby reducing sick days. Financially, the higher initial investment pays for itself in energy savings, increased leasing rates and longer building life.

In many European countries, stricter energy efficiency standards, in some cases accompanied by subsidies, are expanding the market for sustainable technologies. Such technologies then become mainstream among contractors and more affordable. Average electricity use per building is 30% lower in Germany than the US.

In the UK, a nation-wide initiative to make schools more sustainable is encouraging not just curriculum changes but innovative architecture. The most ambitious project to date is a primary school in Hertfordshire, where traditional environmental features like green roofs and rainwater re-use are accompanied by a state-of-the-art heat capture system under the playground that provides warm water in winter. In addition to the environmental benefits, students work and play in a healthier and more stimulating environment, carrying out experiments with insects from the sedum roof and studying the full life cycle of recycling with their own furniture.

The OECD Programme on Educational Building (PEB) promotes the exchange and analysis of policy, research and experience in all matters related to educational building. The PEB's goals are to improve the quality and suitability of educational buildings; ensure that the best use is made of the resources devoted to planning, building, running and maintaining educational buildings; and give early warning of the impact on educational building of trends in education and in society as a whole.

Source:

OECD Programme on Educational Building, *www.oecd.org/edu/facilities*.

Ouroussoff, N. (2007), "Why are they greener than we are?", *New York Times Magazine*, 20 May 2007, *www.nytimes.com*.

Sustainable Schools, *www.teachernet.gov.uk/sustainableschools*.

United States Green Building Council, *www.usgbc.org*.

Walker, E. (2008), "Too cool for school: Britain's most Eco-friendly building", *The Independent*, 10 April 2008, *www.independent.co.uk/environment/green-living*.

first to come to mind, aspects of social and human capital can also be critical. When the social networks and norms that are a basis for communities are depleted, societies break down, as in the case of conflict and war. Similarly, without education, human capital cannot be sustained, making overall sustainability impossible.

The global dimension

That said, many of the key issues for sustainable development are transboundary and even global, meaning they have impacts beyond political or geographical frontiers. Environmental issues such as air pollution or biodiversity loss are obvious examples, but economic and social questions are increasingly globalised too, trade or migration being the most obvious examples. Whatever measurement framework is used, it will need indicators to reflect sustainability for a variety of specific contexts and others that capture issues of global scale, such as climate change.

The WWF uses an analogy that is worth bearing in mind when trying to understand what indicators are and how they can be used. Think of a car. Dials and other displays give drivers a range of indicators as to how the car is performing, but not all of this information is relevant at any given time or for a given purpose. The oil temperature might be perfect, but if you run out of fuel the car is going to stop anyway. And bad drivers will still be a danger, no matter how many fancy gadgets are on the dashboard. Sustainability indicators are like the car's instruments, addressing individual items (energy reserves would be a direct analogy) or combining indicators across a number of domains to give a fuller picture (just as how "good" a car is depends on fuel consumption, safety, comfort, etc.).

Many companies have developed their own metrics for assessing the economic, environmental and social impacts of their facilities and products. Some are combining these into composites or simple indices, which are more likely to get the attention of CEOs. Larger corporations are also formulating ways to assess the sustainability of their supply chains of smaller companies. Ford of Europe, for instance, uses a Product Sustainability Index as a management tool to assess the potential impacts of motor vehicles on a range of factors. This is an engineering approach which combines eight indicators reflecting environmental (global warming potential,

Composite indicators

A composite indicator combines two or more individual indicators or "sub-indicators" into one number. Well-known examples include the Environmental Sustainability Index, the Ecological Footprint and the Human Development Index. Composites have the advantage of expressing complex information in a simple format, making it possible to rank factories, companies or countries in terms of their general sustainability. These simplified evaluations are very media-friendly and used somewhat like an academic grade.

From the point of view of statistical accuracy, though, composites have limitations. Composites may "compare apples and oranges", comparing things that are somehow essentially incomparable. The results or rankings depend on the way in which different indicators are weighted, leaving composites open to accusations of bias and lack of transparency.

Still, composites can give us a good idea of how a complex phenomenon, like "development" or "sustainable development", can be evaluated by looking at several important factors together. There are composites designed specifically to assess sustainability which include sub-indicators of each pillar. Other composites deal with one pillar in particular, but these are still often used in debates around sustainability. In the end, we can use composites for information function, their ability to provide an overview or summary of complex issues, and turn to other methods of measurement for more detailed analysis and decision-making.

materials use), social (mobility, capability, safety) and economic (lifecycle costs) vehicle attributes. Indicators are not aggregated into one ranking but rather tailored to the needs of various departments of the company.

Assessing sustainability

Indicators and sets of indicators are the basis for assessing progress on sustainability. Many different assessment methodologies exist, for example: regulatory impact assessments, poverty impact assessments, environmental impact assessments and strategic environmental assessments. But in these approaches, the exercise tends to focus on a particular pillar of sustainability and economic aspects tend to dominate. What we need are assessments that examine economic, environmental and social impacts and also the longer-term. In other words, we need sustainability impact assessments that can be applied to policies, programmes or agreements; to the national, regional or international levels; and to particular sectors of the economy.

Indicators and assessment tools already exist. The EU *Sustainability A-Test* site (*www.SustainabilityA-Test.net*) gives a good idea of the number of tools available. It presents 44 different types of tools for assessing sustainability classified into participatory processes, scenarios, multi-criteria analysis, cost-benefit analysis, accounting tools and models.

Whatever the methodology (indicators, models, surveys, cost-benefit analyses, cost-effectiveness studies), the procedures for conducting sustainability assessments have to be transparent and encourage the involvement of all concerned. The assessment has to be able to identify economic, environmental and social impacts but also the synergies and trade-offs across these dimensions. Different stages must be specified including a relevance test whether a sustainability assessment is even needed for the problem at hand.

Assessment results have to be presented to policy makers and others in clear and understandable terms. Even a well-designed assessment, carried out in a thorough manner, will have no influence if it neglects the political factors that impede its use. Most approaches may be too complex and too long for policy makers, while the existing bureaucracy may prefer traditional approaches rather than new assessment techniques. Moreover, sustainability assessments are often seen as an add-on rather than as an integral part of policy making. As a result, assessments may come too late with limited consideration of alternative policy options. Approaches for making better use of indicators and assessment tools are needed if we are to operationalise the concepts of sustainable development.

What constitutes the good life?

In essence, sustainable development is a means for improving our quality of life today in ways that can be maintained over time. It teaches us to value all that contributes to our well-being, even if like ecosystems their "worth" cannot be easily calculated. Our job as citizens, scientists or policy makers is to think through the best ways of including what is crucial to our existence in the balance sheet. And to make decisions that keep us out of the red.

Sustainable development has heavily influenced the debate on how we – societies and governments conceive of our role in the search for better, more balanced ways of living. In doing so, it has given new life to a conversation dating at least as far back as Plato: What constitutes the good life? And how does one go about creating it? These seemingly straightforward questions are not simple to answer. Happiness, satisfaction, well-being, welfare and wellness we use all of these concepts to express the idea of what gives life quality, of what makes it good. The questions that we pose as individuals are, in large part,those that drive the debate at the group level.

Thoroughly exploring what constitutes progress in these areas what the goals are, how far we are from reaching them, what kinds of trade-offs it will require to get there is the central task faced by citizens and governments. The tools and measures elaborated through sustainable development will continue to inform this exploration, providing a basis for the on-going work of improving the ways we govern and the ways we live.

Measurement of sustainable development helps us in two important tasks: evaluating where we are going and assessing the effects of specific policies, not only on the current generation, but also on future generations. One essential principle underlying any attempt at measurement is to understand what goes into the measurement process – what data are the most important, how they are collected, how they are compiled to provide evidence and how they can be expressed in different ways. For if we make ourselves smarter as an audience, then we can more easily select and understand the measurements we need to make good decisions, for us and for future generations.

Measuring progess in societies

Recent years have seen an explosion of interest around the world in the development of new, more comprehensive indicators of social progress. Despite the diversity of aims and approaches of these initiatives, they all seek to encourage positive social change. Yet, how can we ensure that this goal is reached? What sets of progress indicators are useful? And how are they used? We asked Kate Scrivens of the OECD's Global Project on Measuring the Progress of Societies to tell us.

What makes a successful set of progress indicators?
Successful outcomes can be defined in a number of ways. A policy change resulting from an indicator set being used in decision-making would be the most direct example. But you could also argue that media coverage of indicator data that raises public awareness is a success, too.

What is the aim of the OECD project?
Building sets of indicators requires a significant investment of time and resources. This can only be justified if you can reasonably expect there to be benefits from the exercise. Research into the circumstances under which indicator projects have been successful helps us to understand what works and what doesn't.

How are you going about it?
We're exploring the perspectives of a wide range of producers, users and advocates of progress indicators to spot common themes and best practices. We've adopted a 'before-during-after' approach, asking questions linked to distinct steps in the indicator development process.

The 'before' part examines how and why the indicator project came about. The aim here is to identify the issue that provided the initial impetus and to assess that relevant data already existed.

'During' explores three separate aspects: project design and development; the final product; and communication and application.

The 'after' questions focus on outcomes. The idea is to evaluate how outcomes measure against the stated objectives, and to try to understand the main factors contributing to success or failure of the enterprise.

What kinds of project are you actually looking at?
We decided to pick examples that provided insight into a wide variety of situations. Among other things, that meant different levels of geographic coverage, so we looked for multinational, national and sub-national projects. In line with the 'Measuring Progress' philosophy, the research focuses on indicator sets designed to give a comprehensive view of society, rather than being issue-specific.

Are any of the projects about sustainable development?
Yes, we'll look at the EU sustainable development indicators and structural indicators underpinning the Lisbon agenda for growth and innovation as examples of multinational indicators. It's generally felt that the Lisbon indicators were driven mainly by political considerations, while the sustainable development indicators were shaped by more technical expertise. It will be interesting to compare the two, and to see how indicators are developed in a regional forum, such as the EU.

To find out more, visit *www.oecd.org/progress*.

Find Out More

... FROM OECD

On the Internet

For a general introduction to OECD work on sustainable development, visit *www.oecd.org/sustainabledevelopment*.

Publications

Conducting Sustainability Assessments (2008):
This volume reviews the state of the art in assessing sustainability. It covers methodologies and tools and current practice in OECD countries, as well as the debate on quantifying and comparing diverse types of short- and long-term policy impacts.

OECD Factbook 2008: Economic, Environmental and Social Statistics
OECD Factbook 2008 presents over 100 indicators covering the economy, agriculture, education, energy, the environment, foreign aid, health and quality of life, industry, information and communications, population/labour force, trade and investment, taxation, public expenditure and R&D.

Statistics, Knowledge and Policy 2007: Measuring and Fostering the Progress of Societies
Is life getting better? Are our societies making progress? Indeed, what does "progress" mean to the world's citizens? The OECD's 2nd World Forum on Statistics, Knowledge and Policy 'Measuring and Fostering the Progress of Societies' brought together a diverse group of leaders from more than 130 countries to debate these issues.

Statistics, Knowledge and Policy: Key Indicators to Inform Decision Making (2006):
This publication discusses why indicator systems are useful and how statistics can be used, how to implement systems related to different kinds of statistics, and what systems are already in place.

Handbook on Constructing Composite Indicators: Methodology and User Guide (2008):
This Handbook is a guide for constructing and using composite indicators that compare and rank country performance in areas such as industrial competitiveness, sustainable development, globalisation and innovation.

Measuring Sustainable Development: Integrated Economic, Environmental and Social Frameworks (2004):
The papers contained in this volume address the various conceptual, measurement and statistical policy issues that arise when applying accounting frameworks to this complex problem.

Also of interest

UNECE/OECD/Eurostat Working Group on Statistics for Sustainable Development, **Report on Measuring Sustainable Development** (forthcoming 2008):
This report presents the capital framework for selecting indicators for measuring sustainable development.
www.oecd.org/sustainabledevelopment

Alternative Measures of Well-Being, an OECD Social, Employment and Migration Working Paper (2006):
This report assesses whether GDP per capita is an adequate proxy as a measure of well-being or whether other indicators used either as substitutes or as complements to GDP per capita are more suitable.
http://dx.doi.org/10.1787/71322233 2167.

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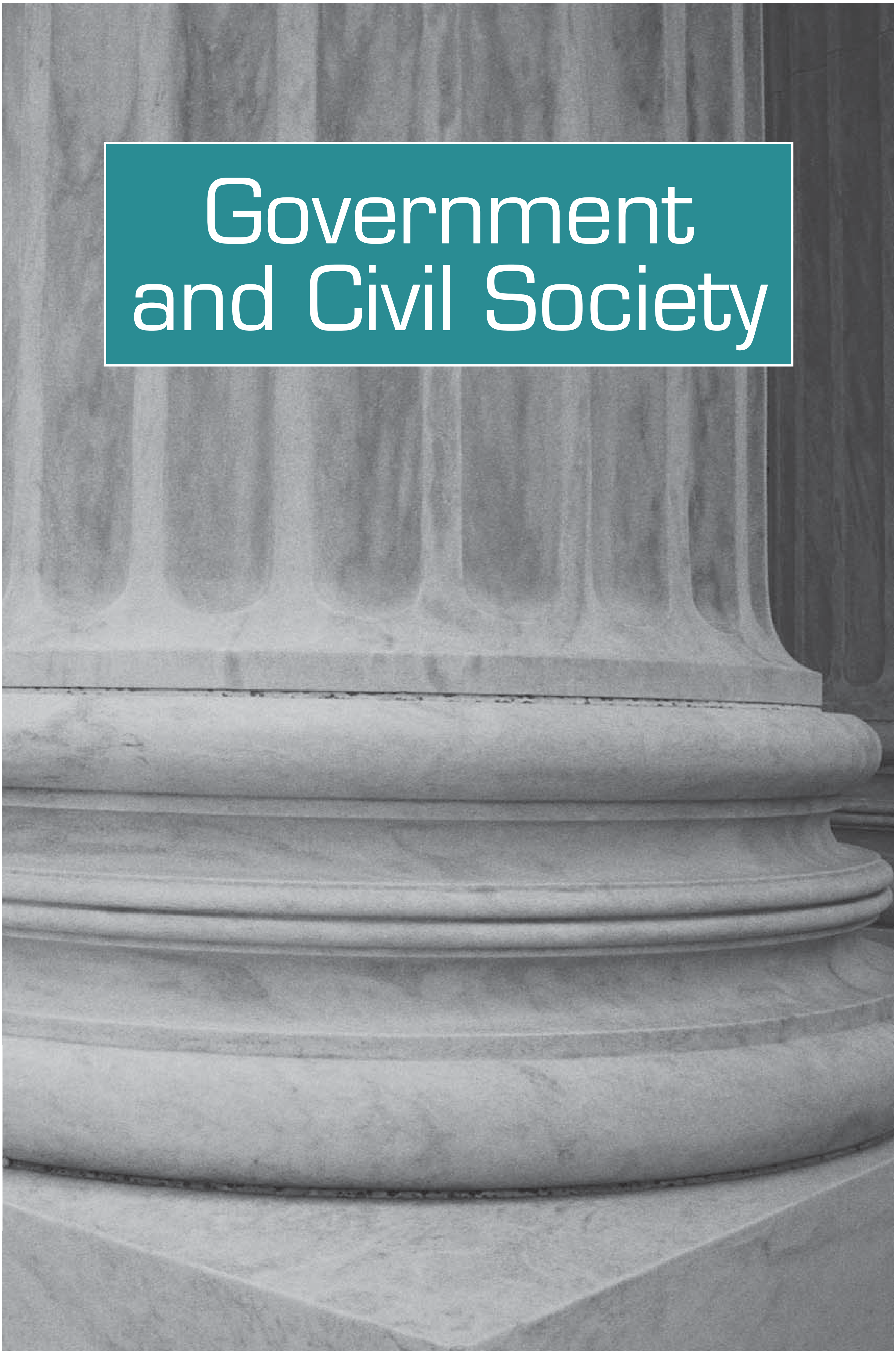
How do societies change or evolve? Whether the means to solve problems on a global scale come through technological innovation, changing consumption patterns or providing access to important services, progress depends on the complex interactions of people, businesses, NGOs and government. Learning to co-ordinate these is key to making real gains in sustainable development.

Government and Civil Society



By way of introduction…

In February 2008, rioters in Burkina-Faso took to the streets, angry at the jump in food and fuel prices over the past year. They burned petrol stations, trashed government buildings and stoned a government delegation that had come to discuss the problem. Within a few weeks, similar scenes were repeated in over 30 countries around the world, from Haiti to Somalia, Yemen to Indonesia. The world's poorest were not the only ones feeling the pinch. Italians and Mexicans were also up in arms over the cost of pasta and tortillas, whose price has considerable symbolic value. In the year leading up to the crisis, prices for many staple foods, including wheat and rice, doubled or even quadrupled. The consequences were visible to consumers on shop shelves worldwide, and the effects ranged from the plummeting popularity of governments to the riots described above.

The food crisis illustrates many of the themes we've talked about throughout this book and emphasises the need for a co-ordinated and coherent approach to sustainable development. The interaction of economic, social and environmental factors produced the crisis. What are these factors? As the world economy has expanded, prices of all commodities have increased. Higher standards of living have driven up demand for beef and dairy products, and added to the energy needs of modern agriculture, already a big consumer of oil and other petroleum products for pesticides, fertilisers and transport. Planting crops for biofuel intended to reduce dependency on oil has taken land away from food production, tightening supply and driving prices higher. Major food producers, including Australia and Myanmar, have been hit by droughts and cyclones respectively, further limiting supply. Changes in international trade have led some countries to rely on imports, whose prices they can no longer afford.

▶ Given the number of factors involved, can anybody control what is happening? Is it possible to reconcile so many conflicting interests? Do we have the means to guide agriculture and other vital activities towards new ways of doing things? This chapter argues that changes, whether negative or positive, do not simply "happen". It looks at how governments and civil society can set local, national and global communities on the path of sustainable development.

Making changes

At its most basic, politics is about making decisions on what is important to a society and how these important issues should be handled. It is a process by which people and groups who may not agree attempt to translate their beliefs into workable rules, or laws, to regulate life within a community. The structures of government that manage these processes are often conservative and the impetus for new thinking has often come from outside. In many cases of major societal change, the pressure to transform laws and attitudes has come from visionary individuals and groups, or "civil society organisations" arguing their case until a critical mass of public opinion and political backing has been reached. Then, what was new and at times shocking, irritating or seemingly impossible, became the norm a part of our political and social fabric.

Think of the changes developed countries have seen over the past 100 years. At the start of the 20th century, horses and walking were the main means of transport, even in the rich metropolises like Berlin, London or New York. If a street was lit at all, it was probably by gaslight. Before penicillin, infectious diseases were often fatal. Women were killed in the fight for the right to vote. Go back a few decades more and slavery was considered normal. Children under 10 years old worked 12-hour shifts in factories, as they still do in some countries today.

How did conditions and attitudes change? How was what seemed natural and unchangeable swept away? There's no single cause for the major changes in human history. Visionary individuals argued and organised for change. Sometimes a book or other cultural event provoked a shift in conventional thinking – Dickens' *Oliver Twist* cast a harsh light on England's 1834 Poor Law Amendment, while Upton Sinclair's novel *The Jungle*, published in 1906, showed the appalling working and sanitary conditions in the meat industry contributing directly to the creation of the US Food and Drug Administration.

What can this teach us about improving the world? About increasing well-being for people today, as well as leaving a world fit for future generations to make the changes they will deem necessary? Whether solutions come through introducing new technologies, changing consumption patterns or providing access to health care, water and sanitation, the fact is that any and all improvements depend on the co-operation of a number of different actors who interact in a complex and dynamic way.

Moving from a traditional development model to one of sustainable development has been, and will continue to be, a transformation along these same lines. Whereas in the past most development decisions were driven primarily by economic considerations without regard to implications for the social or environmental spheres, the last 20 or so years of discussions around sustainability have transformed the way both public and private institutions conceive of growth, quality of life and other development-related concerns.

Citizens, civil society and progress

Just as no inventor alone in the garage has the means to turn a discovery into a meaningful tool for society, no activist can alone achieve widespread social change. Each of them must communicate and interact with others to prove the merits of the new discovery or idea and convince others to adopt and promote it. Human advancement depends on an ongoing exchange between people and institutions. The decisions we make about how the world should be and how it can be improved depend on interactions among individual citizens, businesses, civil society and governments. These four categories function together in the complex and sometimes chaotic process of decision-making that we call politics.

The term civil society is one we hear a great deal today, one which like sustainable development can be hard to pin down to an exact definition on which everyone agrees. The London School of Economics Centre for Civil Society defines it as “the arena of uncoerced collective action around shared interests, purposes and values.

The groups, associations and movements that make up civil society have played a part in all the important societal changes in the past century or more. Civil society organisations can be dedicated to specific issues or more general struggles. Indeed, they have been key to the success of very significant advances including universal suffrage, environmental protection, workers’ rights and combating racial discrimination.

Sustainable development is no exception. Organisations such as the Sierra Club, founded in 1892 in the US, or Australia’s Gould Group, dating from 1909, were advocating what we would now term sustainability long before politicians and the media gave the matter much thought. Civil society organisations have been present at all

Downwinders at Risk

Becky Bornhorst considers herself lucky – mother, homemaker, she loves her neighbourhood, her city, her lifestyle. But when she looks at the smoke pluming in the distance – an all too familiar fixture in the horizon – she feels frustrated. Becky knows that the cement kilns a few miles away emit levels of mercury considered dangerous to human health. For over ten years she has contributed to efforts to regulate effects of this and other forms of pollution through a very active local NGO, part of a network of groups trying to improve environmental quality in the North Texas region.

"I was a stay-at-home Mom in 1987 when I began hearing stories about hazardous waste burning at the three cement plants down the road in Midlothian, Texas" recounts Becky. "My son was four and my daughter just one year old. I found a notice in our local newspaper about an early childhood parent-teacher meeting with speakers discussing the cement plants."

Becky went to the meeting with a couple of other mothers and immediately joined other concerned citizens to form Downwinders at Risk. "My goal was to protect my children – I didn't think we should have to run away from the pollution. But I was naïve. I thought we'd clean up the air easily just by organising. It has proved not to be so easy."

Becky and her colleagues have participated in hundreds of formal hearings and discussions with local and national authorities. They have made progress along the way, winning some important improvements in their efforts to curb the emissions and clean up the air, with support from across the political spectrum. Yet the rapid growth that has occurred in her area has meant that overall reductions in pollution have not yet been achieved. "My kids are now in college and I'm still trying to clean the air," she states matter-of-factly. "I never cease to be amazed at the political power of industry and citizen's lack of it."

The need to balance industrial activities considered important to a local economy against the potential health risks of pollution and citizen's quality of life is a challenge facing virtually every community. And it has very often been the case that a problem of environmental degradation has to reach a critical point – for example, at which air quality reaches a dangerous enough level to cause health threats, forcing people to stay inside their homes – before any action is taken to prevent or mitigate the polluting processes.

How important is air quality? What are the health consequences of pollution? The costs? When is it too late to take action to reverse a dangerous trend? These questions are among the thorniest facing societies today. The level of growth in human activity due to industrialisation has produced what could be seen as a turning point in the late 20th century – the point at which the negative consequences of environmental loss and destruction became starkly evident and at which, simultaneously, standards of living in the developed world reached a level such that meeting basic needs was no longer the central task of most people. In other words, focus began to shift from meeting basic needs to also reflecting on the consequences of human activity. From development alone to sustainable development.

of the major meetings that put sustainable development on the map. In fact, they have been instrumental in developing sustainability as an idea and in its translation into concrete practices. They have consultative status at UN and OECD meetings (inclusion that they had to organise and work for) and participate in policy debates. They do research, write policy briefs, and organise collective social action like protests and boycotts. They raise awareness and help educate the public and policy makers.

We talked about the food crisis at the start of this chapter. The Marine Stewardship Council (MSC) is a concrete example of what a civil society organisation can achieve in a domain like this. The MSC is an independent, global, non-profit organisation set up to find a solution to the problem of overfishing. It was first established by Unilever, the world's largest buyer of seafood, and WWF in 1997. In 1999, it became fully independent from both organisations. The MSC works with fisheries, retailers and others to identify, certify, and promote responsible, environmentally appropriate, socially beneficial and economically viable fishing practices around the world.

The MSC Principles and Criteria for Sustainable Fishing is an internationally recognised set of principles to assess whether a fishery is well managed and sustainable. Only products from fisheries assessed by independent certifiers as meeting the standard are able to use the MSC logo on their products. For the first time, this gives consumers a way to identify – and the choice to purchase – fish and other seafood from well-managed sources.

What is the role of government?

A 2003 poll of Canadians showed that car salespeople are trusted less than almost any other profession, with only 10% of respondents finding them trustworthy. *Almost* any other: "national politicians" do even worse, at only 9%. Other people show similar opinions to the Canadians. Government itself is often criticised for a long list of failures, real or perceived: stifling innovation and entrepreneurship through taxes and red tape, caving in to pressure from lobbies and non-representative interest groups, leaving education or health care systems in poor condition. Governing in such a complex world is a huge challenge. Yet democratic governments at least try to make policies that will satisfy people and take care of important issues.

Before looking in more detail at the various tools governments can use, it's useful to recall what tasks governments perform in working for sustainable development. In general, through their data gathering and analysis, policy making and co-ordination, governments can provide support and leadership for moving society in a given direction. They can make sure that individual interests do not detract from the common good. Sustainable development contributes to this good, but actions to promote it may negatively affect the immediate interests of certain people, such as the shareholders of a factory that has to pay higher wages or install air and water filters.

Governments also intervene to deal with what economists call "market failures", situations in which market forces alone do not produce the most efficient outcome. The "externalities" mentioned in Chapter 5 on production and consumption would be an example of this – situations where the actions of one individual or group have costly consequences for others.

Given the global nature of many of the challenges facing sustainability, nations have to co-operate at the highest levels to design and apply solutions. National governments have the authority and power to do this. They also have the means to ensure that decisions are applied. The three most important means by which governments can influence sustainable development (for better or worse) are regulation, taxation and spending. Each can play a role, but taxes tend to be more cost-effective and flexible than regulations, while subsidies are expensive for taxpayers and consumers.

Regulation

As we said earlier, governments may introduce new regulations in response to social or other pressures, but regulation can in turn have a marked effect on behaviour. Smoking in public places would probably continue without government intervention to ban it, for example. Good regulation is an essential tool for making sustainable development a reality. Social and economic conditions evolve, new materials and technologies are developed, and our understanding of health and environmental effects improves. We have to adapt regulations to correspond to changing conditions, and there will always be a need for new regulation. Nanotechnologies and biotechnologies hold great promise, but they also raise a number of questions regarding their safety and in some cases the ethical implications of their adoption. Governments have to gather and analyse the evidence and see if there is a need to change or create regulation. Their decisions will have a major impact on how these technologies and the industries that use them develop.

Nanotech and biotech reveal one of the weaknesses of regulation – the pace of change in some areas is far faster than the pace at which the regulator works. In other cases, governments may try to move more quickly than the electorate is prepared for – many people are hostile to changes in legislation that affect their working conditions or pensions for instance. Regulation has other limits, too. If, for example, bans were 100% effective, there would be no illegal drug use, no speeding, in fact no crime or delinquency to worry about at all. Moreover, the way bans, restrictions, standards and other types of regulation are drafted and applied can also cause problems, leading to counterproductive "red tape". Instead of providing a coherent framework for activity, red tape hinders innovation, stifles initiative and adds unnecessary administrative burdens to economic and social activity.

Regulation can however lead to desirable outcomes for sustainability and increase individual well-being and that of society as a whole. Vaccination and other public health initiatives are good examples, as is the obligation to educate children. We take some of these regulations so much for granted that we may be surprised to learn that they are comparatively recent and had to be fought for, such as regulations concerning the quality of drinking water and food or the safety and environmental impact of automobiles.

Regulation then is not inherently good or bad. This point is recognised in a set of guiding principles for regulatory quality and performance established by the OECD. The importance attached to identifying how any proposed changes to regulation might affect other policy objectives is especially important for sustainable development, where changes in one area may have important consequences elsewhere. The principles also stress that regulation affects, and is affected, by other types of intervention, notably government spending and subsidies and taxes. These are discussed below.

Spending

Governments are big spenders and the way they allocate funds influences practically every aspect of the economy and society. This can have direct impacts on sustainability. A government with a certain sum to devote to transport can decide to invest it in improving the road network or in developing rail services. It can use the energy budget to build new electricity generating capacity or to promote insulation and other energy-saving technologies. Health spending can focus on developing innovative therapies or on preventing common pathologies. International aid can be used to encourage bilateral trade or to promote technical co-operation. In everything from science budgets to welfare programmes, the choices governments make have an impact.

This section focuses on a type of spending the public is generally less familiar with, but which makes up a significant part of most national budgets: subsidies. Many OECD governments subsidise fossil energy, and removing or reforming these subsidies would help policies to tackle climate change. Agriculture may seem a less obvious example, but it is one of the main beneficiaries of subsidies. Consumers and taxpayers transfer over $300 billion to OECD agriculture each year. Some of this is used to help improve agricultural techniques or quality, but much of it keeps prices high. For example, despite reforms, average OECD domestic prices for rice, sugar and milk are still more than double those on world markets, which is particularly hard on poorer consumers who spend proportionately more than the rich on food.

> **"Subsidies often introduce economic, environmental and social distortions with unintended consequences. They are expensive for governments and may not achieve their objectives while also inducing harmful environmental and social outcomes."**
>
> *Subsidy Reform and Sustainable Development: Political Economy Aspects*

Historically, the goal of farm subsidies has been to increase production and therefore food security for a given nation. Over the course of the 20th century, this has meant increasingly mechanised agriculture, a shift towards single crop (monocrop) cultivation, heavy reliance on fertilisers and pesticides, and depending on climate, drainage and irrigation schemes. This so-called "high input" agriculture resulted in a boom in production. At the start of the 20th century, an American farmer had to feed on average 2.5 people in the country. Today, a farmer feeds over 130 people according to the National Academy of Engineering, and estimates that include exports are even higher.

These advances have major impacts on the environment and on farming communities:

- Highly mechanised agriculture can result in increased soil erosion, as machines break up the soil. This results not only in a loss of fertility locally, but also in water pollution as these sediments run off the surface.
- Conversion from small, diverse fields with hedges to monocrop reduces the niches available to insects and birds. European farmland bird populations have declined by 40% in the last 30 years, and for all but a few species that trend is continuing.
- Nutrient pollution (eutrophication) is the leading water pollution issue. In most areas, farms are the largest source of the nitrogen and phosphorus at the root of these harmful algal blooms.
- Previously pure sources of groundwater are now contaminated by pesticides that have leached through the soil from farms above.
- Irrigation is the largest human use of freshwater, accounting for over 70% of the total worldwide. Reduced river flow and dropping groundwater levels make this use a potential source of conflict. In the case of rivers and other surface waters, habitat for fish and birds is sacrificed to maintain food production.

"Decoupling" aid from production is a key measure: goals for agriculture are changing, and subsidies can be a powerful tool for reaching those new goals. Once again, the food crisis illustrates how numerous strands are interwoven. High prices weaken the case for subsidies and could enable funds to be freed for other uses. But high prices also encourage farmers to produce more. They may as a result abandon schemes to leave land uncultivated so that it can be used for other purposes, such as to encourage biodiversity. Carefully targeted subsidies can help to restore the balance among various policy objectives: this requires transparency regarding who benefits and who pays for subsidies such as the European Union's Common Agricultural Policy (CAP), and careful co-ordination between the many stakeholders.

> **"Subsidy reform…can lead to fiscal savings, structural adjustment and enhanced efficiency and productivity in production. Environmentally, the reduction of harmful subsidies can lower negative externalities such as pollution and waste. Socially, subsidy reform can lead to a more equitable distribution of income and balanced long-run growth of communities and countries."**
>
> *Subsidy Reform and Sustainable Development: Economic, Environmental and Social Aspects*

The impacts of agricultural subsidies (positive or negative) obviously touch the social sphere as well as the economy and the environment. Indeed, it is hoped that the reform of agricultural subsidies will allow farmers from developing countries to compete in the global market. This potential for profit should encourage the development of farming infrastructure in countries that have not traditionally exported, with important implications for local employment, purchasing power and food supply. As seen in the opening of this chapter, food security is once again a concern – worldwide – and all governments will have to develop appropriate measures for encouraging productive and sustainable agriculture.

Taxation and emissions trading

The flip side of the spending coin is, of course, taxes. When we think of taxes and sustainability, so-called "green" or "ecotaxes" come to mind first, since these (like emissions trading) are designed to contribute directly to environmental sustainability by making "bad" environmental behaviours more costly. However, as we've argued throughout, the environment is only one part of the process. The social and economic aspects of sustainability are influenced by taxes, too, and in fact are among the biggest items in national budgets. Education for example represents 5% of government spending in OECD countries on average, while health accounts for another 6%. But since "social taxes" existed long before the concept of sustainable development was invented, and their role is rarely presented in this light, their importance is easy to overlook. Nonetheless, through mechanisms such as social welfare schemes, they play an essential role in addressing issues that market mechanisms and private initiatives alone cannot deal with efficiently.

> **"The environmental effectiveness and economic efficiency of environmentally related taxes could be improved further if existing exemptions and other special provisions were scaled back, and if the tax rates were better aligned with the magnitude of the negative environmental impacts to be addressed."**
>
> *The Political Economy of Environmentally Related Taxes*

Likewise, taxes are often perceived as hindering economic development, but governments use them and the revenues derived from them to shape and promote economic development. The social and economic roles of taxation overlap in many cases too, as when funds are invested in developing certain sectors or regions, or when social measures are used to ease or encourage the transition from traditional to new activities.

Interestingly, for many sustainable development issues there is a very strong argument to be made in favour of using taxation and other market-based mechanisms *instead* of subsidies: what are the chances that policy makers will identify every initiative worthy of support and make the appropriate subsidy, without accidentally supporting some initiatives which turn out to have negative effects? On the other hand, a very simple taxation mechanism can spur innovation on the part of businesses, as they come up with their own solutions to reduce a particular practice.

There are several reasons to use economic tools for sustainable development:

- They can provide incentives for behaviour that fits with sustainable development goals and deter actions that go against those goals.
- Overall environmental, social and economic costs could be built into prices using such measures, driving markets towards a more sustainable economy.
- They encourage innovation by providing market pressure.
- The revenue generated could be used to reduce other taxes or finance social measures.

A May 2008 Chicago Tribune article put it like this: "They [consumers] can pay high prices to oil producers or to themselves. The tax proceeds can be used to finance programs of value here at home or to pay for cuts in other taxes even as they curb the release of carbon dioxide."

National strategies: putting sustainable development to work in governments

The governments that signed Agenda 21 at the Rio Earth Summit expressed a certain degree of optimism about sustainable development. For them, the role of government would be central in achieving those goals. It makes sense: sustainable development is a concept with the potential to change many things for the better, but if not firmly anchored in policy-making bodies at all levels of government local, regional, national and international concrete achievements will remain elusive.

In the same way, if policies within one government ministry undermine those in another, progress stalls. Before promoting large-scale tourism for example, it may be wise to ask if the golf courses and swimming pools will mean there's no water left for farmers. On the other hand, if you favour agriculture over tourism, you may lose the chance to create hundreds of jobs in an area with high unemployment. Governing for sustainable development doesn't mean favouring one aspect and neglecting the others; it's about finding the most coherent balance among different claims and devising the most efficient administrative and other means to implement strategies.

> **"While many countries have formulated and implemented national strategies for sustainable development, many lack the basic design and implementation elements recommended by both the OECD and the UN."**
>
> *Institutionalising Sustainable Development*

But how do you go about making plans for what you would like to accomplish? Agenda 21 signatories agreed to develop National Sustainable Development Strategies (NSDS), documents intended to fit the specific needs and goals of different countries while addressing the basic sustainable development priorities that the international community (OECD and UN) has agreed on. Given the flexibility allowed, strategies vary widely. Most OECD countries now have an NSDS in place, each with particular strengths and weaknesses. So over fifteen years on from Rio, how are they doing? Are certain countries or regions leading the way? If so, how do they do it?

A recent OECD workshop on best practices for institutionalising sustainable development gave some concrete suggestions. Participants identified a number of indicators of success such as inscribing sustainable development in constitutions and legislation and including it in national budgeting processes. In the following section we'll describe how governments are trying to meet the goals of their national strategies in practice.

What works?

An essential part of a programme's success is its perceived importance. For sustainable development to be taken seriously, it needs to be centrally located in a ministry or department with influence across all government activities in the Prime Ministry as in the case of Austria or in the Ministry of Finance as in Norway. When sustainable development is "anchored" in one of these central functions, its impact is enhanced and more easily co-ordinated throughout the different parts of government. Sustainable development can also have its own ministry as in the case of France.

> **"Institutionalising sustainable development, whether through national strategies or other means, will not happen if the person at the top is not determined to make it happen."**
>
> Jim MacNeil, Secretary General of the World Commission on Environment and Development in *Institutionalising Sustainable Development*

In the case of new sustainable development ministries, a diverse range of concerns previously separated across government ministries are re-grouped into one. Putting energy, ecology, maritime affairs, territorial planning, forestry and other domains together allows for integrated analysis and decision-making and makes it easier to avoid the pitfall of policies that contradict and undermine each other. Yet this approach can only be effective if supported by the prime minister or presiden in other words, if its recommendations translate into concrete implementations.

New Zealand shows how the social dimension can be included. The Sustainable Development in New Zealand programme gives equal weight to social sustainable development in relation to the economy and environment, with special attention to demographic trends, new roles of women in society, improvements in health and housing, and better integration of Maori communities.

What does governance for sustainability look like?

> **"Liveable cities with high-quality infrastructure, green spaces, and inner city residential areas and public projects can contribute to economic success, attracting foreign investors as well as highly qualified professionals and tourists."**
>
> *Competitive Cities in the Global Economy*

It sounds great in theory, but in practice? The Vauban neighbourhood of Freiburg in Germany was founded on the principles of sutainable living. The idea was to use intelligent planning and design to co-ordinate the different areas of daily life: traffic, building, energy, sanitation, public space and nature. Colourful three-storey structures are interspersed with gardens and playgrounds. Children attend the on-site pre-school and primary. Stores are within walking distance of homes.

For children and adolescents, unicycles seem to be the favorite means of transport. You won't see lots of cars – nearly half of the residents have agreed to go car-free. Speed limits are only 5km per hour, making the streets safe for pedestrians and cyclists.

With a tram line and several bus stops, Vauban is easily accessible by public transport. Freiburg is also home to one of the first "carshare" programmes, where residents pay a small charge to use a car or van when they need one. Construction for this "sustainable model district" respects a low energy consumption standard, where all of the houses beat standard new constructions in energy efficiency, and an additional 150 "plus energy" units produce more energy than they use.

Vauban also gave homebuyers the chance to take a greater role in designing their living space through the co-operative system. It allowed individual residents to invest in a new set of units together and work as a group to decide on customising their building. Not only does this add a creative element to housing, it gives a different meaning to the notion of investment – of the buyer's time, effort and ideas.

Vauban hasn't solved all the problems, but it seems to be doing better than many more ambitious projects, and its experience provides concrete examples of success. As far as governance is concerned, it shows the importance of the "micro" level – listening to the people who are actually going to live in a street before planning that street. It also shows the importance of coherence among the different layers of government. Social diversity objectives were hit by cuts to subsidised housing. Balancing different social interests can be hard, too. The need to spend more public money on children is provoking intergenerational tensions.

But no scheme is perfect, and governance is also about tackling difficulties. Vauban and Freibourg are now cited around the world as examples of sustainable living. The project shows that when governments and citizens get together to apply the principles of sustainability life is more pleasant. And the kids whizzing around on their unicycles would probably tell you it's more fun.

Intergenerational questions are an important component of the social dimension, which is why the *Swedish Strategy for Sustainable Development* adopted an intergenerational timeframe which includes a vision for the future which should remain valid for a generation or at least 25 years.

Sustainability in all levels of government

Leadership at the national level is one key part of governance for sustainable development. However, initiatives at regional and local levels are also critical to its success. After all, local governments have the closest proximity to what people and businesses actually do how they pollute, how they produce and consume, how they experience health care and education systems. People usually decide to take action on a given issue because of what they perceive in their immediate environment and local governments have a lot to do with how a place looks, feels and functions.

Local governments have to identify the critical relations among many factors likely to shape economic, social, political and environmental quality. But even the city level administration may be too remote from the day to day impacts of decisions. Effective governance also needs lower level local networks that include non-governmental actors, associations and businesses, for example to deal with social tensions or make the most of economic opportunities. As the UK Commission for Sustainable Development says: "National policy sets direction, but it's practical action at the local level that makes sustainable development real."

Identifying the correct level of government for addressing a question is itself an important and often complex task. Large cities or metropolitan regions, for example, regroup a number of localities with divergent views on issues important to the greater metro area, as well as different ways of dealing with the range of problems cities handle. Also, many sustainability issues are "regional" in nature think of air pollution or land use. Coherent governance for sustainable development for these large urban areas often requires a regional institution that can co-ordinate efforts and solve inconsistencies in local policies and initiatives.

Furthermore, strategies that are seen as simply one more government programme imposed from above have less chance of succeeding than those defined through consultation and debate.

The rise of biofuels – a cautionary tale

In the 1920s Henry Ford designed the Model T to run on an ethanol blend, and even constructed a corn fermentation plant in Kansas, but the discovery of oil in Texas and elsewhere made petrol the dominant transport fuel. Corn-to-ethanol saw a resurgence in the US following the oil shocks, and Brazil invested heavily in ethanol from sugar cane, making it a major fuel in that market. At the close of the 20th century, amid concern about climate change, ethanol's advocates argued that in theory, ethanol could provide carbon-neutral fuel; petrol with 15% ethanol would not require any changes to vehicle design or driver lifestyle. Although ethanol does release CO_2 during combustion, the feed plants also absorb CO_2 as they grow. Basically, next year's ethanol crop would clean up this year's carbon emissions. Other advantages include providing farm income and energy security for countries that can devote agricultural land to these crops. Similarly, vegetable oils derived from plants ranging from rapeseed to oil palm can be used in diesel engines.

Sound perfect? Western governments jumped on the bandwagon, with a 2003 EU directive mandating 5.75% biofuel content in transportation fuels by 2010. Worldwide, ethanol production doubled and biodiesel quadrupled in 2000-05.

But clouds are gathering. Environmentalists have been warning for years that dependence on biofuels will not only exacerbate the negative impact of conventional monocrop agriculture (habitat loss, freshwater use and run-off of fertilizers and pesticides), but may not even be carbon neutral at all. For certain ethanol crops, energy used for tractors, fertilizer production and fermentation processes may end up producing more CO_2 than the crops absorb. The sharpest environmental debate has come as vast tracts of Indonesian peatland rainforest have been burned and replaced with oil palm – representing up to 10% of global carbon emissions over the past few years, and a doubling in the rate of habitat loss for unique species such as orang-utans.

In the social sphere, Mexico City's so-called "Tortilla Riots" in February 2007 were linked to price rises following increased demand for corn from the US ethanol industry. Spring 2008 saw commodity price increases and food shortages that drive home the absurdity of turning food crops into fuel. So are we nearing the end of the road for biofuels? The great hope remains that we will develop efficient technologies for generating ethanol or biodiesel from crop residues, "weed" plants or algae. This may involve genetically engineering new microbes to ferment cellulose into ethanol. In the meantime, the EU is reconsidering the 2003 directive as we learn more about biofuel's wide-ranging impacts.

Source:

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It would be unrealistic to imagine that everybody would be satisfied with every aspect of a national strategy, but the strategy is more likely to be implemented if everyone concerned has a chance to influence outcomes. This is why the Czech Government Council for Sustainable Development includes government, business, academics, NGOs and other stakeholders and serves as the umbrella group for developing, implementing and revising the national sustainable development strategy.

Many countries seem to be making progress towards governance for sustainable development. Yet the development of NSDS, no matter how complete, by no means guarantees that goals will be reached that depends in each case how strategies are translated into laws and regulations and how the different levels of government (national, regional and local) manage to execute them.

The governance of uncertainty

The media often emphasise the role of corporations and individuals in sustainable development – after all we're the ones building, purchasing, and so on – but governments play an equally significant role and can have far more influence than even the biggest multinational. Their ability to influence behaviours and co-ordinate efforts can make all the difference in producing substantial results. If not coherent, though, government actions can be a barrier to improvement.

When describing the role of government, it's easy to give the impression that governance for sustainable development is merely a matter of identifying objectives then putting in place a series of measures and bodies to oversee them. It's not. Just about every aspect of the economy, society, and the physical resources on which they ultimately depend, influences sustainability. Outcomes depend on an infinite number of interactions working on different timescales of varying importance. No model, however robust, no foresight, however penetrating, can tell us everything we'd like to know. Governments attempting to implement sustainability have to deal with this uncertainty. Not only their goals, but the strategies and instruments used to achieve them must be sustainable, too. They must be rigorous enough to be effective, but flexible enough to adapt as circumstances and priorities evolve. In the face of uncertainty, governance itself has to be sustainable.

Find Out More

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On the Internet

For a general introduction to OECD work on sustainable development or governance, visit *www.oecd.org/sustainabledevelopment* and *www.oecd.org/governance*.

Publications

Institutionalising Sustainable Development (2007):
"Institutionalisation" embeds the concept of sustainable development in government operations for the long-term and reduces the vulnerability of sustainable development aims to shorter-term political objectives. This volume contains recommendations for true institutionalisation.

Subsidy Reform and Sustainable Development: Political Economy Aspects (2007):
Eliminating unsustainable subsidies requires comprehensive approaches that are supported by top political leadership, transparent in their potential effects on all parties, consistent over the long term, and often accompanied by transition supports. This volume uses sectoral case studies to illustrate that achieving change in structural policies depends largely on good governance.

Subsidy Reform and Sustainable Development: Economic, Environmental and Social Aspects (2006):
This report reviews approaches for assessing subsidies and associated taxes, and looks at country experiences in reforming subsidies in the agriculture, fisheries, industry, and transport sectors.

Environmental Performance of Agriculture at a Glance (2008):
This report provides the latest and most comprehensive data and analysis on the environmental performance of agriculture in OECD countries since 1990. It covers key environmental themes including soil, water, air and biodiversity and looks at recent policy developments in all 30 countries.

Power to the People? Building Open and Inclusive Policy Making (forthcoming 2008):
This book charts emerging practice in ensuring policy-making processes are more open and inclusive and gathers an impressive array of diverse opinions from leading practitioners. It offers a set of guiding principles to support open and inclusive policy making and service delivery in practice.

Environmentally Harmful Subsidies: Challenges for Reform (2005):
Subsidies are pervasive throughout OECD countries and much of this support is potentially harmful environmentally. This report presents sectoral analyses on agriculture, fisheries, water, energy and transport, proposing a checklist approach to identifying and assessing environmentally harmful subsidies. It also identifies the key tensions and conflicts that are likely to influence subsidy policy making.

Also of interest

An OECD Framework for Effective and Efficient Environmental Policies (2008):
www.oecd.org/envmin2008

Good Practices in the National Sustainable Development Strategies of OECD Countries (2006):
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Write Global – Print Local: Just in time publishing and bookselling

The book distribution chain is very wasteful. Books are printed in one place and then shipped via distributors to booksellers for sale to readers. Unsold copies are returned – more handling, packaging and shipping – before either making another trip or being destroyed. This "just-in-case" system is driven by the economics of offset printing technology. The costs of the first print run are very high, but any subsequent copies cost little by comparison. This rules out printing books in small quantities close to bookshops.

Quite apart from the waste of time and materials, this system also has a serious impact on the environment in terms of carbon emissions. A survey carried out in 2007 by the US Book Industry Study Group and Green Press Initiative calculated that each book made emits an average of 8.8 pounds (almost 4kg) of carbon dioxide. If books could be manufactured "as needed, just-in-time" close to bookshops, waste, "book miles" and, hence, carbon emissions would be cut significantly. The good news is that just-in-time publishing is just around the corner.

This book is one of the first to be published on a just-in-time basis. OECD Publishing is based in Paris, France, yet this book was launched in an Angus and Robertson bookshop in Melbourne, Australia without a single copy being shipped anywhere. Copies are manufactured inside the bookshop using a digital press (an Espresso Book Machine from On Demand Books) only when a customer wants to buy one. Just cutting out the shipping from Paris to Melbourne saves an estimated 5.8kg in CO_2 emissions per copy sold.

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In November 2008, when this book was published, there were a dozen Espresso Book Machines scattered across North America, Europe, Africa and Asia-Oceania. In conjunction with the world's largest digital printer – Ingram's Lightning Source – many more are due to be rolled out in bookshops, libraries and other locations. One day you might find just-in time books in airports, coffee shops as well as your local bookshop.

Digital printing means less capital is tied up in storage and transport. Publishers might use the reduced costs to encourage new talent, or publish books that don't have a big market. Bookshops with a print-on-demand machine could have an unlimited catalogue, even supplying out-of-print titles within a few minutes. This will be a boon for readers, publishers and authors. And in addition to a healthier planet, stripping out warehousing, packaging, handling and shipping costs should make books cheaper.

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Sustainable Development

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Sustainability

SEARCH FOR THE meaning of "sustainability" and you'll soon be led to this: "Sustainable development: development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

It comes from "Our Common Future," the 1987 report of the World Commission on Environment and Development, a U.N. exploration of conflicts between development and preservation of the environment.

Growth is also essential, and thus the three goals of social progress (or development), environmental protection, and economic growth, pursued together, have become known as the pillars of sustainability.

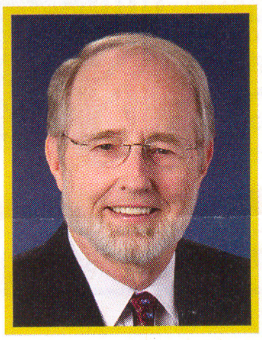
They are important everywhere, in rich countries and poor. If the use of natural resources in developed countries already threatens our environment, how can advances in quality of life and prosperity be extended to all without making the environmental damage far worse?

Sustainability must be approached by both the public and private sectors. Governments can contribute through laws, regulations, planning, and infrastructure development. These actions primarily serve to accelerate progress in the private sector, where opportunities for improving sustainability are great. Businesses are large consumers of energy and natural resources. Their operations often affect our environment, sometimes dramatically, while at the same time there are many business opportunities in sustainable development.

Within the business community, interest seems to be growing. Customers, employees, and stockholders are pushing for more attention to sustainability, and the pillars are sometimes recast as "people, planet, and profit," or the "triple bottom line" of social responsibility.

INDUSTRY INVOLVEMENT

The U.N. Global Compact, which describes itself as "the world's largest corporate sustainability organization," has 7000 business signatories from 135 countries. The World Business Council for Sustainable Development, an organization of CEOs of large corporations, has 200 members committed to "business solutions for a sustainable world." In June, I was among 2500 participants in the U.N. Corporate Sustainability Forum, a prelude to the Rio+20 Conference on Sustainable Development, where more than 200 new commitments to sustainable solutions were announced. Regarding Rio+20, CNN reported: "Businesses played a much bigger role at this summit than they did 20 years ago, with many observers saying they have actually taken the lead by providing real examples of sustainable development."



The position of chief sustainability officer (CSO) has been added to many executive rosters, including those of large corporations, such as 3M, DuPont, Ford, Procter & Gamble, Siemens, and Toyota. Scott Wicker, an electrical engineer and the first CSO of the delivery service company UPS, argues that corporate sustainability strategies require the expertise, mentality, and instincts of engineers. He says these strategies should be approached like an engineering project, with a particular emphasis on data-driven design. One of Wicker's first contributions was to develop computer algorithms to dynamically plan delivery routes, saving substantial time and fuel.

ENGINEER INVOLVEMENT

Most engineers will steer a conversation about sustainability toward energy. It's a big target. By one estimate, 87 percent of the world's primary energy consumption is derived from fossil fuels, principally oil, coal, and natural gas.

And within the energy sector, engineers will focus first on opportunities to improve the efficiency with which energy is converted (such as electricity generation), transported, and used. According to the U.S. National Academy of Engineering, accelerating the deployment of established energy-efficiency technologies could more than offset the growth of energy demand in the United States, a conclusion that probably applies to other developed countries as well. Further, the payback time for investments in efficiency can be relatively short, leading to substantial long-term savings.

Second, engineers will focus on changing the mix of energy sources, recognizing that the optimum may differ widely by country or region. Greater use of natural gas, wind, and solar technologies to generate electricity has reduced U.S. carbon emissions to a 20-year low. Denmark has set a path toward a 35 percent renewable component in its energy supply by 2020 and 100 percent by 2050.

It will also be engineers who answer many of the key questions about energy technology. Is a breakthrough in mass energy storage essential for renewable energy to supply a large fraction of our energy needs? Can carbon-capture and -storage technology be made to work, at scale and with a cost low enough so that coal can remain an important energy source? If the component of fossil fuels in the energy supply is to diminish, is nuclear generation the only way to meet base-load electricity demand?

I'm optimistic. Engineers created the technologies that dramatically advanced quality of life in developed countries. And though our community sometimes failed to adequately consider the environmental consequences of those technologies, ours is also the profession that can mitigate those consequences while extending the benefits of technology to the rest of the world.

Gordon W. Day

Gordon W. Day
IEEE President and CEO

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Research

Planetary Boundaries: Exploring the Safe Operating Space for Humanity

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ABSTRACT. Anthropogenic pressures on the Earth System have reached a scale where abrupt global environmental change can no longer be excluded. We propose a new approach to global sustainability in which we define planetary boundaries within which we expect that humanity can operate safely. Transgressing one or more planetary boundaries may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems. We have identified nine planetary boundaries and, drawing upon current scientific understanding, we propose quantifications for seven of them. These seven are climate change (CO_2 concentration in the atmosphere <350 ppm and/or a maximum change of +1 W m^{-2} in radiative forcing); ocean acidification (mean surface seawater saturation state with respect to aragonite ≥ 80% of pre-industrial levels); stratospheric ozone (<5% reduction in O_3 concentration from pre-industrial level of 290 Dobson Units); biogeochemical nitrogen (N) cycle (limit industrial and agricultural fixation of N_2 to 35 Tg N yr^{-1}) and phosphorus (P) cycle (annual P inflow to oceans not to exceed 10 times the natural background weathering of P); global freshwater use (<4000 km^3 yr^{-1} of consumptive use of runoff resources); land system change (<15% of the ice-free land surface under cropland); and the rate at which biological diversity is lost (annual rate of <10 extinctions per million species). The two additional planetary boundaries for which we have not yet been able to determine a boundary level are chemical pollution and atmospheric aerosol loading. We estimate that humanity has already transgressed three planetary boundaries: for climate change, rate of biodiversity loss, and changes to the global nitrogen cycle. Planetary boundaries are interdependent, because transgressing one may both shift the position of other boundaries or cause them to be transgressed. The social impacts of transgressing boundaries will be a function of the social–ecological resilience of the affected societies. Our proposed boundaries are rough, first estimates only, surrounded by large uncertainties and knowledge gaps. Filling these gaps will require major advancements in Earth System and resilience science. The proposed concept of "planetary boundaries" lays the groundwork for shifting our approach to governance and management, away from the essentially sectoral analyses of limits to growth aimed at minimizing negative externalities, toward the estimation of the safe space for human development. Planetary boundaries define, as it were, the boundaries of the "planetary playing field" for humanity if we want to be sure of avoiding major human-induced environmental change on a global scale.

Key Words: *atmospheric aerosol loading; biogeochemical nitrogen cycle; biological diversity; chemical pollution; climate change; Earth; global freshwater use; land system change; ocean acidification; phosphorus cycle; planetary boundaries; stratospheric ozone; sustainability*

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NEW CHALLENGES REQUIRE NEW THINKING ON GLOBAL SUSTAINABILITY

Human activities increasingly influence the Earth's climate (International Panel on Climate Change (IPPC) 2007a) and ecosystems (Millennium Ecosystem Assessment (MEA) 2005a). The Earth has entered a new epoch, the Anthropocene, where humans constitute the dominant driver of change to the Earth System[i] (Crutzen 2002, Steffen et al. 2007). The exponential growth of human activities is raising concern that further pressure on the Earth System could destabilize critical biophysical systems and trigger abrupt or irreversible environmental changes that would be deleterious or even catastrophic for human well-being. This is a profound dilemma because the predominant paradigm of social and economic development remains largely oblivious to the risk of human-induced environmental disasters at continental to planetary scales (Stern 2007).

Here, we present a novel concept, planetary boundaries, for estimating a safe operating space for humanity with respect to the functioning of the Earth System. We make a first preliminary effort at identifying key Earth System processes and attempt to quantify for each process the boundary level that should not be transgressed if we are to avoid unacceptable global environmental change. Unacceptable change is here defined in relation to the risks humanity faces in the transition of the planet from the Holocene to the Anthropocene. The relatively stable environment of the Holocene, the current interglacial period that began about 10 000 years ago, allowed agriculture and complex societies, including the present, to develop and flourish (Fig. 1). That stability induced humans, for the first time, to invest in a major way in their natural environment rather than merely exploit it (van der Leeuw 2008). We have now become so dependent on those investments for our way of life, and how we have organized society, technologies, and economies around them, that we must take the range within which Earth System processes varied in the Holocene as a scientific reference point for a desirable planetary state.

Despite some natural environmental fluctuations over the past 10 000 years (e.g., rainfall patterns, vegetation distribution, nitrogen cycling), Earth has remained within the Holocene stability domain. The resilience of the planet has kept it within the range of variation associated with the Holocene state, with key biogeochemical and atmospheric parameters fluctuating within a relatively narrow range (Fig. 1; Dansgaard et al. 1993, Petit et al. 1999, Rioual et al. 2001). At the same time, marked changes in regional system dynamics have occurred over that period. Although the imprint of early human activities can sometimes be seen at the regional scale (e.g., altered fire regimes, megafauna extinctions), there is no clear evidence that humans have affected the functioning of the Earth System at the global scale until very recently (Steffen et al. 2007). However, since the industrial revolution (the advent of the Anthropocene), humans are effectively pushing the planet outside the Holocene range of variability for many key Earth System processes (Steffen et al. 2004). Without such pressures, the Holocene state may be maintained for thousands of years into the future (Berger and Loutre 2002).

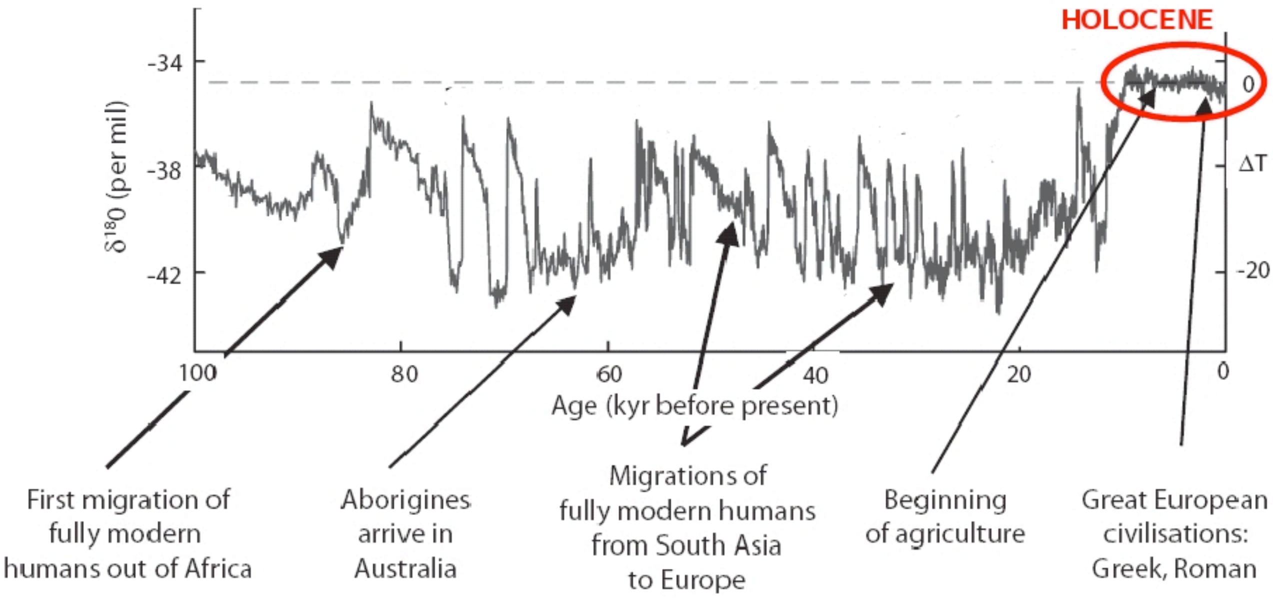
So far, science has provided warnings of planetary risks of crossing thresholds in the areas of climate change and stratospheric ozone (IPCC 1990, 2007a, b, World Meteorological Organization 1990). However, the growing human pressure on the planet (Vitousek et al. 1997, MEA 2005a) necessitates attention to other biophysical processes that are of significance to the resilience[ii] of sub-systems of Earth (Holling 1973, Folke et al. 2004, Gordon et al. 2008) and the Earth System as a whole. Erosion of resilience manifests itself when long periods of seemingly stable conditions are followed by periods of abrupt, non-linear change, reflected in critical transitions from one stability domain to another when thresholds are crossed (Scheffer et al. 2001, Walker et al. 2004, Lenton et al. 2008, Scheffer 2009).

The Anthropocene raises a new question: "What are the non-negotiable planetary preconditions that humanity needs to respect in order to avoid the risk of deleterious or even catastrophic environmental change at continental to global scales?" We make a first attempt at identifying planetary boundaries for key Earth System processes associated with dangerous thresholds, the crossing of which could push the planet out of the desired Holocene state.

INTRODUCING THE CONCEPT OF PLANETARY BOUNDARIES

Here, thresholds are defined as non-linear transitions in the functioning of coupled human–environmental systems (Schellnhuber 2002, Lenton

Fig. 1. The last glacial cycle of 18O (an indicator of temperature) and selected events in human history. The Holocene is the last 10 000 years. Adapted from Young and Steffen (2009).

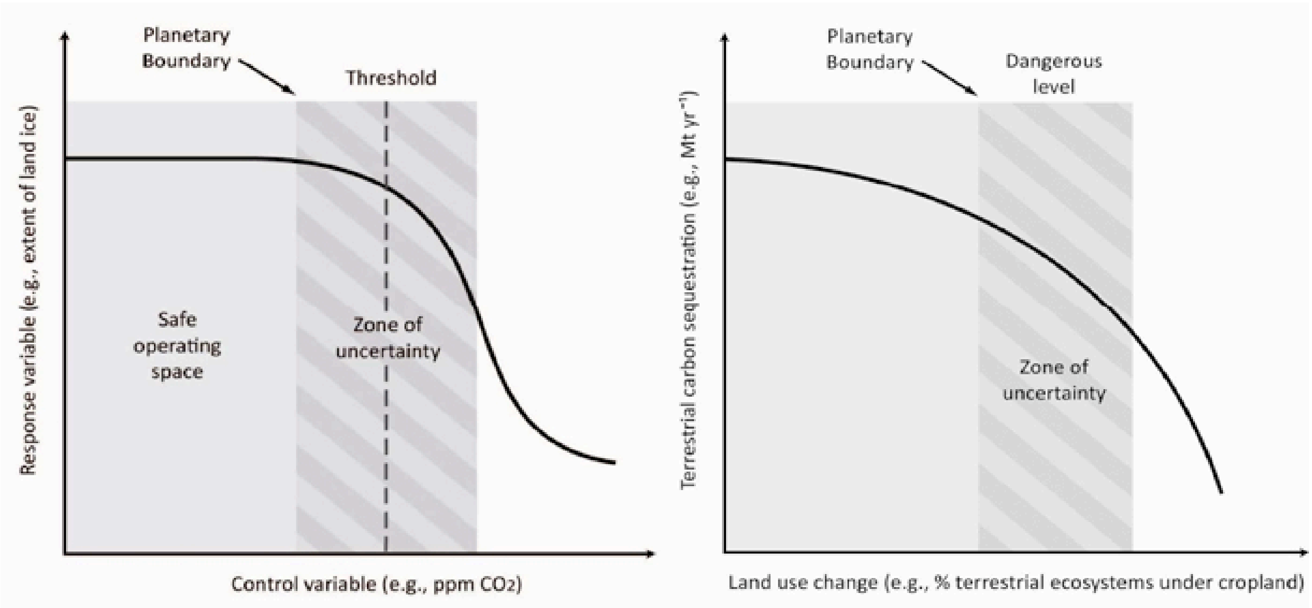


et al. 2008), such as the recent abrupt retreat of Arctic sea ice caused by anthropogenic global warming (Johannessen 2008). Thresholds are intrinsic features of those systems and are often defined by a position along one or more control variables (Fig. 2a), such as temperature and the ice-albedo feedback in the case of sea ice. Some Earth System processes, such as land-use change, are not associated with known thresholds at the continental to global scale, but may, through continuous decline of key ecological functions (such as carbon sequestration), cause functional collapses, generating feedbacks that trigger or increase the likelihood of a global threshold in other processes (such as climate change) (Fig. 2b). Such processes may, however, trigger non-linear dynamics at the lower scales (e.g., crossing of thresholds in lakes, forests, and savannahs, as a result of land-use change, water use, and nutrient loading). Such non-linear changes, from a desired to an undesired state, may on aggregate become a global concern for humanity, if occurring across the planet.

Boundaries, on the other hand, are human-determined values of the control variable set at a "safe" distance from a dangerous level (for processes without known thresholds at the continental to global scales) or from its global threshold. Determining a safe distance involves normative judgments of how societies choose to deal with risk and uncertainty (see Fig. 2a, b). The choice of control variable for each planetary boundary was based on our assessment of the variable that on balance may provide the most comprehensive, aggregated, and measurable parameter for individual boundaries (Appendix 1, Supplementary Methods 1).

Much of the uncertainty in quantifying planetary boundaries is due to our lack of scientific knowledge about the nature of the biophysical thresholds themselves (Appendix 1, Supplementary Discussion 1), the intrinsic uncertainty of how complex systems behave, the ways in which other biophysical processes such as feedback mechanisms interact with the primary control variable, and uncertainty regarding the allowed time of overshoot of a critical control variable in the Earth System before a threshold is crossed. This generates a zone of uncertainty around each threshold (Fig. 2a, b). The

Fig. 2. Conceptual description of planetary boundaries. In (a) the boundary is designed to avoid the crossing of a critical continental to global threshold in an Earth System process. Insufficient knowledge and the dynamic nature of the threshold generate a zone of uncertainty about its precise position, which informs the determination of where to place the boundary. In (b) there is no global threshold effect as far as we know, but exceeding the boundary level will lead to significant interactions with regional and global thresholds and/or may cause a large number of undesired threshold effects at the local to regional scale, which in aggregate add up to a serious global concern for humanity.



nature and size of that zone is critical in determining where to place the planetary boundary.

We have defined the boundary position to correspond to our assessment of the lower end of the uncertainty zone for each boundary (Figs. 2a,b, 3). Each proposed boundary position assumes that no other boundaries are transgressed.

The planetary boundaries approach rests on three branches of scientific inquiry. The first addresses the scale of human action in relation to the capacity of the Earth to sustain it, a significant feature of the ecological economics research agenda (Costanza 1991), drawing on work on the essential role of the life-support environment for human well-being (Odum 1989, Vitousek et al. 1997) and biophysical constraints for the expansion of the economic subsystem (Boulding 1966, Arrow et al. 1995). The second is the work on understanding essential Earth System processes (Bretherton 1988, Schellnhuber 1999, Steffen et al. 2004), including human actions (Clark and Munn 1986, Turner et al. 1990), brought together in the evolution of global change research toward Earth System science and in the development of sustainability science (Clark and Dickson 2003). The third is the framework of resilience (Holling 1973, Gunderson and Holling 2002, Walker et al. 2004, Folke 2006) and its links to complex dynamics (Kaufmann 1993, Holland 1996) and self-regulation of living systems (Lovelock 1979, Levin 1999), emphasizing multiple basins of attraction and thresholds effects (Scheffer et al. 2001, Folke et al. 2004, Biggs et al. 2009).

Our proposed framework builds on and extends approaches based on limits-to-growth (Meadows et al. 1972, 2004), safe minimum standards (Ciriacy-Wantrup 1952, Bishop 1978, Crowards 1998), the

Fig. 3. Summary of criteria and process for the identification and definition of planetary boundaries.

Although current scientific understanding underpins the analysis of the existence, location, and nature of thresholds, normative judgments influence the definition and the position of planetary boundaries:

- The selection of planetary boundaries emerges from the definition of what constitutes unacceptable human-induced global environmental change.
- The position of a planetary boundary is a function of the degree of risk the global community is willing to take, e.g., how close to an uncertainty zone around a dangerous level or threshold of a Earth System process humanity is willing to place itself, and/or for how long a boundary can temporarily be transgressed before a threshold is crossed.
- The position is furthermore a function of the social and ecological resilience of the impacted societies (e.g., the ability of coastal communities to cope with sea level rise later this century if a climate-change boundary is transgressed for too long).
- Boundaries are identified for processes where the time needed to trigger an abrupt or irreversible change is within an "ethical time horizon" - a timeframe (i) short enough to influence today's decisions yet long enough to provide the basis for sustainability over many generations to come, and (ii) within which decisions taken can influence whether or not the estimated threshold is crossed.

Having identified boundary candidates among Earth System processes, a set of criteria were considered in identifying appropriate control variables: (i) that the variable is universally applicable for the sub-systems linked to the same boundary, (ii) that it can function as a robust indicator of process change, and (iii) that there are available and reliable data. This means that we have taken a pragmatic approach in the first round of defining the planetary boundary variables, sometimes choosing a parameter of ultimate ecological impact (e.g., rate of extinction of species for biodiversity loss), a proxy indicator (e.g., aragonite saturation state for ocean acidification), or a human driving-force variable (e.g., *P* load in the oceans).

precautionary principle (Raffensperger and Tickner 1999), and tolerable windows (WBGU 1995, Petschel-Held et al. 1999) (see Appendix 1, Supplementary Discussion 2). A key advance is that the planetary boundaries approach focuses on the biophysical processes of the Earth System that determine the self-regulating capacity of the planet. It incorporates the role of thresholds related to large-scale Earth System processes, the crossing of which may trigger non-linear changes in the functioning of the Earth System, thereby challenging social–ecological resilience at regional to global scales. Together, the set of boundaries represents the dynamic biophysical "space" of the Earth System within which humanity has evolved and thrived. The boundaries respect Earth's "rules of the game" or, as it were, define the "planetary playing field" for the human enterprise. The thresholds in key Earth System processes exist irrespective of peoples' preferences, values, or compromises based on political and socioeconomic feasibility, such as expectations of technological breakthroughs and fluctuations in economic growth.

However, choices and actions will to a large extent determine how close we are to the critical thresholds involved, or whether we cross them. Our approach does not offer a roadmap for sustainable development; it merely provides, in the context of the human predicament in the Anthropocene, the first step by identifying biophysical boundaries at the planetary scale within which humanity has the flexibility to choose a myriad of pathways for human well-being and development. Further work will need to focus on the societal dynamics that have led to the current situation and propose ways in which our societies can stay within these boundaries.

We have done a comprehensive search for these critical Earth System processes and their associated control variables (see Appendix 1, Supplementary Methods 1). So far, we have been able to identify nine such processes for which boundaries need to be established to minimize the risk of crossing critical thresholds that may lead to undesirable outcomes.

CATEGORIZING PLANETARY BOUNDARIES

The nine planetary boundaries identified here (Fig. 4) cover the global biogeochemical cycles of nitrogen, phosphorus, carbon, and water; the major physical circulation systems of the planet (the climate, stratosphere, ocean systems); biophysical features of Earth that contribute to the underlying resilience of its self-regulatory capacity (marine and terrestrial biodiversity, land systems); and two critical features associated with anthropogenic global change (aerosol loading and chemical pollution). We assess that there is enough scientific evidence to make a preliminary, first attempt at quantifying control variables for seven of these boundaries (Table 1). The remaining two (aerosol loading and chemical pollution), we believe, should be included among the planetary boundaries, but we are as yet unable to suggest quantitative boundary levels.

We distinguish between boundaries that are directly related to sharp continental or planetary thresholds, such as the risk of melting of the Greenland and Antarctic ice sheets when permanently crossing a threshold of radiative forcing (Lenton et al. 2008, Schellnhuber 2002), and boundaries based on "slow" planetary processes with no current evidence of planetary scale threshold behavior, which provide the underlying resilience of the Earth System by functioning as sinks and sources of carbon and by regulating water, nutrient, and mineral fluxes (Fig. 4).

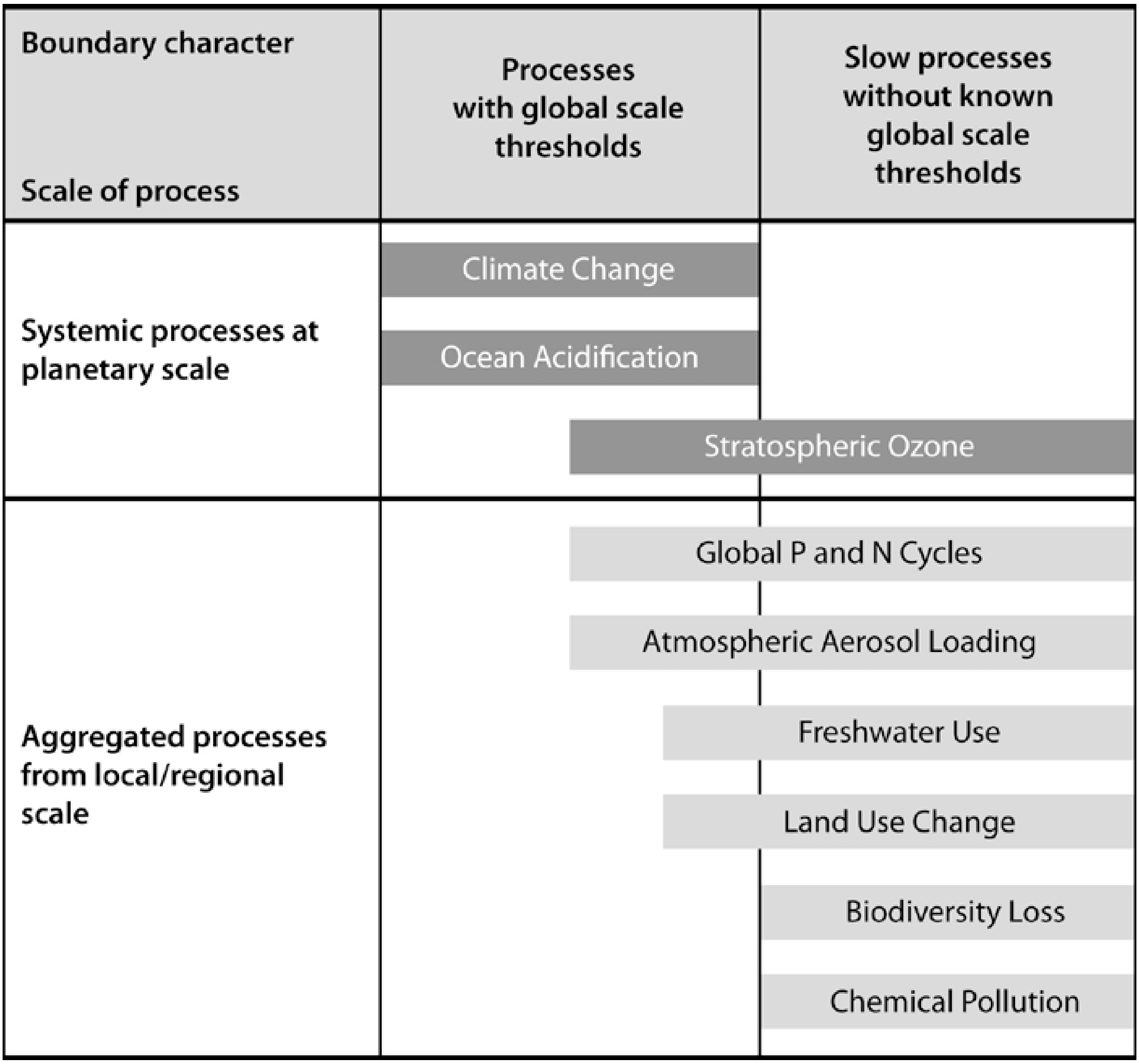
There is ample evidence from local to regional-scale ecosystems, such as lakes, forests, and coral reefs, that gradual changes in certain key control variables (e.g., biodiversity, harvesting, soil quality, freshwater flows, and nutrient cycles) can trigger an abrupt system state change when critical thresholds have been crossed (Carpenter et al. 2001, Folke et al. 2004, Hughes et al. 2007, Scheffer 2009). More research is urgently needed on the dynamics of thresholds and feedbacks that operate at continental and global scales, especially for slow-changing control variables such as land use and cover, water resource use, rate of biodiversity loss, and nutrient flows. Here, we distinguish between identifiable planetary thresholds driven by systemic global-scale processes (impacting sub-systems "top down") and thresholds that may arise at the local and regional scales, which become a global concern at the aggregate level (if occurring in multiple locations simultaneously) or where the gradual aggregate impacts may increase the likelihood of crossing planetary thresholds in other Earth System processes (thus affecting the Earth System "bottom up") (Fig. 4).

Many planetary-scale processes (such as climate change) primarily produce impacts at a sub-Earth System scale, where such sub-systems show varying degrees of sensitivity to change. For example, climate change is associated with at least nine sub-system "tipping elements" (e.g., the Indian monsoon and El Niño events), which all show varying degrees of sensitivity to a change in radiative forcing or temperature rise (Lenton et al. 2008). We deal with such cross-scale complexity by proposing planetary boundaries to avoid all known sub-Earth System thresholds in the foreseeable future.

QUANTIFYING PLANETARY BOUNDARIES

In the following, we present the justification and quantifications for the proposed planetary boundaries in Table 1. Extended and additional descriptions for some of the boundaries are available in the supplementary information (Appendix 1, Supplementary Discussion 3–4).

Fig. 4. Categories of planetary boundaries.



Climate Change

The climate-change boundary is currently under vigorous discussion as the international community approaches the 15th Conference of the Parties to the UNFCCC in Copenhagen in December 2009. There is a growing convergence toward a "2°C guardrail" approach, that is, containing the rise in global mean temperature to no more than 2°C above the pre-industrial level. The consideration of this guardrail is based on a combination of analytical and political arguments, taking into account (i) the scientific projections of the respective climate damages to be expected at various levels of global warming, (ii)

Table 1. Proposed planetary boundaries.

Earth System process	Control variable	Threshold avoided or influenced by slow variable	Planetary Boundary (zone of uncertainty)	State of knowledge*
Climate change	Atmospheric CO_2 concentration, ppm; Energy imbalance at Earth's surface, W m^{-2}	Loss of polar ice sheets. Regional climate disruptions. Loss of glacial freshwater supplies. Weakening of carbon sinks.	Atmospheric CO_2 concentration: 350 ppm (350–550 ppm) Energy imbalance:+1 W m^{-2} (+1.0–+1.5 W m^{-2})	1. Ample scientific evidence. 2. Multiple sub-system thresholds. 3. Debate on position of boundary.
Ocean acidification	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite (Ω_{arag})	Conversion of coral reefs to algal-dominated systems. Regional elimination of some aragonite- and high-magnesium calcite-forming marine biota Slow variable affecting marine carbon sink.	Sustain ≥80% of the pre-industrial aragonite saturation state of mean surface ocean, including natural diel and seasonal variability (≥80%–≥70%)	1. Geophysical processes well known. 2. Threshold likely. 3. Boundary position uncertain due to unclear ecosystem response.
Stratospheric ozone depletion	Stratospheric O_3 concentration, DU	Severe and irreversible UV-B radiation effects on human health and ecosystems.	<5% reduction from pre-industrial level of 290 DU (5%–10%)	1. Ample scientific evidence. 2. Threshold well established. 3. Boundary position implicitly agreed and respected.
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	Disruption of monsoon systems. Human-health effects. Interacts with climate change and freshwater boundaries.	To be determined	1. Ample scientific evidence. 2. Global threshold behavior unknown. 3. Unable to suggest boundary yet.
Biogeo-chemical flows: interference with P and N cycles	P: inflow of phosphorus to ocean, increase compared with natural background weathering N: amount of N_2 removed from atmosphere for human use, Mt N yr^{-1}	P: avoid a major oceanic anoxic event (including regional), with impacts on marine ecosystems. N: slow variable affecting overall resilience of ecosystems via acidification of terrestrial ecosystems and eutrophication of coastal and freshwater systems.	P: < 10× (10× - 100×) N: Limit industrial and agricultural fixation of N_2 to 35 Mt N yr^{-1}, which is ~ 25% of the total amount of N_2 fixed per annum naturally by terrestrial ecosystems (25%–35%)	P: (1) Limited knowledge on ecosystem responses; (2) High probability of threshold but timing is very uncertain; (3) Boundary position highly uncertain. N: (1) Some ecosystem responses known; (2) Acts as a slow variable, existence of global thresholds unknown; (3) Boundary position highly uncertain.
Global freshwater use	Consumptive blue water use, km^3 yr^{-1}	Could affect regional climate patterns (e.g., monsoon behavior). Primarily slow variable affecting moisture feedback, biomass production, carbon uptake by terrestrial systems and reducing biodiversity	<4000 km^3 yr^{-1} (4000–6000 km^3 yr^{-1})	1. Scientific evidence of ecosystem response but incomplete and fragmented. 2. Slow variable, regional or subsystem thresholds exist. 3. Proposed boundary value is a global aggregate, spatial distribution determines regional thresholds

(con'd)

Land-system change	Percentage of global land cover converted to cropland	Trigger of irreversible and widespread conversion of biomes to undesired states. Primarily acts as a slow variable affecting carbon storage and resilience via changes in biodiversity and landscape heterogeneity	≤15% of global ice-free land surface converted to cropland (15%–20%)	1. Ample scientific evidence of impacts of land-cover change on ecosystems, largely local and regional. 2. Slow variable, global threshold unlikely but regional thresholds likely. 3. Boundary is a global aggregate with high uncertainty, regional distribution of land-system change is critical.
Rate of biodiversity loss	Extinction rate, extinctions per million species per year (E/MSY)	Slow variable affecting ecosystem functioning at continental and ocean basin scales. Impact on many other boundaries—C storage, freshwater, N and P cycles, land systems. Massive loss of biodiversity unacceptable for ethical reasons.	<10 E/MSY (10–100 E/MSY)	1. Incomplete knowledge on the role of biodiversity for ecosystem functioning across scales. 2. Thresholds likely at local and regional scales. 3. Boundary position highly uncertain.
Chemical pollution	For example, emissions, concentrations, or effects on ecosystem and Earth System functioning of persistent organic pollutants (POPs), plastics, endocrine disruptors, heavy metals, and nuclear wastes.	Thresholds leading to unacceptable impacts on human health and ecosystem functioning possible but largely unknown. May act as a slow variable undermining resilience and increase risk of crossing other thresholds.	To be determined	1. Ample scientific evidence on individual chemicals but lacks an aggregate, global-level analysis. 2. Slow variable, large-scale thresholds unknown. 3. Unable to suggest boundary yet.

value judgments on the (non-) acceptability of such impacts, and (iii) political considerations of what is perceived as a realistic target given the predicament humanity is facing today due to already committed global warming. It needs to be emphasized, however, that significant risks of deleterious climate impacts for society and the environment have to be faced even if the 2°C line can be held (Richardson et al. 2009).

The approach we present here of defining a climate-change boundary (described below) is based on our scientific understanding of what is required to avoid the crossing of critical thresholds that separate qualitatively different climate system states. As a matter of fact, the boundary so identified gives a high probability that the 2°C guardrail is also respected (Hare and Meinshausen 2006).

The climate-change boundary proposed here aims at minimizing the risk of highly non-linear, possibly abrupt and irreversible, Earth System responses (National Research Council (NRC) 2002, IPCC 2007b) related to one or more thresholds, the crossing of which could lead to the disruption of regional climates (Lenton et al. 2008), trigger the collapse of major climate dynamics patterns such as the thermohaline circulation (Clark et al. 2002), and drive other impacts difficult for society to cope with, such as rapid sea-level rise. The risk of crossing such thresholds will rise sharply with further anthropogenically driven deviation from the natural variability of the Holocene climate.

We propose a dual approach to defining the planetary boundary for climate change, using both atmospheric CO_2 concentration and radiative forcing as global-scale control variables. We suggest boundary values of 350 ppm CO_2 and 1 W m^{-2} above the pre-industrial level, respectively. The boundary is based on (i) an analysis of the equilibrium sensitivity of the climate system to greenhouse gas forcing, (ii) the behavior of the large polar ice sheets under climates warmer than those of the Holocene (Hansen et al. 2008), and (iii) the observed behavior of the climate system at a current CO_2 concentration of about 387 ppm and +1.6 W m^{-2} (+0.8/-1.0 W m^{-2}) net radiative forcing (IPCC 2007a).

Climate sensitivity, as estimated by the current suite of climate models, includes only "fast feedbacks" such as changes in water vapor, clouds, and sea ice, and yields a value of ~ 3°C (range: 2–4.5°C) for a doubling of atmospheric CO_2 concentration above pre-industrial levels (IPCC 2007a). Inclusion of "slow feedbacks" such as decreased ice sheet volume, changed vegetation distribution, and inundation of continental shelves, gives an estimated climate sensitivity of ~ 6°C (range: 4–8° C) (Hansen et al. 2008). Thus, the current suite of climate models may significantly underestimate the severity of long-term future climate change for a given concentration of greenhouse gases.

Palaeo-climatic data from 65 million years ago to the present points to decreasing CO_2 concentration as the major factor in the long-term cooling trend over that period. The data further suggest that the planet was largely ice free until atmospheric CO_2 concentrations fell to 450 ppm (±100 ppm), indicating a danger zone when concentrations of CO_2 rise within the range of 350–550 ppm (Hansen et al. 2008). Despite uncertainties related to the degree of hysteresis in the relationship between ice growth and ice creation in response to temperature change, the above suggests that raising CO_2 concentration above 350 ppm may lead to crossing a threshold that results in the eventual disappearance of some of the large polar ice sheets, with a higher risk of crossing the threshold as the CO_2 concentration approaches the upper end of the range.

The contemporary climate is thus moving out of the envelope of Holocene variability, sharply increasing the risk of dangerous climate change. Observations of a climate transition include a rapid retreat of summer sea ice in the Arctic Ocean (Johannessen 2008), retreat of mountain glaciers around the world (IPCC 2007a), loss of mass from the Greenland and West Antarctic ice sheets (Cazenave 2006), an increased rate of sea-level rise in the last 10–15 years (Church and White 2006), a 4° latitude pole-ward shift of subtropical regions (Seidel and Randel 2006), increased bleaching and mortality in coral reefs (Bellwood et al. 2004, Stone 2007), a rise in the number of large floods (Milly et al. 2002, MEA 2005a), and the activation of slow feedback processes like the weakening of the oceanic carbon sink (Le Quéré et al. 2007).

The present equivalence of the boundary for CO_2 and net radiative forcing arises because the cooling effect of aerosols counteracts the warming effect of non-CO_2 greenhouse gases (IPCC 2007a, Ramanathan and Feng 2008). However, these non-CO_2 forcings could change in future, necessitating an adjustment to the CO_2 boundary.

Ocean Acidification

Ocean acidification poses a challenge to marine biodiversity and the ability of oceans to continue to function as a sink of CO_2 (currently removing roughly 25% of human emissions). The atmospheric removal process includes both dissolution of CO_2 into seawater, and the uptake of carbon by marine organisms. The ocean absorption of anthropogenic CO_2 is not evenly distributed spatially (Sabine et al. 2004) or temporally (Canadell et al. 2007).

Addition of CO_2 to the oceans increases the acidity (lowers pH) of the surface seawater. Many marine organisms are very sensitive to changes in ocean CO_2 chemistry—especially those biota that use carbonate ions dissolved in the seawater to form protective calcium carbonate shells or skeletal structures. Surface ocean pH has decreased by about 0.1 pH units (corresponding to a 30% increase in hydrogen ion concentration and a 16% decline in carbonate concentrations) since pre-industrial times (Guinotte et al. 2003, Feely et al. 2004, Orr et al. 2005, Guinotte and Fabry 2008, Doney et al. 2009). This rate of acidification is at least 100 times faster than at any other time in the last 20 million years.

Marine organisms secrete calcium carbonate primarily in the forms of aragonite (which is produced by corals, many mollusks, and other marine life) and calcite (which is produced by different single-celled plankton and other groups). Aragonite is about 50% more soluble in seawater than calcite (Mucci 1983). Thus, with rising ocean acidity, aragonite shells are expected to dissolve before those made of calcite unless the organism has evolved some mechanism to prevent shell dissolution. A third type of biogenic calcium carbonate, high magnesium calcite, is secreted by some marine life such as coralline red algae and sea urchins. Depending on its magnesium concentration, high magnesium calcite can be more soluble in seawater than aragonite. For all three of these types of calcium carbonate, the carbonate ion concentration strongly affects the saturation state of the mineral in seawater. If the pH of the oceans decreases sufficiently, the concomitant reduction in carbonate ion concentration results in a decrease in the seawater saturation state with respect to either aragonite or calcite. If the calcium carbonate saturation state is less than one, then calcium carbonate produced by marine organisms to make their solid shells becomes soluble unless the organism has some way of preventing dissolution (Feely et al. 2004, Fabry et al. 2008).

Globally, the surface ocean aragonite saturation state (Ω_{arag}) is declining with rising ocean acidity. It has fallen from a pre-industrial value of Ω_{arag} = 3.44 to a current value of 2.9. A Ω_{arag} value of 2.29 is projected for a doubling of CO_2 (Guinotte and Fabry 2008). Even though globally averaged Ω_{arag} values in surface waters remain above unity for a doubling of atmospheric CO_2, large parts of the Southern Ocean and the Arctic Ocean are projected to become undersaturated with respect to aragonite as early as 2030–2060 (Orr et al. 2005, McNeil and Matear 2008, Steinacher et al. 2009). Aragonite undersaturation means that these waters will become corrosive to the aragonite and high-magnesium calcite shells secreted by a wide variety of marine organisms. The projected rate of change in ocean CO_2 chemistry leaves little time for organisms to evolve adaptations. Although some species may be CO_2 insensitive or able to adapt (e.g., Miller et al. 2009), the energetic costs of achieving net shell growth and preventing dissolution in conditions of aragonite undersaturation will likely have other impacts on overall growth rates, predation, metabolism, or reproduction, as observed in organisms from other regions (e.g., Iglesias-Rodriguez et al. 2008, Fabry et al. 2008, Wood et al. 2008, Tunnicliffe et al. 2009).

The large-scale depletion of aragonite-forming organisms would be a major disturbance in marine ecosystems, the consequences and impacts of which are highly uncertain. Deleterious effects on many marine organisms start well above the geochemical threshold of Ω_{arag} = 1, with calcification rates for some organisms being reduced by 10%–60% for a doubling of atmospheric CO_2 (Guinotte and Fabry 2008, Fabry et al. 2008). Even small sensitivities of biota to increased CO_2 will become amplified over successive generations and may drive the restructuring of diverse marine ecosystems, the consequences of which are very difficult to predict (Fabry 2008). Furthermore, by the year 2200, under a business-as-usual scenario for fossil-fuel consumption, the reduction in seawater pH and phytoplankton could induce a large reduction in the export of marine organic matter from coastal waters leading to considerable expansion of hypoxic zones (Hofmann and Schellnhuber 2009).

Ocean acidification may have serious impacts on coral reefs and associated ecosystems. Coral reefs are in danger of being exposed to marginal conditions (Ω_{arag} values between 3–3.5) or extremely marginal conditions (Ω_{arag} values below 3) almost everywhere by as early as 2050 (Kleypas et al. 1999, Guinotte et al. 2003, Langdon and Atkinson 2005, Hoegh-Guldberg et al. 2007), causing substantial changes in species composition and in the dynamics of coral and other reef communities (Kuffner et al. 2008, Guinotte and Fabry 2008, Doney et al. 2009). Similarly, marine plankton are also vulnerable (Riebesell et al. 2000), presumably with ripple effects up the food chain. Ocean acidification and warming combine and interact to decrease the productivity in coral reefs (Anthony et al. 2008), reinforcing the notion that multiple stressors on coral reefs often combine to have negative effects that are well beyond those expected from any single stressor (Bellwood et al. 2004).

Although the threshold for aragonite saturation is easy to define and quantify, significant questions remain as to how far from this threshold the boundary value should be set. Combining estimates of the point at which calcification rates begin to be affected substantially, the values of aragonite saturation state at which conditions for corals go from adequate to marginal, and the point at which surface waters at high latitudes begin to approach aragonite undersaturation suggests a placement of the ocean acidification boundary well away from the aragonite saturation state at dissolution (Ω_{arag} = 1). As a first estimate, we propose a planetary boundary where oceanic aragonite saturation state is maintained at 80% or higher of the average global pre-industrial surface seawater Ω_{arag} of 3.44. Recognizing that carbonate chemistry can be variable over diel and seasonal timescales (Tyrrell et al. 2008, Feely et al. 2008, Miller et al. 2009), we suggest that the typical diel and seasonal range of values of aragonite saturation state be incorporated into this boundary (i.e., >80% of the average surface ocean, pre-industrial aragonite saturation state ± diel and seasonal variability). The major rationale behind this subjective value is twofold: to keep high-latitude surface waters above aragonite undersaturation and to ensure adequate conditions for most coral systems.

Stratospheric Ozone Depletion

Stratospheric ozone filters ultraviolet radiation from the sun. The appearance of the Antarctic ozone hole was a textbook example of a threshold in the Earth System being crossed—completely unexpectedly. A combination of increased concentrations of anthropogenic ozone-depleting substances (like chlorofluorocarbons) and polar stratospheric clouds moved the Antarctic stratosphere into a new regime: one in which ozone effectively disappeared in the lower stratosphere in the region during the Austral spring. This thinning of the Austral polar stratospheric ozone layer has negative impacts on marine organisms (Smith et al. 1992) and poses risks to human health. Although it does not appear that there is a similar threshold for global ozone, there is the possibility that global warming (which leads to a cooler stratosphere) could cause an increase in the formation of polar stratospheric clouds. Were this to happen in the Arctic region, it could trigger ozone holes over the northern hemisphere continents, with potential impacts on populations there.

Although the ozone hole phenomenon is a classic example of a threshold, we have chosen to frame the planetary boundary around extra-polar stratospheric ozone. There are two main reasons for this framing. First, the ozone hole “tipping point” depends on anthropogenic ozone-depleting substances, but also on sufficiently cold temperatures and a sufficient amount of water vapor and, in some cases, nitric acid. Humans contribute directly to the first (and to some extent the last) of these, and indirectly to the others. Second, although polar ozone holes have local impacts, a thinning of the extra-polar ozone layer would have a much larger impact on humans and ecosystems.

In the case of global, extra-polar stratospheric ozone, there is no clear threshold around which to construct a boundary. As such, the placement of our boundary in this case is of necessity more uncertain than, for example, in the case of ocean acidification. We consider the planetary boundary for ozone levels to be a <5% decrease in column ozone levels for any particular latitude with respect to 1964–1980 values (Chipperfield et al. 2006).

Fortunately, because of the actions taken as a result of the Montreal Protocol (and its subsequent amendments), we appear to be on a path that avoids transgression of this boundary. In 2005, the tropospheric concentrations of ozone-depleting gases had decreased by 8%–9% from their peak values in 1992–1994 (Clerbaux et al. 2006). Although there is a considerable lag time between concentration decreases in the troposphere and stratospheric ozone recovery, at least the major anthropogenic driver of ozone depletion is being reduced. The decline in stratospheric ozone concentrations between 60°S and 60°N seen since the 1990s has been halted (Chipperfield et al. 2006). However, the Antarctic ozone hole is expected to exist for some decades, and Arctic ozone losses may continue for the next decade or two. On balance, the case of stratospheric ozone is a good example where concerted human effort and wise decision making seem to have enabled us to stay within a planetary boundary.

Interference with the Global Phosphorus and Nitrogen Cycles

Local to regional-scale anthropogenic interference with the nitrogen cycle and phosphorus flows has induced abrupt shifts in lakes (Carpenter 2005) and marine ecosystems (e.g., anoxia in the Baltic sea) (Zillén et al. 2008). Eutrophication due to human-induced influxes of nitrogen (N) and phosphorus (P) can push aquatic and marine systems across thresholds, generating abrupt non-linear change from, for example, a clear-water oligotrophic state to a turbid-water eutrophic state (Carpenter et al. 1999). Shifts between such alternate stable states depend on complex interactions between N and P flows and on the prevailing biogeochemical setting. Human-induced degradation of ecosystem states (e.g., overfishing, land degradation) and increase in N and P flows at regional to global scales may cause undesired non-linear change in terrestrial, aquatic, and marine systems, while simultaneously functioning as a slow driver influencing anthropogenic climate change at the planetary level.

We cannot exclude the possibility that the N and P cycles should, in fact, be separate planetary boundaries in their own right. They both influence, in complex and non-linear ways, human life-support systems at regional scales, and both have significant aggregate planetary impacts, which makes them key processes of the Anthropocene. The reason to keep them as one boundary in this paper is primarily the close interactions between N and P as key biological nutrients in driving abrupt shifts in sub-systems of the Earth.

Human modification of the N cycle is profound (Galloway and Cowling 2002, Gruber and Galloway 2008). Human activities now convert more N_2 from the atmosphere into reactive forms than all of the Earth's terrestrial processes combined. Human-driven conversion occurs primarily through four processes: industrial fixation of atmospheric N_2 to ammonia (~80 Mt N yr^{-1}); agricultural fixation of atmospheric N_2 via cultivation of leguminous crops (~40 Mt N yr^{-1}); fossil-fuel combustion (~20 Mt N yr^{-1}); and biomass burning (~10 Mt N yr^{-1}). Although the primary purpose of most of this new reactive N is to enhance food production via fertilization, much reactive N eventually ends up in the environment—polluting waterways and coastal zones, adding to the local and global pollution burden in the atmosphere, and accumulating in the biosphere. Efforts to limit N pollution have, to date, been undertaken at local and regional scales only—for example, by limiting the concentration of nitrate in groundwater or the emission of nitric oxides to urban airsheds.

At the global scale, the addition of various forms of reactive N to the environment acts primarily as a slow variable, eroding the resilience of important sub-systems of the Earth System. The exception is nitrous oxide, which is one of the most important greenhouse gases and thus acts as a systemic driver at the planetary scale. Nitrous oxide is included in the climate-change boundary by applying radiative forcing (maximum + 1 W m^{-2} of anthropogenic forcing) as the control variable.

For the other forms of reactive N, setting a planetary boundary is not straightforward. The simplest and most direct approach is to consider the human fixation of N_2 from the atmosphere as a giant valve that controls a massive flow of new reactive N into the Earth System. The boundary can then be set by using that valve to control the amount of additional reactive N flowing into the Earth System. We suggest that the boundary initially be set at approximately 25% of its current value, or to about 35 Mt N yr^{-1}. We emphasize that this is a first guess only. Much more research and synthesis of information is required to enable a more informed boundary to be determined.

Even this initial boundary would greatly reduce the amount of reactive N pushed into land, ocean, and atmospheric systems. It would eliminate the current flux of N onto the land and could trigger much more efficient and less polluting ways of enhancing food production. It would almost surely also trigger the return of N in human effluent back onto productive landscapes, thus further reducing the leakage of reactive N into ecosystems.

Although N forms part of a biological global cycle, P is a finite fossil mineral mined for human use and added naturally into the Earth System through geological weathering processes. The crossing of a critical threshold of P inflow to the oceans has been suggested as the key driver behind global-scale ocean anoxic events (OAE), potentially explaining past mass extinctions of marine life (Handoh and Lenton 2003). The dynamics between bi-stable oxic and anoxic conditions is believed to be induced by positive feedbacks between anoxia, P recycling from sediments, and marine productivity.

Modeling suggests that a sustained increase of P inflow to the oceans exceeding 20% of the natural background weathering rate could have been enough to induce past OAEs (Handoh and Lenton 2003). Assuming a relatively low estimate of "pre-agricultural" P input to the oceans of 1.1 Mt yr^{-1} (3.5 E10 mol P yr^{-1}), this increased inflow corresponds to only ~225,000 tonnes P yr^{-1} (0.72 E10 mol P yr^{-1}). Of the global human extraction of ~20 Mt yr^{-1} of P, an estimated 10.5 Mt yr^{-1} is lost from the world's cropland, the primary source of P inflow to the oceans. The increase of reactive P to the oceans from human activities has been estimated (year 2000) at ~9 Mt yr^{-1} (8.5–9.5 Mt yr^{-1} depending on how detergent and sewage effluent fluxes are handled) (Mackenzie et al. 2002). Despite a substantial increase in anthropogenic P inflow to oceans (up to 8–9 times higher than the natural background rate), it remains highly uncertain whether and, if so, when anthropogenic P inflow could reach a point where a human-induced OAE would be triggered. For the global deep ocean to shift to an anoxic state requires strong recycling of P from sediments as bottom waters become more anoxic, thus fuelling increased productivity and amplifying the initial change in a positive feedback loop. In existing models, the resulting dynamics have a 10 000-year timescale due to the long residence time of deep ocean P (Lenton et al. 2008). Furthermore, even though humans have greatly accelerated the inflow of P to the oceans, it would still take in the order of 10 000 years to double P in the oceans. This suggests that for humans to trigger an OAE should still be over 1000 years away, thus shifting it down the list in our current sphere. Our tentative modeling analyses, using the model by Handoh and Lenton (2003), show that a 10-fold increase of P inflow to the oceans (i.e., slightly higher than the current level), if sustained for 1000 years, would raise the anoxic fraction of the ocean from 0.14 to 0.22. Current estimates of available phosphate rock reserves (up to 20 Gt of P) suggest that such an input could not be sustained for more than 1000 years. Even if P inflows were then returned to pre-industrial levels, the anoxic fraction would continue to rise for another 1000 years. However, a complete OAE (anoxic fraction of 1) would be avoided. It is uncertain what qualitative changes and regional state changes such a sustained inflow would trigger, however, current evidence suggests that it would induce major state changes at local and regional levels, including widespread anoxia in some coastal and shelf seas.

There are very large uncertainties in these analyses, due to the complex interactions between oxic-anoxic states, different forms of P in marine systems, and interactions between abiotic and biotic conditions in the oceans (not least driven by the other planetary boundaries of ocean acidification, N inflow, marine biodiversity, and climate change). Hence it is difficult to precisely quantify a planetary boundary of P inflow to the oceans that places humanity at a safe distance from triggering deleterious, widespread ocean anoxia. The problem is partly one of defining what is deleterious, given (current) observations of abrupt P-induced regional anoxic events.

We suggest that, at the very least, a boundary level should be set that (with current knowledge) allows humanity to safely steer away from the risk of triggering an OAE even over longer time horizons (>1000 years). This in turn may require that anthropogenic P inflow to the ocean is not allowed to exceed a human-induced level of ~10 times the natural background rate of ~1 Mt P yr^{-1}. This is higher than the proposed trigger rate of past OAEs, but a level that is believed to create a safe long-term (over centuries) global operating space. The proposed planetary boundary for anthropogenic P inflow to the oceans is thus tentatively placed at <10 times (<10×) the natural background weathering flux of P, with an equally tentative uncertainty range (<10×–<100×).

Rate of Biodiversity Loss

Like land-system change (see below), local and regional biodiversity changes can have pervasive effects on Earth System functioning and interact with several other planetary boundaries. For example, loss of biodiversity can increase the vulnerability of terrestrial and aquatic ecosystems to changes in climate and ocean acidity, thus reducing the safe boundary levels for these processes.

The current and projected rates of biodiversity loss constitute the sixth major extinction event in the history of life on Earth—the first to be driven specifically by the impacts of human activities on the planet (Chapin et al. 2000). Previous extinction events, such as the Tertiary extinction of the dinosaurs and the rise of mammals, caused massive permanent changes in the biotic composition and functioning of Earth's ecosystems. This suggests non-linear and largely irreversible consequences of large-scale biodiversity loss.

Accelerated biodiversity loss during the Anthropocene (Mace et al. 2005) is particularly serious, given growing evidence of the importance of biodiversity for sustaining ecosystem functioning and services and for preventing ecosystems from tipping into undesired states (Folke et al. 2004). A diversity of functional response mechanisms to environmental variation among species in an ecosystem maintains resilience to disturbances. Consequently, ecosystems (both managed and unmanaged) with low levels of response diversity within functional groups are particularly vulnerable to disturbances (such as disease) and have a greater risk of undergoing catastrophic regime shifts (Scheffer and Carpenter 2003).

Species play different roles in ecosystems, in the sense of having different effects on ecosystem processes and/or different responses to shifts in the physical or biotic environment (i.e., they occupy different niches). Species loss, therefore, affects both the functioning of ecosystems and their potential to respond and adapt to changes in physical and biotic conditions (Elmqvist et al. 2003, Suding et al. 2008).

Currently, the global extinction rate far exceeds the rate of speciation, and consequently, loss of species is the primary driver of changes in global biodiversity. The average extinction rate for marine organisms in the fossil record is 0.1 to 1 extinctions per million species-years (E/MSY), and extinction rates of mammals in the fossil record also fall within this range (Pimm et al. 1995, Mace et al. 2005). Accelerated species loss is increasingly likely to compromise the biotic capacity of ecosystems to sustain their current functioning under novel environmental and biotic circumstances (Walker et al. 1999).

Since the advent of the Anthropocene, humans have increased the rate of species extinction by 100–1000 times the background rates that were typical over Earth's history (Mace et al. 2005), resulting in a current global average extinction rate of ≥100 E/MSY. The average global extinction rate is projected to increase another 10-fold, to 100010 000 E/MSY during the current century (Mace et al. 2005). Currently about 25% of species in well-studied taxonomic groups are threatened with extinction (ranging from 12% for birds to 52% for cycads). Until recently, most extinctions (since 1500) occurred on oceanic islands. In the last 20 years, however, about half of the recorded extinctions have occurred on continents, primarily due to land-use change, species introductions, and increasingly climate change, indicating that biodiversity is now broadly at risk throughout the planet.

The lower and upper bounds of extinction rates in the fossil record (0.1–1.0 E/MSY with a median rate for mammals estimated at 0.3 E/MSY) provide the best long-term estimates of the background extinction rates that have historically conserved global biodiversity. A background extinction rate of 1 E/MSY across many taxa has been proposed as a benchmark against which to assess the impacts of human actions (Pimm et al. 2006). There is ample evidence that the current and projected extinction rates are unsustainable (MEA 2005b). Nonetheless, it remains very difficult to define a boundary level for the rate of biodiversity loss that, if transgressed for long periods of time, could result in undesired, non-linear Earth System change at regional to global scales. Our primary reason for including biological diversity as a planetary boundary is its role in providing ecological functions that support biophysical sub-systems of the Earth, and thus provide the underlying resilience of other planetary boundaries. However, our assessment is that science is, as yet, unable to provide a boundary measure that captures, at an aggregate level, the regulating role of biodiversity. Instead we suggest, as an interim indicator, using extinction rate as a substitute. In doing so, we conclude that humanity has already entered deep into a danger zone where undesired system change cannot be excluded, if the current greatly elevated extinction rate (compared with the natural background extinction) is sustained over long periods of time. We suggest an uncertainty range for this undesired change of 10–100 E/MSY, indicating that a safe planetary boundary (here placed at 10 E/MSY) is an extinction rate within an order of magnitude of the background rate. This relatively safe boundary of biodiversity loss is clearly being exceeded by at least one to two orders of magnitude, indicating an urgent need to radically reduce biodiversity loss rates (Díaz et al. 2005). A major caveat in setting a safe extinction rate is the common observation that species are not equally important for ecosystem function. In particular, the loss of top predators and structurally important species, such as corals and kelp, results in disproportionately large impacts on ecosystem dynamics.

Global Freshwater Use

The global freshwater cycle has entered the Anthropocene (Meybeck 2003) because humans are now the dominant driving force altering global-scale river flow (Shiklomanov and Rodda 2003) and the spatial patterns and seasonal timing of vapor flows (Gordon et al. 2005). An estimated 25% of the world's river basins run dry before reaching the oceans due to use of freshwater resources in the basins (Molden et al. 2007).

Global manipulations of the freshwater cycle affect biodiversity, food, and health security and ecological functioning, such as provision of habitats for fish recruitment, carbon sequestration, and climate regulation, undermining the resilience of terrestrial and aquatic ecosystems. Threats to human livelihoods due to deterioration of global water resources are threefold: (i) the loss of soil moisture resources (green water) due to land degradation and deforestation, threatening terrestrial biomass production and sequestration of carbon, (ii) use and shifts in runoff (blue water) volumes and patterns threatening human water supply and aquatic water needs, and (iii) impacts on climate regulation due to decline in moisture feedback of vapor flows (green water flows) affecting local and regional precipitation patterns.

Estimates indicate that 90% of global green water flows are required to sustain critical ecosystem services (Rockström et al. 1999), whereas 20%–50% of the mean annual blue water flows in river basins are required to sustain aquatic ecosystem functioning (Smakhtin 2008).

Water-induced thresholds at the continental or planetary scale may be crossed as a result of aggregate sub-system impacts at local (e.g., river basin) or regional (e.g., monsoon system) scales (Fig. 4) caused both by changes in water resource use and climate change-induced shifts in the hydrological cycle.

Green water flows influence, at the regional scale, rainfall levels through moisture feedback and, thereby, the availability of blue water resources. Green water-induced thresholds include collapse of biological sub-systems as a result of regional drying processes. Examples include the abrupt change from a wet to a dry stable state in the Sahel region approximately 5000–6000 years BP (Scheffer et al. 2001, Foley et al. 2003) and the future risk of a rapid savannization of the Amazon rainforest due to abrupt decline in moisture feedback (Oyama and Nobre 2003). Blue water-induced thresholds include collapse of riverine habitats if minimum environmental water flow thresholds are crossed (Smakhtin 2008) and the collapse of regional lake systems (such as the Aral Sea).

A planetary boundary for freshwater resources must thus be set to safely sustain enough green water flows for moisture feedback (to regenerate precipitation), allow for the provisioning of terrestrial ecosystem functioning and services (e.g., carbon sequestration, biomass growth, food production, and biological diversity), and secure the availability of blue water resources for aquatic ecosystems. Thresholds related to moisture feedbacks occur “upstream” of and impact directly on runoff water flows. The close interactions between land and water, and between vapor flows and runoff, make it difficult to define an appropriate freshwater boundary that captures the complexity of rainfall partitioning across scales. However, as a first attempt, we propose runoff depletion in the form of consumptive runoff or blue water use as a proxy for capturing the full complexity of global freshwater thresholds.

The upper limit of accessible blue water resources is estimated at ~12 500–15 000 $km^3\ yr^{-1}$ (Postel 1998, DeFraiture et al. 2001). Physical water scarcity is reached when withdrawals of blue water exceed 5000–6000 $km^3\ yr^{-1}$ (Raskin et al. 1997, Vörösmarty et al. 2000, DeFraiture et al. 2001). Based on the global assessments of impacts of global green and blue water use (see Appendix 1, Supplementary Discussion 4), we estimate that transgressing a boundary of ~4,000 $km^3\ yr^{-1}$ of consumptive blue water use (with a zone of uncertainty of 4000–6000 $km^3\ yr^{-1}$) will significantly increase the risk of approaching green and blue water-induced thresholds (collapse of terrestrial and aquatic ecosystems, major shifts in moisture feedback, and freshwater/ocean mixing) at regional to continental scales. Currently, withdrawals of blue water amount to ~4,000 $km^3\ yr^{-1}$ (Oki and Kanae 2006) whereas consumptive use is ~2,600 $km^3\ yr^{-1}$ (Shiklomanov and Rodda 2003), leaving humanity with some room for maneuvering. However, the pressure on global freshwater resources is growing rapidly, mainly due to increasing food demands. Green water use in rainfed agriculture, currently estimated at ~5000 $km^3\ yr^{-1}$, may have to increase by 50% by 2030 to ~7500 km^3/yr, in order to ensure food security (Rockström et al. 2007), whereas consumptive blue water use for irrigation may increase by 25%–50%, corresponding to 400–800 $km^3\ yr^{-1}$ by 2050 (Comprehensive Assessment of Water Management in Agriculture 2007). This indicates that the remaining safe operating space for water may be largely committed already to cover necessary human water demands in the future.

Land-System Change

Land-system change, driven primarily by agricultural expansion and intensification, contributes to global environmental change, with the risk of undermining human well-being and long-term sustainability (Foley et al. 2005, MEA 2005a).

Conversion of forests and other ecosystems to agricultural land has occurred at an average rate of 0.8% yr^{-1} over the past 40–50 years and is the major global driver behind loss of ecosystem functioning and services (MEA 2005a). Humanity may be reaching a point where further agricultural land expansion at a global scale may seriously threaten biodiversity and undermine regulatory capacities of the Earth System (by affecting the climate system and the hydrological cycle).

As a planetary boundary, we propose that no more than 15% of the global ice-free land surface should be converted to cropland. Because this boundary is a complex global aggregate, the spatial distribution and intensity of land-system change is critically important for the production of food, regulation of freshwater flows, and feedbacks to the functioning of the Earth System. In setting a terrestrial land boundary in terms of changes in cultivated area, we acknowledge the limitations this metric entails given the tight coupling with the other boundaries of P and N use, rate of biodiversity loss, and global freshwater use.

For humanity to stay within this boundary, cropland should be allocated to the most productive areas, and processes that lead to the loss of productive land, such as land degradation, loss of irrigation water, and competition with land uses such as urban development or biofuel production, should be controlled. Demand-side processes may also need to be managed; these include diet, per capita food consumption, population size, and wastage in the food distribution chain. Agricultural systems that better mimic natural processes (e.g., complex agro-ecosystems) could also allow an extension of this boundary (Ericksen et al. 2009).

Although the effects of land-system change act as a slow variable that influences other boundaries, such as biodiversity, water, and climate, they can also trigger rapid changes at the continental scale when land-cover thresholds are crossed. For example, conversion of the Amazon rainforest into cultivated or grazing systems may reach a level where an additional small amount of conversion would tip the basin into an irreversible transformation to a semi-arid savanna (Oyama and Nobre 2003, Foley et al. 2007). At the global scale, if enough high-productivity land is lost to degradation, biofuel production, or urbanization, food production may spread into marginal lands with lower yields and a higher risk of degradation. This may constitute a threshold where a small increment of additional food production may trigger an accelerating increase in cultivated land.

The land-system boundary should be implemented at multiple scales through a fine-grained global land architecture (Turner 2009) that (i) reserves the most productive land for agricultural use, (ii) maintains high conservation-value forests and other ecosystems in their current states, and (iii) maintains carbon-rich soils and ecosystems in their undisturbed or carefully managed condition.

About 12% of the global land surface is currently under crop cultivation (Foley et al. 2005, Ramankutty et al. 2008). The allowed 3% expansion (approximately 400 Mha) to the level we propose as a land-system boundary will most likely be reached over the coming decades and includes suitable land that is not either currently cultivated or is under forest cover—e.g., abandoned cropland in Europe, North America, and the former Soviet Union and some areas of Africa's savannas and South America's cerrado.

Aerosol Loading

We consider atmospheric aerosol loading as an anthropogenic global change process with a potential planetary boundary for two main reasons: (i) the influence of aerosols on the climate system and (ii) their adverse effects on human health at a regional and global scale.

Human activities since the pre-industrial era have doubled the global concentration of most aerosols (Tsigaridis et al. 2006). Aerosols[iii] influence the Earth's radiation balance directly by scattering incoming radiation back to space (Charlson et al. 1991, 1992) or indirectly by influencing cloud reflectivity and persistence (Twomey 1977, Albrecht 1989). Aerosols can also influence the hydrological cycle by altering the mechanisms that form precipitation in clouds (Ferek et al. 2000, Rosenfeld 2000). Aerosols may have a substantial influence on the Asian monsoon circulation (Ramanathan et al. 2005, Lau et al. 2008): absorbing aerosols over the Indo-Gangetic plain near the foothills of the Himalayas act as an extra heat source aloft, enhancing the incipient monsoon circulation (Lau and Kim 2006). The same aerosols lead to a surface cooling over central India, shifting rainfall to the Himalayan region. This "elevated heat pump" causes the monsoon rain to begin earlier in May–June in northern India and the southern Tibetan plateau, increases monsoon rainfall over all of India in July–August, and reduces rainfall over the Indian Ocean. Although the influences of aerosols on the Asian monsoon are widely accepted, there is still a great deal of uncertainty surrounding the physical processes underlying the effects and the interactions between them.

>From the perspective of human-health effects, fine particulate air pollution ($PM_{2.5}$) is responsible for about 3% of adult cardiopulmonary disease mortality, about 5% of tracheal, bronchial, and lung cancer mortality, and about 1% mortality from acute respiratory infection in children in urban areas worldwide (Cohen et al. 2005). These effects convert to about 800 000 premature deaths and an annual loss of 6.4 million life years, predominantly in developing Asian countries. Mortality due to exposure to indoor smoke from solid fuels is about double that of urban air pollution (roughly 1.6 million deaths), and exposure to occupational airborne particulates accounts for roughly 300 000 deaths per year, mainly in developing countries.

The same aerosol components (e.g., particulates, tropospheric ozone, oxides of sulphur and N) lead to other deleterious effects. Crop damage from exposure to ozone, forest degradation and loss of freshwater fish due to acidic precipitation, changes in global precipitation patterns and in energy balance are further examples of indirect effects of air pollution on human well-being.

The complexity of aerosols, in terms of the large variety of particles involved, with different sources, impacts, and spatial and temporal dynamics, makes it difficult to define a planetary boundary above which effects may cause unacceptable change. Additionally, although aerosols have been clearly linked with changes in monsoon circulation and with adverse human-health effects, the processes and mechanisms behind these correlations remain to be fully explained. For these reasons, we conclude that it is not yet possible to identify a safe boundary value for aerosol loading.

Chemical Pollution

Primary types of chemical pollution include radioactive compounds, heavy metals, and a wide range of organic compounds of human origin. Chemical pollution adversely affects human and ecosystem health, which has most clearly been observed at local and regional scales but is now evident at the global scale. Our assessment on why chemical pollution qualifies as a planetary boundary rests on two ways in which it can influence Earth System functioning: (i) through a global, ubiquitous impact on the physiological development and demography of humans and other organisms with ultimate impacts on ecosystem functioning and structure and (ii) by acting as a slow variable that affects other planetary boundaries. For example, chemical pollution may influence the biodiversity boundary by reducing the abundance of species and potentially increasing organisms' vulnerability to other stresses such as climate change (Jenssen 2006, Noyes et al. 2009). Chemical pollution also interacts with the climate-change boundary through the release and global spread of mercury from coal burning and from the fact that most industrial chemicals are currently produced from petroleum, releasing CO_2 when they are degraded or incinerated as waste. There could be even more complex connections between chemical, biodiversity, and climate-change boundaries. For example, climate change will change the distributions of pests, which could lead to increased and more widespread use of pesticides.

Setting a planetary boundary for chemical pollution requires knowledge of the critical impacts on organisms of exposure to myriad chemicals and the threshold concentrations at which these effects occur. Deleterious consequences could be caused by direct exposure to chemicals in the abiotic environment—air, water, or soil—or through bioaccumulation or biomagnification up food chains, which could lead to effects in, for example, top predators.

By current estimates, there are 80 000 to 100 000 chemicals on the global market (U.S. Environmental Protection Agency 1998, Commission of the European Commmunities 2001). It is impossible to measure all possible chemicals in the environment, which makes it very difficult to define a single planetary boundary derived from the aggregated effects of tens of thousands of chemicals. Some toxicity data exist for a few thousand of these chemicals, but there is virtually no knowledge of their combined effects.

We can identify two complementary approaches for defining a planetary boundary for chemical pollution. One is to focus on persistent pollutants with global distributions, and the other to identify unacceptable, long-term, and large-scale effects on living organisms of chemical pollution.

The first approach highlights chemicals such as mercury that are capable of undergoing long-range transport via ocean or atmospheric dynamics. Specifically, it identifies pollutants that have significant effects on a range of organisms at the global scale and the threshold levels associated with these effects. Chronic, low-dose exposure may lead to subtle sub-lethal effects that hinder development, disrupt endocrine systems, impede reproduction, or cause mutagenesis. Often, younger organisms are most vulnerable to exposures to a particular pollutant (e.g., lead neurotoxicity in children). Thresholds can be identified for only a few single chemicals or chemical groups and for only a few biological species, such as some top predators (de Wit et al. 2004, Fisk et al. 2005). A well-known example is the DDT threshold concentration in the eggs of birds of prey that causes critical eggshell thinning and reproductive failure (Lincer 1975).

Although most efforts to reduce chemical pollution have focused on local and regional scales, the 2001 UN Stockholm Convention on Persistent Organic Pollutants (POPs) implicitly recognized that global concentrations of a few specific POPs (e.g., PCB, dioxins, DDT, and several other pesticides) have crossed an, as yet unquantified, planetary boundary. The bans imposed were based on known effects and observed high concentrations of these POPs in some top predators and human populations. Widening the approach from a few well-studied pollutants would require determination of critical effects for each chemical or chemical group, which is a gigantic task and would require identification of thresholds associated with mixtures of chemicals, an equally daunting challenge.

A boundary focusing on effects of chemical pollution, on the other hand, could be based on reduced or failed reproduction, neurobehavioral deficits, or compromised immune systems, which are linked to the combined exposure to many chemicals. Such a planetary boundary would need to cover subtle effects on the most sensitive life stages in the most sensitive species and/or humans, with effects observable at the global scale. An example of this approach has been reviewed based on the suggested increase in neurodevelopmental disorders such as autism and attention deficit and hyperactivity disorder (ADHD) in children. The widespread exposure to low concentrations of multiple chemicals with known or suspected neurotoxic effects may have created a silent pandemic of subtle neurodevelopmental disorders in children, possibly on a global scale (Grandjean and Landrigan 2006). Of the 80 000 chemicals in commerce, 1000 are known to be neurotoxic in experiments, 200 are known to be neurotoxic in humans, and five (methyl mercury, arsenic, lead, PCBs, toluene) are known to be toxic to human neurodevelopment.

Ultimately, a chemical pollution boundary may require setting a range of sub-boundaries based on the effects of many individual chemicals combined with identifying specific effects on sensitive organisms. Furthermore, a chemical pollution boundary interacts with the planetary boundary for aerosols, because many persistent pollutants are transported long distances on aerosol particles. In summary, however, we conclude that it is not possible at this time to define these nor is it clear how to aggregate them into a comprehensive single planetary boundary.

INTERACTIONS AMONG THE BOUNDARIES

Interactions among planetary boundaries may shift the safe level of one or several boundaries, which we have provisionally set under the (strong) assumption that no other boundaries are transgressed. In reality, what may appear as a physical boundary with a clearly defined threshold may change position as a slowly changing variable (without known global thresholds), such as the rate of biodiversity loss, exceeds its boundary level. At the aggregate level, desiccation of land due to water scarcity induced by transgressing the climate boundary, for example, may cause such a large loss of available land for agricultural purposes that the land boundary also shifts downward. At the regional scale, deforestation in the Amazon in a changing climate regime may reduce water resource availability in Asia (see Appendix 1, Supplementary Discussion 5 for other examples), highlighting the sensitivity of the water boundary to changes in the land-use and climate-change boundaries.

Tropical forests are a key component of both the regional and global energy balances and hydrological cycles. In the Amazon basin, a significant amount of the water in the atmosphere is recycled through the vegetation. In addition, the forest produces aerosol particles that can form cloud droplets. Changing particle concentration influences how likely the clouds are to produce rain and the strength of the convective circulation. Deforestation and biomass burning associated with land-use practices have changed convection and precipitation over the Amazon basin (Andreae et al. 2004). These changes in precipitation complete a feedback loop, because the availability of water influences the amount and kind of aerosol particles that the vegetation emits (Kesselmeier et al. 2000). Such interacting processes driven by change in land use and climate could reach a tipping point where the Amazon forest is replaced by savanna-like vegetation by the end of the 21st century (Nepstad et al. 2008).

This feedback loop is not limited to regional effects; it can also influence surface temperatures as far away as Tibet (see Fig. 5). Model simulations predict that large-scale deforestation in the northern Amazon would drastically change the surface energy balance, leading to a weakening of deep convection (Snyder et al. 2004a,b). This, in turn, would drive a weakening and northward shift in the Inter-Tropical Convergence Zone, which causes changes in the jet stream that directs the trajectory of mid-latitude weather systems, ultimately influencing surface temperature and precipitation in Tibet.

Changes in climatic conditions in Tibet directly affect much of Asia's water resources. The 15 000 glaciers in the Himalaya-Hindu Kush region store an estimated 12 000 km^3 of freshwater, which is a main source of freshwater for roughly 500 million people in the region, plus an additional 250 million people in China (Cruz et al. 2007). Glacier melting, initially causing short-term increases in runoff, leads to increased flood risks, seasonal shifts in water supply, and increasing variability in precipitation. Although the calculated land-cover changes discussed here are extreme, the results illustrate that changes in the global climate system driven by land-use change in one region can affect water resources in other parts of the planet.

Although we have not analyzed the interactions among planetary boundaries, the examples we present suggest that many of these interactions will reduce rather than expand the boundary levels we propose, thereby shrinking the safe operating space for humanity. This suggests the need for extreme caution in approaching or transgressing any individual planetary boundaries.

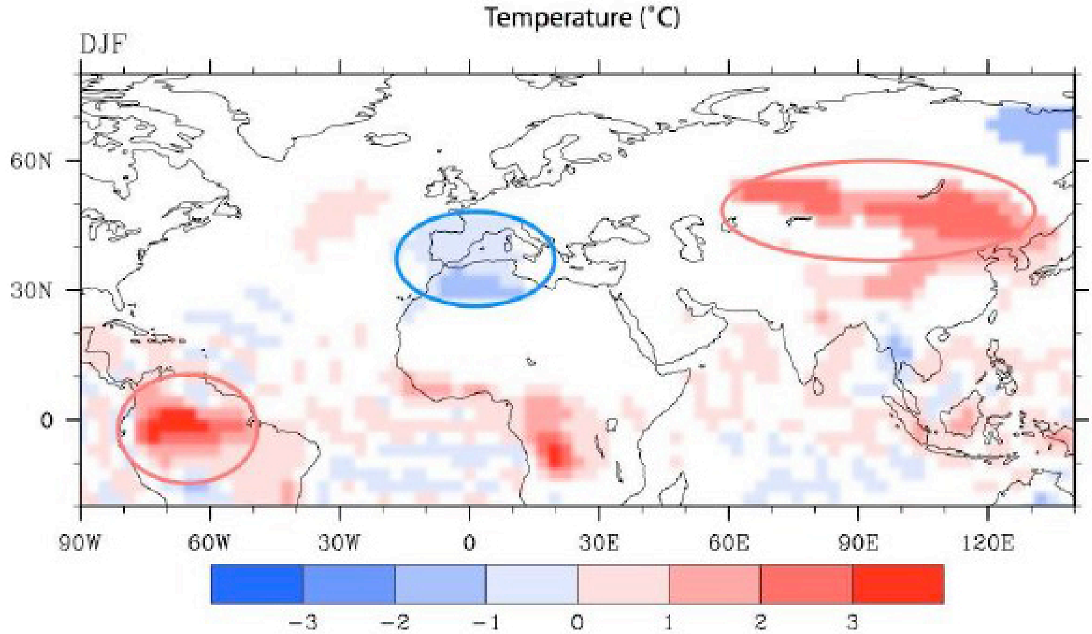
HUMANITY HAS ALREADY TRANSGRESSED AT LEAST THREE PLANETARY BOUNDARIES

We have attempted to quantify the temporal trajectory of seven of the proposed planetary boundaries from pre-industrial levels to the present (Fig. 6) (see Appendix 1, Supplementary Methods 2 for data sources and data treatment). The acceleration of the human enterprise since the 1950s, particularly the growth of fertilizer use in modern agriculture, resulted in the transgression of the boundary for the rate of human interference with the global nitrogen cycle. Aggregate data over longer time periods for the biodiversity boundary are not available, but the boundary definition proposed here is greatly exceeded (even out of scale in Fig. 6, illustrated by the shading). We are not suggesting that the current state of biodiversity has passed a boundary. We are saying that the world cannot sustain the current rate of loss of species without resulting in functional collapses. It was not until the 1980s that humanity approached the climate boundary, but the trend of higher atmospheric CO_2 concentration shows no signs of slowing down. In contrast, as a result of the signing of the Montreal Protocol, humanity succeeded in reversing the trend with regard to the stratospheric ozone boundary in the 1990s. As seen from Fig. 6, our estimates indicate that humanity is approaching, moreover at a rapid pace, the boundaries for freshwater use and land-system change. The ocean acidification boundary is at risk, although there is a lack of time-series data for the selected boundary variable, as well as information on the response of marine organisms and ecosystems to the projected CO_2 perturbation.

DISCUSSION

There are, as far as we have determined in this proof-of-concept paper, nine planetary boundaries. On condition that these are not transgressed for too long, humanity appears to have freedom to maneuver in the pursuit of long-term social and economic development within the stability domain provided by the observed resilience of the Earth System in the Holocene.

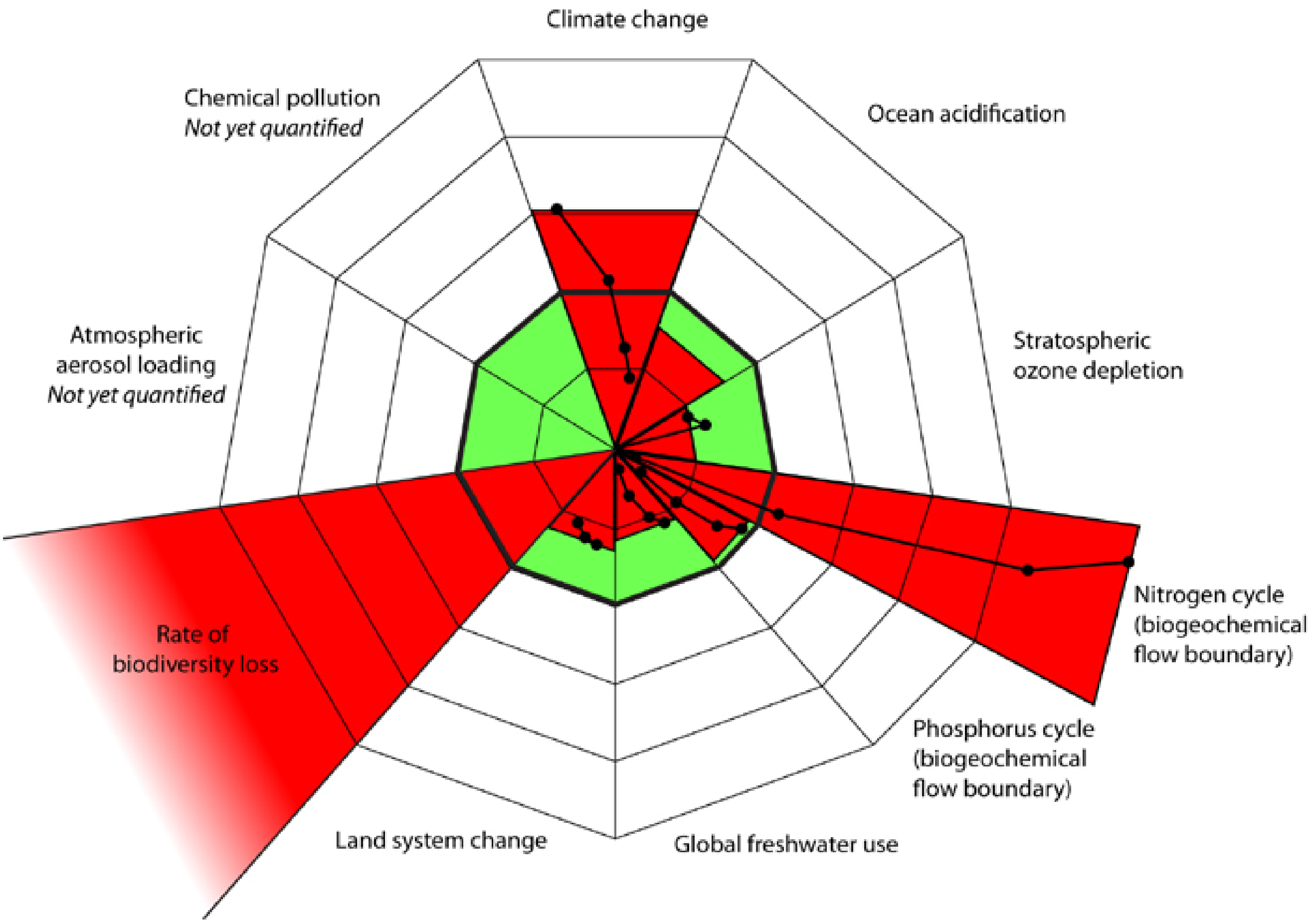
Fig. 5. Simulated global surface temperature changes as a result of converting the tropical forest basins of the Amazon, Africa, and the Indian archipelago from rainforest to bare ground. In this simulation, changes in the tropical forest vegetation cover of the Amazon cause widespread temperature changes in the region, but also significant tele-connections to other parts of the world, including western Europe and central Asia. This simulation was performed by the CCM3 climate model, coupled to the IBIS land surface / ecosystem model (Snyder et al. 2004a,b).



A planetary boundaries framework provides a new challenge for Earth System science and may have profound impacts on environmental governance from local to global scales. Many knowledge gaps remain, however, to implement a planetary boundaries framework. As indicated for several boundaries, they present a spatial variability and a patchiness both in terms of impacts (of transgressing a boundary level) and in terms of feedback mechanisms, which may require a widened approach combining both global and regional boundary estimates. Moreover, we are only able to quantify three with some confidence. Four are tentative suggestions, some of them only our best guesses based on the current state of knowledge. Transgressing one boundary may, furthermore, seriously threaten the ability to stay within safe levels for other boundaries. This means that no boundary can be transgressed for long periods without jeopardizing the safe operating space for humanity. Humanity thus needs to become an active steward of all planetary boundaries—the nine identified in this paper and others that may be identified in the future—in order to avoid risk of disastrous long-term social and environmental disruption.

The knowledge gaps are disturbing. There is an urgent need to identify Earth System thresholds, to analyze risks and uncertainties, and, applying a precautionary principle, to identify planetary boundaries to avoid crossing such undesired thresholds. Current governance and management paradigms are often oblivious to or lack a mandate to act upon these planetary risks (Walker et al. 2009), despite the evidence of an acceleration of anthropogenic pressures on the biophysical processes of the Earth System. Moreover, the planetary boundary framework presented here suggests the need for novel and adaptive governance

Fig. 6. Estimate of quantitative evolution of control variables for seven planetary boundaries from pre-industrial levels to the present (see Appendix 1, Supplementary Methods 2 for details). The inner (green) shaded nonagon represents the safe operating space with proposed boundary levels at its outer contour. The extent of the wedges for each boundary shows the estimate of current position of the control variable (see Table 2). Points show the estimated recent time trajectory (1950–present) of each control variable. For biodiversity loss, the estimated current boundary level of >100 extinctions per million species-years exceeds the space available in the figure. Although climate change, ocean acidification, stratospheric ozone depletion, land-use change, freshwater use, and interference with the phosphorus cycle are boundaries defined as the state of a variable (concentration of atmospheric CO_2, aragonite saturation state, and stratospheric ozone concentration, percentage of land under crops, maximum amount of global annual freshwater use, cumulative P loading in oceans, respectively), the remaining boundary, biodiversity loss, and the component of the biogeochemical boundary related to the human interference with the N cycle are defined by rates of change for each respective control variable (extinctions per million species per year, rate of N_2 removed from atmosphere for human use).



approaches at global, regional, and local scales (Dietz et al. 2003, Folke et al. 2005, Berkman and Young 2009).

Our preliminary analysis indicates that humanity has already transgressed three boundaries (climate change, the rate of biodiversity loss, and the rate of interference with the nitrogen cycle). There is significant uncertainty surrounding the duration over which boundaries can be transgressed before causing unacceptable environmental change and before triggering feedbacks that may result in crossing of thresholds that drastically reduce the ability to return within safe levels. Fast feedbacks (e.g., loss of Arctic sea ice) appear to already have kicked-in after having transgressed the climate boundary for a couple of decades. Slow feedbacks (e.g., loss of land-based polar ice sheets) operate over longer time frames. Despite the phasing-out of CFC emissions and the fact that the ozone holes did not spread beyond the polar vortex regions, which remained largely intact, the ozone holes over the polar regions will only slowly decline over the next half century.

There is little doubt, however, that the complexities of interconnected slow and fast processes and feedbacks in the Earth System provide humanity with a challenging paradox. On the one hand, these dynamics underpin the resilience that enables planet Earth to stay within a state conducive to human development. On the other hand, they lull us into a false sense of security because incremental change can lead to the unexpected crossing of thresholds that drive the Earth System, or significant sub-systems, abruptly into states deleterious or even catastrophic to human well-being. The concept of planetary boundaries provides a framework for humanity to operate within this paradox.

Footnotes

[i] The Earth System is defined as the integrated biophysical and socioeconomic processes and interactions (cycles) among the atmosphere, hydrosphere, cryosphere, biosphere, geosphere, and anthroposphere (human enterprise) in both spatial —from local to global—and temporal scales, which determine the environmental state of the planet within its current position in the universe. Thus, humans and their activities are fully part of the Earth System, interacting with other components.

[ii] Resilience provides a system with the ability to persist (absorb and resist shocks), adapt, and transform in the face of natural and human-induced disturbances. In this paper, our focus is on the ability of desirable (from a human perspective) states of the Earth System to persist in the face of anthropogenic disturbance.

[iii] Aerosols are inorganic or organic particles suspended in the atmosphere and are either directly emitted as primary aerosols (dust or particle emissions from diesel engines) or secondary aerosols, including nitrates, sulfates, ammonium compounds, and non-volatile organics, formed from conversion in atmospheric chemical reactions originating from nitrogen oxides, ammonia, and organic compounds. Aerosols vary in size, ranging from a few nanometers to tens of micrometers, and have a lifetime spanning from a couple of days to weeks, and are transported, chemically transformed, and affect areas far away from their origins. Aerosols have both a cooling effect on the climate by reflecting incoming solar radiation (e.g., from nitrates, sulfates, and sulfuric acids) and a warming effect, directly absorbing heat radiation and indirectly by changing surface albedo (e.g., black carbon soot from biomass combustion).

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol14/iss2/art32/responses/

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Appendix 1. Supplementary Information.

Please click here to download file 'appendix1.pdf'.

1 INTRODUCTION

The development of ideas

To what extent have humans transformed their natural environment? This is a crucial question that intrigued the eighteenth century French natural historian, Count Buffon. He can be regarded as the first Western scientist to be concerned directly and intimately with the human impact on the natural environment (Glacken, 1963, 1967). He contrasted the appearance of inhabited and uninhabited lands: the anciently inhabited countries have few woods, lakes or marshes, but they have many heaths and scrub; their mountains are bare, and their soils are less fertile because they lack the organic matter which woods, felled in inhabited countries, supply, and the herbs are browsed. Buffon was also much interested in the **domestication** of plants and animals – one of the major transformations in nature brought about by human actions.

Studies of the torrents of the French and Austrian Alps, undertaken in the late eighteenth and early nineteenth centuries, deepened immeasurably the realization of human capacity to change the environment. Fabre and Surell studied the flooding, siltation, erosion and division of watercourses brought about by **deforestation** in the Alps. Similarly de Saussure showed that Alpine lakes had suffered a lowering of water levels in recent times because of deforestation. In Venezuela, von Humboldt concluded that the lake level of Lake Valencia in 1800 (the year of his visit) was lower than it had been in previous times, and that deforestation, the clearing of plains, and the cultivation of indigo were among the causes of the gradual drying up of the basin.

Comparable observations were made by the French rural economist, Boussingault (1845). He returned to Lake Valencia some 25 years after von Humboldt and noted that the lake was actually rising. He described this reversal to political and social upheavals following the granting of independence to the colonies of the erstwhile Spanish Empire. The freeing of slaves had led to a decline in agriculture, a reduction in the application of irrigation water, and the re-establishment of forest.

Boussingault also reported some pertinent hydrological observations that had been made on Ascension Island in the South Atlantic:

In the Island of Ascension there was an excellent spring situated at the foot of a mountain originally covered with wood; the spring became scanty and dried up after the trees which covered the mountain had been felled. The loss of the spring was rightly ascribed to the cutting down of the timber. The mountain was therefore planted anew. A few years afterwards the spring reappeared by degrees, and by and by followed with its former abundance. (p. 685)

Charles Lyell, in his *Principles of geology*, one of the most influential of all scientific works, referred to the human impact and recognized that tree felling and drainage of lakes and marshes tended 'greatly to vary the state of the habitable surface'. Overall, however, he believed that the forces exerted by people were insignificant in comparison with those exerted by nature:

If all the nations of the earth should attempt to quarry away the lava which flowed from one eruption of the Icelandic volcanoes in 1783, and the two following years, and should attempt to consign it to the deepest abysses of the ocean they might toil for thousands of years before their task was accomplished. Yet the matter borne down by the Ganges and Burrampooter, in a single year, probably very much exceeds, in weight and volume, the mass of Icelandic lava produced by that great eruption. (Lyell, 1835: 197)

Lyell somewhat modified his views in later editions of the *Principles* (see e.g., Lyell, 1875), largely as a result of his experiences in the USA, where recent deforestation in Georgia and Alabama had produced numerous ravines of impressive size.

One of the most important physical geographers to show concern with our theme was Mary Somerville (1858) (who clearly appreciated the unexpected results that occurred as man 'dextrously avails himself of the powers of nature to subdue nature'):

Man's necessities and enjoyments have been the cause of great changes in the animal creation, and his destructive propensity of still greater. Animals are intended for our use, and field-sports are advantageous by encouraging a daring and active spirit in young men; but the utter destruction of some races in order to protect those destined for his pleasure, is too selfish, and cruelty is unpardonable: but the ignorant are often cruel. A farmer sees the rook pecking a little of his grain, or digging at the roots of the springing corn, and poisons all his neighbourhood. A few years after he is surprised to find his crop destroyed by grubs. The works of the Creator are nicely balanced, and man cannot infringe his Laws with impunity. (Somerville, 1858: 493)

This is in effect a statement of one of the basic laws of **ecology**: that everything is connected to everything else and that one cannot change just one thing in nature.

Considerable interest in conservation, climatic change and extinctions arose amongst European colonialists who witnessed some of the consequences of western-style economic development in tropical lands (Grove, 1997). However, the extent of human influence on the environment was not explored in detail and on the basis of sound data until George Perkins Marsh published *Man and nature* (1864), in which he dealt with human influence on the woods, the waters and the sands. The following extract illustrates the breadth of his interests and the ramifying connections he identified between human actions and environmental changes:

Vast forests have disappeared from mountain spurs and ridges; the vegetable earth accumulated beneath the trees by the decay of leaves and fallen trunks, the soil of the alpine pastures which skirted and indented the woods, and the mould of the upland fields, are washed away; meadows, once fertilized by irrigation, are waste and unproductive, because the cisterns and reservoirs that supplied the ancient canals are broken, or the springs that fed them dried up; rivers famous in history and song have shrunk to humble brooklets; the willows that ornamented and protected the banks of lesser watercourses are gone, and the rivulets have ceased to exist as perennial currents, because the little water that finds its way into their old channels is evaporated by the droughts of summer, or absorbed by the parched earth, before it reaches the lowlands; the beds of the brooks have widened into broad expanses of pebbles and gravel, over which, though in the hot season passed dryshod, in winter sealike torrents thunder, the entrances of navigable streams are obstructed by sandbars, and harbours, once marts of an extensive commerce, are shoaled by the deposits of the rivers at whose mouths they lie; the elevation of the beds of estuaries, and the consequently diminished velocity of the streams which flow into them, have converted thousands of leagues of shallow sea and fertile lowland into unproductive and miasmatic morasses. (Marsh, 1965: 9)

More than a third of the book is concerned with 'the woods'; Marsh does not touch upon important themes such as the modifications of mid-latitude grasslands, and he is much concerned with Western civilization. Nevertheless, employing an eloquent style and copious footnotes, Marsh, the versatile Vermonter, stands as a landmark in the study of environment (Thomas, 1956; Lowenthal, 2000).

Marsh, however, was not totally pessimistic about the future role of humankind or entirely unimpressed by positive human achievements (1965: 43–4):

New forests have been planted; inundations of flowing streams restrained by heavy walls of masonry and other constructions; torrents compelled to aid, by depositing the slime with which they are charged, in filling up lowlands, and raising the level of morasses which their own overflows had created; ground submerged by the encroachment of the ocean, or exposed to be covered by its tides, has been rescued from its dominion by diking; swamps and even lakes have been drained, and their beds brought within the domain of agricultural industry; drifting coast dunes have been checked and made productive by plantation; sea and inland waters have been repeopled with fish, and even the sands of the Sahara have been fertilized by artesian fountains. These achievements are far more glorious than the proudest triumphs of war . . .

Reclus (1873), one of the most prominent French geographers of his generation, and an important influence in the USA, also recognized that the 'action of man may embellish the earth, but it may also disfigure it; according to the manner and social condition of any nation, it contributes either to the degradation or glorification of nature' (p. 522). He warned rather darkly (p. 523) that 'in a spot where the country is disfigured, and where all the grace of poetry has disappeared from the landscape, imagination dies out, and the mind is impoverished; a spirit of routine and servility takes possession of the soul, and leads it on to torpor and death'. Reclus (1871) also displayed a concern with the relationship between forests, torrents and sedimentation.

In 1904 Friedrich coined the term 'Raubwirtschaft', which can be translated as economic plunder, robber economy or, more simply, devastation. This concept has been extremely influential but is open to criticism. He believed that destructive exploitation of resources leads of necessity to foresight and to improvements, and that after an initial phase of ruthless exploitation and resulting deprivation human measures would, as in the old countries of Europe, result in conservation and improvement. This idea was opposed by Sauer (1938) and Whitaker (1940), the latter pointing out that some soil erosion could well be irreversible (p. 157):

It is surely impossible for anyone who is familiar with the eroded loessial lands of northwestern Mississippi, or the burned and scarred rock hills of north central Ontario, to accept so complacently the damage to resources involved in the process of colonization, or to be so certain that resource depletion is but the forerunner of conservation.

Nonetheless Friedrich's concept of robber economy was adopted and modified by the great French geographer, Jean Brunhes, in his *Human geography* (1920). He recognized the interrelationships involved in anthropogenic environmental change (p. 332): 'Devastation always brings about, not a catastrophe, but a series of catastrophes, for in nature things are dependent one upon the other.' Moreover, Brunhes acknowledged that the 'essential facts' of human geography included 'Facts of Plant and Animal Conquest' and 'Facts of Destructive Exploitation'. At much the same time other significant studies were made of the same theme. Shaler of Harvard (*Man and the earth*, 1912) was very much concerned with the destruction of mineral resources (a topic largely neglected by Marsh).

Sauer led an effective campaign against destructive exploitation (Speth, 1977), reintroduced Marsh to a wide public, recognized the ecological virtues of some so-called primitive peoples, concerned himself with the great theme of domestication, concentrated on the landscape changes that resulted from human action, and gave clear and far-sighted warnings about the need for conservation (Sauer, 1938: 494):

We have accustomed ourselves to think of ever expanding productive capacity, of ever fresh spaces of the world to be filled with people, of ever new discoveries of kinds and sources of raw materials, of continuous technical progress operating indefinitely to solve problems of supply. We have lived so long in what we have regarded as an expanding world, that we reject in our contemporary theories of economics and of population the realities which contradict such views. Yet our modern expansion has been affected in large measure at the cost of an actual and permanent impoverishment of the world.

The theme of the human impact on the environment has, however, been central to some historical geographers studying the evolution of the cultural landscape. The clearing of woodland (Darby, 1956; Williams, 1989, 2003), the domestication process (Sauer, 1952), the draining of marshlands (Williams, 1970), the introduction of alien plants and animals (McKnight, 1959), and the transformation of the landscape of North America (Whitney, 1994) are among some of the recurrent themes of a fine tradition of historical geography.

In 1956, some of these themes were explored in detail in a major symposium volume, *Man's role in changing the face of the earth* (Thomas, 1956). Kates et al. (1990: 4) write of it:

Man's role seems at least to have anticipated the ecological movement of the 1960s, although direct links between the two have not been demonstrated. Its dispassionate, academic approach was certainly foreign to the style of the movement . . . Rather, *Man's role* appears to have exerted a much more subtle, and perhaps more lasting, influence as a reflective, broad-ranging and multidimensional work.

In the past three decades many geographers have contributed to, and been affected by, the phenomenon which is often called the environmental revolution or the ecological movement. The subject of the human impact on the environment, dealing as it does with such matters as environmental degradation, pollution and **desertification**, has close links with these developments, and is once again a theme in many textbooks and research monographs in geography (see e.g., Manners and Mikesell, 1974; Wagner, 1974; Cooke and Reeves, 1976; Gregory and Walling, 1979; Simmons, 1979; Tivy and O'Hare, 1981; Turner et al., 1990; Bell and Walker, 1992; Middleton, 1995; Meyer, 1996; Mannion, 1997, 2002).

Concerns about the human impact have become central to many disciplines and to the public, particularly since the early 1970s, when a range of major developments in the literature and in legislation have taken place (Table 1.1). The concepts of **global change** or global environmental change have developed. These phrases are much used, but seldom rigorously defined. Wide use of the term global change seems to have emerged in the 1970s but in that period was used principally, although by no means invariably, to refer to changes in international social, economic, and political systems (Price, 1989). It included such issues as proliferation of nuclear weapons, population growth, inflation, and matters relating to international insecurity and decreases in the quality of life.

Since the early 1980s the concept of global change has taken on another meaning which is more geocentric in focus. The geocentric meaning of global change can be seen in the development of the International Geosphere–Biosphere Program: a Study of Global Change (IBGP). This was established in 1986 by the International Council of Scientific Unions, 'to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities'.

Table 1.1 Some environmental milestones

1864	George Perkins Marsh, *Man and nature*
1892	John Muir founds Sierra Club in USA
1935	Establishment of Soil Conservation Service in USA
1956	Man's role in changing the face of the earth
1961	Establishment of World Wildlife Fund
1962	Rachel Carson's *Silent spring*
1969	Friends of the Earth established
1971	Greenpeace established
1971	Ramsar Treaty on International Wetlands
1972	United Nations Environmental Program (UNEP) established
1972	*Limits to growth* published by Club of Rome
1973	Convention on International Trade in Endangered Species (CITES)
1974	F. S. Rowland and M. Molina warn about CFCs and ozone hole
1975	Worldwatch Institute established
1979	Convention on Long-range Transboundary Air Pollution
1980	IUCN's (International Union for the Conservation of Nature and Natural Resources) World Conservation Strategy
1985	British Antarctic Survey finds ozone hole over Antarctic
1986	International Geosphere Biosphere Program (IGBP)
1986	Chernobyl nuclear disaster
1987	World Commission on Environment and Development (Brundtland Commission). *Our common future*
1987	Montreal Protocol on substances that deplete the ozone layer
1988	Intergovernmental Panel on Climate Change (IPCC)
1989	Global Environmental Facility
1992	Earth Summit in Rio and Agenda 21
1993	United Nations Commission on Sustainable Development
1994	United Nations Convention to Combat Desertification
1996	International Human Dimensions Program on Global Environmental Change
1997	Kyoto Protocol on greenhouse gas emissions
2001	Amsterdam Declaration
2002	Johannesburg Earth Summit

The term 'global environmental change' has in many senses come to be used synonymously with the more geocentric use of 'global change'. Its validity and wide currency were recognized when *Global environmental change* was established in 1990 as

an international journal that addresses the human ecological and public policy dimensions of the environmental

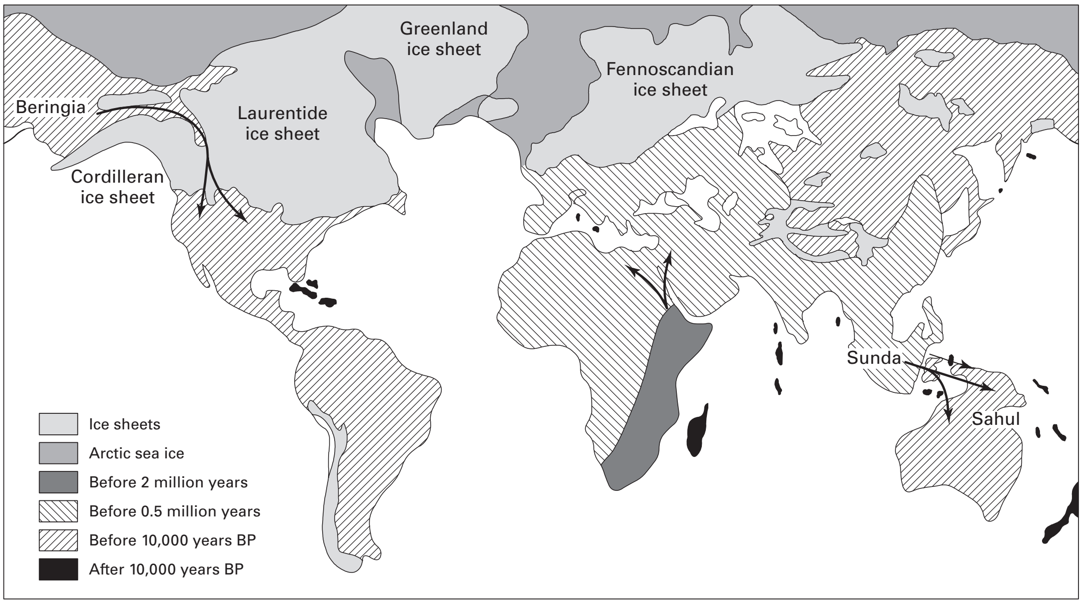

Figure 1.1 The human colonization of Ice Age Earth (after Roberts, 1989, figure 3.7).

processes which are threatening the sustainability of life of Earth. Topics include, but are not limited to, deforestation, desertification, soil degradation, species extinction, sea-level rise, acid precipitation, destruction of the ozone layer, atmospheric warming/cooling, nuclear winter, the emergence of new technological hazards, and the worsening effects of natural disasters.

In addition to the concept of global change, there is an increasing interest in the manner in which biogeochemical systems interact at a global scale, and an increasing appreciation of the fact that Earth is a single system. Earth system science has emerged in response to this realization (see Steffen et al., 2004).

The huge increase in interest in the study of the human impact on the environment and of global change has not been without its great debates and controversies, and some have argued that environmentalists have overplayed their hand (see e.g., Lomborg's *The skeptical environmentalist*, 2001) and have exaggerated the amount of environmental harm that is being caused by human activities. In this book, I take a long-term perspective and seek to show the changes that humankind has caused to a wide spectrum of environmental phenomena.

The development of human population and stages of cultural development

Some six or so million years ago, primitive human precursors or **hominids** appear in the fossil record (Wood, 2002). However, the first recognizable human, *Homo habilis*, evolved about 2.4 million years ago, more or less at the time that the ice ages were developing in mid-latitudes. The oldest remains have been found either in sediments from the Rift Valleys of East Africa, or in cave deposits in South Africa. Since that time the human population has spread over virtually the entire land surface of the planet (Oppenheimer, 2003) (Figure 1.1). *Homo* may have reached Asia by around two million years ago (Larick and Ciochan, 1996) and Europe not much later. In Britain the earliest fossil evidence, from Boxgrove, is from around half a million years ago. Modern humans, *Homo sapiens*, appeared in Africa around 160,000 years ago (Crow, 2002, Stringer, 2003; White et al., 2003).

Table 1.2 gives data on recent views of the dates for the arrival of humans in selected areas. Some of these dates are controversial, and this is especially true of Australia, where they range from *c.* 40,000 years to as much as 150,000 years (Kirkpatrick, 1994: 28–30). There

Table 1.2 Dates of human arrivals

Area	*Source*	*Date (years BP)*
Africa	Klein (1983)	2,700,000–2,900,000
China	Huang et al. (1995)	1,900,000
Georgian Republic	Gabunia and Vekua (1995)	1,600,000–1,800,000
Java	Swisher et al. (1994)	1,800,000
Europe	Champion et al. (1984)	c. 1,600,000 but most post-350,000
Britain	Roberts et al. (1995)	c. 500,000
Japan	Ikawa-Smith (1982)	c. 50,000
New Guinea	Bulmer (1982)	c. 50,000
Australia	Bowler et al. (2003)	c. 40,000–50,000
North America	Irving (1985)	15,000–40,000
South America	Guidon and Delibrias (1986)	32,000
Peru	Keefer et al. (1998)	12,500–12,700
Ireland	Edwards (1985)	9000
Caribbean	Morgan and Woods (1986)	4500
Polynesia	Kirch (1982)	2000
Madagascar	Battistini and Verin (1972)	c. AD 500
New Zealand	Green (1975)	AD 700–800

is also considerable uncertainty about the dates for humans arriving in the Americas. Many authorities have argued that the first colonizers of North America, equipped with so-called Clovis spears, arrived via the Bering landbridge from Asia around 12,000 years ago. However, some earlier dates exist for South America and these perhaps imply an earlier phase of colonization (Dillehay, 2003).

There are at least three interpretations of global population trends over the past two to three million years (Whitmore et al., 1990). The first, described as the 'arithmetic-exponential' view, sees the history of the global population as a two-stage phenomenon: the first stage is one of slow growth, while the second stage, related to the industrial revolution, displays a staggering acceleration in growth rates. The second view, described as 'logarithmic-logistic', sees the past million years or so in terms of three revolutions – the tool, agricultural and industrial revolutions. In this view, humans have increased the carrying capacity of Earth at least three times. There is also a third view, described as 'arithmetic-logistic', which sees the global population history over the past 12,000 years as a set of three cycles: the 'primary cycle', the 'medieval cycle' and the 'modernization cycle'; these three alternative models are presented graphically in Figure 1.2.

Estimates of population levels in the early stages of human development are difficult to make with any degree of certainty (Figure 1.3a). Before the agricultural 'revolution' some 10,000 years ago, human groups lived by hunting and gathering in parts of the world where this was possible. At that time the world population may have been of the order of five million people (Ehrlich et al., 1977: 182) and large areas would only recently have witnessed human migration. The Americas and Australia, for example, were probably virtually uninhabited until about 11,000 and 40,000 years ago respectively.

The agricultural revolution probably enabled an expansion of the total human population to about 200 million by the time of Christ, and to 500 million by AD 1650. It is since that time, helped by the medical and industrial revolutions and developments in agriculture and colonization of new lands, that human population has exploded, reaching about 1000 million by AD 1850, 2000 million by AD 1930 and 4000 million by AD 1975. The figure had reached over 6000 million by the end of the millennium. Victory over malaria, smallpox, cholera and other diseases has been responsible for marked decreases in death rates throughout the non-industrial world, but death-rate control has not in general been matched by birth control. Thus the annual population growth rate in the late 1980s in South Asia was 2.64%, Africa 2.66% and Latin America (where population increased sixfold between 1850 and 1950) 2.73%. The global annual growth in population over the past decade has been around 80 million people (Figure 1.3b).

The history of the human impact, however, has not been a simple process of increasing change in response to linear population growth over time, for in specific places at specific times there have been periods of reversal in population growth and ecological change as cultures collapsed, wars occurred, disease struck and **habitats** abandoned. Denevan (1992), for example, has pointed to the decline of native American populations in the new world following European entry into the Americas. This created what was 'probably the greatest demographic disaster ever'. The overall population of the western hemisphere in 1750 was perhaps less than a third of what it may have been in 1492, and the ecological consequences were legion.

Clearly, this growth of the human population of Earth is in itself likely to be a highly important cause of the transformation of nature. Of no lesser importance,

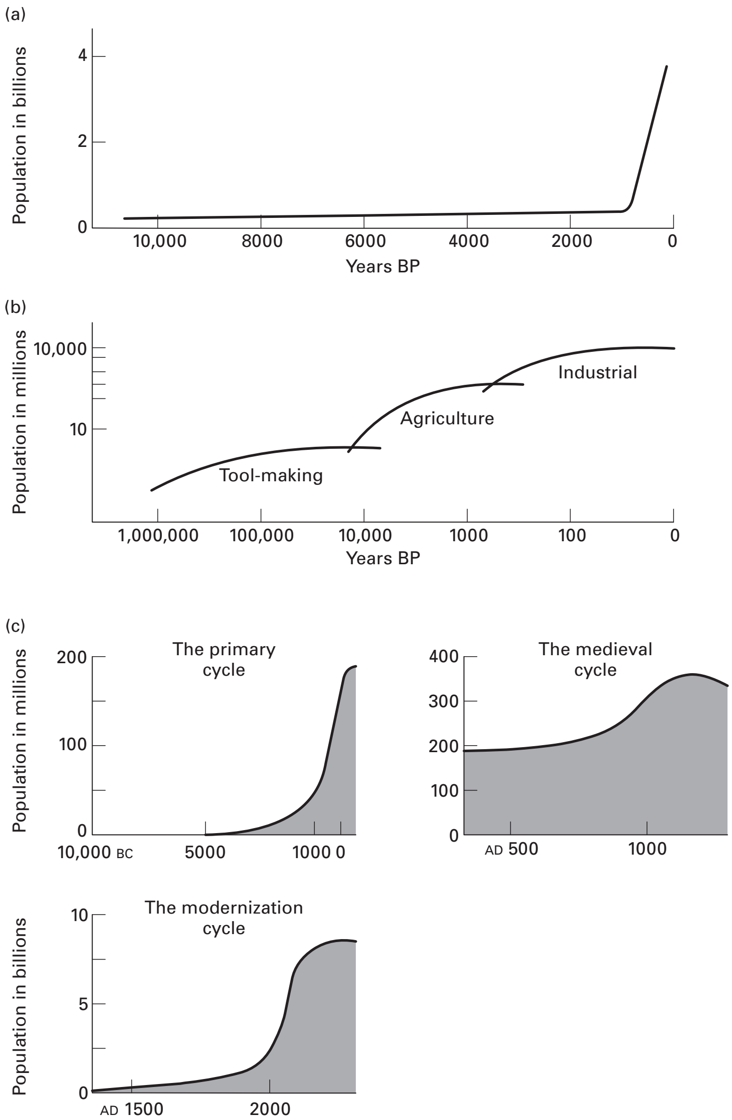

Figure 1.2 Three interpretations of global population trends over the millennia (billion = thousand million): (a) the arithmetic-exponential; (b) the logarithmic-logistic; (c) the arithmetic-logistic (after Whitmore et al., 1990, figure 2.1).

however, has been the growth and development of culture and technology. Sears (1957: 51) has put the power of humankind into the context of other species:

Man's unique power to manipulate things and accumulate experience presently enabled him to break through the barriers of temperature, aridity, space, seas and mountains that have always restricted other species to specific habitats within a limited range. With the cultural devices of fire, clothing, shelter, and tools he was able to do what no other organism could do without changing its original character. Cultural change was, for the first time, substituted for biological evolution as a means of adapting an organism to new habitats in a widening range that eventually came to include the whole earth.

The evolving impact of humans on the environment has often been expressed in terms of a simple equation:

$$I = P\ A\ T$$

where I is the amount of pressure or impact that humans apply on the environment, P is the number of people, A is the affluence (or the demand on resources per person), and T is a technological factor (the power that humans can exert through technological change).

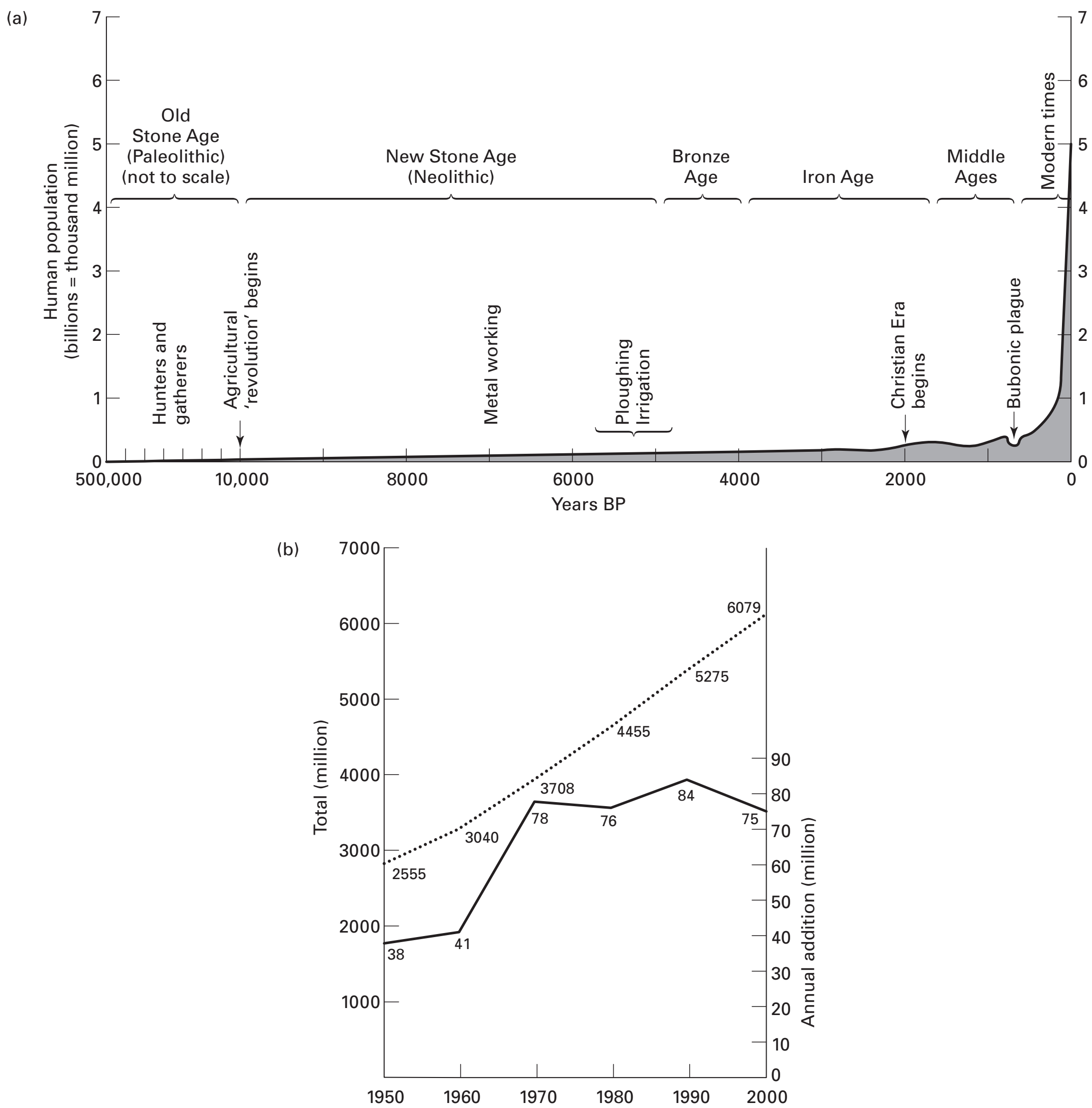

Figure 1.3 (a) The growth of human numbers for the past half million years (after Ehrlich et al., 1977, figure 5.2). (b) Annual growth of population since 1950.

The variables *P*, *A* and *T* have been seen by some as 'the three horsemen of the environmental apocalypse' (Meyer, 1996: 24). There may be considerable truth in the equation and in that sentiment; but as Meyer points out, the formula cannot be applied in too mechanistic a way. The 'cornucopia view', indeed, sees population not as the ultimate depleter of resources but as itself the ultimate resource capable of causing change for the better (see e.g., Simon, 1981, 1996). There are cases where strong population growth has appeared to lead to a reduction in environmental degradation (Tiffen et al., 1994). Likewise, there is debate about whether it is poverty or affluence that creates deterioration in the environment. On the one hand many poor countries have severe environmental problems and do not have the resources to clear them up, whereas affluent countries do. Conversely it can be argued that affluent countries have plundered and fouled less fortunate countries, and that it would be environmentally catastrophic if all countries used resources at the rate that the rich countries do. Similarly, it would be naïve to see all technologies as malign, or indeed benign.

Technology can be a factor either of mitigation and improvement or of damage. Sometimes it is the problem (as when ozone depletion has been caused by a new technology – the use of **chlorofluorocarbons**) and sometimes it can be the solution (as when renewable energy sources replace the burning of polluting lignite in power stations).

In addition to the three factors of population, affluence, and technology, environmental changes also depend on variations in the way in which different societies are organized and in their economic and social structures (see Meyer, 1996: 39–49 for an elaboration of this theme). For example, the way in which land is owned is a crucial issue.

The controls of environmental changes caused by the human impact are thus complex and in many cases contentious, but all the factors discussed play a role of some sort, at some places, and at some times.

We now turn to a consideration of the major cultural and technical developments that have taken place during the past two to three million years. Three main phases will form the basis of this analysis: the phase of hunting and gathering; the phase of plant cultivation, animal keeping and metal working; and the phase of modern urban and industrial society. These developments are treated in much greater depth by Ponting (1991) and Simmons (1996).

Hunting and gathering

The definition of 'human' is something of a problem, not least because, as is the case with all existing organisms, new forms tend to emerge by perceptible degrees from antecedent ones. Moreover, the fossil evidence is scarce, fragmentary and can rarely be dated with precision. Although it is probably justifiable to separate the hominids from the great apes on the basis of their assumption of an upright posture, it is much less justifiable or possible to distinguish on purely zoological grounds between those hominids that remained pre-human and those that attained human status. To qualify as a human, a hominid must demonstrate cultural development: the systematic manufacture of implements as an aid to manipulating the environment.

The oldest records of human activity and technology, pebble tools (crude stone tools which consist of a pebble with one end chipped into a rough cutting edge), have been found with human bone remains in various parts of Africa (Gosden, 2003). For example, at Lake Turkana in northern Kenya, and the Omo Valley in southern Ethiopia, a tool-bearing bed of volcanic material called tuff has been dated by isotopic means at about 2.6 million years old, another from Gona in the northeast of Ethiopia at about 2.5 million years old (Semaw et al., 1997), while another bed at the Olduvai Gorge in Tanzania has been dated by similar means at 1.75 million years. Indeed, these very early tools are generally termed 'Oldowan'.

As the Stone Age progressed the tools became more sophisticated, varied and effective. Greater exploitation of plant and animal resources became feasible. Stone may not, however, have been the only material used. Sticks and animal bones, the preservation of which is less likely than stone, are among the first objects that may have been used as implements, although the sophisticated utilization of antler and bone as materials for weapons and implements appears to have developed surprisingly late in pre-history. There is certainly a great deal of evidence for the use of wood throughout the Paleolithic Age, for ladders, fire, pigment (charcoal), the drying of wood and digging sticks. Tyldesley and Bahn (1983: 59) go so far as to suggest that 'The Palaeolithic might more accurately be termed the "Palaeoxylic" or "Old Wood Age".'

The building of shelters and the use of clothing became a permanent feature of human life as the Paleolithic period progressed, and permitted habitation in areas where the climate was otherwise not congenial. European sites from the Mousterian of the Middle Paleolithic have revealed the presence of purposefully made dwellings as well as caves, and by the Upper Paleolithic more complex shelters were in use, allowing people to live in the **tundra** lands of central Europe and Russia.

Another feature of early society that seems to have distinguished humans from the surviving non-human primates was their seemingly omnivorous diet. Biological materials recovered from settlements in many different parts of the world indicate that in the Paleolithic Age humans secured a wide range of animal meats, whereas the great apes, although not averse to an occasional taste of animal food, are predominately vegetarian. One consequence of enlarging the range of their diet was that, in the long run, humans

Figure 1.4 Fire was one of the first and most powerful tools of environmental transformation employed by humans. The high grasslands of southern Africa may owe much of their character to regular burning, as shown here in Swaziland.

were able to explore a much wider range of environment (G. Clark, 1977: 19). Another major difference that set humankind above the beasts was the development of communicative skills such as speech. Until hominids had developed words as symbols, the possibility of transmitting, and so accumulating, culture hardly existed. Animals can express and communicate emotions, but they never designate or describe objects.

At an early stage humans discovered the use of fire (Figure 1.4). This, as we shall see (Chapter 2), is a major agent by which humans have influenced their environment. The date at which fire was first deliberately employed is a matter of ongoing controversy (Bogucki, 1999: 51–54; Caldararo, 2002). It may have been employed very early in East Africa, where Gowlett et al. (1981) have claimed to find evidence for deliberate manipulation of fire from over 1.4 million years ago. However, it is not until after around 400,000 years ago that evidence for the association between human and fire becomes compelling. Nonetheless, as Pyne (1982: 3) has written:

> It is among man's oldest tools, the first product of the natural world he learned to domesticate. Unlike floods, hurricanes or windstorms, fire can be initiated by man; it can be combated hand to hand, dissipated, buried, or 'herded' in ways unthinkable for floods or tornadoes.

He goes on to stress the implications that fire had for subsequent human cultural evolution (p. 4):

> It was fire as much as social organisation and stone tools that enabled early big game hunters to encircle the globe and to begin the extermination of selected species. It was fire that assisted hunting and gathering societies to harvest insects, small game and edible plants; that encouraged the spread of agriculture outside the flood plains by allowing for rapid landclearing, ready fertilization, the selection of food grains, the primitive herding of grazing animals that led to domestication, and the expansion of pasture and grasslands against climate gradients; and that, housed in machinery, powered the prime movers of the industrial revolution.

Overall, compared with later stages of cultural development, early hunters and gatherers had neither the numbers nor the technological skills to have a very substantial effect on the environment. Besides the effects of fire, early cultures may have caused some diffusion of seeds and nuts, and through hunting activities (see Chapter 3) may have had some dramatic effects on animal populations, causing the extinction of many great mammals (the so-called 'Pleistocene overkill'). Locally some **eutrophication** may have occurred, and around some archaeological sites phosphate and nitrate levels may be sufficiently raised to make them an indicator of habitation to archaeologists today (Holliday, 2004). Equally, although we often assume that early humans were active and effective hunters, they may well have been dedicated scavengers of carcasses of animals that had either died natural deaths or been killed by carnivores such as lion.

It is salutary to remember, however, just how significant this stage of our human cultural evolution has been. As Lee and DeVore (1968: 3) wrote:

> Of the estimated 80,000,000,000 men who have ever lived out a life span on earth, over 90% have lived as hunters and gatherers, about 6% have lived by agriculture and the remaining few per cent have lived in industrial societies. To date, the hunting way of life has been the most successful and persistent adaptation man has ever achieved.

Figure 1.5 indicates the very low population densities of hunter/gatherer/scavenger groups in comparison with those that were possible after the development of pastoralism and agriculture.

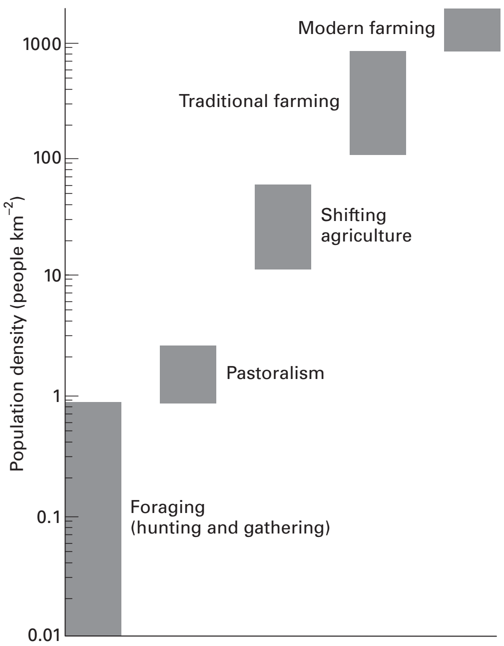

Figure 1.5 Comparison of carrying capacities of foraging, pastoralist, and agricultural societies.

Humans as cultivators, keepers, and metal workers

It is possible to identify some key stages of economic development that have taken place since the end of the Pleistocene (Table 1.3). First, around the beginning of the Holocene, about 10,000 years ago, humans started in various parts of the world to domesticate rather than to gather food plants and to keep, rather than just hunt, animals. This phase of human cultural development is well reviewed in Roberts (1998). By taking up farming and domesticating food plants, they reduced enormously the space required for sustaining each individual by a factor of the order of 500 at least (Sears, 1957: 54). As a consequence we see shortly thereafter, notably in the Middle East, the establishment of the first major settlements – towns. So long as man had

> to subsist on the game animals, birds and fish he could catch and trap, the insects and eggs he could collect and the foliage, roots, fruits and seeds he could gather, he was limited in the kind of social life he could develop; as a rule he could only live in small groups, which gave small scope for specialization and the subdivision of labour, and in the course of a year he would have to move over extensive tracts of country, shifting his habitation so that he could tap the natural resources of successive areas. It is hardly to be wondered at that among communities whose energies were almost entirely absorbed by the mere business of keeping alive, technology remained at a low ebb. (Clark, 1962: 76)

Although it is now recognized that some hunters and gathers had considerable leisure, there is no doubt that through the controlled breeding of animals and plants humans were able to develop a more reliable and readily expandable source of food and thereby create a solid and secure basis for cultural advance, an advance which included civilization and the 'urban revolution' of Childe (1936) and others. Indeed, Isaac (1970) has termed domestication 'the single most important intervention man had made in his environment'; and Harris (1996) has termed the transition from foraging to farming as 'the most fateful change in the human career'. Diamond (2002) termed it 'the most momentous change in Holocene human history'.

A distinction can be drawn between cultivation and domestication. Whereas cultivation involves deliberate sowing or other management, and entails plants that do not necessarily differ genetically from wild populations of the same species, domestication results in genetic change brought about through conscious or unconscious human selection. This creates plants that differ morphologically from their wild relatives and which may be dependent on humans for their survival. Domesticated plants are thus necessarily cultivated plants, but cultivated plants may or may not be domesticated. For example, the first plantations of *Hevea* rubber and quinine in the Far East were established from seed that had been collected from the wild in South America. Thus at this stage in their history these crops were cultivated but not yet domesticated.

The origin of agriculture remains controversial (Harris, 1996). Some early workers saw agriculture as a divine gift to humankind, while others thought that animals were domesticated for religious reasons. They argued that it would have been improbable that humans could have predicted the usefulness of domestic cattle before they were actually domesticated. Wild cattle are large, fierce beasts, and no one could have foreseen their utility for labor or milk until they were tamed – tamed perhaps for ritual sacrifice in connection with lunar goddess cults (the great curved horns being

Table 1.3 Five stages of economic development. Source: adapted from Simmons (1993: 2–3)

Economic stage	*Dates and characteristics*
Hunting–gathering and early agriculture	Domestication first fully established in southwestern Asia around 7500 BC; hunter–gatherers persisted in diminishing numbers until today. Hunter–gatherers generally manipulate the environment less than later cultures, and adapt closely to environmental conditions
Riverine civilizations	Great irrigation-based economies lasting from *c.* 4000 BC to 1st century AD in places such as the Nile Valley and Mesopotamia. Technology developed to attempt to free civilizations from some of the constraints of a dry season
Agricultural empires	From 500 BC to around AD 1800 a number of city-dominated empires existed, often affecting large areas of the globe. Technology (e.g., terracing and selective breeding) developed to help overcome environmental barriers to increased production
The Atlantic industrial era	From *c.* AD 1800 to today a belt of cities from Chicago to Beirut, and around the Asian shores to Tokyo, form an economic core area based primarily on fossil fuel use. Societies have increasingly divorced themselves from the natural environment, through air conditioning for example. These societies have also had major impacts on the environment
The Pacific global era	Since the 1960s there has been a shifting emphasis to the Pacific Basin as the primary focus of the global economy, accompanied by globalization of communications and the growth of multinational corporations

the reason for the association). Another major theory was that domestication was produced by crowding, possibly brought on by a combination of climatic deterioration (alleged post-glacial progressive desiccation) and population growth. Such pressure may have forced communities to intensify their methods of food production. Current paleoclimatological research tends not to support this interpretation, but that is not to say that other severe climatic changes could not have played a role (Sherratt, 1997).

Sauer (1952), a geographer, believed that plant domestication was initiated in Southeast Asia by fishing folk, who found that lacustrine and riverine resources would underwrite a stable economy and a sedentary or semi-sedentary life style. He surmises that the initial domesticates would be multi-purpose plants set around small fishing villages to provide such items as starch foods, substances for toughening nets and lines and making them water-resistant, and drugs and poisons. He suggested that 'food production was one and perhaps not the most important reason for bringing plants under cultivation.'

Yet another model was advanced by Jacobs (1969) who turned certain more traditional models upside down. Instead of following the classic pattern whereby farming leads to village, which leads to town, which leads to civilization, she proposed that one could be a hunter–gatherer and live in a town or city, and that agriculture originated in and around such cities rather than in the countryside. Her argument suggests that even in primitive hunter–gatherer societies particularly valuable commodities such as fine stones, pigments and shells could create and sustain a trading center which would possibly become large and stable. Food would be exchanged for goods, but natural produce brought any distance would have to be durable, so meat would be transported on the hoof for example, but not all the animals would be consumed immediately; some would be herded together and might breed. This might be the start of domestication.

The process of domestication and cultivation was also once considered a revolutionary system of land procurement that had evolved in only one or two hearths and diffused over the face of Earth, replacing the older hunter–gathering systems by stimulus diffusion. It was felt that the deliberate rearing of plants and animals for food was a discovery or invention so radical and complex that it could have developed only once (or possibly twice) – the so-called 'Eureka model'. In reality, however, the domestication of plants occurred at approximately the same time in widely separated areas (Table 1.4). This might be construed to suggest that developments in one area triggered experiments with local plant materials in others. The balance of botanical and archaeological evidence seems to suggest that humans started experimenting with domestication and cultivation of different plants at different times in different parts of the world (Figure 1.6).

Table 1.4 Dates that indicate that there may have been some synchroneity of plant domestication in different centers

Center	*Dates (000 years BP)*	*Plant*
Mesoamerica	10.7–9.8	Squash-pumpkin
	9.0	Bottle gourd
Near East	10.0–9.3	Emmer wheat
		Two-rowed barley
	9.8–9.6	Einkorn wheat
		Pea
		Lentil
Far East	8.0–7.0	Broomcorn millet
		Rice
		Gourd
		Water chestnut
Andes	9.4–8.0	Chile pepper
		Common bean
		Ullucu
		White potato
		Squash and gourd

The locations and dates for domestication of some important domestic animals are shown in Figure 1.7.

The Near East, and in particular the Fertile Crescent, was especially important for both plant and animal domestication (Lev-Yadun et al., 2000; Zohary and Hopf, 2000), and wild progenitors were numerous in the area, including those of wheat, barley, lentils, peas, sheep, goats, cows, and pigs – a list that includes what are still the most valuable crops and livestock of the modern world (Diamond, 2002).

One highly important development in agriculture, because of its rapid and early effects on environment, was irrigation (Figure 1.8) and the adoption of riverine agriculture. This came rather later than domestication. Amongst the earliest evidence of artificial irrigation is the mace-head of the Egyptian Scorpion King, which shows one of the last pre-dynastic kings ceremonially cutting an irrigation ditch around 5050 years ago (Butzer, 1976), although it is possible that irrigation in Iraq started even earlier.

A major difference has existed in the development of agriculture in the Old and New Worlds; in the New World there were few counterparts to the range of domesticated animals which were an integral part of Old World systems (Sherratt, 1981). A further critical difference was that in the Old World the secondary applications of domesticated animals were explored. The plow was particularly important in this process (Figure 1.9) – the first application of animal power to the mechanization of agriculture. Closely connected to this was the use of the cart, which both permitted more intensive farming and enabled the transportation of its products. Furthermore, the development of textiles from animal fibers afforded, for the first time, a commodity that could be produced for exchange in areas where arable farming was not the optimal form of land use. Finally, the use of animal milk provided a means whereby large herds could use marginal or exhausted land, encouraging the development of the pastoral sector with transhumance or nomadism.

This secondary utilization of animals therefore had radical effects, and the change took place over quite a short period. The plow was invented some 5000 years ago, and was used in Mesopotamia, Assyria and Egypt. The remains of plow marks have also been found beneath a burial mound at South Street, Avebury in

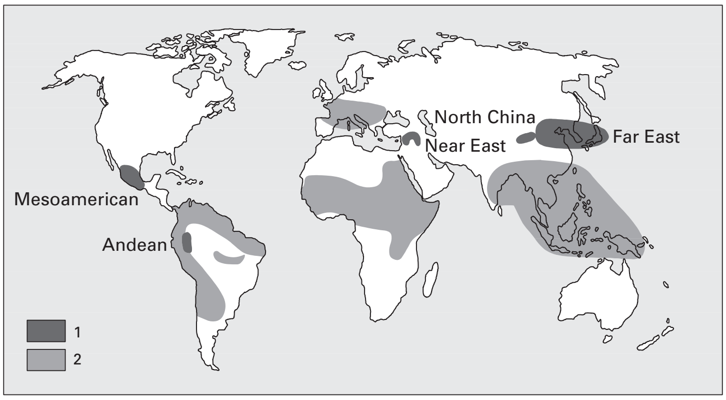

Figure 1.6 Major areas of domestication of plants identified by various workers. (1) The prime centers in which a number of plants were domesticated and which then diffused outwards into neighboring regions. (2) Broader regions in which plant domestication occurred widely and which may have received their first domesticated plants from the prime centers.

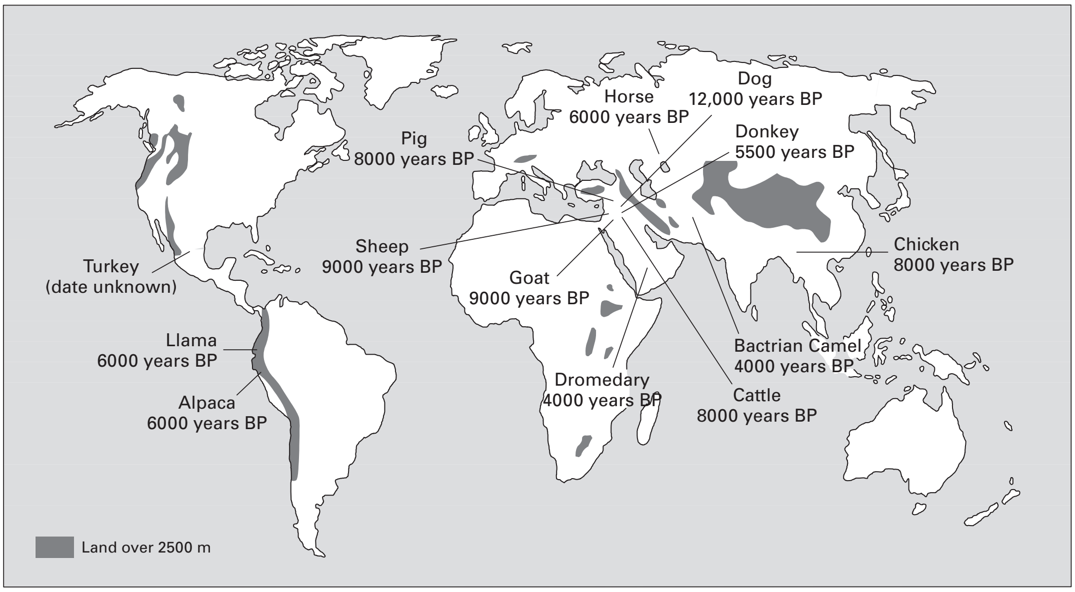

Figure 1.7 The places of origin, with approximate dates, for the most common domesticated animals.

Figure 1.8 Irrigation using animal power, as here in Rajasthan, India, is an example of the use of domesticated stock to change the environment.

England, dated at around 3000 BC, and ever since that time have been a dominant feature of the English landscape (Taylor, 1975). The wheeled cart was first produced in the Near East in the fourth millennium BC, and rapidly spread from there to both Europe and India during the course of the third millennium.

The development of other means of transport preceded the wheel. Sledge-runners found in Scandinavian bogs have been dated to the Mesolithic period (Cole, 1970: 42), while by the Neolithic era humans had developed boats, floats and rafts that were able to cross to Mediterranean islands and sail the Irish Sea. Dug-out canoes could hardly have been common before polished stone axes and adzes came into general use during Neolithic times, although some paddle and canoe remains are recorded from Mesolithic sites in northern Europe. The middens of the hunter–fishers of the Danish Neolithic contain bones of deep-sea fish such as cod, showing that these people certainly had seaworthy craft with which to exploit ocean resources.

Both the domestication of animals and the cultivation of plants have been among the most significant causes of the human impact (see Mannion, 1995). Pastoralists have had many major effects – for example, on soil erosion – though Passmore (1974: 12) believed that nomadic pastoralists are probably more conscious than agriculturists that they share the earth with other living things. Agriculturists, on the other hand, deliberately transform nature in a sense which nomadic pastoralists do not. Their main role has been to simplify the world's ecosystems. Thus in the prairies of North America, by plowing and seeding the grasslands, farmers have eliminated a hundred species of native prairie herbs and grasses, which they replace with pure

Figure 1.9 The development of plows provided humans with the ability to transform soils. This simple type is in Pakistan.

stands of wheat, corn or alfalfa. This simplification may reduce stability in the ecosystem (but see Chapter 13, section on 'The susceptibility to change'). Indeed, on a world basis (see Harlan, 1976) such simplification is evident. Whereas people once enjoyed a highly varied diet, and have used for food several thousand species of plants and several hundred species of animals, with domestication their sources are greatly reduced. For example, today four crops (wheat, rice, maize, and potatoes) at the head of the list of food supplies contribute more tonnage to the world total than the next twenty-six crops combined. Simmonds (1976) provides an excellent account of the history of most of the major crops produced by human society.

Table 1.5 Estimated changes in the areas of the major land cover types between pre-agricultural times and the present*. Source: from J. T. Matthews (personal communication), in Meyer and Turner (1994). With permission of Cambridge University Press

Land cover type	*Pre-agricultural area*	*Present area*	*Percent change*
Total forest	46.8	39.3	–16.0
Tropical forest	12.8	12.3	–3.9
Other forest	34.0	27.0	–20.6
Woodland	9.7	7.9	–18.6
Shrubland	16.2	14.8	–8.6
Grassland	34.0	27.4	–19.4
Tundra	7.4	7.4	0.0
Desert	15.9	15.6	–1.9
Cultivation	0.0	17.6	+1760.0

*Figures are given in millions of square kilometers.

The spread of agriculture has transformed **land cover** at a global scale. As Table 1.5 shows, there have been great changes in the area covered by particular biomes since pre-agricultural times. Even in the past three hundred years the areas of cropland and pasture have increased by around five to sixfold (Goldewijk, 2001). It is possible (Ruddiman, 2003) that Holocene deforestation and land-cover change modified global climates by releasing carbon dioxide into the atmosphere.

One further development in human cultural and technological life that was to increase human power was the mining of ores and the smelting of metals. Neolithic cultures used native copper from the eighth millennium BC onwards, but evidence for its smelting occurs at Catal Hüyük in Turkey from the sixth millennium BC. The spread of metal working into other areas was rapid, particularly in the second half of the fifth millennium (Muhly, 1997) (Figure 1.10), and by 2500 BC bronze products were in use from Britain in the west to northern China in the east. The smelting of iron ores may date back to the late third millennium BC. Metalworking required enormous amounts of wood and so led to deforestation.

In recent decades fossil-fuelled machinery has allowed mining activity to expand to such a degree that in terms of the amount of material moved its effects are reputed to rival the natural processes of erosion. Taking overburden into account, the total

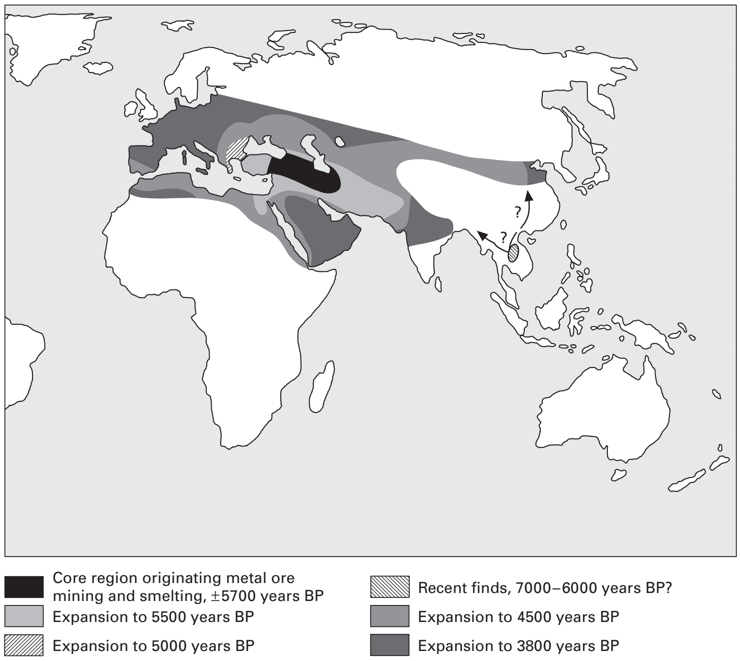

Figure 1.10 The diffusion of mining and smelting in the Old World (after Spencer and Thomas, 1978, figure 4.4).

Table 1.6 Environmental impacts of mineral extraction. Source: Young (1992, table 5)

Activity	*Potential impacts*
Excavation and ore removal	Destruction of plant and animal habitat, human settlements, and other features (surface mining)
	Land subsidence (underground mining)
	Increased erosion: silting of lakes and streams
	Waste generation (overburden)
	Acid drainage (if ore or overburden contain sulfur compounds) and metal contamination of lakes, streams, and groundwater
Ore concentration	Waste generation (tailings)
	Organic chemical contamination (tailings often contain residues of chemicals used in concentrators)
	Acid drainage (if ore contains sulfur compounds) and metal contamination of lakes, streams, and groundwater
Smelting/refining	Air pollution (substances emitted can include sulfur dioxide, arsenic, lead, cadmium, and other toxic substances)
	Waste generation (slag)
	Impacts of producing energy (most of the energy used in extracting minerals goes into smelting and refining)

amount of material moved by the mining industry globally is probably at least 28 billion tonnes – about 1.7 times the estimated amount of sediment carried each year by the world's rivers (Young, 1992). The environmental impacts of mineral extraction are diverse but extensive, and relate not only to the process of excavation and removal, but also to the processes of mineral concentration, smelting, and refining (Table 1.6).

Modern industrial and urban civilizations

In ancient times, certain cities had evolved which had considerable human populations. It has been estimated that Nineveh may have had a population of 700,000, that Augustan Rome may have had a population of around one million, and that Carthage, at its fall in 146 BC, had 700,000 (Thirgood, 1981). Such cities would have already exercised a considerable influence on their environs, but this influence was never as extensive as that of the past few centuries; for the modern era, especially since the late seventeenth century, has witnessed the transformation of, or revolution in, culture and technology – the development of major industries.

Figure 1.11 Urbanization (and, in particular, the growth of large conurbations such as Toronto in Canada) is an increasingly important phenomenon. Urbanization causes and accelerates a whole suite of environmental problems.

Table 1.7 World's urban agglomerations of ten million or more inhabitants, estimated 1999

City and country	*Includes*	*Population*
Tokyo, Japan	Yokohama, Kawasaki	34,200,000
New York, USA	Newark, Patterson	20,150,000
São Paulo, Brazil		19,750,000
Seoul, South Korea	Inchon, Songnam	19,350,000
Mexico City, Mexico	Nezahualcoyotl, Ecatepec de Morelos	18,000,000
Osaka, Japan	Kobe, Kyoto	17,700,000
Bombay (Mumbai), India	Kalyan, Thane, Ulhasnagar	17,200,000
Los Angeles, USA	Riverside, Anaheim	15,950,000
Cairo, Egypt	El Giza	13,950,000
Moscow, Russia		13,200,000
Buenos Aires, Argentina	San Justo, La Plata	13,100,000
Manila, Philippines	Quezon City, Caloocan	13,000,000
Calcutta (Kolkata), India	Haora	12,650,000
Lagos, Nigeria		12,450,000
Jakarta, Indonesia		12,100,000
Karachi, Pakistan		11,800,000
London, England		11,750,000
Shanghai, China		11,600,000
Rio de Janeiro, Brazil		11,450,000
Delhi, India		11,100,000
Tehran, Iran	Karaj	10,150,000
Paris, France		10,050,000

This, like domestication, has reduced the space required to sustain each individual and has increased the intensity with which resources are utilized. Modern science and modern medicine have compounded these effects, leading to accelerating population increase even in non-industrial societies. Urbanization has gone on apace (Figure 1.11), and it is now recognized that large cities have their own environmental problems (Cooke et al., 1982), and environmental effects (Douglas, 1983). As Table 1.7 shows, the world now has some enormous urban agglomerations. These, in turn, have large **ecological footprints**.

The perfecting of sea-going ships in the sixteenth and seventeenth centuries was part of this industrial and economic transformation, and this was the time when mainly self-contained but developing regions of the world coalesced so that the ecumene became to all intents and purposes continuous. The invention of the steam engine in the late eighteenth century, and the internal combustion engine in the late nineteenth century, massively increased human access to energy and lessened dependence on animals, wind, and water.

Modern science, technology, and industry have also been applied to agriculture, and in recent decades some spectacular progress has been made through, for example, the use of fertilizers and the selective breeding of plants and animals.

The twentieth century was a time of extraordinary change (McNeill, 2003). Human population increased from 1.5 to 6 billion, the world's economy increased fifteenfold, the world's energy use increased thirteen to fourteenfold, freshwater use increased ninefold, and the irrigated area by fivefold. In the hundred centuries from the dawn of agriculture to 1900, McNeill calculates that humanity only used about two-thirds as much energy (most of it from biomass) as it used in the twentieth century. Indeed, he argued that humankind used more energy in the twentieth century than in all preceding human history put together. In addition he suggests that the seas surrendered more fish in the twentieth century than in all previous centuries, and that the forest and woodland area shrank by about 20%, accounting for perhaps half the net deforestation in world history.

To conclude, we can recognize certain trends in human manipulation of the environment which have taken place in the modern era. The first of these is that the ways in which humans are affecting the environment are proliferating, so that we now live on what some people have argued is a human dominated planet

Table 1.8 Some indicators of change in the global economy from 1950–2000

World indicator	*1950*	*2000*	*Change (× n)*
Grain production (million tons)	631	1863	2.95
Meat production (million tons)	44	232	5.27
Coal consumption (million tons of oil equivalent)	1074	2217	2.06
Oil consumption (million tons)	470	3519	7.49
Natural gas consumption (million tons of oil equivalent)	171	2158	12.62
Car production (million)	8.0	41.1	5.14
Bike production (million)	11	104	9.45
Human population (million)	2555	6079	2.38

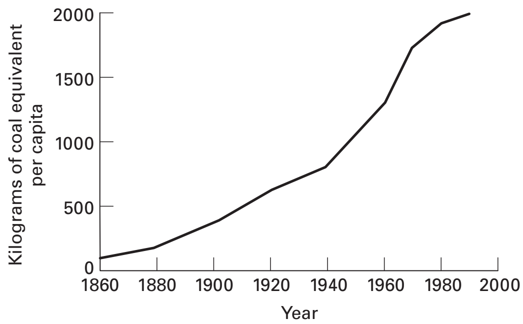

Figure 1.12 World per capita energy consumption since 1860, based on data from the United Nations.

(Vitousek et al., 1997). For example, nearly all the powerful pesticides post-date the Second World War, and the same applies to the construction of nuclear reactors. Second, environmental issues that were once locally confined have become regional or even global problems. An instance of this is the way in which substances such as DDT (dichlorodiphenyltrichloroethane), lead and sulfates are found at the poles, far removed from the industrial societies that produced them. This is one aspect of increasing globalization. Third, the complexity, magnitude, and frequency of impacts are probably increasing; for instance, massive modern dams such as at Aswan in Egypt and the Three Gorges Dam in China have very different impacts from a small Roman one. Finally, compounding the effects of rapidly expanding populations is a general increase in per capita consumption and environmental impact (Myers and Kent, 2003) (Table 1.8). Energy resources are being developed at an ever increasing rate, giving humans enormous power to transform the environment. One index of this is world commercial energy consumption, which trebled in size between the 1950s and 1980. Figure 1.12 shows worldwide energy consumption since 1860 on a per capita basis. Nonetheless, it is important to recognize that there are huge differences in the likely environmental impacts of different economies in different parts of the world. As Table 1.9 indicates, the environmental impact, as measured by the so-called ecological footprint, is twelve times greater, for example, for the average American than for the average Indian (Wackernagel and Rees, 1995).

Modern technologies have immense power output. A pioneer steam engine in AD 1800 might rate at 8–16 kW. Modern railway diesels top 3.5 MW, and a large aero engine 60 MW. Figure 1.13 shows how the human impact on six 'component indicators of the **biosphere**' has increased over time. This graph is based on work by Kates et al. (1990). Each component indicator

Table 1.9 Comparing people's average consumption in Canada, USA, India, and the world. Source: Wackernagel and Rees (1995)

Consumption per person in 1991	*Canada*	*USA*	*India*	*World*
CO_2 emission (tonnes per year)	15.2	19.5	0.81	4.2
Purchasing power ($US)	19,320	22,130	1150	3800
Vehicles per 100 persons	46	57	0.2	10
Paper consumption (kg $year^{-1}$)	247	317	2	44
Fossil energy use (GJ $year^{-1}$)	250 (234)	287	5	56
Freshwater withdrawal (m^3 $year^{-1}$)	1688	1868	612	644
Ecological footprint* (hectares per person)	4.3	5.1	0.4	1.8

*An ecological footprint is an accounting tool for ecological resources in which various categories of human consumption are translated into areas of productive land required to provide resources and assimilate waste products. It is thus a measure of how sustainable the lifestyles of different population groups are.

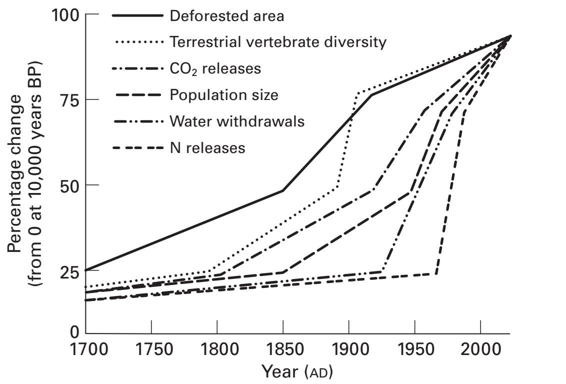

Figure 1.13 Percentage change (from assumed zero human impact at 10,000 years BP) of selected human impacts on the environment.

was taken to be 0% for 10,000 years ago (before the present = BP) and 100% for 1985. They then estimated the dates by which each component had reached successive quartiles (that is, 25, 50 and 75%) of its total change at 1985. They believe that about half of the components have changed more in the single generation since 1950 than in the whole of human history before that date. McNeill (2000) provides an exceptionally fine picture of all the changes in the environment that humans achieved in the twentieth century, and Carpenter (2001) examines the issue of whether civil engineering projects are environmentally sustainable.

Likewise, we can see stages in the pollution history of Earth. Mieck (1990), for instance, has identified a sequence of changes in the nature and causes of pollution: *pollution microbienne* or *pollution bacterielle*, caused by bacteria living and developing in decaying and putrefying materials and stagnant water associated with settlements of growing size; *pollution artisanale*, associated with small-scale craft industries such as tanneries, potteries, and other workshops carrying out various rather disagreeable tasks, including soap manufacture, bone burning, and glue-making; *pollution industrielle*, involving large-scale and pervasive pollution over major centers of industrial activity, particularly from the early nineteenth century in areas such as the Ruhr and the English 'Black Country'; *pollution fondamentale*, in which whole regions are affected by pollution, as with the desiccation and subsequent salination of the Aral Sea area; *pollution foncière*, in which vast quantities of chemicals are deliberately applied to the land as fertilizers and biocides; and finally, *pollution accidentale*, in which major accidents can cause pollution which is neither foreseen nor calculable (e.g., the Chernobyl nuclear disaster).

Above all, as a result of the escalating trajectory of environmental transformation it is now possible to talk about *global* environmental change. There are two components to this (Turner et al., 1990): systemic global change and cumulative global change. In the systemic meaning, 'global' refers to the spatial scale of operation and comprises such issues as global changes in climate brought about by atmospheric pollution. This is a topic discussed at length in Chapters 7–12. In the cumulative meaning, 'global' refers to the areal or substantive accumulation of localized change, and a change is seen to be 'global' if it occurs on a worldwide scale, or represents a significant fraction of the total environmental phenomenon or global resource. Both types of change are closely intertwined. For example, the burning of vegetation can lead to systemic change through such mechanisms as carbon dioxide release and albedo change, and to cumulative change through its impact on soil and biotic diversity (Table 1.10). It is for this reason that we now talk of

Table 1.10 Types of global environmental change. Source: from Turner et al. (1990, table 1)

Type	*Characteristic*	*Examples*
Systemic	Direct impact on globally functioning system	(a) Industrial and land use emissions of 'greenhouse' gases (b) Industrial and consumer emissions of ozone-depleting gases (c) Land cover changes in albedo
Cumulative	Impact through worldwide distribution of change	(a) Groundwater pollution and depletion (b) Species depletion/genetic alteration (biodiversity)
	Impact through magnitude of change (share of global resource)	(a) Deforestation (b) Industrial toxic pollutants (c) Soil depletion on prime agricultural lands

Earth system science and recognize the complex interactions that take place at a multitude of scales on our planet (Steffen et al., 2004).

We can conclude this introductory chapter by quoting from Kates et al. (1991: 1):

> Most of the change of the past 300 years has been at the hands of humankind, intentionally or otherwise. Our ever-growing role in this continuing metamorphosis has itself essentially changed. Transformation has escalated through time, and in some instances the scales of change have shifted from the locale and region to the earth as a whole. Whereas humankind once acted primarily upon the visible 'faces' or 'states' of the earth, such as forest cover, we are now also altering the fundamental flows of chemicals and energy that sustain life on the only inhabited planet we know.

Points for review

What have been the main stages in the development of ideas about the human impact on the environment?

How have human population levels changed over the past few millions of years?

To what extent did early humans change their environment?

What have been the main changes in the environment wrought by humans over the past 300 years?

What do you think is meant by the term Earth system science?

Guide to reading

Baker, A. R. H., 2003, *Geography and history, bridging the divide.* Cambridge: Cambridge University Press. Chapter 3 contains a valuable and perceptive discussion of environmental geographies and histories.

Freedman, B., 1995, *Environmental ecology,* 2nd edn. San Diego: Academic Press. An enormously impressive and wide-ranging study with a strong ecological emphasis.

Goudie, A. S. (ed.), 1997, *The human impact reader. Readings and case studies*. Oxford: Blackwell. A collection of key papers on many of the themes discussed in this book.

Goudie, A. S. (ed.), 2002, *Encyclopedia of global change.* New York: Oxford University Press. A multi-author, two-volume compilation.

Goudie, A. S. and Viles, H., 1997, *The Earth transformed*. Oxford: Blackwell. An introductory treatment of the human impact, with many case studies.

Kemp, D. D., 2004, *Exploring environmental issues: an integrated approach.* London: Routledge. A balanced, accessible, and comprehensive analysis of many environmental issues.

Mannion, A. M., 2002, *Dynamic world: land-cover and land-use change.* London: Hodder Arnold. A new and comprehensive study of the important role that land use plays in land transformation.

Meyer, W. B., 1996, *Human impact on the Earth.* Cambridge: Cambridge University Press. A good point of entry to the literature that brims over with thought-provoking epigrams.

Middleton, N. J., 2003, *The global casino*. London: Edward Arnold. The third edition of an introductory text, by a geographer, which is well illustrated and clearly written.

Oppenheimer, S., 2002, *Out of Eden. Peopling of the world.* London: Constable. A very accessible account of human development in prehistory.

Pickering, K. T. and Owen, L. A., 1997, *Global environmental issues* (2nd edn.) London: Routledge. A well illustrated survey.

Ponting, C., 1991, *A green history of the world.* London: Penguin. An engaging and informative treatment of how humans have transformed Earth through time.

Simmons, I. G., 1996, *Changing the face of the Earth: culture, environment and history*, 2nd edn. Oxford: Blackwell. A characteristically amusing and perceptive review of many facets of the role of humans in transforming Earth, from an essentially historical perspective.

Simmons, I. G., 1997, *Humanity and environment: a cultural ecology*. A broad account of some major themes relating to humans and the environment.

State of the Environment Advisory Council, 1996, *Australia State of the Environment 1996*. Collingword, Australia: CSIRO Publishing. A large compendium which discusses major environmental issues in the context of Australia.

Steffen, W. and 10 others, 2004, *Global change and the Earth system.* Berlin: Springer-Verlag. A multi-author, high-level, earth system science based overview of environmental change at a global scale.

Turner, B. L. II (ed.), 1990, *The Earth as transformed by human action.* Cambridge: Cambridge University Press. A very good analysis of global and regional changes over the past 300 years.

13 CONCLUSION

The power of nonindustrial and pre-industrial civilizations

It has become apparent that Marsh was correct over a century ago to express his cogently argued views of the importance of human agency in environmental change. Since his time the impact that humans have had on the environment has increased, as has our awareness of this impact. There has been 'a screeching acceleration of so many processes that bring ecological change' (McNeill, 2000: 4). However, it is worth making the point here that, although much of the concern expressed about the undesirable effects humans have tends to focus on the role played by sophisticated industrial societies, this should not blind us to the fact that many highly significant environmental changes were and are being achieved by nonindustrial societies.

In recent years it has become apparent that fire, in particular, enabled early societies to alter vegetation substantially, so that plant assemblages that were once thought to be natural climatic climaxes may in reality be in part anthropogenic fire climaxes. This applies to many areas of both savanna and mid-latitude grassland (see p. 39). Such alteration of natural vegetation has been shown to re-date the arrival of European settlers in the Americas (Denevan, 1992), New Zealand, and elsewhere. The effects of fire may have been compounded by the use of the stone axe and by the grazing effects of domestic animals. In turn the removal and modification of vegetation would have led to adjustment in fauna. It is also apparent that soil erosion resulting from vegetation removal has a long history and that it was regarded as a threat by the classical authors.

Recent studies (see p. 50) tend to suggest that some of the major environmental changes in highland Britain and similar parts of western Europe that were once explained by climatic changes can be explained more effectively by the activities of Mesolithic and Neolithic peoples. This applies, for example, to the decline in the numbers of certain plants in the pollen record and to the development of peat bogs and podzolization (see p. 103). Even soil salinization started at an early date because of the adoption of irrigation practices in arid areas, and its effects on crop yields were noted in Iraq more than 4000 years ago (see p. 102). Similarly (see p. 84) there is an increasing body of evidence that the hunting practices of early civilization may have caused great changes in the world's megafauna as early as 11,000 years ago.

In spite of the increasing pace of world industrialization and urbanization, it is plowing and pastoralism which are responsible for many of our most serious environmental problems and which are still causing some of our most widespread changes in the landscape. Thus, soil erosion brought about by agriculture is, it can be argued, a more serious pollutant of the world's waters than is industry: many of the habitat changes which so affect wild animals are brought about through agricultural expansion (see p. 79); and soil salinization and desertification can be regarded as two of the most serious problems facing the human race. Land-use changes, such as the conversion of forests to fields, may be as effective in causing anthropogenic changes in climate as the more celebrated burning of fossil fuels and emission of industrial aerosols into the atmosphere. The liberation of CO_2 in the atmosphere through agricultural expansion, changes in surface albedo values, and the production of dust, are all major ways in which agriculture may modify world climates. Perhaps most remarkably of all, humans, who only represent roughly 0.5% of the total heterotroph biomass on Earth, appropriate for their use something around one-third of the total amount of net primary production on land (Imhoff et al., 2004).

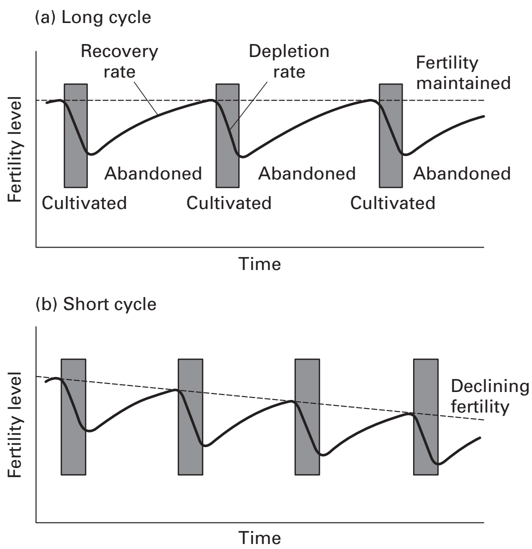

Figure 13.1 Land rotation and population density. The relationship of soil fertility cycles to cycles of slash-and-burn agriculture: (a) fertility levels are maintained under the long cycles characteristic of low-density populations; (b) fertility levels are declining under the shorter cycles characteristic of increasing population density. Notice that in both diagrams the curves of both depletion and recovery have the same slope (after Haggett, 1979, figure 8.4).

The proliferation of impacts

A further point we can make is that, with developments in technology, the number of ways in which humans are affecting the environment is proliferating. It is these recent changes, because of the uncertainty which surrounds them and the limited amount of experience we have of their potential effects, which have caused greatest concern. Thus it is only since the Second World War, for example, that humans have had nuclear reactors for electricity generation, that they have used powerful pesticides such as DDT (dichlorodiphenyltrichloroethane), and that they have sent supersonic aircraft into the stratosphere. Likewise, it is only since around the turn of the century that the world's oil resources have been extensively exploited, that chemical fertilizers have become widely used, and that the internal combustion engine has revolutionized the scale and speed of transport and communications.

Above all, however, the complexity, frequency, and magnitude of impacts are increasing, partly because of steeply rising population levels and partly because of a general increase in *per capita* consumption. Thus some traditional methods of land use, such as shifting agriculture (see p. 36) and nomadism, which have been thought to sustain some sort of environmental equilibrium, seem to break down and to cause environmental deterioration when population pressures exceed a particular threshold. This is illustrated for shifting agriculture systems by Figure 13.1, which shows the relationship of soil fertility levels to cycles of slash-and-burn agriculture. Fertility can be maintained (Figure 13.1a) under the long cycles characteristic of low-density populations. However, as population levels increase, the cycles necessarily become shorter, and soil fertility levels are not maintained, thereby imposing greater stresses on the land (Figure 13.1b).

Figure 13.2 The impact of recreation pressures is well displayed at a prehistoric hill-fort, Badbury Rings, Dorset, England. Pedestrians and motorcyclists have caused severe erosion of the ramparts.

At the other end of the spectrum, increasing incomes, leisure, and ease of communication have generated a stronger demand for recreation and tourism in the developed nations (Figure 13.2). These have created additional environmental problems (see p. 62), especially in coastal and mountain areas. Some of the environmental consequences of recreation, which are reviewed at length by Liddle (1997), can be listed as follows:

1 desecration of cave formations by speleologists;
2 trampling by human feet leading to soil compaction;
3 nutrient additions at campsites by people and their pets;
4 decrease in soil temperatures because of snow compaction by snowmobiles;
5 footpath erosion and off-road vehicle erosion;
6 dune reactivation by trampling;
7 vegetation change due to trampling and collecting;
8 creating of new habitats by cutting trails and clearing campsites;
9 pollution of lakes and inland waterways by gasoline discharge from outboard motors and by human waste;
10 creation of game reserves and protection of ancient domestic breeds;
11 disturbance of wildlife by proximity of persons and by hunting, fishing, and shooting;
12 conservation of woodland for pheasant shooting.

Likewise, it is apparent when considering the range of possible impacts of one major type of industrial development that they are significant. As Table 13.1 indicates, the exploitation of an oilfield and all the activities that it involves (e.g., pipelines, new roads, refineries, drilling, etc.) have a wide range of likely effects on land, air, water, and organisms.

Conversely, if one takes one ecosystem type as an example – the coral reef – one can see the diversity of stresses to which it is now being exposed (Figure 13.3) as a result of a whole range of different human activities, which include global warming, increased sedimentation and pollution from river runoff, and overharvesting of fish and other organisms (Bellwood et al., 2004).

A very substantial amount of change has been achieved in recent decades. Table 13.2, based on the work of Kates et al. (1990), attempts to make quantitative comparisons of the human impact on ten 'component indicators of the biosphere'. For each component they defined total net change clearly induced by humans to be 0% for 10,000 years ago and 100% for 1985. They estimated dates by which each component had reached successive quartiles (i.e., 5, 50 and 75%) of its 1985 total change. They believe that about half of the components have changed more in the single generation since 1950 than in the whole of human history before that date.

Are changes reversible?

It is evident that while humans have imposed many undesirable and often unexpected changes on the environment, they often have the capacity to modify the rate of such changes or to reverse them. There are cases where this is not possible: once soil has been eroded from an area it cannot be restored; once a plant or animal has become extinct it cannot be brought back; and once a laterite iron pan has become established it is difficult to destroy.

However, through the work of George Perkins Marsh and others, people became aware that many of the changes that had been set in train needed to be reversed or reduced in degree. Sometimes this has simply involved discontinuing a practice which has proved undesirable (such as the cavalier use of DDT or CFCs), or replacing it with another which is less detrimental

Table 13.1 Qualitative environmental impacts of mineral industries with particular reference to an oilfield. Source: Denisova (1977: 650, table 2)

Facility	*Direction of the impact and reaction to the environment*			
	Land	*Air*	*Water*	*Biocenosis*
Well	Alienation of land surface Extraction of oil associated gas, groundwater Pollution by crude oil, refined products, drilling mud Disturbance of internal structure of soil and subsoil Destruction of soil	Pollution by associated gas and volatile hydrocarbons, products of combustion	Withdrawal of surface water and groundwater Pollution by crude oil and refined products, salination of freshwater Disturbance of water balance of both subsurface and surface waters	Pollution by crude oil and refined products Disturbance and destruction over a limited surface area
Pipeline	Alienation of land Accidental oil spills Disturbance of landforms and internal structure of soil and subsoil	Pollution by volatile hydrocarbons	Disturbance and destruction over limited surface area	
Motor roads	Alienation of land Pollution by oil products Disturbance of landforms and internal structure of soil and subsoil	Pollution by combustion products, volatile hydrocarbons, sulfur dioxide, nitrogen oxides	Pollution by combustion products Disturbances and destruction over limited surface area	
Collection point	Alienation of land Pollution by crude oil and refined products (spills) Disturbance of internal structure of soil and subsoil	Pollution by volatile hydrocarbons	Disturbance and destruction over limited surface area	

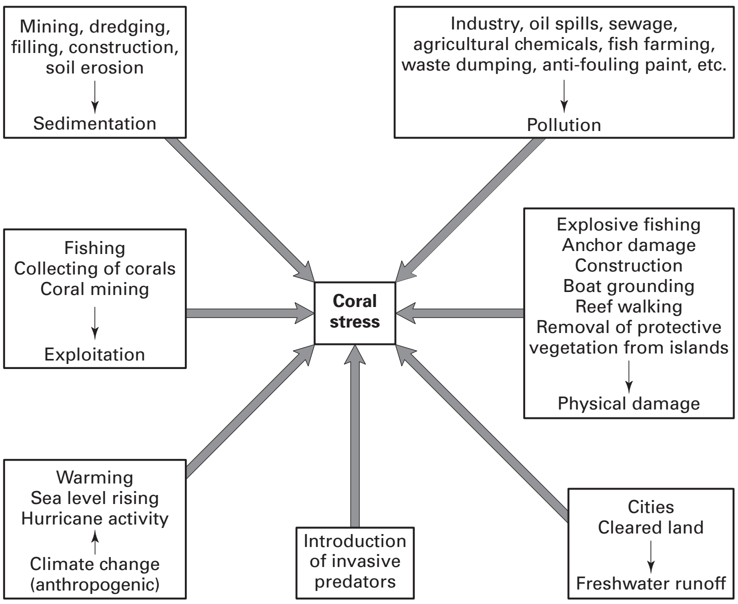

Figure 13.3 Some causes of anthropogenic stress on coral reef ecosystems.

Table 13.2 Chronologies of human-induced transformations. Source: from Kates et al. (1990, table 1.3).
(a) Quartiles of change from 10,000 BC to mid-1980s

Form of transformation	*Dates of quartiles*		
	25%	*50%*	*75%*
Deforested area	1700	1850	1915
Terrestrial vertebrate diversity	1790	1880	1910
Water withdrawals	1925	1955	1975
Population size	1850	1950	1970
Carbon releases	1815	1920	1960
Sulfur releases	1940	1960	1970
Phosphorus releases	1955	1975	1980
Nitrogen releases	1970	1975	1980
Lead releases	1920	1950	1965
Carbon tetrachloride production	1950	1960	1970

(b) Percentage change by time of Marsh and Princeton symposium

Form of transformation	*Percentage change*	
	1860	*1950*
Deforested area	50	90
Terrestrial vertebrate diversity	25–50	75–100
Water withdrawals	15	40
Population size	30	50
Carbon releases	30	65
Sulfur releases	5	40
Phosphorus releases	< 1	20
Nitrogen releases	< 1	5
Lead releases	5	50
Carbon tetrachloride production	0	25

in its effects. Often, however, specific measures have been taken which have involved deliberate decisions of management and conservation. Denson (1970), for example, outlines a sophisticated six-stage model for wildlife conservation:

1 immediate physical protection from humans and from changes in the environment;
2 educational efforts to awaken the public to the need for protection and to gain acceptance of protective measures;
3 life-history studies of the species to determine their habitat requirements and the causes of their population decline;
4 dispersion of the stock to prevent loss of the species by disease or by a chance event such as fire;
5 captive breeding of the species to assure higher survival of young, to aid research, and to reduce the chances of catastrophic loss;
6 habitat restoration or rehabilitation when this is necessary before introducing the species.

Many conservation measures have been successful, while others have created as many problems as they were intended to solve. This applies, for example, to certain schemes for the reduction of coast erosion. On balance, however, there has been notable progress in dealing with such problems as acid rain in Europe, and the depletion of stratospheric ozone. Many governments, though not all, have signed up to the Kyoto Protocol in an attempt to reduce greenhouse gas emissions.

The concern with preservation and conservation has been longstanding, with many important landmarks. Interest has grown dramatically in recent years. Lowe (1983) has identified four stages in the history of British nature conservation:

1 the natural history/humanitarian period (1830–90)
2 the preservation period (1870–1940)
3 the scientific period (1910–70)
4 the popular/political period (1960–present)

The first of these stages was rooted in a strong enthusiasm for natural history, and the crusade against cruelty to animals. Although many Victorian naturalists were avid collectors, numerous clubs were established to study nature and some of them sought to preserve species to make them available for observation. As we shall see, certain acts were introduced at this time to protect birds. During the preservationist period, there was the formation of a spate of societies devoted to preserving open land and its associated wildlife (e.g., the National Trust, 1894; and the Council for the Preservation of Rural England, 1926). There was a growing sense of vulnerability of wildlife and landscapes to urban and industrial expansion and geographers such as Vaughan Cornish (see Goudie, 1972b) campaigned for the creation of national parks and the preservation of scenery, made possible through the National Parks and Access to Countryside Act of

1949. From the First World War onwards ecological research developed, and there arose an increasing understanding of ecological relationships. Scientists pressed for the regulation of habitats and species, and the Nature Conservancy Council was established in 1949. In the 1960s and the years that followed popular interest in conservation and widespread media attention first developed. This was partly generated by pollution incidents (such as the wrecks of the *Torrey Canyon* and *Amoco Cadiz*), and a gathering sense of impending environmental doom, generated by such persuasive books as Rachel Carson's *Silent Spring*. Ecology became a political issue in various European nations, including the UK. In many countries major developments in land use, construction, and industrialization now have to be preceded by the production of an Environmental Impact Assessment, and the European Union has introduced measures such as the Water Framework Directive (2000) and the Landfill Directive to improve the ecological status of water resources.

Thus in some countries, and in connection with particular species, conservation and protection have had a long and sometimes successful impact. In Britain, for example, the Wild Birds Protection Act dates back to 1880, and the Sea Birds Protection Act even further to 1869. The various acts have been modified and augmented over the years to outlaw egg-collecting, pole-trapping, plumage importation, and the capture or possession of a range of species. The effectiveness of the different acts can be measured in real terms. Over the past 60 years no species have been lost as British breeding birds due to lack of protection – the only major loss has been the Kentish plover, which was in any case on the edge of its range. Perhaps more importantly, several species have successfully recolonized Britain, the most celebrated being the avocet and the osprey. Today both are firmly established, together with other species lost in the nineteenth century: the black-tailed godwit, the goshawk, and the bittern. Also as a result of protection the red kites of Wales have not only survived but also increased in number, and the peregrine falcon maintains its largest numbers in Europe outside Spain.

One further ground which gives some basis for hope that humans soon may be reconciled with the environment is that there are some signs of a widespread shift in public attitudes to nature and the environment. These changing social values, combined with scientific facts, influence political action. This point of view, which acts as an antidote for some of the more pessimistic views of the world's future, was elegantly presented by Ashby (1978). He contended that the rudiments of a healthy environmental ethic are developing, and explained (pp. 84–5)

> Its premise is that respect for nature is more moral than lack of respect for nature. Its logic is to put the Teesdale Sandwort . . . into the same category of value as a piece of Ming porcelain, the Yosemite Valley in the same category as Chartres Cathedral: a Suffolk landscape in the same category as a painting of the landscape by Constable. Its justification for preserving these and similar things is that they are unique, or irreplaceable, or simply part of the fabric of nature, just as Chartres and the painting by Constable are part of the fabric of civilisation; also that we do not understand how they have acquired their durability and what all the consequences would be if we destroy them.

Although there may be considerable controversy surrounding the precise criteria that can be used to select and manage sites that are particularly worthy of conservation (Goldsmith, 1983), there are nonetheless many motives behind the increasing desire to protect species and landscapes. These can be listed under the following general headings:

1 *The ethical.* It is asserted that wild species have a right to coexist with us on our planet, and that we have no right to exterminate them. Nature, it is maintained, is not simply there for humans to transform and modify as they please for their own utilitarian ends.
2 *The scientific*. We know very little about our surrounding environments, including, for example, the rich insect faunas of the tropical rain forest; therefore such environments should be preserved for future scientific study.
3 *The aesthetic.* Plants and animals, together with landscapes, may be beautiful and so enrich the life of humans.
4 *The need to maintain genetic diversity*. By protecting species we maintain the species diversity upon which future plant- and animal-breeding work will depend. Once genes have been lost (see Chapter 2, section on 'The change in genetic and species diversity') they cannot be replaced.

5 *Environmental stability*. It is argued that in general the more diverse an ecosystem is, the more checks and balances there are to maintain stability. Thus environments that have been greatly simplified by humans may be inherently unstable, and prone to disease, etc.
6 *Recreational.* Preserved habitats and landscapes have enormous recreational value, and in the case of some game reserves and natural parks may have economic value as well (e.g., the safari industry of East Africa).
7 *Economic*. Many of the species in the world are still little known, and there is the possibility that we have great storehouses of plants and animals, which, when knowledge improves, may become useful economic resources.
8 *Future generations.* One of the prime arguments for conservation, whether of beautiful countryside, rare species, soil, or mineral resources, is that future generations (and possibly ourselves later in life) will require them, and may think badly of a generation that has squandered them.
9 *Unintended impacts.* As we have seen so often in this book, profligate or unwise actions can lead to side-effects and consequences that may be disadvantageous to humans.
10 *Spiritual imperatives.* This includes a belief in the need for environmental stewardship.

Some of these arguments are more utilitarian than others (e.g., 4, 5, 6, 7 and 9), and some may be subject to doubt – it could, for example, be argued that future generations will have technology to use new resources and may not need some of those we regard as essential – but overall they provide a broadly based platform for the conservation ideal (Myers, 1979).

The susceptibility to change

Ecosystems respond in different ways to the human impact, and some are more vulnerable to human perturbation than others (Kasperson et al., 1995). It has often been thought, for example, that complex ecosystems are more stable than simple ones. Thus in Clements' Theory of Succession the tendency towards community stabilization was ascribed in part to an increasing level of integration of community functions. As Goodman (1975: 238) has expressed it:

> In general the predisposition to expect greater stability of complex systems was probably a combined legacy of eighteenth century theories of political economics, aesthetically and perhaps religiously motivated attraction to the belief that the wondrous variety of nature must have some purpose in an orderly work, and ageless folkwisdom regarding eggs and baskets.

Indeed, as Murdoch (1975) has pointed out, it makes good intuitive sense that a system with many links, or 'multiple fail-safes', is more stable than one with few links or feedback loops. As an example, if a type of herbivore is attacked by several predatory species, the loss of any one of these species will be less likely to allow the herbivore to erupt or explode in numbers than if only one predator species were present and that single predator type disappeared. The basic idea therefore is that diverse groups of species are more stable because complementary species compensate for one another if one species suffers severe declines (Doak and Marvier, 2003). A diverse ecosystem will have a variety of species that help to insure it against a range of environmental upsets (Naeem, 2002).

Various other arguments have been marshaled to support the idea that great diversity and complexity affords greater ability to minimize the magnitude, duration, and irreversibility of changes brought about by some external perturbation such as human activity (Noy-Meir, 1974). It has been stated that natural systems, which are generally more diverse than artificial systems such as crops or laboratory populations, are also more stable. Likewise, the tropical rain forest has been thought of as more diverse and more stable than less complex temperate communities, while simple Arctic ecosystems of oceanic islands have always appeared highly vulnerable to disturbance brought about by anthropogenic plant and animal introductions (see p. 54).

However, considerable doubt has been expressed as to whether the classic concept of the causal linkage between diversity/complexity and stability is entirely valid (see, e.g., Hurd et al., 1971). Murdoch (1975) indicated that there is not convincing field evidence that diverse natural communities are generally more stable than simple ones. He cited various papers which show that fluctuations of microtine rodents (lemmings, field voles, etc.) are as violent in relatively complex temperate zone ecosystems as they are in the less complex Arctic zone ecosystems. This was supported by Goodman (1975: 239) who wrote:

> As for the apparent stability of tropical biota, that could well be an illusion attributable to insufficient study of bewilderingly complex assemblages in which many species are so poorly represented in samples of feasible size that even considerable fluctuations might go undetected. Indeed, there are countervailing anecdotes regarding ecological instability in the tropics, such as recent reports on an insect virtually defoliating the wild Brazil-nut trees in Bolivia and of monkeys succumbing in large numbers to epidemics.

He went on to add: 'There is growing awareness of the surprising susceptibility of the rain forest ecosystems to man-made perturbation.' This is a point of view supported by May (1979) and discussed by Hill (1975). Hill pointed out that a very high species diversity is frequently associated with areas which have relatively constant physical environmental conditions over the course of a year and a series of years. The rain forest may be construed to be such an environment, and one where this constancy has allowed the presence of many specialized species, each pursuing a narrow range of activities. It has been argued that because of the high degree of specialization, the indigenous species have a limited ability to recover from major stresses caused by human intervention.

Goodman (1975) has also queried the sufficiency of the argument in its reference to the apparent instability of island ecosystems, suggesting that islands, being evolutionary backwaters and dead-ends, may accumulate species that are especially susceptible to competitive or exploitative displacement. In this case, lack of diversity may not necessarily be the sole or prime cause of instability.

The apparent instability of agricultural compared with natural communities is also often attributed to lack of diversity (see p. 62), and indeed modern agriculture does involve significant ecosystem simplification. However, such instability as there is may not, once again, necessarily result from simplification. Other factors could promote instability: agricultural communities are disrupted, even destroyed, more frequently and more massively as part of the cultivation process than those natural systems we tend to think of as stable; the component species of natural systems are co-evolved (co-adapted), and this is not usually true of agricultural communities. As Murdoch (1975: 799) suggests, it may be that:

> Natural systems are more stable than crop systems because their interacting species have had a long shared evolutionary history. In contrast with these natural communities the dominant plant species of a crop system is thrust into an often alien landscape . . . the crops have undergone radical selection in breeding programs, often losing their genetic defense mechanisms.

Thus the idea that complex natural ecosystems will be less susceptible to human interference and that simple artificial ecosystems will inevitably be unstable are not necessarily tenable. Nonetheless, it is apparent that there are differences in susceptibility between different ecosystem types, and these differences may result from factors other than the degree of diversity and complexity (Cairns and Dickson, 1977).

Some systems tend to be *vulnerable*. Lakes, for example, are natural traps and sinks and are thus more vulnerable to the effect of disadvantageous inputs than are rivers (which are continually receiving new inputs) or oceans (which are so much larger). Other systems display the property of *elasticity* – the ability to recover from damage. This may be because nearby epicenters exist to provide organisms to reinvade a damaged system. Small, isolated systems will often tend to possess low elasticity (see p. 88). Two of the most important properties, however, are *resilience* (being a measure of the number of times a system can recover after stress), and *inertia* (the ability to resist displacement of structural and functional characteristics).

Two systems which display resilience and inertia are deserts and estuaries. In both cases their indigenous organisms are highly accustomed to variable environmental conditions. Thus most desert fauna and flora evolved in an environment where the normal pattern is one of more or less random alternations of short favorable periods and long stress periods. They have pre-adapted resilience (Noy-Meir, 1974) so that they can tolerate extreme conditions, have the ability for rapid recovery, have various delay and trigger mechanisms (in the case of plants), and have flexible and opportunistic eating habits (in the case beasts). Estuaries, on the other hand, although the subject of increasing human pressures, also display some resilience. The vigor of their water circulation continuously and endogenously renews the supply of water, food, larvae, etc.; this aids recovery. Also, many species have biological characteristics that provide special advantages in estuarine survival. These characteristics usually protect the species against the natural violence of estuaries and are often helpful in resisting external forces such as humans.

The relationship between biodiversity and ecosystem stability continues to be a hot topic in ecology (Loreau et al., 2002; Kareiva and Levin, 2003). Some studies continue to throw doubt upon any simple relationship between biodiversity and stability (e.g., Pfisterer and Schmid, 2002), but there is perhaps an emerging consensus that diversity is crucial to ecosystem operation (McCann, 2000). As Loreau et al. (2001: 807) write,

> There is consensus that at least some minimum number of species is essential for ecosystem functioning under constant conditions and that a larger number of species is probably essential for maintaining the stability of ecosystem processes in changing environments.

Human influence or nature?

From many of the examples given in this book it is apparent that in many cases of environmental change it is impossible to state, without risk of contradiction, that people rather than nature are responsible. Most systems are complex and human agency is but one component of them, so that many human actions can lead to end-products that are intrinsically similar to those that may be produced by natural forces. How to distinguish between human-induced perturbations and ill-defined natural oscillations is a crucial question when considering issues such as coral reef degradation (Sapp, 1999). It is a case of equifinality, whereby different processes can lead to basically similar results. Humans are not always responsible for some of the changes with which they are credited. This book has given many examples of this problem and a selection is presented in Table 13.3. Deciphering the cause is often a ticklish problem, given the intricate interdependence of different components of ecosystems, the frequency and complexity of environmental changes, and the varying relaxation times that different ecosystem components may have when subject to a new impulse. This problem plainly does not apply to the

Table 13.3 Human influence or nature? Some examples, with page references to this book where applicable

Change	*Causes*		
	Natural	*Anthropogenic*	*Page reference*
Late Pleistocene animal extinction	Climate	Hunting	84
Death of savanna trees	Soil salinization through climatically induced groundwater rise	Overgrazing	–
Desertification of semi-arid areas	Climatic change	Overgrazing, etc.	42
Holocene peat-bog development in highland Britain	Climatic change and progressive soil deterioration	Deforestation and plowing	103
Holocene elm and linden decline	Climatic change	Feeding and stalling of animals	51
Tree encroachment into alpine pastures in USA	Temperature amelioration	Cessation of burning	–
Gully development	Climatic change	Land-use change	171
Late twentieth-century climatic warming	Changes in solar emission and volcanic activity	CO_2-generated greenhouse effect	196
Increasing coast recession	Rising sea level	Disruption of sediment supply	185
Increasing coastal flood risk	Rising sea level, natural subsidence	Pumping of aquifers creating subsidence	168
Increasing river flood intensity	Higher intensity rainfall	Creation of drainage ditches	134
Ground collapse	Karstic process	Dewatering by overpumping	157
Forest decline	Drought	Air, soil, and water pollution	59

same extent to changes that have been brought about deliberately and knowingly by humans, but it does apply to the many cases where humans may have initiated change inadvertently and unintentionally.

This fundamental difficulty means that environmental impact statements of any kind are extremely difficult to make. As we have seen, humans have been living on the earth and modifying it in different degrees for several millions of years, so that it is problematic to reconstruct any picture of the environment before human intervention. We seldom have any clear baseline against which to measure changes brought about by human society. Moreover, even without human interference, the environment would be in a perpetual state of flux on a great many different timescales. In addition, there are spatial and temporal discontinuities between cause and effect. For example, erosion in one locality may lead to deposition in another, while destruction of key elements of an animal's habitat may lead to population declines throughout its range. Likewise, in a time context, a considerable interval may elapse before the full implications of an activity are apparent. Also, because of the complex interaction between different components of different environmental systems and subsystems, it is almost impossible to measure total environmental impact. For example, changes in soil may lead to changes in vegetation, which in turn may trigger changes in water quality and in animal populations. Primary impacts give rise to a myriad of successive repercussions throughout ecosystems, which may be impracticable to trace and monitor. Quantitative cause-and-effect relationships can seldom be established.

Into the unknown

During the 1980s and 1990s the full significance of possible future environmental changes has become apparent, and national governments and international institutions have begun to ponder whether the world is entering a spasm of unparalleled humanly induced modification. For example, Steffen et al. (2004) have suggested that Earth is currently operating in a no-analogue state. They remark (p. 262):

> In terms of key environmental parameters, the Earth System has recently moved well outside the range of the natural variability exhibited over at least the last half million years. The nature of changes now occurring simultaneously in the Earth System, their magnitudes and rates of change are unprecedented.

Likewise, the Amsterdam Declaration of 2001 pointed to the role of thresholds and surprises (see Steffen et al., 2004, p. 298):

> Global change cannot be understood in terms of a simple cause-effect paradigm. Human-driven changes cause multiple effects that cascade through the Earth System in complex ways. These effects interact with each other and with local- and regional-scale changes in multidimensional patterns that are difficult to understand and even more difficult to predict. Surprises abound.
>
> Earth System dynamics are characterized by critical thresholds and abrupt changes. Human activities could inadvertently trigger such changes with severe consequences for Earth's environment and inhabitants.

Our models and predictions are still highly inadequate, and there are great ranges in some of the values we give for such crucial changes as sea-level rise and global climatic warming, but the balance of scientific argument favors the view that change will occur and that change will be substantial. Some of the changes may be advantageous for humans or for particular ecosystems; others will be extremely disadvantageous.

It is clear that many environmental problems are interrelated and transboundary in scope so that integrated approaches and international cooperation are required. Environmental issues and environmental solutions have become globalized (Steffen et al., 2004, p. 290).

Some environments will change very substantially during the twenty-first century in response to a rise of land-use changes and climatic changes, with some predictions suggesting that the world's grasslands and Mediterranean biomes being particularly impacted (Sala et al., 2000). Marine ecosystems will also be impacted and Jenkins (2003: 1176) suggests that by 2050: 'If present trends . . . continue, the world's marine ecosystems in 2050 will look very different from today's, large species, and particularly top predators, will be by and large extremely scarce and some will have disappeared entirely . . .' Human populations will increase, and will probably be greater by 2 to 4 billion people by 2050 (Cohen, 2003).

But all change, if it is rapid and of a great magnitude, is likely to create uncertainties and instabilities. The study of future events will not only become a major concern for the environmental sciences but will also become a major concern for economists, sociologists, lawyers, and political scientists. George Perkins Marsh was a lawyer and politician, but it is only now, over a century since he wrote *Man and nature*, that the wisdom, perspicacity, and prescience of his ideas have begun to be given the praise and attention they deserve.

Points for review

Why has there been a 'screeching acceleration' in the twentieth century of so many processes that bring ecological change?

How may adverse environmental changes be reversed?

Why should one conserve nature?

In the context of ecosystems, what do you understand by such terms as 'stability', 'resilience', 'elasticity', and 'inertia'?

Why is it often difficult to disentangle natural and anthropogenic causes of environmental changes?

Guide to reading

Liddle, M., 1997, *Recreation ecology*. London: Chapman and Hall. An excellent review of the multiple ways in which recreation and tourism have an impact on the environment.

O'Riordan, T. (ed.), 1995, *Environmental science for environmental management*. Harlow: Longman Scientific. A multi-author guide to managing environmental change.

Roberts, N. (ed.), 1994, *The changing global environment*. Oxford: Blackwell. A good collection of case studies with a wide perspective.

Simon, J. L. (ed.), 1995, *The state of humanity*. Oxford: Blackwell. A multi-author work with an optimistic message.

Simon, J. L., 1996, *The ultimate resource 2.* Princeton: Princeton University Press. A view that the state of the world is improving.

Steffen, W. and 10 others, 2004, *Global change and the earth system.* Berlin: Springer. Chapter 6 of this multi-author volume addresses ways of global management for global sustainability.

Turner, B. L. (ed.), 1990, *The Earth as transformed by human action*. Cambridge: Cambridge University Press. A magnificent study of change in the past 300 years.

Climate Change 2007:
Synthesis Report

Summary for Policymakers

An Assessment of the Intergovernmental Panel on Climate Change

This summary, approved in detail at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

Based on a draft prepared by:

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Introduction

This Synthesis Report is based on the assessment carried out by the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

A complete elaboration of the Topics covered in this summary can be found in this Synthesis Report and in the underlying reports of the three Working Groups.

1. Observed changes in climate and their effects

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Figure SPM.1). *{1.1}*

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C[1] is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the Third Assessment Report (TAR) (Figure SPM.1). The temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans (Figures SPM.2, SPM.4). *{1.1, 1.2}*

Rising sea level is consistent with warming (Figure SPM.1). Global average sea level has risen since 1961 at an average rate of 1.8 [1.3 to 2.3] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets. Whether the faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear. *{1.1}*

Observed decreases in snow and ice extent are also consistent with warming (Figure SPM.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. *{1.1}*

From 1900 to 2005, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia but declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has *likely*[2] increased since the 1970s. *{1.1}*

It is *very likely* that over the past 50 years: cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. It is *likely* that: heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level[3] has increased worldwide. *{1.1}*

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones. It is difficult to ascertain longer-term trends in cyclone activity, particularly prior to 1970. *{1.1}*

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. *{1.1}*

Observational evidence[4] from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. *{1.2}*

Changes in snow, ice and frozen ground have with *high confidence* increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions and led to changes in some Arctic and Antarctic ecosystems. *{1.2}*

There is *high confidence* that some hydrological systems have also been affected through increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers and through effects on thermal structure and water quality of warming rivers and lakes. *{1.2}*

In terrestrial ecosystems, earlier timing of spring events and poleward and upward shifts in plant and animal ranges are with *very high confidence* linked to recent warming. In some marine and freshwater systems, shifts in ranges and changes in algal, plankton and fish abundance are with *high confidence* associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. *{1.2}*

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Fig-

[1] Numbers in square brackets indicate a 90% uncertainty interval around a best estimate, i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Uncertainty intervals are not necessarily symmetric around the corresponding best estimate.

[2] Words in italics represent calibrated expressions of uncertainty and confidence. Relevant terms are explained in the Box 'Treatment of uncertainty' in the Introduction of this Synthesis Report.

[3] Excluding tsunamis, which are not due to climate change. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

[4] Based largely on data sets that cover the period since 1970.

Changes in temperature, sea level and Northern Hemisphere snow cover

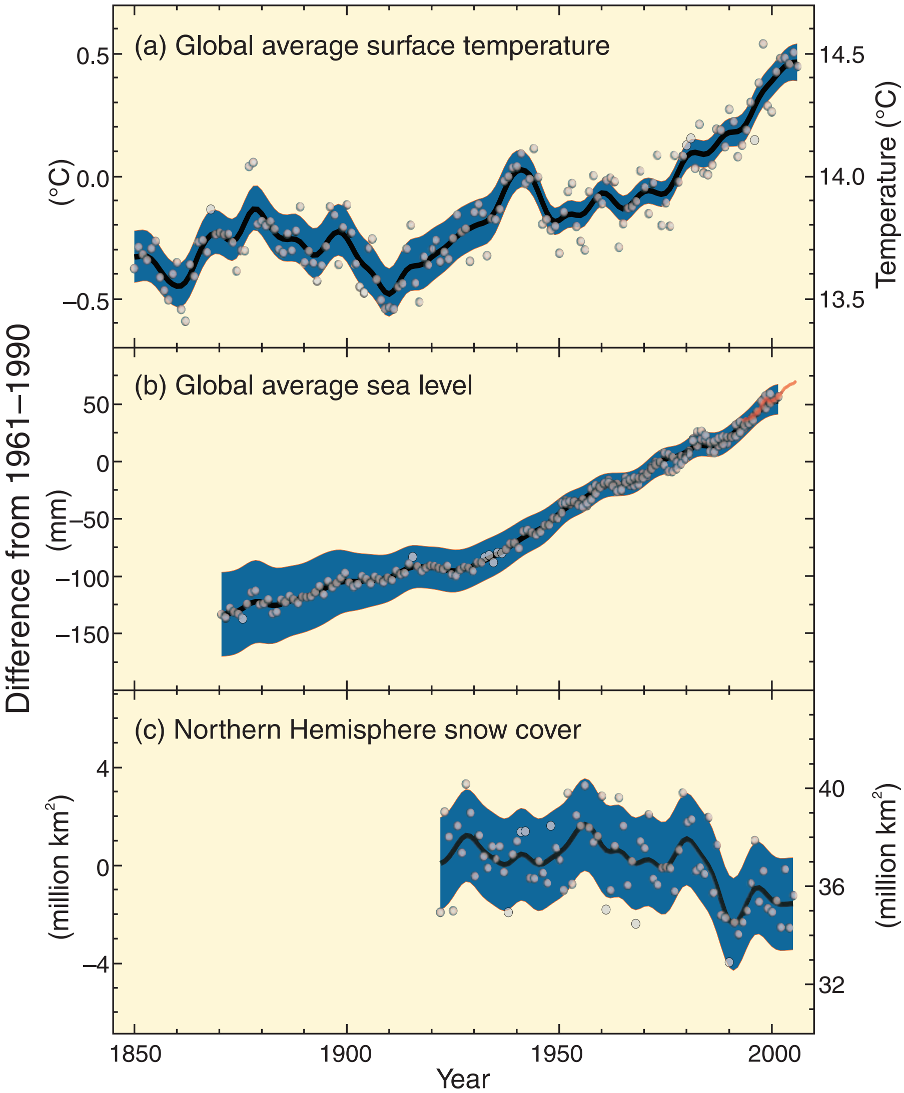


Figure SPM.1. *Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {Figure 1.1}*

ure SPM.2). However, there is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. *{1.2, 1.3}*

There is *medium confidence* that other effects of regional climate change on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. *{1.2}*

They include effects of temperature increases on: *{1.2}*

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests
- some aspects of human health, such as heat-related mortality in Europe, changes in infectious disease vectors in some areas, and allergenic pollen in Northern Hemisphere high and mid-latitudes
- some human activities in the Arctic (e.g. hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports).

Changes in physical and biological systems and surface temperature 1970-2004

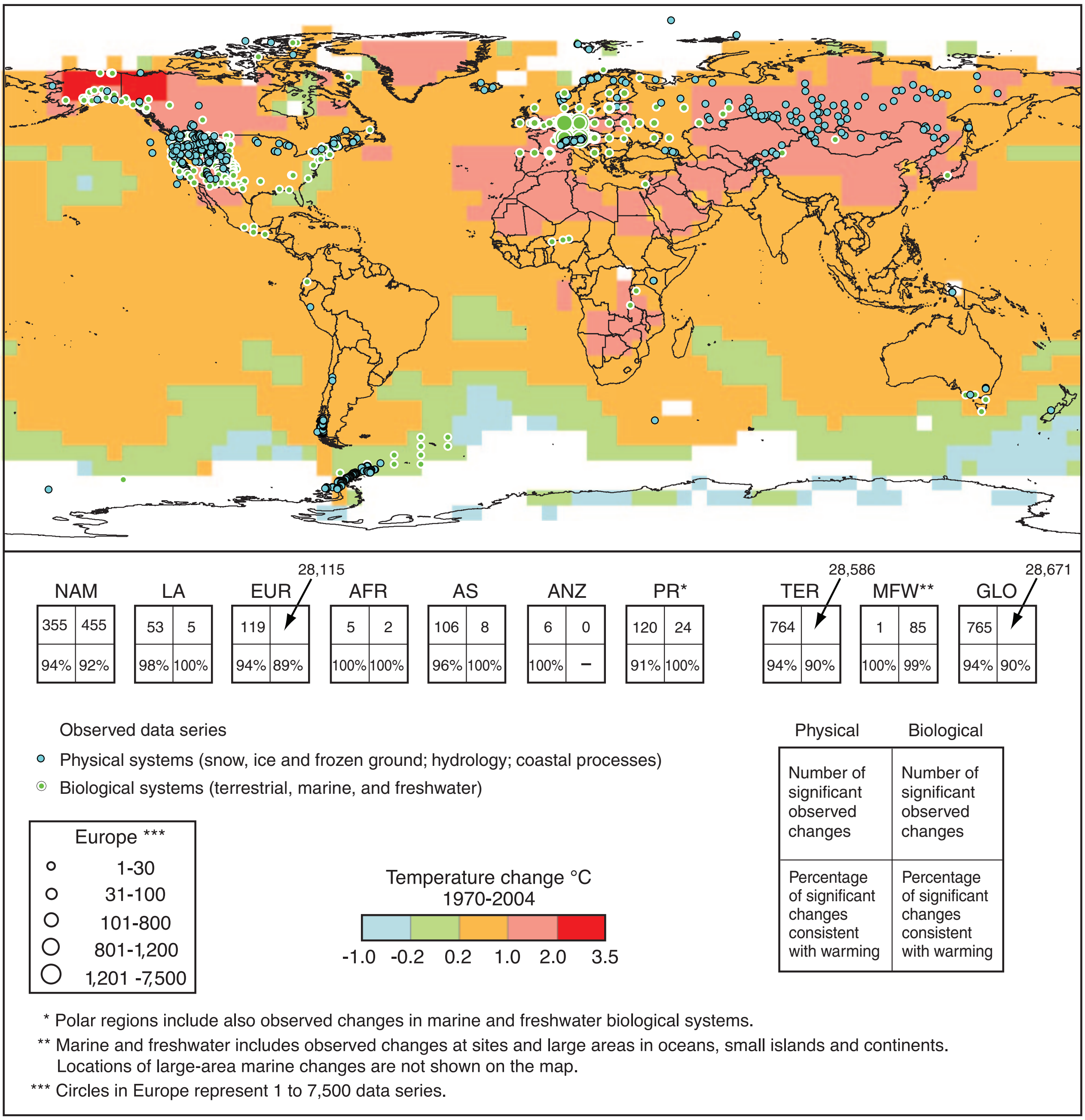


Figure SPM.2. *Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 × 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, EUR, AFR, AS, ANZ, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. {Figure 1.2}*

2. Causes of change

Changes in atmospheric concentrations of greenhouse gases (GHGs) and aerosols, land cover and solar radiation alter the energy balance of the climate system. *{2.2}*

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure SPM.3).[5] *{2.1}*

Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions grew by about 80% between 1970 and 2004. The long-term trend of declining CO_2 emissions per unit of energy supplied reversed after 2000. *{2.1}*

Global atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. *{2.2}*

Atmospheric concentrations of CO_2 (379ppm) and CH_4 (1774ppb) in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. CH_4 growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. The increase in N_2O concentration is primarily due to agriculture. *{2.2}*

There is *very high confidence* that the net effect of human activities since 1750 has been one of warming.[6] *{2.2}*

Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.[7] It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (Figure SPM.4). *{2.4}*

During the past 50 years, the sum of solar and volcanic forcings would *likely* have produced cooling. Observed patterns of warming and their changes are simulated only by models that include anthropogenic forcings. Difficulties remain in simulating and attributing observed temperature changes at smaller than continental scales. *{2.4}*

Global anthropogenic GHG emissions

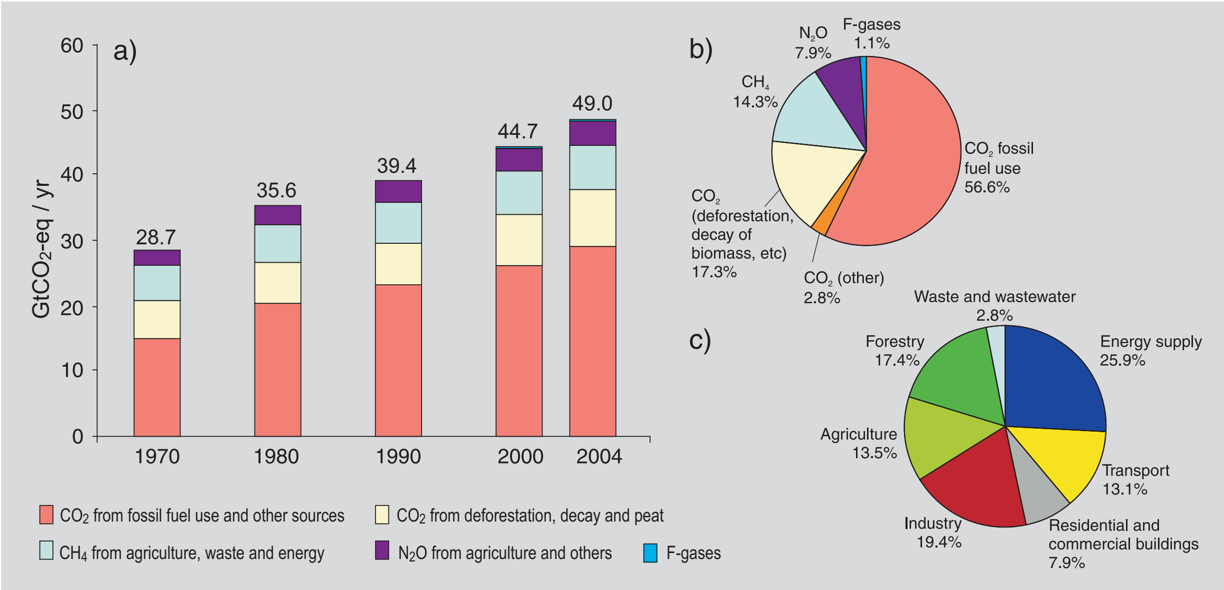


Figure SPM.3. *(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.) {Figure 2.1}*

[5] Includes only carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6), whose emissions are covered by the United Nations Framework Convention on Climate Change (UNFCCC). These GHGs are weighted by their 100-year Global Warming Potentials, using values consistent with reporting under the UNFCCC.

[6] Increases in GHGs tend to warm the surface while the net effect of increases in aerosols tends to cool it. The net effect due to human activities since the pre-industrial era is one of warming (+1.6 [+0.6 to +2.4] W/m²). In comparison, changes in solar irradiance are estimated to have caused a small warming effect (+0.12 [+0.06 to +0.30] W/m²).

[7] Consideration of remaining uncertainty is based on current methodologies.

Global and continental temperature change

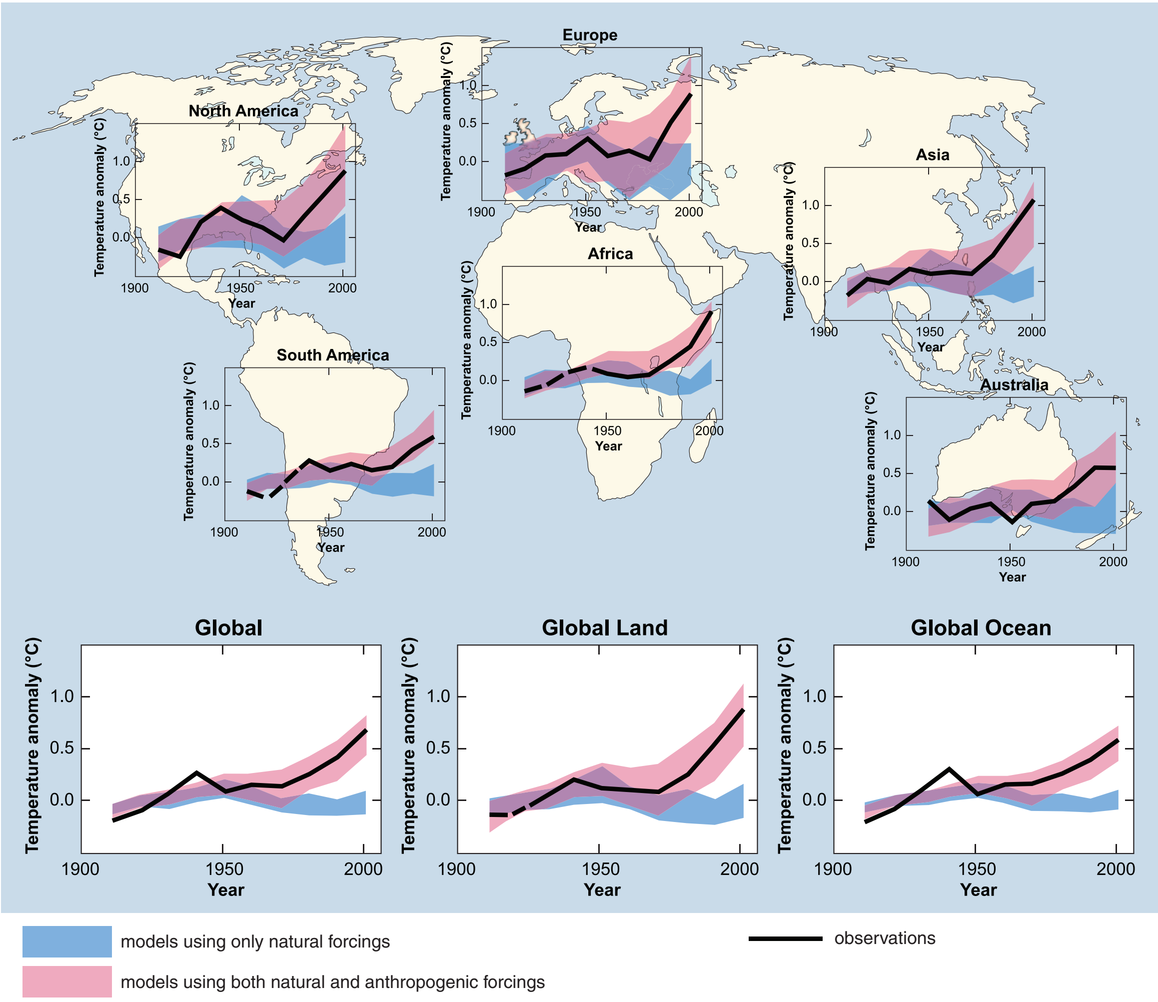


Figure SPM.4. *Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {Figure 2.5}*

Advances since the TAR show that discernible human influences extend beyond average temperature to other aspects of climate. *{2.4}*

Human influences have: *{2.4}*

- *very likely* contributed to sea level rise during the latter half of the 20th century
- *likely* contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns
- *likely* increased temperatures of extreme hot nights, cold nights and cold days
- *more likely than not* increased risk of heat waves, area affected by drought since the 1970s and frequency of heavy precipitation events.

Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. *{2.4}*

Spatial agreement between regions of significant warming across the globe and locations of significant observed changes in many systems consistent with warming is *very unlikely* to be due solely to natural variability. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming. *{2.4}*

More complete attribution of observed natural system responses to anthropogenic warming is currently prevented by the short time scales of many impact studies, greater natural climate variability at regional scales, contributions of non-climate factors and limited spatial coverage of studies. *{2.4}*

3. Projected climate change and its impacts

There is *high agreement* and *much evidence* that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. *{3.1}*

The IPCC Special Report on Emissions Scenarios (SRES, 2000) projects an increase of global GHG emissions by 25 to 90% (CO_2-eq) between 2000 and 2030 (Figure SPM.5), with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. More recent scenarios without additional emissions mitigation are comparable in range.[8,9] *{3.1}*

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century (Table SPM.1, Figure SPM.5). *{3.2.1}*

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios. *{3.2}*

The range of projections (Table SPM.1) is broadly consistent with the TAR, but uncertainties and upper ranges for temperature are larger mainly because the broader range of available models suggests stronger climate-carbon cycle feedbacks. Warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. The strength of this feedback effect varies markedly among models. *{2.3, 3.2.1}*

Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Table SPM.1 shows model-based projections

Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures

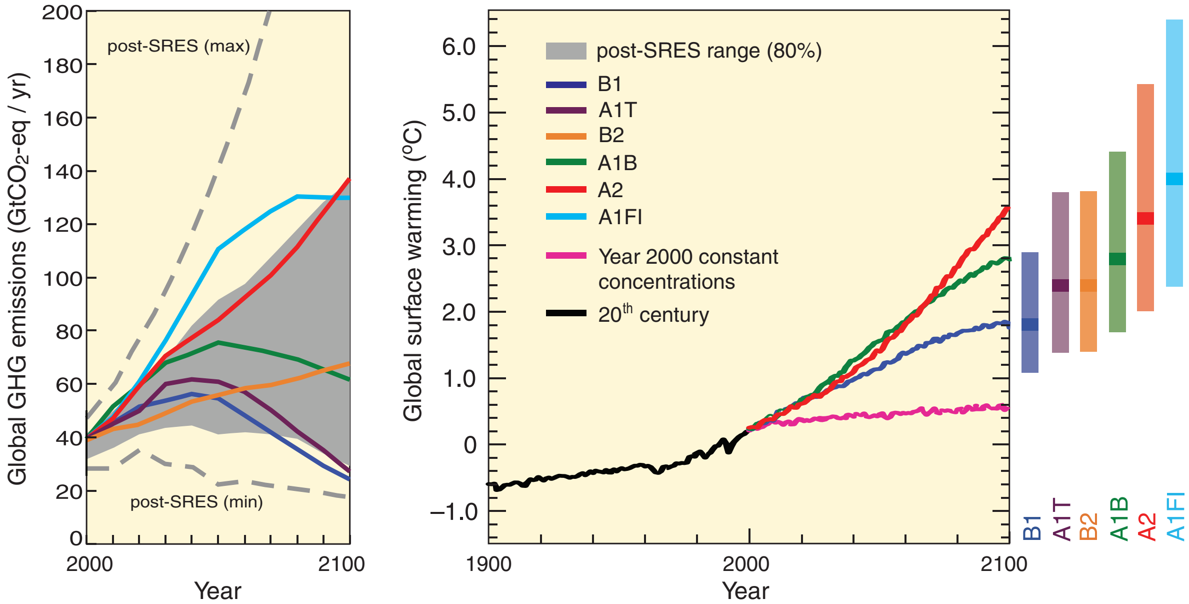


Figure SPM.5. ***Left Panel:*** *Global GHG emissions (in GtCO$_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases.* ***Right Panel:*** *Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the* likely *range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. {Figures 3.1 and 3.2}*

[8] For an explanation of SRES emissions scenarios, see Box 'SRES scenarios' in Topic 3 of this Synthesis Report. These scenarios do not include additional climate policies above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion.

[9] Emission pathways of mitigation scenarios are discussed in Section 5.

Table SPM.1. *Projected global average surface warming and sea level rise at the end of the 21st century. {Table 3.1}*

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

a) Temperatures are assessed best estimates and *likely* uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the Working Group I TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.

d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

of global average sea level rise for 2090-2099.[10] The projections do not include uncertainties in climate-carbon cycle feedbacks nor the full effects of changes in ice sheet flow, therefore the upper values of the ranges are not to be considered upper bounds for sea level rise. They include a contribution from increased Greenland and Antarctic ice flow at the rates observed for 1993-2003, but this could increase or decrease in the future.[11] *{3.2.1}*

There is now higher confidence than in the TAR in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea ice. ***{3.2.2}***

Regional-scale changes include: *{3.2.2}*

- warming greatest over land and at most high northern latitudes and least over Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends (Figure SPM.6)
- contraction of snow cover area, increases in thaw depth over most permafrost regions and decrease in sea ice extent; in some projections using SRES scenarios, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century
- *very likely* increase in frequency of hot extremes, heat waves and heavy precipitation
- *likely* increase in tropical cyclone intensity; less confidence in global decrease of tropical cyclone numbers
- poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation and temperature patterns
- *very likely* precipitation increases in high latitudes and *likely* decreases in most subtropical land regions, continuing observed recent trends.

There is *high confidence* that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics. There is also *high confidence* that many semi-arid areas (e.g. Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. *{3.3.1, Figure 3.5}*

Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. ***{3.3.1, 3.3.2}***

Figure SPM.7 presents examples of this new information for systems and sectors. The top panel shows impacts increasing with increasing temperature change. Their estimated magnitude and timing is also affected by development pathway (lower panel). *{3.3.1}*

Examples of some projected impacts for different regions are given in Table SPM.2.

[10] TAR projections were made for 2100, whereas the projections for this report are for 2090-2099. The TAR would have had similar ranges to those in Table SPM.1 if it had treated uncertainties in the same way.

[11] For discussion of the longer term, see material below.

Geographical pattern of surface warming

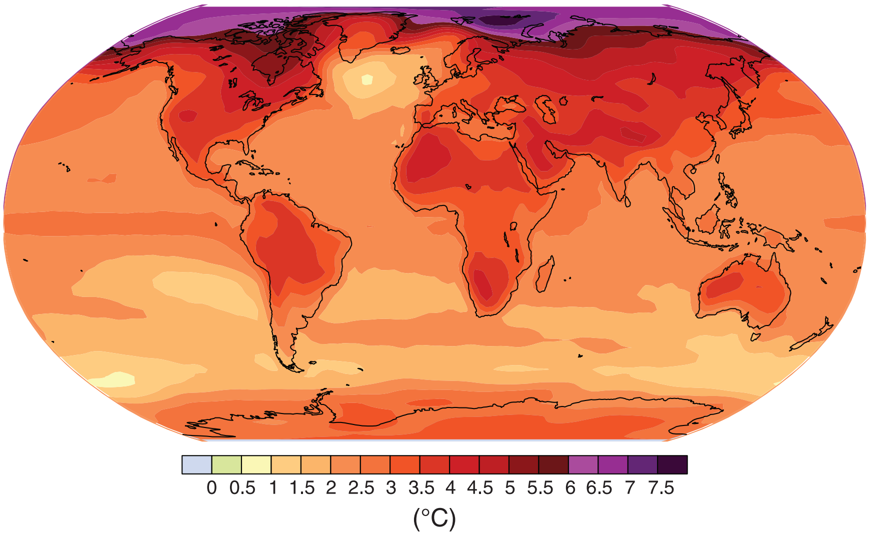


Figure SPM.6. *Projected surface temperature changes for the late 21st century (2090-2099). The map shows the multi-AOGCM average projection for the A1B SRES scenario. Temperatures are relative to the period 1980-1999. {Figure 3.2}*

Some systems, sectors and regions are *likely* to be especially affected by climate change.[12] *{3.3.3}*

Systems and sectors: *{3.3.3}*

- particular ecosystems:
  - terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
  - coastal: mangroves and salt marshes, due to multiple stresses
  - marine: coral reefs due to multiple stresses; the sea ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes[13] and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions: *{3.3.3}*

- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children and the elderly) can be particularly at risk, and also some areas and some activities. *{3.3.3}*

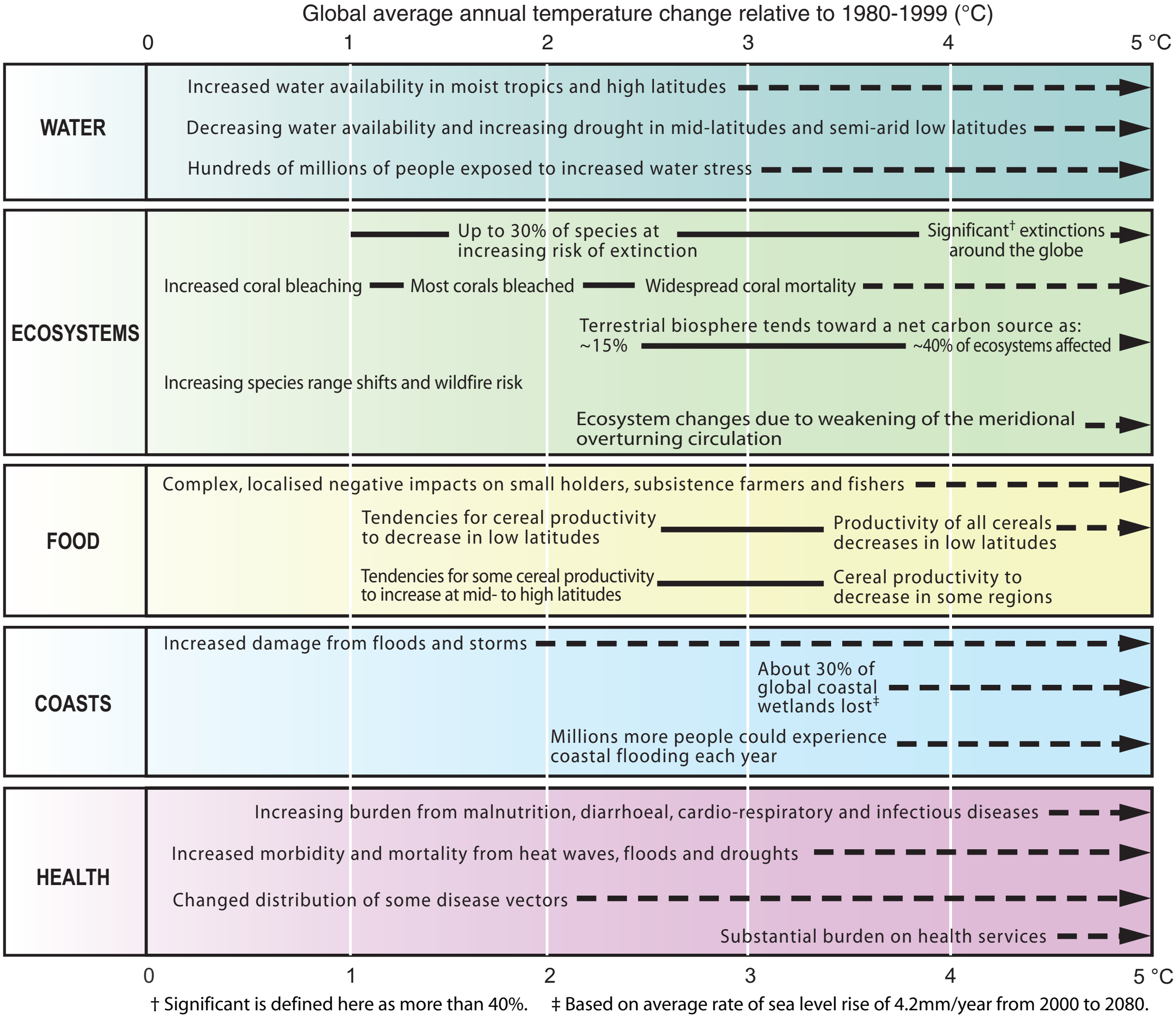
Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO_2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species. *{3.3.4}*

[12] Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

[13] Including arid and semi-arid regions.

Examples of impacts associated with global average temperature change
(Impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway)



Warming by 2090-2099 relative to 1980-1999 for non-mitigation scenarios

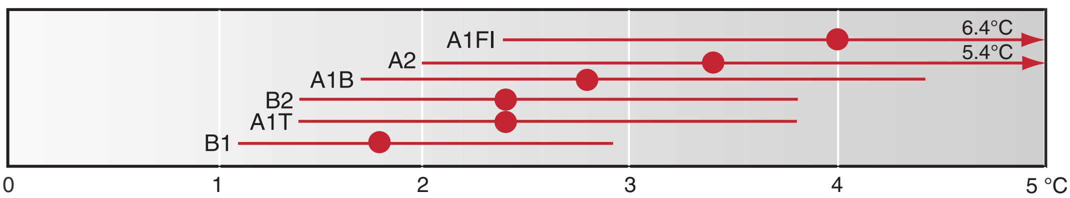


Figure SPM.7. *Examples of impacts associated with projected global average surface warming.* ***Upper panel:*** *Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are* high. ***Lower panel:*** *Dots and bars indicate the best estimate and* likely *ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. {Figure 3.6}*

Table SPM.2. Examples of some projected regional impacts. {3.3.2}

Africa	• By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. • By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. • Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of Gross Domestic Product (GDP). • By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (TS).
Asia	• By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease. • Coastal areas, especially heavily populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. • Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development. • Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle.
Australia and New Zealand	• By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. • By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. • By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. • By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding.
Europe	• Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). • Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080). • In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. • Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires.
Latin America	• By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. • There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. • Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (TS; *medium confidence*). • Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation.
North America	• Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. • In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. • Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. • Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution.

continued...

Table SPM.2. *continued...*

Polar Regions	• The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. • For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. • Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. • In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered.
Small Islands	• Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. • Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. • By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. • With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands.

Note:
Unless stated explicitly, all entries are from Working Group II SPM text, and are either *very high confidence* or *high confidence* statements, reflecting different sectors (agriculture, ecosystems, water, coasts, health, industry and settlements). The Working Group II SPM refers to the source of the statements, timelines and temperatures. The magnitude and timing of impacts that will ultimately be realised will vary with the amount and rate of climate change, emissions scenarios, development pathways and adaptation.

Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems. *{3.3.5}*

Examples for selected extremes and sectors are shown in Table SPM.3.

Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. *{3.2.3}*

Estimated long-term (multi-century) warming corresponding to the six AR4 Working Group III stabilisation categories is shown in Figure SPM.8.

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m if global average warming were sustained for millennia in excess of 1.9 to 4.6°C relative to pre-industrial values. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when palaeoclimatic information suggests reductions of polar land ice extent and 4 to 6m of sea level rise. *{3.2.3}*

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. *{3.2.3}*

Estimated multi-century warming relative to 1980-1999 for AR4 stabilisation categories

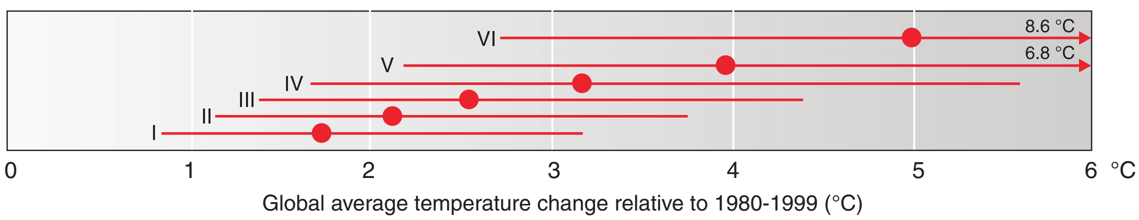


Figure SPM.8. *Estimated long-term (multi-century) warming corresponding to the six AR4 Working Group III stabilisation categories (Table SPM.6). The temperature scale has been shifted by -0.5°C compared to Table SPM.6 to account approximately for the warming between pre-industrial and 1980-1999. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For GHG emissions scenarios that lead to stabilisation at levels comparable to SRES B1 and A1B by 2100 (600 and 850ppm CO_2-eq; category IV and V), assessed models project that about 65 to 70% of the estimated global equilibrium temperature increase, assuming a climate sensitivity of 3°C, would be realised at the time of stabilisation. For the much lower stabilisation scenarios (category I and II, Figure SPM.11), the equilibrium temperature may be reached earlier. {Figure 3.4}*

Table SPM.3. *Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column two relate to the phenomena listed in column one. {Table 3.2}*

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlement and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	*Virtually certain*[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	*Very likely*	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	*Very likely*	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	*Likely*	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	*Likely*	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	*Likely*[d]	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:
a) See Working Group I Table 3.7 for further details regarding definitions.
b) Warming of the most extreme days and nights each year.
c) Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
d) In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. *{3.4}*

Partial loss of ice sheets on polar land could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur over millennial time scales, but more rapid sea level rise on century time scales cannot be excluded. *{3.4}*

Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20 to 30% of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. *{3.4}*

Based on current model simulations, the meridional overturning circulation (MOC) of the Atlantic Ocean will *very likely* slow down during the 21st century; nevertheless temperatures over the Atlantic and Europe are projected to increase. The MOC is *very unlikely* to undergo a large abrupt transition during the 21st century. Longer-term MOC changes cannot be assessed with confidence. Impacts of large-scale and persistent changes in the MOC are *likely* to include changes in marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation. Changes in terrestrial and ocean CO_2 uptake may feed back on the climate system. *{3.4}*

4. Adaptation and mitigation options[14]

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. *{4.2}*

Societies have a long record of managing the impacts of weather- and climate-related events. Nevertheless, additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. Moreover, vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. *{4.2}*

Some planned adaptation to climate change is already occurring on a limited basis. Adaptation can reduce vulnerability, especially when it is embedded within broader sectoral initiatives (Table SPM.4). There is *high confidence* that there are viable adaptation options that can be implemented in some sectors at low cost, and/or with high benefit-cost ratios. However, comprehensive estimates of global costs and benefits of adaptation are limited. *{4.2, Table 4.1}*

Adaptive capacity is intimately connected to social and economic development but is unevenly distributed across and within societies. *{4.2}*

A range of barriers limits both the implementation and effectiveness of adaptation measures. The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. *{4.2}*

Both bottom-up and top-down studies indicate that there is *high agreement* and *much evidence* of substantial economic potential for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels (Figures SPM.9, SPM.10).[15] While top-down and bottom-up studies are in line at the global level (Figure SPM.9) there are considerable differences at the sectoral level. *{4.3}*

No single technology can provide all of the mitigation potential in any sector. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed (Table SPM.5). *{4.3}*

Bottom-up studies suggest that mitigation opportunities with net negative costs have the potential to reduce emissions by around 6 $GtCO_2$-eq/yr in 2030, realising which requires dealing with implementation barriers. *{4.3}*

[14] While this Section deals with adaptation and mitigation separately, these responses can be complementary. This theme is discussed in Section 5.

[15] The concept of '**mitigation potential**' has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of 'market mitigation potential' and 'economic mitigation potential'.

Market mitigation potential is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

Economic mitigation potential is the mitigation potential that takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

Mitigation potential is estimated using different types of approaches. ***Bottom-up studies*** are based on assessment of mitigation options, emphasising specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. ***Top-down studies*** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

Table SPM.4. *Selected examples of planned adaptation by sector. {Table 4.1}*

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; *italics = opportunities*)
Water	Expanded rainwater harvesting; water storage and conservation techniques; water re-use; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; *integrated water resources management; synergies with other sectors*
Agriculture	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological and financial constraints; access to new varieties; markets; *longer growing season in higher latitudes; revenues from 'new' products*
Infrastructure/ settlement (including coastal zones)	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; *integrated policies and management; synergies with sustainable development goals*
Human health	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthened health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; *upgraded health services; improved quality of life*
Tourism	Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); *revenues from 'new' attractions; involvement of wider group of stakeholders*
Transport	Ralignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; *improved technologies and integration with key sectors (e.g. energy)*
Energy	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; *stimulation of new technologies; use of local resources*

Note:
Other examples from many sectors would include early warning systems.

Future energy infrastructure investment decisions, expected to exceed US$20 trillion[16] between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO_2 emissions to 2005 levels by 2030 would require a large shift in investment patterns, although the net additional investment required ranges from negligible to 5 to 10%. *{4.3}*

[16] 20 trillion = 20,000 billion = 20×10^{12}

Comparison between global economic mitigation potential and projected emissions increase in 2030

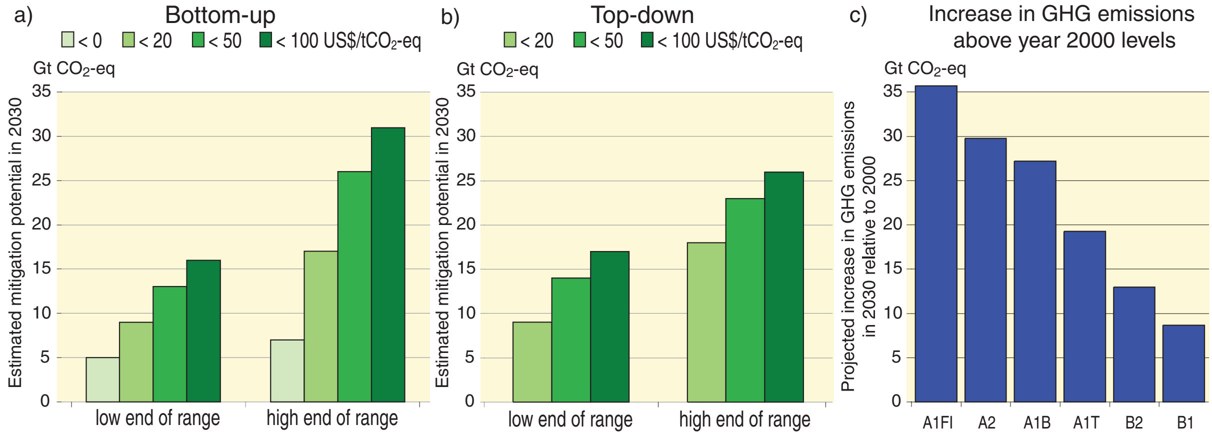


Figure SPM.9. *Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 GtCO$_2$-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emission results. {Figure 4.1}*

Economic mitigation potentials by sector in 2030 estimated from bottom-up studies

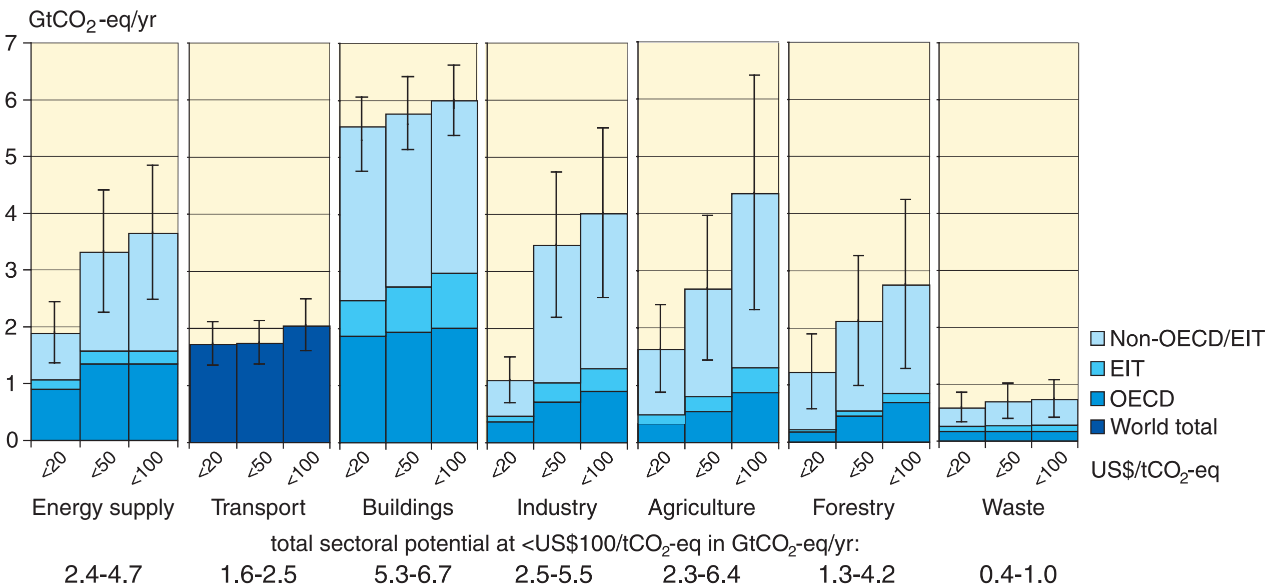


Figure SPM.10. *Estimated economic mitigation potential by sector in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. The potentials do not include non-technical options such as lifestyle changes. {Figure 4.2}*

Notes:

a) The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.

b) The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.

c) Sectors used different baselines. For industry, the SRES B2 baseline was taken, for energy supply and transport, the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.

d) Only global totals for transport are shown because international aviation is included.

e) Categories excluded are: non-CO$_2$ emissions in buildings and transport, part of material efficiency options, heat production and co-generation in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

Table SPM.5 *Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {Table 4.2}*

Sector	Key mitigation technologies and practices currently commercially available. ***Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.***	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; *italics = opportunities*)
Energy supply	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO_2 from natural gas); *CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics*	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
		Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies	*May be appropriate to create markets for low-emissions technologies*
Transport	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; *second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries*	Mandatory fuel economy; biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
		Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing	Effectiveness may drop with higher incomes
		Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport	*Particularly appropriate for countries that are building up their transportation systems*
Buildings	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; *integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings*	Appliance standards and labelling	Periodic revision of standards needed
		Building codes and certification	*Attractive for new buildings.* Enforcement can be difficult
		Demand-side management programmes	Need for regulations so that utilities may profit
		Public sector leadership programmes, including procurement	*Government purchasing can expand demand for energy-efficient products*
		Incentives for energy service companies (ESCOs)	*Success factor: Access to third party financing*
Industry	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and a wide array of process-specific technologies; *advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture*	Provision of benchmark information; performance standards; subsidies; tax credits	*May be appropriate to stimulate technology uptake.* Stability of national policy important in view of international competitiveness
		Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
		Voluntary agreements	Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertiliser application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; *improvements of crop yields*	Financial incentives and regulations for improved land management; maintaining soil carbon content; efficient use of fertilisers and irrigation	*May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation*
Forestry/ forests	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; *tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land-use change*	Financial incentives (national and international) to increase forest area, to reduce deforestation and to maintain and manage forests; land-use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. *Can help poverty alleviation*
Waste	Landfill CH_4 recovery; waste incineration with energy recovery; composting of organic waste; controlled wastewater treatment; recycling and waste minimisation; *biocovers and biofilters to optimise CH_4 oxidation*	Financial incentives for improved waste and wastewater management	*May stimulate technology diffusion*
		Renewable energy incentives or obligations	Local availability of low-cost fuel
		Waste management regulations	Most effectively applied at national level with enforcement strategies

A wide variety of policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and sectoral context (Table SPM.5). *{4.3}*

They include integrating climate policies in wider development policies, regulations and standards, taxes and charges, tradable permits, financial incentives, voluntary agreements, information instruments, and research, development and demonstration (RD&D). *{4.3}*

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show that global carbon prices rising to US$20-80/t$CO_2$-eq by 2030 are consistent with stabilisation at around 550ppm CO_2-eq by 2100. For the same stabilisation level, induced technological change may lower these price ranges to US$5-65/t$CO_2$-eq in 2030.[17] *{4.3}*

There is *high agreement* and *much evidence* that mitigation actions can result in near-term co-benefits (e.g. improved health due to reduced air pollution) that may offset a substantial fraction of mitigation costs. *{4.3}*

There is *high agreement* and *medium evidence* that Annex I countries' actions may affect the global economy and global emissions, although the scale of carbon leakage remains uncertain.[18] *{4.3}*

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spillover depends strongly on assumptions related to policy decisions and oil market conditions. *{4.3}*

There is also *high agreement* and *medium evidence* that changes in lifestyle, behaviour patterns and management practices can contribute to climate change mitigation across all sectors. *{4.3}*

Many options for reducing global GHG emissions through international cooperation exist. There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to climate change, stimulation of an array of national policies, and the creation of an international carbon market and new institutional mechanisms that may provide the foundation for future mitigation efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional international initiatives have been suggested. *{4.5}*

Greater cooperative efforts and expansion of market mechanisms will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Efforts can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development-oriented actions; or expanding financing instruments. *{4.5}*

In several sectors, climate response options can be implemented to realise synergies and avoid conflicts with other dimensions of sustainable development. Decisions about macroeconomic and other non-climate policies can significantly affect emissions, adaptive capacity and vulnerability. *{4.4, 5.8}*

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions and reduce vulnerability, but there may be barriers to implementation. On the other hand, it is *very likely* that climate change can slow the pace of progress towards sustainable development. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. *{5.8}*

5. The long-term perspective

Determining what constitutes "dangerous anthropogenic interference with the climate system" in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled 'key'. *{Box 'Key Vulnerabilities and Article 2 of the UNFCCC', Topic 5}*

Key vulnerabilities[19] may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. *{Box 'Key Vulnerabilities and Article 2 of the UNFCCC', Topic 5}*

[17] Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least-cost approach to mitigation portfolios, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

[18] Further details may be found in Topic 4 of this Synthesis Report.

[19] Key vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

The five 'reasons for concern' identified in the TAR remain a viable framework to consider key vulnerabilities. These 'reasons' are assessed here to be stronger than in the TAR. Many risks are identified with higher confidence. Some risks are projected to be larger or to occur at lower increases in temperature. Understanding about the relationship between impacts (the basis for 'reasons for concern' in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. *{5.2}*

This is due to more precise identification of the circumstances that make systems, sectors and regions especially vulnerable and growing evidence of the risks of very large impacts on multiple-century time scales. *{5.2}*

- ***Risks to unique and threatened systems.*** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-industrial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of indigenous communities in the Arctic and small island communities to warming is projected. *{5.2}*
- ***Risks of extreme weather events.*** Responses to some recent extreme events reveal higher levels of vulnerability than the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. *{5.2}*
- ***Distribution of impacts and vulnerabilities.*** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. Moreover, there is increased evidence that low-latitude and less developed areas generally face greater risk, for example in dry areas and megadeltas. *{5.2}*
- ***Aggregate impacts.*** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude of warming, while damages would be higher for larger magnitudes of warming. The net costs of impacts of increased warming are projected to increase over time. *{5.2}*
- ***Risks of large-scale singularities.*** There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. *{5.2}*

There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts; however, they can complement each other and together can significantly reduce the risks of climate change. *{5.3}*

Adaptation is necessary in the short and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs, but these are not fully understood. Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. The time at which such limits could be reached will vary between sectors and regions. Early mitigation actions would avoid further locking in carbon intensive infrastructure and reduce climate change and associated adaptation needs. *{5.2, 5.3}*

Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. *{5.3, 5.4, 5.7}*

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter. The lower the stabilisation level, the more quickly this peak and decline would need to occur.[20] *{5.4}*

Table SPM.6 and Figure SPM.11 summarise the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium global warming and long-

[20] For the lowest mitigation scenario category assessed, emissions would need to peak by 2015, and for the highest, by 2090 (see Table SPM.6). Scenarios that use alternative emission pathways show substantial differences in the rate of global climate change.

term sea level rise due to thermal expansion only.[21] The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. *{5.4, 5.7}*

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. The long time scales of thermal expansion and ice sheet response to warming imply that stabilisation of GHG concentrations at or above present levels would not stabilise sea level for many centuries. *{5.3, 5.4}*

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for their development, acquisition, deployment and diffusion and addressing related barriers. *{5.5}*

All assessed stabilisation scenarios indicate that 60 to 80% of the reductions would come from energy supply and use and industrial processes, with energy efficiency playing a key role in many scenarios. Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Low stabilisation levels require early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies. *{5.5}*

Without substantial investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. *{5.5}*

Table SPM.6. *Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] {Table 5.1}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d, e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).
b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.
c) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure SPM.3).
d) The best estimate of climate sensitivity is 3°C.
e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 21).
f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

[21] Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels, global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure SPM.11), the equilibrium temperature may be reached earlier.

CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

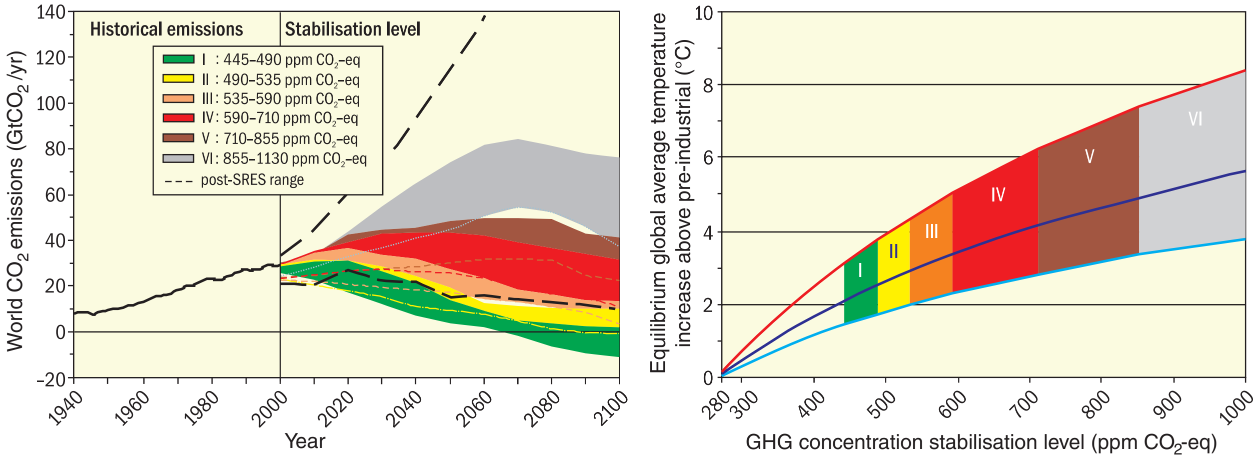


Figure SPM.11. *Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the* likely *equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of* likely *range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of* likely *range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10th to 90th percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {Figure 5.1}*

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target (Table SPM.7). For specific countries and sectors, costs vary considerably from the global average.[22] *{5.6}*

In 2050, global average macro-economic costs for mitigation towards stabilisation between 710 and 445ppm CO_2-eq are between a 1% gain and 5.5% decrease of global GDP (Table SPM.7). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. *{5.6}*

Table SPM.7. *Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {Table 5.2}*

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points) [c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		< 3	< 5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:
Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.
a) Global GDP based on market exchange rates.
b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO_2-eq) gives the upper bound estimate of the literature only.
c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.
d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.
e) The values correspond to the highest estimate for GDP reduction shown in column three.

[22] See Footnote 17 for more detail on cost estimates and model assumptions.

Responding to climate change involves an iterative risk management process that includes both adaptation and mitigation and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk. *{5.1}*

Impacts of climate change are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. Peer-reviewed estimates of the social cost of carbon[23] in 2005 average US$12 per tonne of CO_2, but the range from 100 estimates is large (-$3 to $95/t$CO_2$). This is due in large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses and discount rates. Aggregate estimates of costs mask significant differences in impacts across sectors, regions and populations and *very likely* underestimate damage costs because they cannot include many non-quantifiable impacts. *{5.7}*

Limited and early analytical results from integrated analyses of the costs and benefits of mitigation indicate that they are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. *{5.7}*

Climate sensitivity is a key uncertainty for mitigation scenarios for specific temperature levels. *{5.4}*

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. *{5.7}*

[23] Net economic costs of damages from climate change aggregated across the globe and discounted to the specified year.

WORLD POPULATION PROSPECTS: THE 2017 REVISION

SUMMARY AND KEY FINDINGS

People and therefore populations are at the centre of sustainable development and will be influential in the realization of the 2030 Agenda for Sustainable Development. The *2017 Revision* of the *World Population Prospects* is the twenty-fifth round of official United Nations population estimates and projections, which have been prepared since 1951 by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. The *2017 Revision* builds on previous revisions by incorporating additional results from the 2010 and 2020 rounds of national population censuses as well as findings from recent specialized sample surveys from around the world. The *2017 Revision* provides a comprehensive set of demographic data and indicators to assess population trends at the global, regional and national levels and to calculate many other key indicators commonly used by the United Nations system.

Snapshot of global population in 2017

According to the results of the *2017 Revision*, the world's population numbered nearly 7.6 billion as of mid-2017 (table 1), implying that the world has added approximately one billion inhabitants over the last twelve years. Sixty per cent of the world's people live in Asia (4.5 billion), 17 per cent in Africa (1.3 billion), 10 per cent in Europe (742 million), 9 per cent in Latin America and the Caribbean (646 million), and the remaining 6 per cent in Northern America (361 million) and Oceania (41 million). China (1.4 billion) and India (1.3 billion) remain the two most populous countries of the world, comprising 19 and 18 per cent of the global total, respectively.

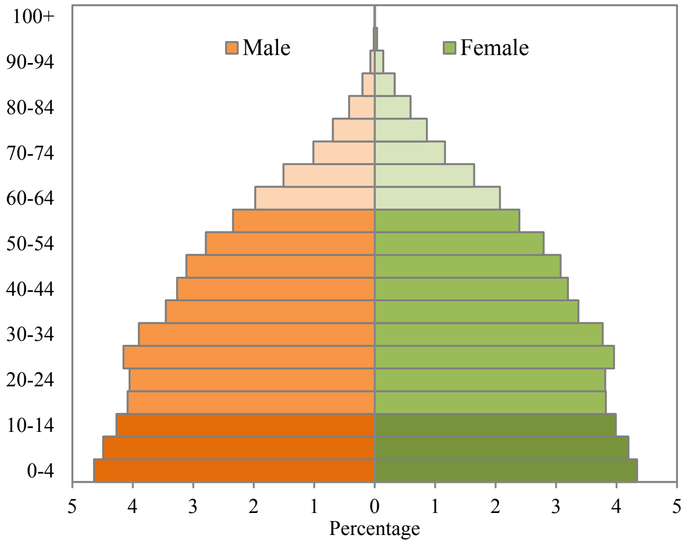
TABLE 1. POPULATION OF THE WORLD AND REGIONS, 2017, 2030, 2050 AND 2100, ACCORDING TO THE MEDIUM-VARIANT PROJECTION

	Population (millions)			
Region	*2017*	*2030*	*2050*	*2100*
World	7 550	8 551	9 772	11 184
Africa	1 256	1 704	2 528	4 468
Asia	4 504	4 947	5 257	4 780
Europe	742	739	716	653
Latin America and the Caribbean	646	718	780	712
Northern America	361	395	435	499
Oceania	41	48	57	72

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

At the global level, the numbers of men and women are roughly equal, with the male population being slightly larger than the female population. Currently, in 2017, there are 102 men for every 100 women. Thus, in a group of 1,000 people selected at random from the world's population, 504 would be male and 496 would be female on average (figure 1). Children under 15 years of age represent roughly one quarter of the world's inhabitants (26 per cent), while older persons aged 60 or over account for just over one eighth (13 per cent). More than half (61 per cent) are adults between 15 and 59 years of age. If the total number of people were split in half according to the age distribution of the world's population (at the median age), one group would bring together all persons younger than 30 years of age, while the other would include everyone aged 30 years or older.

Figure 1. Distribution of the world's population by age and sex, 2017

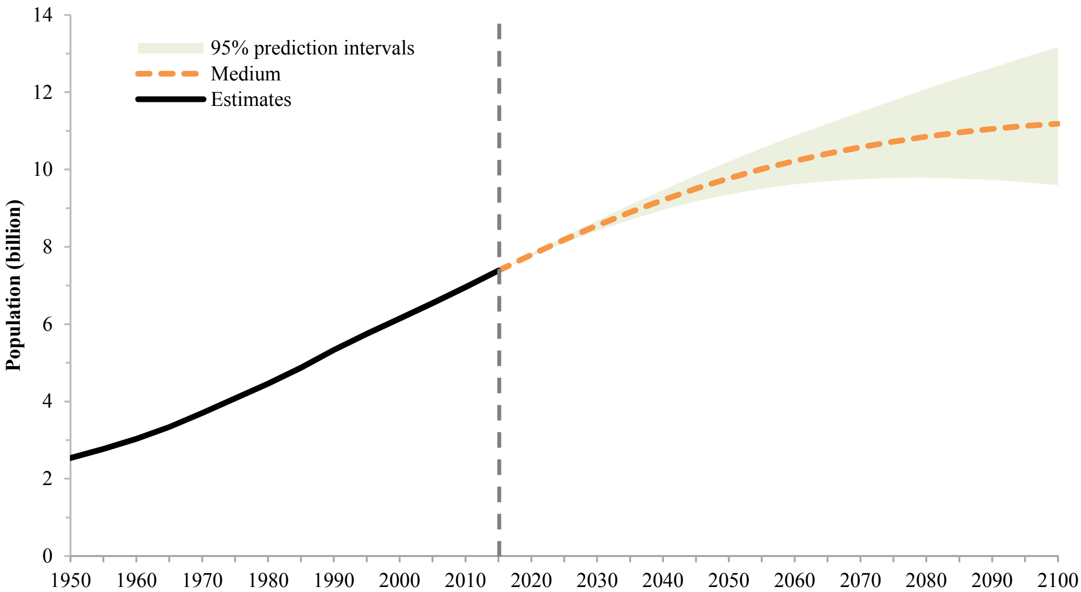


Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

Projected growth of the global population

Today, the world's population continues to grow, albeit more slowly than in the recent past. Ten years ago, the global population was growing by 1.24 per cent per year. Today, it is growing by 1.10 per cent per year, yielding an additional 83 million people annually. The world's population is projected to increase by slightly more than one billion people over the next 13 years, reaching 8.6 billion in 2030, and to increase further to 9.8 billion in 2050 and 11.2 billion by 2100 (table 1).

Figure 2. Population of the world: estimates, 1950-2015, and medium-variant projection with 95 per cent prediction intervals, 2015-2100



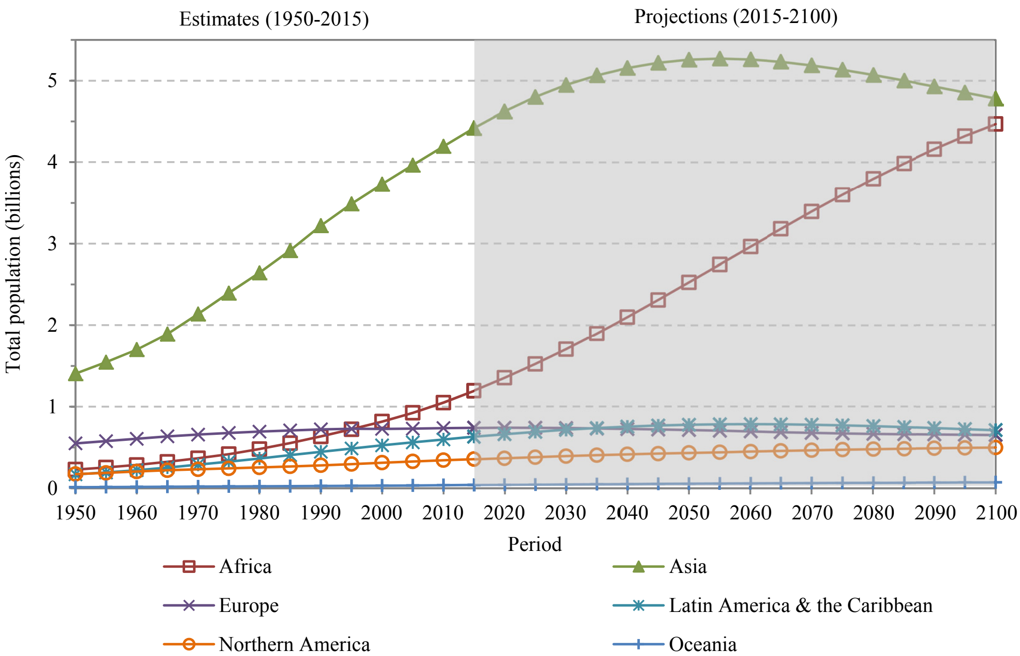
Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

There is inherent uncertainty in population projections, which depend on assumptions about plausible future trends in specific demographic variables. The results presented above for future years are based on the medium-variant projection of the *2017 Revision*, which assumes a decline of fertility for countries where large families are still prevalent, as well as a slight increase of fertility in several countries where women have fewer than two live births on average over a lifetime. Survival rates are projected to increase in all countries as death rates continue to decline throughout the age range. The uncertainty surrounding the projected trends in fertility and mortality has been assessed using statistical methods that generate statements about a range of plausible outcomes. For example, the analysis has concluded that, with a certainty of 95 per cent, the size of the global population will stand between 8.4 and 8.7 billion in 2030, between 9.4 and 10.2 billion in 2050, and between 9.6 and 13.2 billion in 2100 (figure 2). Thus, the size of the world's population is virtually certain to rise over the next few decades. Later in the century, although a continued increase of the global population is considered the most likely outcome, there is roughly a 27 per cent chance that the world's population could stabilize or even begin to fall sometime before 2100.

Diversity in population growth rates across regions

More than half of the anticipated growth in global population between now and 2050 is expected to occur in Africa (figure 3). Of the additional 2.2 billion people who may be added between 2017 and 2050, 1.3 billion will be added in Africa. Asia is expected to be the second largest contributor to this future growth, adding just over 750 million people between 2017 and 2050. Africa and Asia will be followed by Latin America and the Caribbean, Northern America and Oceania, where growth is projected to be much more modest. In the medium-variant projection, Europe is the only region with a smaller population in 2050 than in 2017. Beyond 2050, Africa will be the main contributor to global population growth.

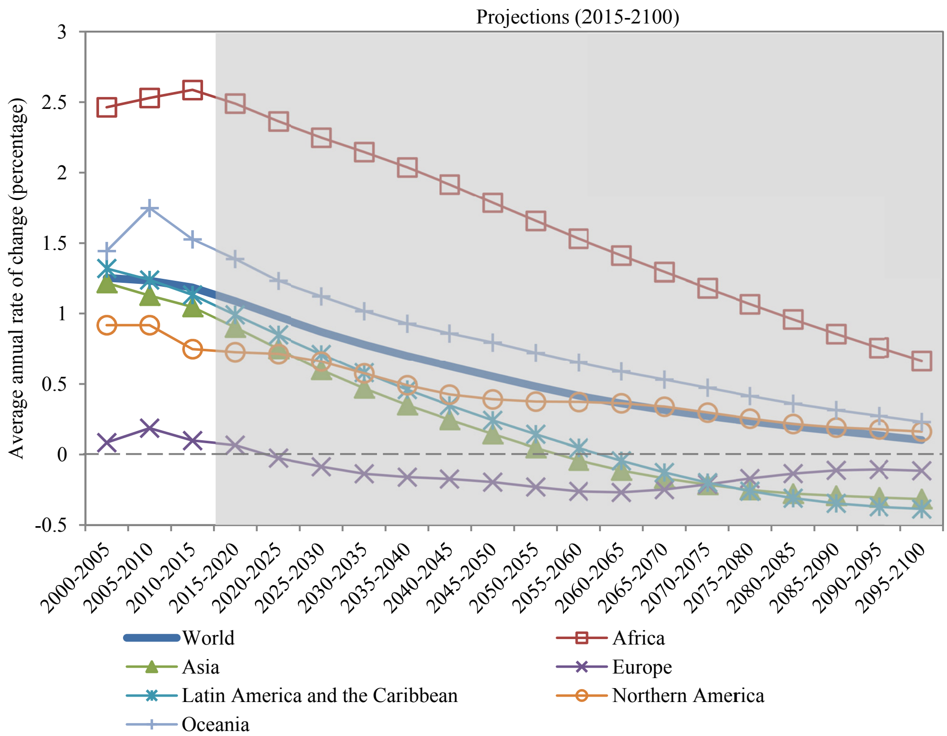
Figure 3. Population by region: estimates, 1950-2015, and medium-variant projection, 2015-2100



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

Although the world's population is expected to continue growing until the end of the 21st century, the rate at which this growth will occur is expected to continue to fall. In recent years, the population of Africa has had the fastest growth among all regions, increasing at a rate of 2.6 per cent annually in 2010-2015; however, this rate is beginning to fall and is projected to reach 1.8 in 2045-2050 and 0.66 in 2095-2100 (figure 4).

Figure 4. Average annual rate of population change for the world and by region, estimates, 2000-2015, and medium-variant projection, 2015-2100



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

Rapid population growth in Africa is anticipated even assuming that there will be a substantial reduction of fertility levels in the near future. The medium-variant projection assumes that fertility in Africa will fall from around 4.7 births per woman[1] in 2010-2015 to 3.1 in 2045-2050, reaching a level slightly above 2.1 in 2095-2100. After 2050, it is expected that Africa will be the only region still experiencing substantial population growth. As a result, Africa's share of global population, which is projected to grow from roughly 17 per cent in 2017 to around 26 per cent in 2050, could reach 40 per cent by 2100. At the same time, the share residing in Asia, currently estimated as 60 per cent, is expected to fall to around 54 per cent in 2050 and 43 per cent in 2100. It should be noted that the population of Africa will continue to increase in future decades even if the number of births per woman falls instantly to the level required for stabilization of population size in the long run, known also as "replacement-level fertility". Growth continues in that scenario thanks to the age structure of the population, which is currently quite youthful. The large numbers of children and youth in Africa today will reach adulthood in future decades. Because of their large numbers, their childbearing will contribute to a further increase of population even assuming that they will bear fewer children on average than their parents' generation. In all plausible scenarios of future trends, Africa will play a central role in shaping the size and distribution of the world's population over the next few decades.

[1] Throughout this report, when fertility is measured by the average number of births per woman, this refers to live births only.

Population growth remains especially high in the group of 47 countries designated by the United Nations as the least developed countries (LDCs), including 33 countries in Africa.[2] Although the growth of LDCs is projected to slow from its current annual rate of 2.4 per cent, the population of this group is projected to nearly double in size from 1 billion inhabitants in 2017 to 1.9 billion in 2050, and to increase further to 3.2 billion in 2100. Between 2017 and 2100, the populations of 33 countries, most of them LDCs, have a high probability of at least tripling in size. Among them, the populations of Angola, Burundi, Niger, Somalia, the United Republic of Tanzania and Zambia are projected to be at least five times as large in 2100 as they are today. The concentration of population growth in the poorest countries will make it harder for those governments to eradicate poverty, reduce inequality, combat hunger and malnutrition, expand and update education and health systems, improve the provision of basic services and ensure that no-one is left behind.

Continued low fertility to lead to shrinking population in some countries

In sharp contrast, the populations of another 51 countries or areas of the world are expected to decrease between 2017 and 2050. Several countries are expected to see their populations decline by more than 15 per cent by 2050, including Bulgaria, Croatia, Latvia, Lithuania, Poland, Republic of Moldova, Romania, Serbia, Ukraine and the United States Virgin Islands. Fertility in all European countries is now below the level required for replacement of the population in the long run (around 2.1 births per woman, on average) and, in most cases, has been below the replacement level for several decades. Fertility for Europe as a whole is projected to increase from 1.6 births per woman in 2010-2015 to nearly 1.8 in 2045-2050. Such an increase, however, will not prevent a likely contraction in the size of the total population.

Most of the increase in global population can be attributed to a small number of countries

Much of the overall increase in population between now and 2050 is projected to occur either in high-fertility countries, mostly in Africa, or in countries with large populations. From 2017 to 2050, it is expected that half of the world's population growth will be concentrated in just nine countries: India, Nigeria, Democratic Republic of the Congo, Pakistan, Ethiopia, the United Republic of Tanzania, the United States of America, Uganda and Indonesia (ordered by their expected contribution to total growth).

The new projections include some notable findings at the country level. For example, in roughly seven years, the population of India is expected to surpass that of China. Currently, the population of China is approximately 1.41 billion compared with 1.34 billion in India. In 2024, both countries are expected to have roughly 1.44 billion people. Thereafter, India's population is projected to continue growing for several decades to around 1.5 billion in 2030 and approaching 1.66 billion in 2050, while the population of China is expected to remain stable until the 2030s, after which it may begin a slow decline.

Among the ten largest countries of the world, one is in Africa (Nigeria), five are in Asia (Bangladesh, China, India, Indonesia, and Pakistan), two are in Latin America (Brazil and Mexico), one is in Northern America (United States of America), and one is in Europe (Russian Federation). Amongst these, Nigeria's population, currently the seventh largest in the world, is growing the most rapidly. Consequently, the population of Nigeria is projected to surpass that of the United States shortly before 2050, at which point it would become the third largest country in the world. In 2050, the populations in six of the ten largest countries are expected to exceed 300 million: China, India, Indonesia, Nigeria, Pakistan, and United States of America (in alphabetical order).

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[2] The group of least developed countries, as defined by the United Nations General Assembly in its resolutions (59/209, 59/210, 60/33, 62/97, 64/L.55, 67/L.43, 64/295 and 68/18) included 47 countries as of 4 June 2017: 33 in Africa, 9 in Asia, 4 in Oceania and one in Latin America and the Caribbean.

Future population growth is highly dependent on the path that future fertility will take

The population trends projected as part of the medium variant are an outcome of substantial projected declines in fertility. According to the medium variant of the *2017 Revision*, global fertility is projected to fall from just over 2.5 births per woman in 2010-2015 to around 2.4 in 2025-2030 and 2.0 in 2095-2100. Steep reductions are projected for the group of least developed countries, which currently has a relatively high average level of fertility, estimated at 4.3 births per woman in 2010-2015, and projected to fall to around 3.5 in 2025-2030 and 2.1 in 2095-2100. However, for countries with high levels of fertility, there is significant uncertainty in projections of future trends, even within the 15-year horizon of the 2030 Agenda for Sustainable Development, and more so for the projections to 2100. Fertility declines that are slower than projected would result in higher population totals in all subsequent time periods. The potential effect on the global population of a slower decline in fertility is illustrated by the upper bound of the prediction interval in figure 2 (see above).

To achieve the substantial reductions in fertility projected in the medium variant, it will be essential to support continued improvements in access to reproductive health care services, including family planning, especially in the least developed countries, with a focus on enabling women and couples to achieve their desired family size.

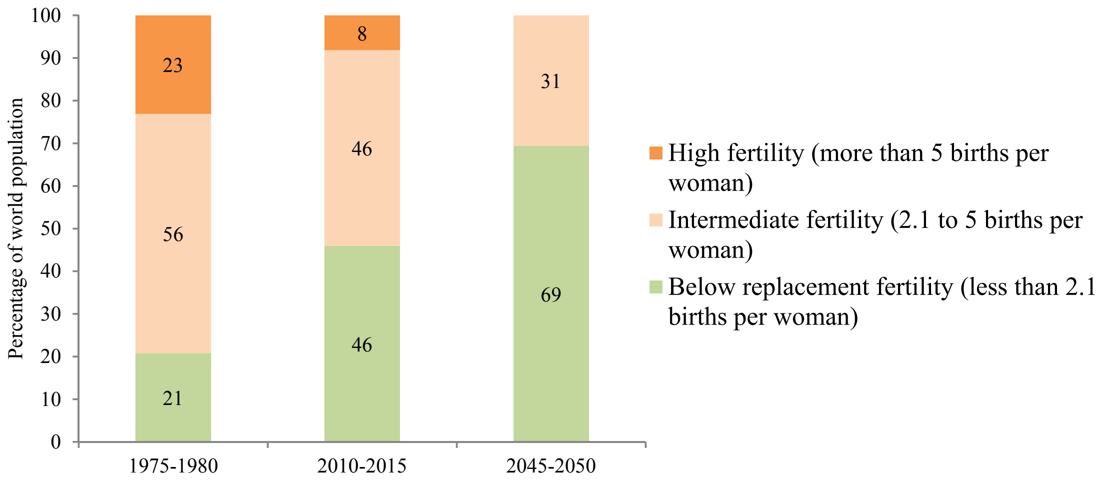
Large variations in fertility levels across countries and regions

In recent decades many countries have experienced major reductions in the average number of births per woman (figure 5). While in 1975-1980, close to a quarter of the world's population lived in countries where fertility was above five births per woman, in 2010-2015 only 8 per cent of the world's population lived in countries with fertility in this range. Of the 22 countries with relatively high levels of fertility in the most recent period, 20 are found in Africa and 2 in Asia. The largest are Nigeria, the Democratic Republic of Congo, the United Republic of Tanzania, Uganda and Afghanistan. In 2045-2050, it is expected that no country will experience a fertility level greater than five births per woman.

In 2010-2015, around 46 per cent of the world's population lived in intermediate-fertility countries, where women have on average between 2.1 and 5 births over a lifetime. Intermediate-fertility countries are found in many regions, with the largest being India, Indonesia, Pakistan, Bangladesh, Mexico and the Philippines. In 2045-2050, it is expected that slightly less than a third of the world's population will live in countries with fertility in this range. By that time, most of the world's population will be living in countries with relatively low levels of fertility, where women bear fewer than 2.1 children on average.

In 2010-2015, 46 per cent of the world's population lived in countries with a fertility level below 2.1 births per woman. Low-fertility countries now include all of Europe and Northern America, plus 19 countries of Asia, 15 in Latin America and the Caribbean, 3 in Oceania and 2 in Africa. The largest low-fertility countries are China, the United States of America, Brazil, the Russian Federation, Japan and Viet Nam (in order of population size). In 2045-2050, it is expected that 69 per cent of the world's population will live in countries where women give birth to fewer than 2.1 children on average.

Figure 5. Distribution of the world's population by level of total fertility, 1975-1980, 2010-2015 and 2045-2050



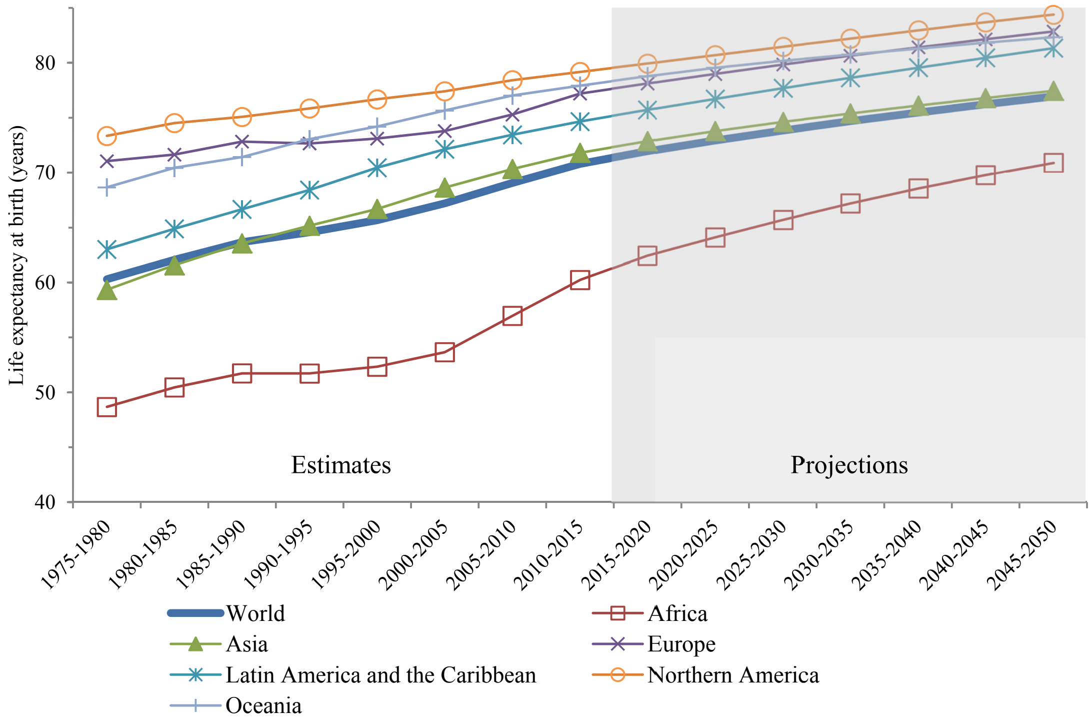
Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

While women today bear fewer children on average over a lifetime, some regions of the world are still characterized by high levels of adolescent fertility (births to mothers aged 15-19 years). Since adolescent childbearing can have adverse health and social consequences both for the young mothers and for their children, it remains a topic of concern for many countries. Among regions of the world, the adolescent birth rate in 2010-2015 was highest in Africa at 99 per 1,000 women aged 15-19, followed by Latin America and the Caribbean at 67 per 1,000. The ratio of adolescent to total fertility was highest in Latin America and the Caribbean, where the birth rate at ages 15-19 years contributed 16 per cent of the total fertility of the average woman.

Increasing longevity around the world; progress against major challenges

The *2017 Revision* confirms that significant gains in life expectancy have been achieved in recent years. Globally, life expectancy at birth rose by 3.6 years between 2000-2005 and 2010-2015, or from 67.2 to 70.8 years. All regions shared in the rise of life expectancy over this period, but the greatest gains were in Africa, where life expectancy rose by 6.6 years between these two periods after rising by less than 2 years over the previous decade. Life expectancy in Africa in 2010-2015 stood at 60.2 years, compared to 71.8 in Asia, 74.6 in Latin America and the Caribbean, 77.2 in Europe, 77.9 in Oceania and 79.2 in Northern America (figure 6).

Figure 6. Life expectancy at birth (years) by region: estimates 1975-2015 and projections 2015-2050



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

The under-five mortality rate, equal to the probability of dying between birth and a child's fifth birthday, is an important indicator of development and children's well-being. The 2030 Agenda for Sustainable Development calls for ending preventable deaths of newborns and of all children under 5 years of age, with all countries aiming to reduce under-five mortality to no more than 25 deaths per 1,000 live births by 2030. Globally, deaths among children under age 5 fell from an estimated 70 per 1,000 live births in 2000-2005 to 48 per 1,000 in 2010-2015. Absolute declines were especially large in Sub-Saharan Africa (from 141 to 95 per 1,000) and in the least developed countries (from 123 to 83 per 1,000). The reduction of under-five mortality, which has received intensive global scrutiny as part of Millennium Development Goal 4 and Sustainable Development Goal 3, has proceeded swiftly in many countries in recent years. In most countries of Sub-Saharan Africa and in LDCs, the annual pace of decline in under-five mortality accelerated after 2000.

Globally, life expectancy at birth is projected to rise from 71 years in 2010-2015 to 77 years in 2045-2050 (figure 6). Africa is projected to gain nearly 11 years of life expectancy by mid-century, reaching 71 years in 2045-2050. Such increases are contingent on further reductions in HIV/AIDS, and combating successfully other infectious as well as non-communicable diseases. Asia, Europe, and Latin America and the Caribbean are projected to gain around 6 or 7 years of life expectancy by 2045-2050, while Northern America and Oceania are projected to gain around 4 or 5 years.

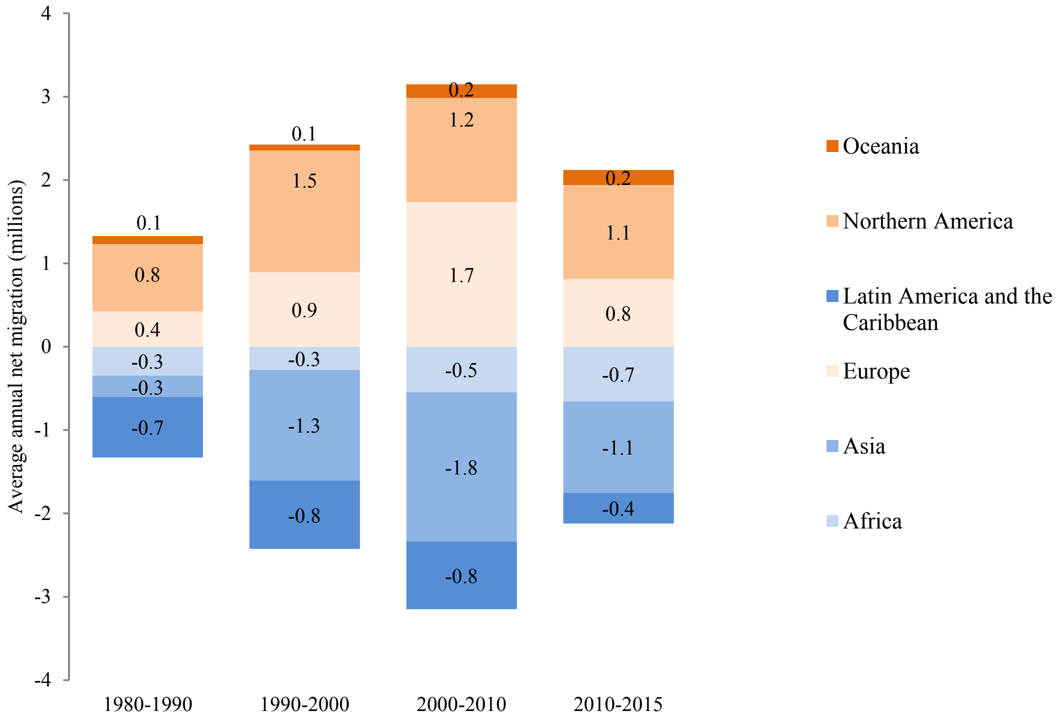
Due to the increased accessibility and effectiveness of treatment, and based on the evaluation of data not previously available, the estimated and projected impact on mortality from the HIV/AIDS epidemic has been reduced in the *2017 Revision* compared to earlier assessments, resulting in a faster increase of population size in several countries affected by the epidemic.

Europe, Northern America and Oceania are net receivers of international migrants; Africa, Asia, and Latin America and the Caribbean are net senders

The 2030 Agenda for Sustainable Development recognizes that international migration can be a positive force for economic and social development, offering a mechanism to rebalance labour markets between areas of origin and destination and thereby increase the global productivity of labour. Migration across international borders can also help to promote investment and higher standards of living in countries of origin through remittances sent by migrants to families and communities back home, and to accelerate the global diffusion of new ideas and technologies. From a demographic perspective, migration is a much smaller component of population change than births and deaths in most countries and regions of the world. However, in some situations the contribution of international migration to the change in population size or distribution is quite significant, in particular for countries and regions where the number of migrants who depart or arrive, including refugees, is relatively large compared to the size of the sending or receiving population.

The migration estimates of the *2017 Revision* refer to net migration, which is the difference between the number of immigrants and the number of emigrants for a given country or group of countries. Overall, between 1950 and 2015, the regions of Europe, Northern America and Oceania were net receivers of international migrants, while Africa, Asia and Latin America and the Caribbean were net senders, with the volume of net migration generally increasing over time. Figure 7 shows average annual net migration by world region from 1980 to 2015. The overall volume of net migration across regions of the world increased steadily until 2010. In the decade from 2000 to 2010, the net inflow to Europe, Northern America and Oceania combined reached a level of 3.1 million migrants per annum. In the period from 2010 to 2015, such inflows showed signs of contraction, especially for Europe, while net outflows from Asia and from Latin America and the Caribbean demonstrated a corresponding decrease in magnitude.

Figure 7. Average annual net migration by region, 1980-2015



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

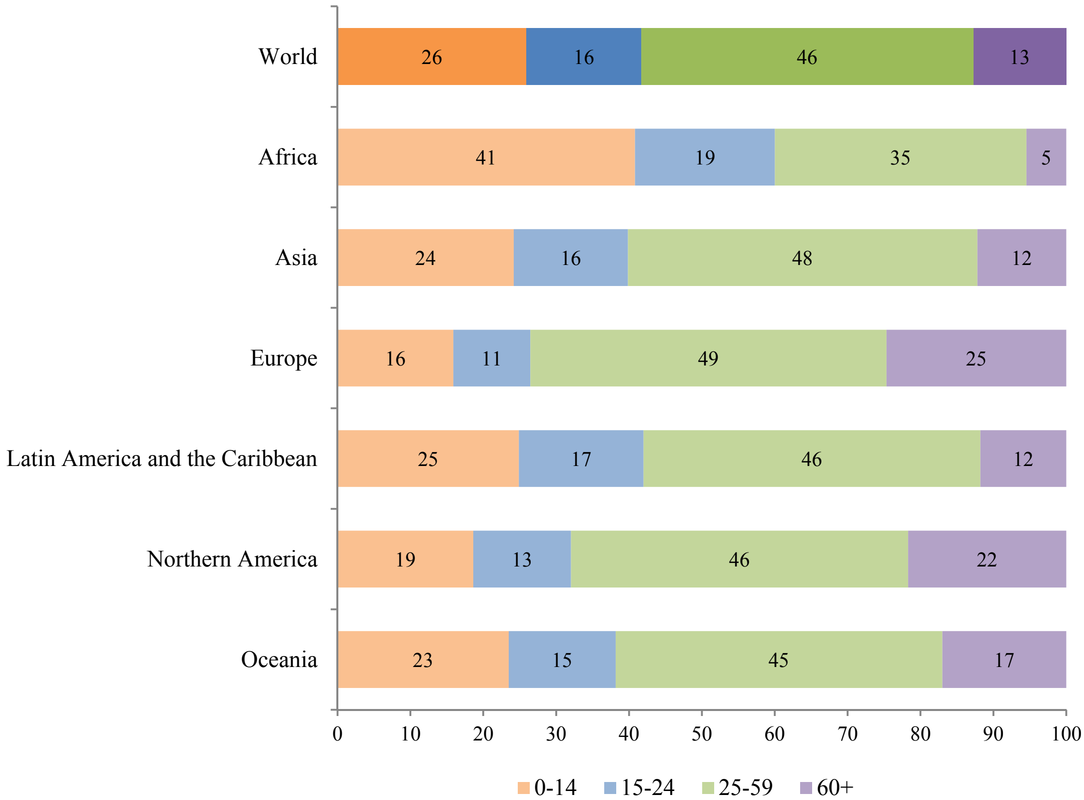
While movements of people from Asia, Africa, and Latin America and the Caribbean toward Europe, Northern America and Oceania have been a key feature of global migration patterns for almost half a century, migration flows within regions have also been important. Some high-income and middle-income countries located in Africa, Asia, or Latin America and the Caribbean have also been attracting migrants in large numbers for several years.

Large and persistent economic and demographic asymmetries between countries are likely to remain key drivers of international migration for the foreseeable future. Between 2015 and 2050, the top net receivers of international migrants (more than 100,000 annually) are projected to be the United States of America, Germany, Canada, the United Kingdom, Australia and the Russian Federation. The countries projected to be net senders of more than 100,000 migrants annually include India, Bangladesh, China, Pakistan, and Indonesia.

Populations in many parts of the world are still young; opportunity for demographic dividend

Populations in many regions are still comparatively young. In Africa, children under age 15 account for 41 per cent of the population in 2017 and young persons aged 15 to 24 account for an additional 19 per cent (figure 8). Latin America and the Caribbean, and Asia, which have experienced greater declines in fertility, have smaller percentages of children (25 and 24 per cent, respectively) but similar percentages of youth (17 and 16 per cent, respectively). In total, these three regions are home to 1.8 billion children and 1.1 billion young persons in 2017. Providing these generations of children and youth with health care, education, and employment opportunities, including in the poorest countries and groups, will be critical for the successful implementation of the 2030 Agenda for Sustainable Development.

Figure 8. Percentage of population in broad age groups for the world and by region, 2017



Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. New York: United Nations.

Proportions of children in these regions are projected to decline further in the near future, while numbers and proportions in the prime working ages can be expected to grow. Countries with relatively high ratios of working to dependent populations have the possibility of benefitting from a “demographic dividend,” provided that there are sufficient opportunities for productive engagement in the labour force by the expanded working-age population. Success in this regard requires sufficient investment in the human capital of children and youth through universal access to education and health care. In Africa, the proportion of the population aged 25-59 is projected to continue to grow for many decades, from 35 per cent in 2017 to 45 per cent by 2090. In Latin America and the Caribbean, the window of time for an increasing proportion of the population at working ages will be shorter, with a peak around 2030, while in Asia the proportion aged 25-59 will peak sooner around 2020.

Globally, population aged 60 or over is growing faster than all younger age groups

As fertility declines and life expectancy rises, the proportion of the population above a certain age rises as well. This phenomenon, known as population ageing, is occurring throughout the world.

In 2017, there are an estimated 962 million people aged 60 or over in the world, comprising 13 per cent of the global population. The population aged 60 or above is growing at a rate of about 3 per cent per year. Currently, Europe has the greatest percentage of population aged 60 or over (25 per cent). Rapid ageing will occur in other parts of the world as well, so that by 2050 all regions of the world except Africa will have nearly a quarter or more of their populations at ages 60 and above. The number of older persons in the world is projected to be 1.4 billion in 2030 and 2.1 billion in 2050, and could rise to 3.1 billion in 2100. Over the next few decades, a further increase in the population of older persons is almost inevitable, given the size of the cohorts born in recent decades.

Population ageing is projected to have a profound effect on the support ratio, defined as the number of workers per retiree. Although it is difficult to know the actual number of workers per retiree, a useful proxy is the ratio of the numbers of persons who are likely to be workers or retirees by virtue of their age. Thus, a potential support ratio can be defined as the number of persons aged 20 to 64 divided by the number aged 65 or over. In 2017, Africa has 12.9 persons aged 20 to 64 for each person aged 65 or above. This ratio is 7.4 for Asia, 7.3 for Latin America and the Caribbean, 4.6 for Oceania, 3.8 for Northern America and 3.3 for Europe. At 2.1, Japan in 2017 has the lowest potential support ratio in the world, while those of nine European countries and the United States Virgin Islands are also below 3. By 2050, seven countries in Asia, 24 in Europe, and five in Latin America and the Caribbean are expected to have potential support ratios below 2. These low values underscore the fiscal and political pressures that many countries are likely to face in the coming decades in relation to public systems of health care, pensions and social protections for a growing older population.

Key Findings

1. According to the results of the *2017 Revision*, the world's population reached nearly 7.6 billion in mid-2017. The world has added one billion people since 2005 and two billion since 1993. In 2017, an estimated 50.4 per cent of the world's population was male and 49.6 per cent female. In 2017, 9 per cent of the global population was under age 5, 26 per cent was under age 15, 13 per cent was aged 60 or over and 2 per cent was aged 80 or over.

2. Current estimates indicate that roughly 83 million people are being added to the world's population every year. Even assuming that fertility levels will continue to decline, the global population is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100, according to the medium-variant projection.

3. In fact, continued growth of the world's population is expected at least until 2050, even if the decline of fertility would accelerate. The projections of the *2017 Revision* indicate that there is a 95 per cent probability that the global population will be between 8.4 and 8.7 billion in 2030, between 9.4 and 10.2 billion in 2050 and between 9.6 and 13.2 billion in 2100.

4. Future population growth is highly dependent on the path that future fertility will take, as relatively small changes in the frequency of childbearing, when projected over several decades, can generate large differences in total population. In the medium-variant projection, it is assumed that the global fertility level will decline from 2.5 births per woman in 2010-2015 to 2.2 in 2045-2050, and then fall to 2.0 by 2095-2100. In an illustrative example where the future fertility level of each country is consistently half a child above the levels assumed for the medium-variant projection, the global population would reach 10.8 billion in 2050 and 16.5 billion in 2100. Conversely, fertility levels consistently half a child below the assumption used for the medium variant would lead to a global population of 8.8 billion at mid-century, declining to 7.3 billion in 2100 (data not shown in tables).

5. Future growth will be influenced not only by future levels of fertility, mortality, and migration but also by the current age distribution of the world's population. Thanks to "population momentum", a relatively youthful age distribution promotes a more rapid pace of population growth, whereas a relatively older age distribution contributes to a slower rate of growth or even population decline. The magnitude of population growth or decline attributable to this momentum can be found by projecting the population forward assuming that: (a) mortality remains constant, (b) fertility instantly reaches the replacement level, and (c) the population is closed to migration. To illustrate the importance of population momentum, a new 'Momentum' variant was included in projections of the *2017 Revision*.

6. In recent years, fertility has declined in virtually all regions of the world. In Africa, where fertility levels are the highest of any region, total fertility has fallen from 5.1 births per woman in 2000-2005 to 4.7 in 2010-2015. Over the same period, fertility levels also fell in Asia (from 2.4 to 2.2), Latin America and the Caribbean (from 2.5 to 2.1), and Northern America (from 2.0 to 1.85). Europe has been an exception to this trend in recent years, with total fertility increasing from 1.4 births per woman in 2000-2005 to 1.6 in 2010-2015. Total fertility in Oceania has changed little since 2000, at roughly 2.4 births per woman in both 2000-2005 and 2010-2015.

7. The 47 least developed countries (LDCs) as a group continue to have a relatively high level of fertility, at 4.3 births per woman in 2010-2015, and rapid population growth, at 2.4 per cent per year. Although this rate of increase is expected to slow significantly over the next decades, the combined population of the LDCs, roughly one billion in 2017, is projected to increase by 33 per cent between 2017 and 2030, and then to reach 1.9 billion persons in 2050.

8. A reduction in the fertility level results not only in a slower pace of population growth but also in a more aged population; for the population of the world and of many countries and regions, as the population growth rate has fallen over time, the proportion of older persons has increased while that of younger persons has decreased. In 2017, there are more than twice as many children under the age of 15 in the world as there are older persons aged 60 or above. In 2050, however, the number of persons aged 60 or above will be roughly equal to the number of children under the age of 15, with about 2.1 billion in each group.

9. In Europe, 25 per cent of the population is already aged 60 years or over and that proportion is projected to reach 35 per cent in 2050 and 36 per cent in 2100. Populations in other regions are also projected to age significantly over the next several decades. For Latin America and the Caribbean, the population will go from having just 12 per cent of the total at ages 60 and above in 2017 to having 25 per cent at these ages in 2050. Similarly, the population aged 60 or over in Asia is expected to shift from being 12 per cent of the total in 2017 to 24 per cent in 2050, while in Northern America it will move from 22 to 28 per cent, and in Oceania, from 17 to 23 per cent over the same period. Africa, which has the youngest age distribution of any region, is also projected to experience a rapid ageing of its population over the coming decades, with the percentage of its population aged 60 or over rising from 5 per cent in 2017 to around 9 per cent in 2050.

10. Compared to 2017, the number of persons aged 60 or above is expected to more than double by 2050 and more than triple by 2100, rising from 962 million in 2017 to 2.1 billion in 2050 and 3.1 billion in 2100. For this age range, 65 per cent of the global increase between 2017 and 2050 will occur in Asia, 14 per cent in Africa, 11 per cent in Latin America and the Caribbean, and the remaining 10 per cent in other areas.

11. The number of persons aged 80 or over is projected to triple by 2050, and by 2100 to increase to nearly seven times its value in 2017. Globally, the number of persons aged 80 or over is projected to increase from 137 million in 2017 to 425 million in 2050, and further to 909 million in 2100. In 2017, 27 per cent of all persons aged 80 or over reside in Europe, but that share is expected to decline to 17 per cent in 2050 and to 10 per cent in 2100 as the populations of other regions continue to increase in size and to grow older themselves.

12. Although the populations of all countries are expected to grow older within the foreseeable future, populations will remain relatively young, at least for the short-term, in regions where fertility is still high. In Africa, for example, 60 per cent of the population is below age 25 in 2017. This percentage will fall slightly to 57 per cent in 2030 and will decline further to around 50 per cent in 2050, but that remains a higher percentage of young people than observed in the other world regions in 2017.

13. Africa continues to experience very high rates of population growth. Between 2017 and 2050, the populations of 26 African countries are projected to reach at least double their current size. For six African countries, the populations are projected to increase by 2100 to more than five times their current size: Angola, Burundi, Niger, Somalia, the United Republic of Tanzania and Zambia.

14. Fifty-one countries or areas are projected to undergo a reduction in population size between 2017 and 2050. For ten countries or areas, populations are expected to decrease by more than 15 per cent by 2050: Bulgaria, Croatia, Latvia, Lithuania, Poland, the Republic of Moldova, Romania, Serbia, Ukraine and the United States Virgin Islands.

15. Ten countries are expected to account collectively for more than half of the world's projected population increase over the period 2017-2050: India, Nigeria, the Democratic Republic of Congo, Pakistan, Ethiopia, the United Republic of Tanzania, the United States of America, Uganda, Indonesia and Egypt (ordered by their expected contribution to global growth).

16. The *2017 Revision* confirms that fertility has continued to fall in almost countries where it was recently at high levels. Among 201 countries or areas with at least 90,000 inhabitants in 2017, the number with high levels of fertility (5 children or more per woman) has been reduced roughly by half, from 41 countries in 2000-2005 to 22 in 2010-2015. Afghanistan and Timor-Leste were the only two countries outside of Africa where total fertility was above 5 births per woman during 2010-2015. Among 125 countries where total fertility was above the replacement level (2.1 births per woman) in 2005-2010, fertility fell in 117 of them between 2005-2010 and 2010-2015.

17. More and more countries now have fertility rates that lie below the replacement level, and several have been in this situation for several decades. Eighty-three countries had below-replacement-level fertility during 2010-2015, and for 26 of them, fertility was below 1.5 births per woman. In several countries, fertility rates have fluctuated slightly in the recent past. Fifty-nine countries with below-replacement-level fertility in 2010-2015 recorded a slight increase in fertility at some point between 2000-2005 and 2010-2015, although for 21 of these countries an increase from 2000-2005 to 2005-2010 was followed by a downturn from 2005-2010 to 2010-2015. Only four European countries have had fertility rates above the replacement level during any 5-year period since 1990-1995.

18. In 2010-2015, the 83 countries with below-replacement-level fertility accounted for 46 per cent of the world's population. The ten most populous countries with below replacement fertility are China, the United States of America, Brazil, the Russian Federation, Japan, Viet Nam, Germany, the Islamic Republic of Iran, Thailand, and the United Kingdom (in order of population size).

19. Globally, total fertility is expected to fall from 2.5 births per woman in 2010-2015 to 2.2 in 2045-2050 and to 2.0 in 2095-2100, according to the medium-variant projection. However, in Europe and Northern America, total fertility is projected to increase between 2010-2015 and 2045-2050 from 1.60 to 1.78 in Europe and from 1.85 to 1.89 in Northern America. In Africa, Asia, Latin America and the Caribbean, and Oceania, fertility is expected to fall between 2010-2015 and 2045-2050, with the largest reductions projected to occur in Africa. In all regions of the world, fertility levels are projected to converge to levels around or below the replacement level by 2095-2100.

20. Levels of adolescent childbearing, which can have adverse health and social consequences both for the young mothers and for the children they bear, has fallen in most countries. Nevertheless, high adolescent fertility remains a concern in some parts of the world. Among regions, the adolescent birth rate (births per 1,000 women aged 15-19) in 2010-2015 was highest in Africa, at 99 per 1,000 women, followed by Latin America and the Caribbean at 67 per 1,000. The ratio of adolescent to total fertility was highest in Latin America and the Caribbean, where the birth rate at ages 15-19 years contributed 16 per cent of total fertility.

21. The *2017 Revision* confirms that substantial improvements in life expectancy have occurred in recent years. Globally, life expectancy at birth has risen from 65 years for men and 69 years for women in 2000-2005 to 69 years for men and 73 years for women in 2010-2015. However, large disparities between countries remain. At one extreme, countries or areas with a life expectancy of 82 years or more for both sexes combined include Australia, Hong Kong SAR (China), Iceland, Italy, Japan, Macao SAR (China), Singapore, Spain and Switzerland. At the other

extreme, countries with a life expectancy below 55 years include the Central African Republic, Chad, Côte d'Ivoire, Lesotho, Nigeria, Sierra Leone, Somalia and Swaziland. Globally, life expectancy for both sexes combined is projected to rise from 71 years in 2010-2015 to 77 years in 2045-2050 and eventually to 83 years in 2095-2100.

22. Life expectancy at birth has increased significantly in the least developed countries in recent years. The gain in life expectancy made by these countries, around 6 years between 2000-2005 and 2010-2015, is roughly double the increase achieved by the rest of the world. Nonetheless, the least developed countries still lag behind other developing countries, where the average level of life expectancy was 70 years in 2010-2015. The gap in life expectancy at birth between the least developed countries and other developing countries narrowed from 11 years in 2000-2005 to 8 years in 2010-2015. Although differences in life expectancy across regions and income groups are projected to persist in future years, such differences are expected to diminish significantly by 2045-2050.

23. The under-five mortality rate, equal to the probability of dying between birth and age 5, is an important indicator of development and children's well-being. Progress in reducing under-five mortality has been substantial and far-reaching in recent years. Between 2000-2005 and 2010-2015, under-five mortality decreased by more than 20 per cent in 163 countries, including countries in Africa (47 out of 57 countries), Asia (46 out of 51 countries), Europe (38 out of 40 countries), Latin America and the Caribbean (24 out of 38 countries), and Oceania (8 out of 13 countries). Over this period, under-five mortality fell by more than 30 per cent in 89 countries, with 10 countries seeing a decline of more than 50 per cent.

24. Although the HIV/AIDS epidemic continues to be a major public health concern, HIV/AIDS-related mortality among adults appears to have reached a peak over the past decade in most countries that have been highly affected by the epidemic, thanks mostly to the increasing availability of antiretroviral treatments. Nevertheless, in countries where HIV prevalence has been high, the impact of the epidemic in terms of morbidity, mortality and slower population growth continues to be evident. Thus, in Southern Africa, the sub-region with the highest prevalence of the disease, life expectancy at birth fell from 62 years in 1990-1995 to 53 years in 2000-2005 and 2005-2010, and then increased to 59 years in 2010-2015. While life expectancy in Southern Africa is expected to return to the level where it was in the early 1990s by 2015-2020, this represents a loss of two decades of potential improvements in survival rates.

25. Several Eastern European countries experienced reductions in life expectancy at birth in the late 1980s and 1990s. By 2010-2015 life expectancy in the sub-region had recovered substantially. Nevertheless, with an average level of 72 years, life expectancy in Eastern European countries lags far behind the levels found in Western Europe. At about 70 or 71 years, the Republic of Moldova, the Russian Federation and Ukraine have the lowest levels of life expectancy at birth in Europe.

26. Since 1990, 61 countries have experienced a decline in life expectancy at birth between consecutive five-year periods at least once. These included countries heavily affected by the HIV/AIDS epidemic, countries in conflict, and countries experiencing increased mortality following the breakup of the Soviet Union. The number of countries experiencing a decrease in life expectancy compared to the previous five-year period has fallen dramatically, from a high of 39 in 1990-1995, to 15 in 2000-2005 and just 2 in 2010-2015.

27. There continue to be large movements of migrants between regions, often from low- and middle-income countries toward high-income countries. The volume of the net inflow of migrants to high-income countries in 2010-2015 (3.2 million per year) represented a decline from a peak

attained in 2005-2010 (4.5 million per year). High-income countries with a net inflow of more than 100 thousand migrants per year in 2010-2015 included the United States of America, Germany, Saudi Arabia, Canada, the United Kingdom, Australia, Oman, Kuwait and Qatar (ordered by size of the net inflow). Among upper-middle-income countries, excluding those experiencing a large influx of refugees, the Russian Federation, South Africa and Malaysia also had a net inflow of more than 100 thousand migrants per year in 2010-2015. The countries with a net outflow of more than 100 thousand migrants per year in 2010-2015, excluding those dominated by refugee movements, were India, Bangladesh, China, Pakistan, the Philippines and Spain.

28. The Syrian refugee crisis has had a major impact on levels and patterns of international migration in recent years, affecting several countries. The estimated net outflow from the Syrian Arab Republic was 4.2 million persons in 2010-2015. Most of these refugees went to Syria's neighbouring countries, contributing to an unusually large influx of migrants to Turkey (net inflow of 1.6 million over five years), Lebanon (1.25 million) and Jordan (975 thousand).

29. In countries or areas where fertility is already below the replacement level, the population is expected to decline in size unless the loss due to the excess of deaths over births is counterbalanced by a gain due to positive net migration. However, international migration at or around current levels will be unable to compensate fully for the expected loss of population tied to low levels of fertility, especially in the European region. Between 2015 and 2050, the excess of deaths over births in Europe is projected to total 57 million, whereas the net inflow of international migrants is expected to be around 32 million, implying an overall reduction of Europe's population by about 25 million.

The value of the world's ecosystem services and natural capital

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The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet. We have estimated the current economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US\$16–54 trillion (10^{12}) per year, with an average of US\$33 trillion per year. Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US\$18 trillion per year.

Because ecosystem services are not fully 'captured' in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions. This neglect may ultimately compromise the sustainability of humans in the biosphere. The economies of the Earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite. However, it can be instructive to estimate the 'incremental' or 'marginal' value of ecosystem services (the estimated rate of change of value compared with changes in ecosystem services from their current levels). There have been many studies in the past few decades aimed at estimating the value of a wide variety of ecosystem services. We have gathered together this large (but scattered) amount of information and present it here in a form useful for ecologists, economists, policy makers and the general public. From this synthesis, we have estimated values for ecosystem services per unit area by biome, and then multiplied by the total area of each biome and summed over all services and biomes.

Although we acknowledge that there are many conceptual and empirical problems inherent in producing such an estimate, we think this exercise is essential in order to: (1) make the range of potential values of the services of ecosystems more apparent; (2) establish at least a first approximation of the relative magnitude of global ecosystem services; (3) set up a framework for their further analysis; (4) point out those areas most in need of additional research; and (5) stimulate additional research and debate. Most of the problems and uncertainties we encountered indicate that our estimate represents a minimum value, which would probably increase: (1) with additional effort in studying and valuing a broader range of ecosystem services; (2) with the incorporation of more realistic representations of ecosystem dynamics and interdependence; and (3) as ecosystem services become more stressed and 'scarce' in the future.

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Ecosystem functions and ecosystem services

Ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems. Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions. For simplicity, we will refer to ecosystem goods and services together as ecosystem services. A large number of functions and services can be identified[1–4]. Reference 5 provides a recent, detailed compendium on describing, measuring and valuing ecosystem services. For the purposes of this analysis we grouped ecosystem services into 17 major categories. These groups are listed in Table 1. We included only renewable ecosystem services, excluding non-renewable fuels and minerals and the atmosphere. Note that ecosystem services and functions do not necessarily show a one-to-one correspondence. In some cases a single ecosystem service is the product of two or more ecosystem functions whereas in other cases a single ecosystem function contributes to two or more ecosystem services. It is also important to emphasize the interdependent nature of many ecosystem functions. For example, some of the net primary production in an ecosystem ends up as food, the consumption of which generates respiratory products necessary for primary production. Even though these functions and services are interdependent, in many cases they can be added because they represent 'joint products' of the ecosystem, which support human welfare. To the extent possible, we have attempted to distinguish joint and 'addable' products from products that would represent 'double counting' (because they represent different aspects of the same service) if they were added. It is also important to recognize that a minimum level of ecosystem 'infrastructure' is necessary in order to allow production of the range of services shown in Table 1. Several authors have stressed the importance of this 'infrastructure' of the ecosystem itself as a contributor to its total value[6,7]. This component of the value is not included in the current analysis.

Natural capital and ecosystem services

In general, capital is considered to be a stock of materials or information that exists at a point in time. Each form of capital stock generates, either autonomously or in conjunction with services from other capital stocks, a flow of services that may be used to transform materials, or the spatial configuration of materials, to enhance the welfare of humans. The human use of this flow of services may or may not leave the original capital stock intact. Capital stock takes different identifiable forms, most notably in physical forms including natural capital, such as trees, minerals, ecosystems, the atmosphere and so on; manufactured capital, such as machines and buildings; and the human capital of physical bodies. In addition, capital stocks can take intangible forms, especially as information such as that stored in computers and in individual human brains, as well as that stored in species and ecosystems.

Ecosystem services consist of flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare. Although it is possible to imagine generating human welfare without natural capital and ecosystem services in artificial 'space colonies', this possibility is too remote and unlikely to be of

Table 1 Ecosystem services and functions used in this study

Number	Ecosystem service*	Ecosystem functions	Examples
1	Gas regulation	Regulation of atmospheric chemical composition.	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels.
2	Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.	Greenhouse gas regulation, DMS production affecting cloud formation.
3	Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
4	Water regulation	Regulation of hydrological flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation.
5	Water supply	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
6	Erosion control and sediment retention	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes, storage of stilt in lakes and wetlands.
7	Soil formation	Soil formation processes.	Weathering of rock and the accumulation of organic material.
8	Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
9	Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification.
10	Pollination	Movement of floral gametes.	Provisioning of pollinators for the reproduction of plant populations.
11	Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
12	Refugia	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.
13	Food production	That portion of gross primary production extractable as food.	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing.
14	Raw materials	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder.
15	Genetic resources	Sources of unique biological materials and products.	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
16	Recreation	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, and other outdoor recreational activities.
17	Cultural	Providing opportunities for non-commercial uses.	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

* We include ecosystem 'goods' along with ecosystem services.

much current interest. In fact, one additional way to think about the value of ecosystem services is to determine what it would cost to replicate them in a technologically produced, artificial biosphere. Experience with manned space missions and with Biosphere II in Arizona indicates that this is an exceedingly complex and expensive proposition. Biosphere I (the Earth) is a very efficient, least-cost provider of human life-support services.

Thus we can consider the general class of natural capital as essential to human welfare. Zero natural capital implies zero human welfare because it is not feasible to substitute, in total, purely 'non-natural' capital for natural capital. Manufactured and human capital require natural capital for their construction[7]. Therefore, it is not very meaningful to ask the total value of natural capital to human welfare, nor to ask the value of massive, particular forms of natural capital. It is trivial to ask what is the value of the atmosphere to humankind, or what is the value of rocks and soil infrastructure as support systems. Their value is infinite in total.

However, it is meaningful to ask how changes in the quantity or quality of various types of natural capital and ecosystem services may have an impact on human welfare. Such changes include both small changes at large scales and large changes at small scales. For example, changing the gaseous composition of the global atmosphere by a small amount may have large-scale climate change effects that will affect the viability and welfare of global human populations. Large changes at small scales include, for example, dramatically changing local forest composition. These changes may dramatically alter terrestrial and aquatic ecosystems, having an impact on the benefits and costs of local human activities. In general, changes in particular forms of natural capital and ecosystem services will alter the costs or benefits of maintaining human welfare.

Valuation of ecosystem services

The issue of valuation is inseparable from the choices and decisions we have to make about ecological systems[6,8]. Some argue that valuation of ecosystems is either impossible or unwise, that we cannot place a value on such 'intangibles' as human life, environmental aesthetics, or long-term ecological benefits. But, in fact, we do so every day. When we set construction standards for highways, bridges and the like, we value human life (acknowledged or not) because spending more money on construction would save lives. Another frequent argument is that we should protect ecosystems for purely moral or aesthetic reasons, and we do not need valuations of ecosystems for this purpose. But there are equally compelling moral arguments that may be in direct conflict with the moral argument to protect ecosystems; for example, the moral argument that no one should go hungry. Moral arguments translate the valuation and decision problem into a different set of dimensions and a different language of discourse[6]; one that, in our view, makes the problem of valuation and choice more difficult and less explicit. But moral and economic arguments are certainly not mutually exclusive. Both discussions can and should go on in parallel.

So, although ecosystem valuation is certainly difficult and fraught with uncertainties, one choice we do not have is whether or not to do it. Rather, the decisions we make as a society about ecosystems imply valuations (although not necessarily expressed in monetary terms). We can choose to make these valuations explicit or not; we can do them with an explicit acknowledgement of the huge uncertainties involved or not; but as long as we are forced to make choices, we are going through the process of valuation.

The exercise of valuing the services of natural capital 'at the margin' consists of determining the differences that relatively small changes in these services make to human welfare. Changes in quality or quantity of ecosystem services have value insofar as they either change the benefits associated with human activities or change the costs of those activities. These changes in benefits and costs either have an impact on human welfare through established markets or through non-market activities. For example, coral reefs provide habitats for fish. One aspect of their value is to increase and concentrate fish stocks. One effect of changes in coral reef quality or quantity would be discernible in commercial fisheries markets, or in recreational fisheries. But other aspects of the value of coral reefs, such as recreational diving and biodiversity conservation, do not show up completely in markets. Forests provide timber materials through well established markets, but the associated habitat values of forests are also felt through unmarketed recreational activities. The chains of effects from ecosystem services to human welfare can range from extremely simple to exceedingly complex. Forests provide timber, but also hold soils and moisture, and create microclimates, all of which contribute to human welfare in complex, and generally non-marketed ways.

Valuation methods

Various methods have been used to estimate both the market and non-market components of the value of ecosystem services[9–16]. In this analysis, we synthesized previous studies based on a wide variety of methods, noting the limitations and assumptions underlying each.

Many of the valuation techniques used in the studies covered in our synthesis are based, either directly or indirectly, on attempts to estimate the 'willingness-to-pay' of individuals for ecosystem services. For example, if ecological services provided a $50 increment to the timber productivity of a forest, then the beneficiaries of this service should be willing to pay up to $50 for it. In addition to timber production, if the forest offered non-marketed, aesthetic, existence, and conservation values of $70, those receiving this non-market benefit should be willing to pay up to $70 for it. The total

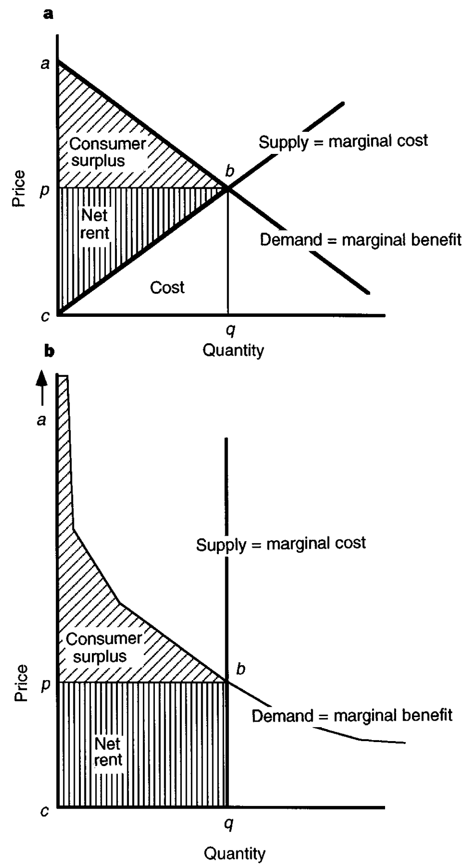


Figure 1 Supply and demand curves, showing the definitions of cost, net rent and consumer surplus for normal goods (**a**) and some essential ecosystem services (**b**). See text for further explanation.

Table 2 Summary of average global value of annual ecosystem services

Biome	Area (ha × 10^6)	1 Gas regulation	2 Climate regulation	3 Disturbance regulation	4 Water regulation	5 Water supply	6 Erosion control	7 Soil formation	8 Nutrient cycling	9 Waste treatment	10 Pollination	11 Biological control	12 Habitat/refugia	13 Food production	14 Raw materials	15 Genetic resources	16 Recreation	17 Cultural	Total value per ha (\$ ha^{-1} yr^{-1})	Total global flow value (\$ yr^{-1} × 10^9)
		Ecosystem serivces (1994 US\$ ha^{-1} yr^{-1})																		
Marine	36,302																		577	20,949
Open ocean	33,200	38							118			5		15	0			76	252	8,381
Coastal	3,102			88					3,677			38	8	93	4		82	62	4,052	12,568
Estuaries	180			567					21,100			78	131	521	25		381	29	22,832	4,110
Seagrass/algae beds	200								19,002						2				19,004	3,801
Coral reefs	62			2,750						58		5	7	220	27		3,008	1	6,075	375
Shelf	2,660								1,431			39		68	2			70	1,610	4,283
Terrestrial	15,323																		804	12,319
Forest	4,855		141	2	2	3	96	10	361	87		2		43	138	16	66	2	969	4,706
Tropical	1,900		223	5	6	8	245	10	922	87				32	315	41	112	2	2,007	3,813
Temperate/boreal	2,955		88		0			10		87		4		50	25		36	2	302	894
Grass/rangelands	3,898	7	0		3		29	1		87	25	23		67		0	2		232	906
Wetlands	330	133		4,539	15	3,800				4,177			304	256	106		574	881	14,785	4,879
Tidal marsh/mangroves	165			1,839						6,696			169	466	162		658		9,990	1,648
Swamps/floodplains	165	265		7,240	30	7,600				1,659			439	47	49		491	1,761	19,580	3,231
Lakes/rivers	200				5,445	2,117				665				41			230		8,498	1,700
Desert	1,925																			
Tundra	743																			
Ice/rock	1,640																			
Cropland	1,400										14	24		54					92	128
Urban	332																			
Total	51,625	1,341	684	1,779	1,115	1,692	576	53	17,075	2,277	117	417	124	1,386	721	79	815	3,015		33,268

Numbers in the body of the table are in \$ ha^{-1} yr^{-1}. Row and column totals are in \$ yr^{-1} × 10^9, column totals are the sum of the products of the per ha services in the table and the area of each biome, not the sum of the per ha services themselves. Shaded cells indicate services that do not occur or are known to be negligible. Open cells indicate lack of available information.

value of ecological services would be $120, but the contribution to the money economy of ecological services would be $50, the amount that actually passes through markets. In this study we have tried to estimate the total value of ecological services, regardless of whether they are currently marketed.

Figure 1 shows some of these concepts diagrammatically. Figure 1a shows conventional supply (marginal cost) and demand (marginal benefit) curves for a typical marketed good or service. The value that would show up in gross national product (GNP) is the market price *p* times the quantity *q*, or the area *pbqc*. There are three other relevant areas represented on the diagram, however. The cost of production is the area under the supply curve, *cbq*. The 'producer surplus' or 'net rent' for a resource is the area between the market price and the supply curve, *pbc*. The 'consumer surplus' or the amount of welfare the consumer receives over and above the price paid in the market is the area between the demand curve and the market price, *abp*. The total economic value of the resource is the sum of the producer and consumer surplus (excluding the cost of production), or the area *abc* on the diagram. Note that total economic value can be greater or less than the price times quantity estimates used in GNP.

Figure 1a refers to a human-made, substitutable good. Many ecosystem services are only substitutable up to a point, and their demand curves probably look more like Fig. 1b. Here the demand approaches infinity as the quantity available approaches zero (or some minimum necessary level of services), and the consumer surplus (as well as the total economic value) approaches infinity. Demand curves for ecosystem services are very difficult, if not impossible, to estimate in practice. In addition, to the extent that ecosystem services cannot be increased or decreased by actions of the economic system, their supply curves are more nearly vertical, as shown in Fig. 1b.

In this study we estimated the value per unit area of each ecosystem service for each ecosystem type. To estimate this 'unit value' we used (in order of preference) either: (1) the sum of consumer and producer surplus; or (2) the net rent (or producer surplus); or (3) price times quantity as a proxy for the economic value of the service, assuming that the demand curve for ecosystem services looks more like Fig. 1b than Fig. 1a, and that therefore the area *pbqc* is a conservative underestimate of the area *abc*. We then multiplied the unit values times the surface area of each ecosystem to arrive at global totals.

Ecosystem values, markets and GNP

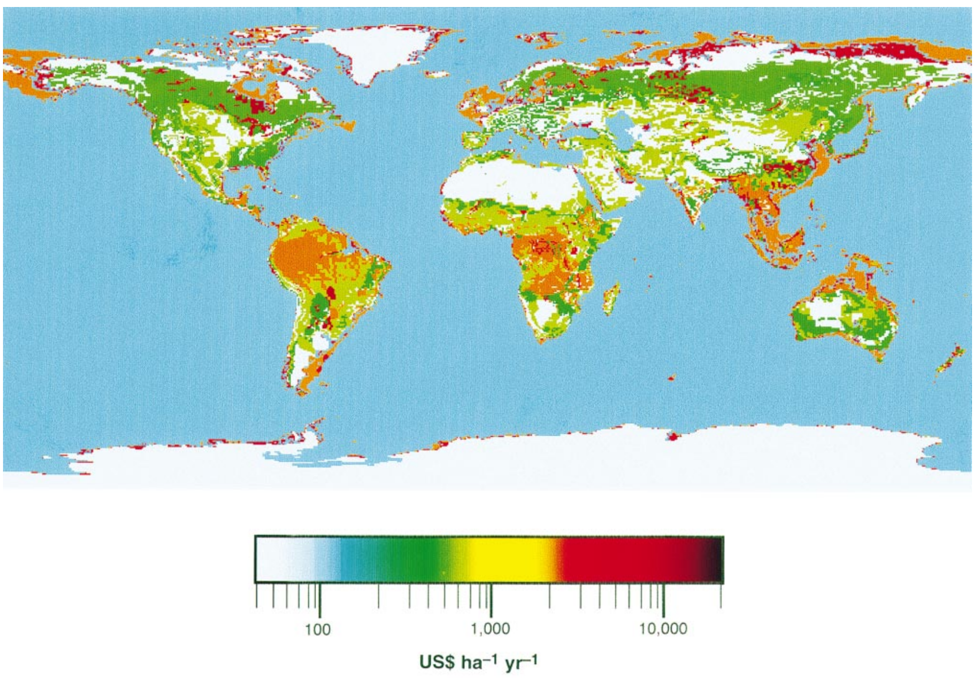
As we have noted, the value of many types of natural capital and ecosystem services may not be easily traceable through well functioning markets, or may not show up in markets at all. For example, the aesthetic enhancement of a forest may alter recreational expenditures at that site, but this change in expenditure bears no necessary relation to the value of the enhancement. Recreationists may value the improvement at $100, but transfer only $20 in spending from other recreational areas to the improved site. Enhanced wetlands quality may improve waste treatment, saving on potential treatment costs. For example, tertiary treatment by wetlands may save $100 in alternative treatment. Existing treatment may cost only $30. The treatment cost savings does not show up in any market. There is very little relation between the value of services and observable current spending behaviour in many cases.

There is also no necessary relationship between the valuation of natural capital service flows, even on the margin, and aggregate spending, or GNP, in the economy. This is true even if all capital service flows had an impact on well functioning markets. A large part of the contributions to human welfare by ecosystem services are of a purely public goods nature. They accrue directly to humans without passing through the money economy at all. In many cases people are not even aware of them. Examples include clean air and water, soil formation, climate regulation, waste treatment, aesthetic values and good health, as mentioned above.

Global land use and land cover

In order to estimate the total value of ecosystem services, we needed estimates of the total global extent of the ecosystems themselves. We devised an aggregated classification scheme with 16 primary categories as shown in Table 2 to represent current global land use. The major division is between marine and terrestrial systems. Marine was further subdivided into open ocean and coastal, which itself includes estuaries, seagrass/algae beds, coral reefs, and shelf systems. Terrestrial systems were broken down into two types of forest (tropical and temperate/boreal), grasslands/rangelands, wetlands, lakes/rivers, desert, tundra, ice/rock, cropland, and urban. Primary

Figure 2 Global map of the value of ecosystem services. See Supplementary Information and Table 2 for details.



data were from ref. 17 as summarized in ref. 4 with additional information from a number of sources[18–22]. We also used data from ref. 23, as a cross-check on the terrestrial estimates and refs 24 and 25 as a check on the marine estimates. The 32 landcover types of ref. 17 were recategorized for Table 2 and Fig. 2. The major assumptions were: (1) chaparral and steppe were considered rangeland and combined with grasslands; and (2) a variety of tropical forest and woodland types were combined into 'tropical forests'.

Synthesis

We conducted a thorough literature review and synthesized the information, along with a few original calculations, during a one-week intensive workshop at the new National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California at Santa Barbara. Supplementary Information lists the primary results for each ecosystem service and biome. Supplementary Information includes all the estimates we could identify from the literature (from over 100 studies), their valuation methods, location and stated value. We converted each estimate into 1994 US\$ $ha^{-1} yr^{-1}$ using the USA consumer price index and other conversion factors as needed. These are listed in the notes to the Supplementary Information. For some estimates we also converted the service estimate into US\$ equivalents using the ratio of purchasing power GNP per capita for the country of origin to that of the USA. This was intended to adjust for income effects. Where possible the estimates are stated as a range, based on the high and low values found in the literature, and an average value, with annotated comments as to methods and assumptions. We also included in the Supplementary Information some estimates from the literature on 'total ecosystem value', mainly using energy analysis techniques[10]. We did not include these estimates in any of the totals or averages given below, but only for comparison with the totals from the other techniques. Interestingly, these different methods showed fairly close agreement in the final results.

Each biome and each ecosystem service had its special considerations. Detailed notes explaining each biome and each entry in Supplementary Information are given in notes following the table. More detailed descriptions of some of the ecosystems, their services, and general valuation issues can be found in ref. 5. Below we briefly discuss some general considerations that apply across the board.

Sources of error, limitations and caveats

Our attempt to estimate the total current economic value of ecosystem services is limited for a number of reasons, including:

(1) Although we have attempted to include as much as possible, our estimate leaves out many categories of services, which have not yet been adequately studied for many ecosystems. In addition, we could identify no valuation studies for some major biomes (desert, tundra, ice/rock, and cropland). As more and better information becomes available we expect the total estimated value to increase.

(2) Current prices, which form the basis (either directly or indirectly) of many of the valuation estimates, are distorted for a number of reasons, including the fact that they exclude the value of ecosystem services, household labour and the informal economy. In addition to this, there are differences between total value, consumer surplus, net rent (or producer surplus) and $p \times q$, all of which are used to estimate unit values (see Fig. 1).

(3) In many cases the values are based on the current willingness-to-pay of individuals for ecosystem services, even though these individuals may be ill-informed and their preferences may not adequately incorporate social fairness, ecological sustainability and other important goals[16]. In other words, if we actually lived in a world that was ecologically sustainable, socially fair and where everyone had perfect knowledge of their connection to ecosystem services, both market prices and surveys of willingness-to-pay would yield very different results than they currently do, and the value of ecosystem services would probably increase.

(4) In calculating the current value, we generally assumed that the demand and supply curves look something like Fig. 1a. In reality, supply curves for many ecosystem services are more nearly inelastic vertical lines, and the demand curves probably look more like Fig. 1b, approaching infinity as quantity goes to zero. Thus the consumer and producer surplus and thereby the total value of ecosystem services would also approach infinity.

(5) The valuation approach taken here assumes that there are no sharp thresholds, discontinuities or irreversibilities in the ecosystem response functions. This is almost certainly not the case. Therefore this valuation yields an underestimate of the total value.

(6) Extrapolation from point estimates to global totals introduces error. In general, we estimated unit area values for the ecosystem services (in \$ $ha^{-1} yr^{-1}$) and then multiplied by the total area of each biome. This can only be considered a crude first approximation and can introduce errors depending on the type of ecosystem service and its spatial heterogeneity.

(7) To avoid double counting, a general equilibrium framework that could directly incorporate the interdependence between ecosystem functions and services would be preferred to the partial equilibrium framework used in this study (see below).

(8) Values for individual ecosystem functions should be based on sustainable use levels, taking account of both the carrying capacity for individual functions (such as food-production or waste recycling) and the combined effect of simultaneous use of more functions. Ecosystems should be able to provide all the functions listed in Table 1 simultaneously and indefinitely. This is certainly not the case for some current ecosystem services because of overuse at existing prices.

(9) We have not incorporated the 'infrastructure' value of ecosystems, as noted above, leading to an underestimation of the total value.

(10) Inter-country comparisons of valuation are affected by income differences. We attempted to address this in some cases using the relative purchasing power GNP per capita of the country relative to the USA, but this is a very crude way to make the correction.

(11) In general, we have used annual flow values and have avoided many of the difficult issues involved with discounting future flow values to arrive at a net present value of the capital stock. But a few estimates in the literature were stated as stock values, and it was necessary to assume a discount rate (we used 5%) in order to convert them into annual flows.

(12) Our estimate is based on a static 'snapshot' of what is, in fact, a complex, dynamic system. We have assumed a static and 'partial equilibrium' model in the sense that the value of each service is derived independently and added. This ignores the complex interdependencies between the services. The estimate could also change drastically as the system moved through critical non-linearities or thresholds. Although it is possible to build 'general equilibrium' models in which the value of all ecosystem services are derived simultaneously with all other values, and to build dynamic models that can incorporate non-linearities and thresholds, these models have rarely been attempted at the scale we are discussing. They represent the next logical step in deriving better estimates of the value of ecosystem services.

We have tried to expose these various sources of uncertainty wherever possible in Supplementary Information and its supporting notes, and state the range of relevant values. In spite of the limitations noted above, we believe it is very useful to synthesize existing valuation estimates, if only to determine a crude, initial magnitude. In general, because of the nature of the limitations noted, we expect our current estimate to represent a minimum value for ecosystem services.

Total global value of ecosystem services

Table 2 is a summary of the results of our synthesis. It lists each of the major biomes along with their current estimated global surface area, the average (on a per hectare basis) of the estimated values of the 17 ecosystem services we have identified from Supplementary Information, and the total value of ecosystem services by biome, by service type and for the entire biosphere.

We estimated that at the current margin, ecosystems provide at least US$33 trillion dollars worth of services annually. The majority of the value of services we could identify is currently outside the market system, in services such as gas regulation (US$1.3 trillion yr^{-1}), disturbance regulation (US$1.8 trillion yr^{-1}), waste treatment (US$2.3 trillion yr^{-1}) and nutrient cycling (US$17 trillion yr^{-1}). About 63% of the estimated value is contributed by marine systems (US$20.9 trillion yr^{-1}). Most of this comes from coastal systems (US$10.6 trillion yr^{-1}). About 38% of the estimated value comes from terrestrial systems, mainly from forests (US$4.7 trillion yr^{-1}) and wetlands (US$4.9 trillion yr^{-1}).

We estimated a range of values whenever possible for each entry in Supplementary Information. Table 2 reports only the average values. Had we used the low end of the range in Supplementary Information, the global total would have been around US$19 trillion. If we eliminate nutrient cycling, which is the largest single service, estimated at US$17 trillion, the total annual value would be around US$16 trillion. Had we used the high end for all estimates, along with estimating the value of desert, tundra and ice/rock as the average value of rangelands, the estimate would be around US$54 trillion. So the total range of annual values we estimated were from US$16–$54 trillion. This is not a huge range, but other sources of uncertainty listed above are much more critical. It is important to emphasize, however, that despite the many uncertainties included in this estimate, it is almost certainly an underestimate for several reasons, as listed above.

There have been very few previous attempts to estimate the total global value of ecosystem services with which to compare these results. We identified two, based on completely different methods and assumptions, both from each other and from the methods used in this study. They thus provide an interesting check.

One was an early attempt at a static general equilibrium input–output model of the globe, including both ecological and economic processes and commodities[26,27]. This model divided the globe in to 9 commodities or product groups and 9 processes, two of which were ‘economic’ (urban and agriculture) and 7 of which were ‘ecological’, including both terrestrial and marine systems. Data were from about 1970. Although this was a very aggregated breakdown and the data was of only moderate quality, the model produced a set of ‘shadow prices’ and ‘shadow values’ for all the flows between processes, as well as the net outputs from the system, which could be used to derive an estimate of the total value of ecosystem services. The input–output format is far superior to the partial equilibrium format we used in this study for differentiating gross from net flows and avoiding double counting. The results yielded a total value of the net output of the 7 global ecosystem processes equal to the equivalent of US$9.4 trillion in 1972. Converted to 1994 US$ this is about $34 trillion, surprisingly close to our current average estimate. This estimate broke down into US$11.9 trillion (or 35%) from terrestrial ecosystem processes and US$22.1 trillion (or 65%) from marine processes, also very close to our current estimate. World GNP in 1970 was about $14.3 trillion (in 1994 US$), indicating a ratio of total ecosystem services to GNP of about 2.4 to 1. The current estimate has a corresponding ratio of 1.8 to 1.

A more recent study[28] estimated a ‘maximum sustainable surplus’ value of ecosystem services by considering ecosystem services as one input to an aggregate global production function along with labour and manufactured capital. Their estimates ranged from US$3.4 to US$17.6 trillion yr^{-1}, depending on various assumptions. This approach assumed that the total value of ecosystem services is limited to that which has an impact on marketed value, either directly or indirectly, and thus cannot exceed the total world GNP of about US$18 trillion. But, as we have pointed out, only a fraction of ecosystem services affects private goods traded in existing markets, which would be included in measures such as GNP. This is a subset of the services we estimated, so we would expect this estimate to undervalue total ecosystem services.

The results of both of these studies indicate, however, that our current estimate is at least in approximately the same range. As we have noted, there are many limitations to both the current and these two previous studies. They are all only static snapshots of a biosphere that is a complex, dynamic system. The obvious next steps include building regional and global models of the linked ecological economic system aimed at a better understanding of both the complex dynamics of physical/biological processes and the value of these processes to human well-being[29,30]. But we do not have to wait for the results of these models to draw the following conclusions.

Discussion

What this study makes abundantly clear is that ecosystem services provide an important portion of the total contribution to human welfare on this planet. We must begin to give the natural capital stock that produces these services adequate weight in the decision-making process, otherwise current and continued future human welfare may drastically suffer. We estimate in this study that the annual value of these services is US$16–54 trillion, with an estimated average of US$33 trillion. The real value is almost certainly much larger, even at the current margin. US$33 trillion is 1.8 times the current global GNP. One way to look at this comparison is that if one were to try to replace the services of ecosystems at the current margin, one would need to increase global GNP by at least US$33 trillion, partly to cover services already captured in existing GNP and partly to cover services that are not currently captured in GNP. This impossible task would lead to no increase in welfare because we would only be replacing existing services, and it ignores the fact that many ecosystem services are literally irreplaceable.

If ecosystem services were actually paid for, in terms of their value contribution to the global economy, the global price system would be very different from what it is today. The price of commodities using ecosystem services directly or indirectly would be much greater. The structure of factor payments, including wages, interest rates and profits would change dramatically. World GNP would be very different in both magnitude and composition if it adequately incorporated the value of ecosystem services. One practical use of the estimates we have developed is to help modify systems of national accounting to better reflect the value of ecosystem services and natural capital. Initial attempts to do this paint a very different picture of our current level of economic welfare than conventional GNP, some indicating a levelling of welfare since about 1970 while GNP has continued to increase[31–33]. A second important use of these estimates is for project appraisal, where ecosystem services lost must be weighed against the benefits of a specific project[8]. Because ecosystem services are largely outside the market and uncertain, they are too often ignored or undervalued, leading to the error of constructing projects whose social costs far outweight their benefits.

As natural capital and ecosystem services become more stressed and more ‘scarce’ in the future, we can only expect their value to increase. If significant, irreversible thresholds are passed for irreplaceable ecosystem services, their value may quickly jump to infinity. Given the huge uncertainties involved, we may never have a very precise estimate of the value of ecosystem services. Nevertheless, even the crude initial estimate we have been able to assemble is a useful starting point (we stress again that it is only a starting point). It demonstrates the need for much additional research and it also indicates the specific areas that are most in need of additional study. It also highlights the relative importance of ecosystem services and the potential impact on our welfare of continuing to squander them. □

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Changes in the global value of ecosystem services

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ABSTRACT

In 1997, the global value of ecosystem services was estimated to average $33 trillion/yr in 1995 $US ($46 trillion/yr in 2007 $US). In this paper, we provide an updated estimate based on updated unit ecosystem service values and land use change estimates between 1997 and 2011. We also address some of the critiques of the 1997 paper. Using the same methods as in the 1997 paper but with updated data, the estimate for the total global ecosystem services in 2011 is $125 trillion/yr (assuming updated unit values and changes to biome areas) and $145 trillion/yr (assuming only unit values changed), both in 2007 $US. From this we estimated the loss of eco-services from 1997 to 2011 due to land use change at $4.3–20.2 trillion/yr, depending on which unit values are used. Global estimates expressed in monetary accounting units, such as this, are useful to highlight the magnitude of eco-services, but have no specific decision-making context. However, the underlying data and models can be applied at multiple scales to assess changes resulting from various scenarios and policies. We emphasize that valuation of eco-services (in whatever units) is not the same as commodification or privatization. Many eco-services are best considered public goods or common pool resources, so conventional markets are often not the best institutional frameworks to manage them. However, these services must be (and are being) valued, and we need new, common asset institutions to better take these values into account.

1. Introduction

Ecosystems provide a range of services that are of fundamental importance to human well-being, health, livelihoods, and survival (Costanza et al., 1997; Millennium Ecosystem Assessment (MEA), 2005; TEEB Foundations, 2010; TEEB Synthesis, 2010). Interest in ecosystem services in both the research and policy communities has grown rapidly (Braat and de Groot, 2012; Costanza and Kubiszewski, 2012). In 1997, the value of global ecosystem services was estimated to be around US$ 33 trillion per year (in 1995 $US), a figure significantly larger than global gross domestic product (GDP) at the time. This admittedly crude underestimate of the welfare benefits of natural capital, and a few other early studies (Daily, 1997; de Groot, 1987; Ehrlich and Ehrlich, 1981; Ehrlich and Mooney, 1983; Odum, 1971; Westman, 1977) stimulated a huge surge in interest in this topic.

In 2005, the concept of ecosystem services gained broader attention when the United Nations published its Millennium Ecosystem Assessment (MEA). The MEA was a four-year, 1300-scientist study for policymakers. Between 2007 and 2010, a second international initiative was undertaken by the UN Environment Programme, called the Economics of Ecosystems and Biodiversity (TEEB) (TEEB Foundations, 2010). The TEEB report was picked up extensively by the mass media, bringing ecosystem services to a broader audience. Ecosystem services have now also entered the consciousness of mainstream media and business. The World Business Council for Sustainable Development has actively supported and developed the concept (WBCSD, 2011, 2012). Hundreds of projects and groups are currently working toward

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better understanding, modeling, valuation, and management of ecosystem services and natural capital. It would be impossible to list all of them here, but emerging regional, national, and global networks, like the Ecosystem Services Partnership (ESP), are doing just that and are coordinating their efforts (Braat and de Groot, 2012; de Groot et al., 2011).

Probably the most important contribution of the widespread recognition of ecosystem services is that it reframes the relationship between humans and the rest of nature. A better understanding of the role of ecosystem services emphasizes our natural assets as critical components of inclusive wealth, well-being, and sustainability. Sustaining and enhancing human well-being requires a balance of all of our assets—individual people, society, the built economy, and ecosystems. This reframing of the way we look at "nature" is essential to solving the problem of how to build a sustainable and desirable future for humanity.

Estimating the relative magnitude of the contributions of ecosystem services has been an important part of changing this framing. There has been an on-going debate about what some see as the "commodification" of nature that this approach supposedly implies (Costanza, 2006; McCauley, 2006) and what others see as the flawed methods and questionable wisdom of aggregating ecosystem services values to larger scales (Chaisson, 2002). We think that these critiques are largely misplaced once one understands the context and multiple potential uses of ecosystem services valuation, as we explain further on.

In this paper we (1) update estimates of the value of global ecosystem services based on new data from the TEEB study (de Groot et al., 2012, 2010a,b); (2) compare those results with earlier estimates (Costanza et al., 1997) and with alternative methods (Boumans et al., 2002); (3) estimate the global changes in ecosystem service values from land use change over the period 1997–2011; and (4) review some of the objections to aggregate ecosystem services value estimates and provide some responses (Howarth and Farber, 2002).

We do not claim that these estimates are the only, or even the best way, to understand the value of ecosystem services. Quite the contrary, we advocate pluralism based on a broad range of approaches at multiple scales. However, within this range of approaches, estimates of aggregate accounting value for ecosystem services in monetary units have a critical role to play in heightening awareness and estimating the overall level of importance of ecosystem services relative to and in combination with other contributors to sustainable human well-being (Luisetti et al., 2013).

2. What is valuation?

Valuation is about assessing trade-offs toward achieving a goal (Farber et al., 2002). All decisions that involve trade-offs involve valuation, either implicitly or explicitly (Costanza et al., 2011). When assessing trade-offs, one must be clear about the goal. Ecosystem services are defined as the benefits people derive from ecosystems – the support of sustainable human well-being that ecosystems provide (Costanza et al., 1997; Millennium Ecosystem Assessment (MEA), 2005). The value of ecosystem services is therefore the *relative* contribution of ecosystems to that goal. There are multiple ways to assess this contribution, some of which are based on individual's perceptions of the benefits they derive. But the support of sustainable human well-being is a much larger goal (Costanza, 2000) and individual's perceptions are limited and often biased (Kahneman, 2011). Therefore, we also need to include methods to assess benefits to individuals that are not well perceived, benefits to whole communities, and benefits to sustainability (Costanza, 2000). This is an on-going challenge in ecosystem services valuation, but even some of the existing valuation methods like avoided and replacement cost estimates

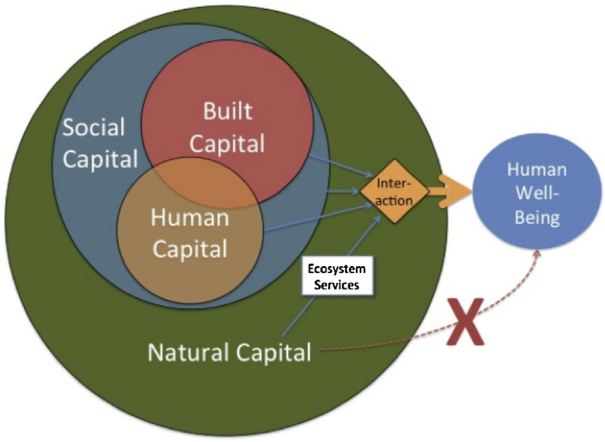

Fig. 1. Interaction between built, social, human and natural capital required to produce human well-being. Built and human capital (the economy) are embedded in society which is embedded in the rest of nature. Ecosystem services are the relative contribution of natural capital to human well-being, they do not flow directly. It is therefore essential to adopt a broad, transdisciplinary perspective in order to address ecosystem services.

are not dependent on individual perceptions of value. For example, estimating the storm protection value of coastal wetlands requires information on historical damage, storm tracks and probability, wetland area and location, built infrastructure location, population distribution, etc. (Costanza et al., 2008). It would be unrealistic to think that the general public understands this complex connection, so one must bring in much additional information not connected with perceptions to arrive at an estimate of the value. Of course, there is ultimately the link to built infrastructure, which people perceive as a benefit and value, but the link is complex and not dependent on the general public's understanding of or perception of the link.

It is also important to note that ecosystems cannot provide any benefits to people without the presence of people (human capital), their communities (social capital), and their built environment (built capital). This interaction is shown in Fig. 1. Ecosystem services do not flow directly from natural capital to human well-being – it is only through interaction with the other three forms of capital that natural capital can provide benefits. This is also the conceptual valuation framework for the recent UK National Ecosystem Assessment (http://uknea.unep-wcmc.org) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES – http://www.ipbes.net). The challenge in ecosystem services valuation is to assess the relative contribution of the natural capital stock in this interaction and to balance our assets to enhance sustainable human well-being.

The relative contribution of ecosystem services can be expressed in multiple units – in essence any of the contributors to the production of benefits can be used as the "denominator" and other contributors expressed in terms of it. Since built capital in the economy, expressed in monetary units, is one of the required contributors, and most people understand values expressed in monetary units, this is often a convenient denominator for expressing the relative contributions of the other forms of capital, including natural capital. But other units are certainly possible (i.e. land, energy, time, etc.) – the choice is largely about which units communicate best to different audiences in a given decision-making context.

3. Valuation is not privatization

It is a misconception to assume that valuing ecosystem services in monetary units is the same as privatizing them or commodifying them for trade in private markets (Costanza, 2006; Costanza et al., 2012; McCauley, 2006; Monbiot, 2012). Most ecosystem services are public goods (non-rival and non-excludable) or common pool resources (rival but non-excludable), which means that privatization and conventional markets work poorly, if at all. In addition, the non-market values estimated for these ecosystem services often relate more to *use* or *non-use* values rather than *exchange* values (Daly, 1998). Nevertheless, knowing the value of ecosystem services is helpful for their effective management, which in some cases can include economic incentives, such as those used in successful systems of payment for these services (Farley and Costanza, 2010). In addition, it is important to note that valuation is unavoidable. We already value ecosystems and their services every time we make a decision involving trade-offs concerning them. The problem is that the valuation is implicit in the decision and hidden from view. Improved transparency about the valuation of ecosystem services (while recognizing the uncertainties and limitations) can only help to make better decisions.

It is also incorrect to suggest (McCauley, 2006) that conservation based on protecting ecosystem services is betting against human ingenuity. Recognizing and measuring natural capital and ecosystem services in terms of stocks and flows is a prime example of enlightened human ingenuity. The study of ecosystem services has merely identified the limitations and costs of 'hard' engineering solutions to problems that in many cases can be more efficiently solved by natural systems. Pointing out that the 'horizontal levees' of coastal marshes are more cost-effective protectors against hurricanes than constructed vertical levees (Costanza et al., 2008) and that they also store carbon that would otherwise be emitted into the atmosphere (Luisetti et al., 2011) implies that restoring or recreating them for this and other benefits is only using our intelligence and ingenuity, not betting against it.

The ecosystem services concept makes it abundantly clear that the choice of "the environment versus the economy" is a false choice. If nature contributes significantly to human well-being, then it is a major contributor to the *real* economy (Costanza et al., 1997), and the choice becomes how to manage all our assets, including natural and human-made capital, more effectively and sustainably (Costanza et al., 2000).

4. Uses of valuation of ecosystem services

The valuation of ecosystem services can have many potential uses, at multiple time and space scales. Confusion can arise, however, if one is not clear about the distinctions between these uses. Table 1 lists some of the potential uses of ecosystem services valuation, ranging from simply raising awareness to detailed analysis of various policy choices and scenarios. For example, Costanza et al. (1997) was clearly an awareness raising exercise with no specific policy or decision in mind. As its citation history verifies, it was very successful for this purpose. It also pointed out that ecosystem service values could be useful for several of the other purposes listed in Table 1, and it stimulated subsequent research and application in these areas. There have been thousands of subsequent studies addressing the full range of uses listed in Table 1.

5. Aggregating values

Ecosystem services are often assessed and valued at specific sites for specific services. However some uses require aggregate values over larger spatial and temporal scales (Table 1). Producing such aggregates suffers from many of the same problems as producing any aggregate estimate, including macroeconomic aggregates such as GDP. Table 2 lists a range of possible approaches for aggregating ecosystem service values (Kubiszewski et al., 2013a). Basic benefit transfer, the technique used in Costanza et al. (1997) assumes a constant unit value per hectare of ecosystem type and multiplies that value by the area of each type to arrive at aggregate totals. This can be improved somewhat by adjusting values using expert opinion of local conditions (Batker et al., 2008). Benefit transfer is analogous to the approach taken in GDP accounting, which aggregates value by multiplying price times quantity for each sector of the economy. Our aggregate is an accounting measure of the quantity of ecosystem services (Howarth and Farber, 2002). In this accounting dimension the measure is based on virtual non-market prices and incomes, not real prices and incomes. We return to this point later when we examine some of the criticisms of the original 1997 study.

While simple and easy, this approach obviously glosses over many of the complexities involved. This degree of approximation is appropriate for some uses (Table 1) but ultimately a more spatially explicit and dynamic approach would be preferable or essential for some other uses. These approaches are beginning to be implemented (Bateman et al., 2013; Boumans et al., 2002; Burkhard et al., 2013; Costanza et al., 2008; Costanza and Voinov, 2003; Crossman et al., 2012; Goldstein et al., 2012; Nelson et al., 2009) and this represents the cutting edge of research in this field.

Regional aggregates are useful for assessing land use change scenarios. National aggregates are useful for revising national income accounts. Global aggregates are useful for raising awareness and emphasizing the importance of ecosystem services relative to other contributors to human well-being. In this paper, we provide some updated global estimates, recognizing that this is only one among many potential uses for ecosystem services valuation, and that this use has special requirements, limitations, and interpretations.

6. Estimates of global value

Costanza et al. (1997) estimated the value of 17 ecosystem services for 16 biomes and an aggregate global value expressed in monetary units. This estimate was based on a simple benefit transfer method described above.

Notwithstanding the limitations and restrictions in benefit transfer techniques (Brouwer, 2000; Defra, 2010; Johnston and

Table 1
Range of uses for ecosystem service valuation.

Use of valuation	Appropriate values	Appropriate spatial scales	Precision needed
Raising awareness and interest	Total values, macro aggregates	Regional to global	Low
National income and well-being accounts	Total values by sector and macro aggregates	National	Medium
Specific policy analyses	Changes by policy	Multiple depending on policy	Medium to high
Urban and regional land use planning	Changes by land use scenario	Regional	Low to medium
Payment for ecosystem services	Changes by actions due payment	Multiple depending on system	Medium to high
Full cost accounting	Total values by business, product, or activity and changes by business, product, or activity	Regional to global, given the scale of international corporations	Medium to high
Common asset trusts	Totals to assess capital and changes to assess income and loss	Regional to global	Medium

Table 2
Four levels of ecosystem service value aggregation (Kubiszewski et al., 2013a,b).

Aggregation method	Assumptions/approach	Examples
1. Basic value transfer	Assumes values constant over ecosystem types	Costanza et al. (1997), Liu et al. (2010a,b)
2. Expert modified value transfer	Adjusts values for local ecosystem conditions using expert opinion surveys	Batker et al. (2008)
3. Statistical value transfer	Builds statistical model of spatial and other dependencies	de Groot et al. (2012)
4. Spatially explicit functional modeling	Builds spatially explicit statistical or dynamic systems models incorporating valuation	Boumans et al. (2002), Costanza et al. (2008), Nelson et al. (2009)

Rosenberger, 2010) it is an attractive option for researchers and policy-makers facing time and budget constraints. Value transfer has been used for valuation of environmental resources in many instances. Nelson and Kennedy (2009) provide a critical overview of 140 meta-analyses.

de Groot et al. (2012) estimated the value of ecosystem services in monetary units provided by 10 main biomes (Open oceans, Coral reefs, Coastal systems, Coastal wetlands, Inland wetlands, Lakes, Tropical forests, Temperate forests, Woodlands, and Grasslands) based on local case studies across the world. These studies covered a large number of ecosystems, types of landscapes, different definitions of services, different areas, different levels of scale, time and complexity and different valuation methods. In total, approximately 320 publications were screened and more than 1350 data-points from over 300 case study locations were stored in the Ecosystem Services Value Database (ESVD) (http://www.fsd.nl/esp/80763/5/0/50). A selection of 665 of these value data points were used for the analysis. Values were expressed in terms of 2007 'International' $/ha/year, i.e. translated into US$ values on the basis of Purchasing Power Parity (PPP) and contains site-, study-, and context-specific information from the case studies. We added some additional estimates for this paper, notably for urban and cropland systems (see Supporting Material for details).

A detailed description of the ESVD is given in van der Ploeg et al. (2010). de Groot et al. (2012) provides details of the results. Below, we provide a comparison of the de Groot et al. (2012) results with the Costanza et al. (1997) results in order to estimate the changes in the flow of ecosystem services over this time period.

After some consolidation of the typologies used in the two studies we can compare the de Groot et al. (2012) estimates per service and per biome with the Costanza et al. (1997) estimates in Table 3, and in more detail in Supporting Material, Table S1. Table S1 lists the mean value for each service and biome for both 1997 and 2011. Table 4 is a summary of the number of estimates, mean, standard deviation, median, and minimum and maximum values used in de Groot et al. (2012). All values are in international $/ha/yr and were derived from the ESV database. Note that there is a wide range of the number of studies for each biome, ranging from 14 for open ocean to 168 for inland wetlands. This is a significantly larger number of studies than were available for the Costanza et al. study (less than 100). One can also note the wide variation and high standard deviation for several of the biomes. For example, values for coral reefs varied from a low of 36,794 $/ha/yr to a high of 2,129,122 $/ha/yr. Given a sufficient number of studies, some of this variation can be explained by other variables. For example, De Groot et al. performed a meta-regression analysis for inland wetlands using 16 independent variables in a model with an adjusted R^2 of 0.442. Variables that were significant in explaining the value of inland wetlands included the area of the study site, the type of inland wetland, GDP/capita, and population of the country in which the wetland occurred, the proximity of other wetlands, and the valuation method used for the study. If this number of studies were available for the other biomes in our global assessment, we could use this type of meta-regression to produce more accurate estimates. However, for the current estimate, we must continue to rely on global averages.

Global averages per ha may vary between the two time periods we are comparing for three distinct reasons: (1) new (and generally more numerous and complete) estimates of the unit values of ecosystem services per ha; (2) changes in the average functionality of ecosystem per ha; and (3) changes in value per ha due to changes in human, social, or built capital. The actual estimates conflate these causes and we see no way of disentangling them at this point. However, since global population only increased by 16% between 1997 and 2011 (from 5.83 to 7 billion), and, if anything, ecosystems are becoming more stressed and less functional, we can attribute most of the increase in unit values to more comprehensive, value estimates available in 2011 than in 1997.

Table 3 shows that values per ha estimated by de Groot et al. (2012) are an average of 8 times higher than the equivalent estimates from Costanza et al. (1997) (both converted into $2007). Only inland wetlands and estuaries did not show a significant increase in estimated value per ha, but these were among the best studied biomes in 1997. Some biomes showed significant increases in value. For example, tidal marsh/mangroves increased from abound 14,000 to around 194,000 $/ha/yr. This is largely due to new studies of the storm protection, erosion control, and waste treatment values of these systems. Coral reefs also increased tremendously in estimated value from around 8000 to around 352,000 $/ha/yr due to additional studies of storm protection, erosion protection, and recreation. Cropland and urban system also increased dramatically, largely because there were almost no studies of these systems in 1997 and there have subsequently been several new studies (Wratten et al., 2013).

Table 3 also shows the aggregate global annual value of services, estimated by multiplying the land area of each biome by the unit values. Column A uses the original values from Costanza et al. (1997) converted to 2007 dollars (total = $45.9 trillion/yr). If we assume that land areas did not change between the two time periods, the new estimate, shown in column B is $145 trillion/yr, are more than 3 times larger than the original estimate. This is due solely to updated unit values. However, land use *has* changed significantly between the two years, changing the supply (the flow) of ecosystem services. If we use the new land use estimates shown in Table 3 (see Supporting Material for details) and the 1997 unit values, we get the estimates in column C – a total of $41.6 trillion/yr. Column E is the change in value due to land use change using the 1997 unit values. Marine systems show a slight increase in value, while terrestrial systems show a large decrease. This decrease is largely due to decreases in the area of high value per ha biomes (tropical forests, wetlands, and coral reefs – shown in red in Table 3) and increases in low value per ha biomes. The total net decrease is estimated to be $4.3 trillion/yr. It is almost certain that the functionality of ecosystems per ha has also declined in many cases so the supply effects are surely greater than this. Column D

Table 3
Changes in area, unit values and aggregate global flow values from 1997 to 2011 (green are values that have increased, red are values that have decreased).

							A. Original	**B.** Change unit values only	**C.** Change area only	**D.** Change both unit values and area	**E.** Column C - Column A	**F.** Column D - Column B
							Assuming 1997 area and 1997 unit values	Assuming 1997 area and 2011 unit values	Assuming 2011 area and 1997 unit values	Assuming 2011 area and 2011 unit values	2011-1997	
Biome	**Area**			**Unit values**			**Aggregate Global Flow Value**				**Change in Value**	
	(e6 ha)		Change	2007$/ha/yr		Change	e12 2007$/yr				e12 2007$/yr	
	1997	2011	2011-1997	1997	2011	2011-1997	1997	2011	2011	2011	1997 unit values	2011 unit values
Marine	**36,302**	**36,302**	0	796	1,368	572	**28.9**	**60.5**	**29.5**	**49.7**	0.6	(10.9)
Open Ocean	**33,200**	**33,200**	0	348	660	312	11.6	21.9	11.6	21.9	-	-
Coastal	**3,102**	**3,102**	0	5,592	8,944	3,352	17.3	38.6	18.0	27.7	0.6	(10.9)
Estuaries	180	180	0	31,509	28,916	-2,593	5.7	5.2	5.7	5.2	-	-
Seagrass/Algae Beds	200	234	34	26,226	28,916	2,690	5.2	5.8	6.1	6.8	0.9	1.0
Coral Reefs	62	28	-34	8,384	352,249	343,865	0.5	21.7	0.2	9.9	(0.3)	(11.9)
Shelf	2,660	2,660	0	2,222	2,222	0	5.9	5.9	5.9	5.9	-	-
Terrestrial	**15,323**	**15,323**	0	1,109	4,901	3,792	**17.0**	**84.5**	**12.1**	**75.1**	(4.9)	(9.4)
Forest	**4,855**	**4,261**	-594	1,338	3,800	2,462	6.5	19.5	4.7	16.2	(1.8)	(3.3)
Tropical	1,900	1,258	-642	2,769	5,382	2,613	5.3	10.2	3.5	6.8	(1.8)	(3.5)
Temperate/Boreal	2,955	3,003	48	417	3,137	2,720	1.2	9.3	1.3	9.4	0.0	0.2
Grass/Rangelands	**3,898**	**4,418**	520	321	4,166	3,845	1.2	16.2	1.4	18.4	0.2	2.2
Wetlands	**330**	**188**	-142	20,404	140,174	119,770	6.7	36.2	3.4	26.4	(3.3)	(9.9)
Tidal Marsh/Mangroves	165	128	-37	13,786	193,843	180,057	2.3	32.0	1.8	24.8	(0.5)	(7.2)
Swamps/Floodplains	165	60	-105	27,021	25,681	-1,340	4.5	4.2	1.6	1.5	(2.8)	(2.7)
Lakes/Rivers	**200**	**200**	0	11,727	12,512	785	2.3	2.5	2.3	2.5	-	-
Desert	**1,925**	**2,159**	234	-	-	0	-	-	-	-	-	-
Tundra	**743**	**433**	-310	-	-	0	-	-	-	-	-	-
Ice/Rock	**1,640**	**1,640**	0	-	-	0	-	-	-	-	-	-
Cropland	**1,400**	**1,672**	272	126	5,567	5,441	0.2	7.8	0.2	9.3	0.0	1.5
Urban	**332**	**352**	20	-	6,661	6,661	-	2.2	-	2.3	-	0.1
Total	**51,625**	**51,625**	0				**45.9**	**145.0**	**41.6**	**124.8**	**(4.3)**	**(20.2)**

shows the combined effects of both changes in land areas and updated unit values. The net effect yields an estimate of $124.8 trillion/yr – 2.7 times the original estimate. For comparison, global GDP was approximately 46.3 trillion/yr in 1997 and $75.2 trillion/yr in 2011 (in $2007).

The difference between columns D and B is the estimated loss of ecosystem services based on land use changes and using the 2011 unit value estimates. This is shown in column F. In this case marine systems show a large loss ($10.9 trillion/yr), due mainly to a decrease in coral reef area and the substantially larger unit value for coral reef using the 2011 unit values. Terrestrial systems also show a large loss, dominated by tropical forests and wetlands, but countered by small increases in the value of grasslands, cropland, and urban systems. Overall, the total net decrease is estimated to be $20.2 trillion in annual services since 1997. Given the more comprehensive unit values employed in the 2011 estimates, this is a better approximation than using the 1997 unit values, but certainly still a conservative estimate. The present value of the discounted flow of ecosystem services consumed would represent part of the stock of inclusive wealth lost/gained over time (UNU-IHDP, 2012).

As we have previously noted, basic value transfer is a crude first approximation at best. We could put ranges on these numbers based on the standard deviations shown in Table 4, but there are other sources of error and caveats as well, as described in Costanza et al. including errors in estimating land use changes. However, we think that solving these problems will most likely lead to even larger estimates. For example, one problem is the limited number of valuation studies available and we expected that as more studies became available from 1997 to 2011 the unit value estimates would increase, and they did.

We also anticipate that more sophisticated techniques for estimating value will lead to larger estimates. For example, more sophisticated integrated dynamic and spatially explicit modeling

Table 4
Summary of the number of estimates, mean, standard deviation, median, minimum and maximum values used in de Groot et al. (2012). Values are in international $/ha/yr, derived from the ESV database.

	No. of estimates	Total of service means (TEV)	Total of St. Dev. of means	Total of median values	Total of minimum values	Total of maximum values
Open oceans	14	491	762	135	85	1664
Coral reefs	94	352,915	668,639	197,900	36,794	2129,122
Coastal systems	28	28,917	5045	26,760	26,167	42,063
Coastal wetlands	139	193,845	384,192	12,163	300	887,828
Inland wetlands	168	25,682	36,585	16,534	3018	104,924
Rivers and lakes	15	4267	2771	3938	1446	7757
Tropical forest	96	5264	6526	2355	1581	20,851
Temperate forest	58	3013	5437	1127	278	16,406
Woodlands	21	1588	317	1522	1373	2188
Grasslands	32	2871	3860	2698	124	5930

techniques have been developed and applied at regional scales (Barbier, 2007; Bateman et al., 2013; Bateman and Jones, 2003; Costanza and Voinov, 2003; Goldstein et al., 2012; Nelson et al., 2009). However, few have been applied at the global scale. One example is the Global Unified Metamodel of the Biosphere (GUMBO) that was developed specifically to simulate the integrated earth system and assess the dynamics and values of ecosystem services (Boumans et al., 2002). GUMBO is a 'metamodel' in that it represents a synthesis and simplification of several existing dynamic global models in both the natural and social sciences at an intermediate level of complexity. It includes dynamic feedbacks among human technology, economic production, human welfare, and ecosystem goods and services within and across 11 biomes. The dynamics of eleven major ecosystem goods and services for each of the biomes have been simulated and evaluated. A range of future scenarios representing different assumptions about future technological change, investment strategies and other factors, have been simulated. The relative value of ecosystem services in terms of their contribution to supporting both conventional economic production and human well-being more broadly defined were estimated under each scenario. The value of global ecosystem services was estimated to be about 4.5 times the value of Gross World Product (GWP) in the year 2000 using this approach. For a current global GDP of $75 trillion/yr this would be about $347 trillion/yr, or almost three times the column D estimate in Table 3. This is to be expected since the dynamic simulation can include a more comprehensive picture of the complex interdependencies involved. It is also important to note that this type of model is the only way to potentially assess more than marginal changes in ecosystem services, including irreversible thresholds and tipping points (Rockström et al., 2009; Turner et al., 2003).

7. Caveats and misconceptions

We want to make clear that expressing the value of ecosystem services in monetary units does not mean that they should be treated as private commodities that can be traded in private markets. Many ecosystem services are public goods or the product of common assets that cannot (or should not) be privatized (Wood, 2014). Even if fish and other provisioning services enter the market as private goods, the ecosystems that produce them (i.e. coastal systems and oceans) are common assets. Their value in monetary units is an estimate of their benefits to society expressed in units that communicate with a broad audience. This can help to raise awareness of the importance of ecosystem services to society and serve as a powerful and essential communication tool to inform better, more balanced decisions regarding trade-offs with policies that enhance GDP but damage ecosystem services.

Some have argued that estimating the global value of ecosystem services is meaningless, because if we lost all ecosystem services human life would end, so their value must be infinite (Chaisson, 2002). While this is certainly true, as was clearly pointed out in the 1997 paper (Costanza et al., 1997), it is a simple misinterpretation of what our estimate refers to. Our estimate is more analogous to estimating the total value of agriculture in national income accounting. Whatever the fraction of GDP that agriculture contributes now, it is clear that if all agriculture were to stop, economies would collapse to near zero. What the estimates are referring to, in both cases, is the *relative* contribution, expressed in monetary units, of the assets or activities at the current point in time. Referring to Fig. 1, human well-being comes from the interaction of the four basic types of capital shown. GDP picks up only a fraction of this total contribution (Costanza et al., 2014; Kubiszewski et al., 2013b). What we have estimated is the relative contribution of natural capital now, with the current balance of asset types. Some of this contribution is already included in GDP, embedded in the contribution of natural capital to marketed goods and services. But much of it is not captured in GDP because it is embedded in services that are not marketed or not fully captured in marketed products and services. Our estimate shows that these services (i.e. storm protection, climate regulation, etc.) are much larger in relative magnitude right now than the sum of marketed goods and services (GDP). Some have argued that this result is impossible, wrongly assuming that all of our value estimates are based on willingness-to-pay and that that cannot exceed aggregate ability-to-pay (i.e. GDP). But for it to be impossible, one would have to argue that *all* human benefits are marketed and captured in GDP. This is obviously not the case. Another example is the many other types of goods and services traded on "black markets" that in some countries far exceed GDP. Moreover, our estimate is an accounting measure based on virtual not real prices and incomes and it is these virtual total expenditures that should not be exceeded (Costanza et al., 1998; Howarth and Farber, 2002). It is also important for policy to evaluate gains/losses in stocks and consequent service flows (analogous to net GDP). The discounted present value of such stock/flow changes is a measure of a component of inclusive wealth or wellbeing.

8. Conclusions

The concepts of ecosystem services flows and natural capital stocks are increasingly useful ways to highlight, measure, and value the degree of interdependence between humans and the rest of nature. This approach is complementary with other approaches to nature conservation, but provides conceptual and empirical tools that the others lack and it communicates with different audiences for different purposes. Estimates of the global accounting value of ecosystem services expressed in monetary units, like those in this paper, are mainly useful to raise awareness about the magnitude of these services relative to other services provided by human-built capital at the current point in time. Our estimates show that global land use changes between 1997 and 2011 have resulted in a loss of ecosystem services of between $4.3 and $20.2 trillion/yr, and we believe that these estimates are conservative. One should not underestimate the importance of the change in awareness and worldview that these global estimates can facilitate – it is a necessary precursor to practical application of the concept using changes in the flows of services for decision-making at multiple scales. It allows us to build a more comprehensive and balanced picture of the assets that support human well-being and human's interdependence with the well-being of all life on the planet.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.04.002.

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