Principles of Environmental Sciences

Jan J. Boersema • Lucas Reijnders
Editors

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With Editorial Assistance by
Joeri Bertels and Henk Bezemer

Springer

Editors

Jan J. Boersema
Institute for Environmental Studies
Vrije Universiteit
De Boelelaan 1087
1081 HV Amsterdam
The Netherlands
jan.boersema@ivm.vu.nl

Lucas Reijnders
IBED/EDCO
University Amsterdam
Nieuwe Achtergracht 166
1018 WV Amsterdam
The Netherlands
L.Reijnders@uva.nl

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Preface

Why this book?

This academic textbook is meant to be *complementary* to the many existing textbooks on environmental science. It distinguishes itself for two main reasons:

- Environmental problems, the object of the environmental sciences, are seen and described as resulting from observed phenomena in our natural environment on one hand, and the societal awareness and evaluation of these phenomena on the other. A combination of the two causes a phenomenon to be considered ‘an environmental problem’. Therefore, students must learn that right from the beginning there is a *cultural and historical dimension* when it comes to defining and analysing environmental problems. That is why we pay attention to environmental history and to the variations in both perception and the implementation of solutions. In more philosophical terms: this book tries to avoid the ‘Scylla of positivism’ (as natural scientists, we know what the problems are) and the ‘Charybdis of constructivism’ (problems only exist if we see them as problems).
- This book provides a comprehensive picture of the various principles, concepts, and methods applicable to environmental problems, and relates these methods to underlying guiding principles and the adjacent policy measures. The focus is on multi- and interdisciplinary methods, although most of the methods originate from a specific discipline and many have a limited domain. Wherever possible, examples of application of a method in practice are given, as well as evaluations in terms of gains of a particular method over other methods. This *focus on methodology* distinguishes this book from other textbooks. To give just two examples: The LCA-approach (Life Cycle Analysis/Assessment) is given only a few lines in most basic textbooks, although this methodology has become widely and officially accepted by professionals and scientists (as an ISO-standard). Modelling is not explicitly dealt with in most textbooks either, although many different kinds of models are common practice in environmental studies.

Throughout this book the term sciences is meant to include the social sciences and even disciplines of the humanities.

Aim

The aim of this academic textbook is threefold:

- To describe environmental problems in their historical context
- To delineate how complex environmental problems can be analysed and tackled by using various (inter)disciplinary concepts, methods and tools and
- To illustrate how solutions work out in their social context

Readership
The book is intended to be a course text for students who take environmental science as a major or as a minor. So, the book is primarily meant for:

- Undergraduate and graduate students of multi- and interdisciplinary courses in environmental studies/sciences and courses focusing on methodology
- Graduate students specialising in environmental topics of their discipline

To a lesser degree, the book or chapters of the book may be useful as a reference to students of some post-academic course or 'lifetime learning' course for professionals in the environmental field.

Assumed background: an introductory course in environmental science and/or some years of disciplinary training.

Outline

In line with the three aims, the book is subdivided into three parts.

Part I, *Stating the Problem* (Chapters 1–6)

This part introduces the environmental sciences and gives an overview of the historical context. This is done on a large timescale, including geological and human history. It concludes with a concise description of recent developments and trends.

Part II, *Principles and Methods* (Chapters 7–18)

This is the core of the book. It starts with two chapters on the guiding principles, followed by seven chapters in which disciplinary and multidisciplinary methods are described and explained at length. The text will include many practical examples, including evaluations of the pros and cons of each example. This part concludes with three chapters on integrative methods. Special emphasis is given to the concept of integration, modelling (both as a learning and research tool) and integrated assessment.

Part III, *Context and Perspectives* (Chapters 19–28)

The last part is designed to illustrate the way solutions work in a specific societal context. The first chapter introduces the topic, which is followed by three case studies on different spatial scales. Solutions need to be implemented in and/or accepted by a given society. The same (technical/practical) solution of a more or less similar problem may provoke quite different reactions in different societies. The case studies will be used to illustrate this point. Finally the book offers perspectives on economic growth and on major societal sectors and the most likely course they will take in the future.

Although it is acknowledged that (by definition) there is no such phenomenon as an objective description of environmental problems, the book tries to avoid a too outspoken standpoint.

Learning Objectives

We expect students to learn some specific skills, e.g. the essentials of building a model or applying LCA, but our main objective is to improve their ability to analyse and conceptualise environmental problems in context, to make students aware of the value and scope of different methods and to teach them the results and insights of previous work in this field.

Amsterdam, August 2008 Jan J. Boersema & Lucas Reijnders,

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As editors we are ultimately responsible for the book as it stands, although authors remain responsible for the content of their chapters.

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Contributors

Jan Bakkes, M.Sc. is senior scientist at the Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands. jan.bakkes@mnp.nl

Dr. Wilfred Beckerman is emeritus fellow at Balliol College, Oxford, UK. wilfred.beckerman@econs.ox.uk

Dr. Frans Berkhout is professor of Innovation and Sustainability, and Director of The Institute for Environmental Studies (IVM) at the VU University Amsterdam, The Netherlands. frans.berkhout@ivm.vu.nl

Dr. Egbert Boeker is professor emeritus of Theoretical Physics at the VU University Amsterdam, The Netherlands. egbertb@xs4all.nl

Dr. Jan J. Boersema is professor of Environmental Science and Worldviews at the Institute for Environmental Studies (IVM) at the VU University Amsterdam, The Netherlands. jan.boersema@ivm.vu.nl

Dr. Maurie Cohen is associate professor of Environmental Policy and Sustainability at the New Jersey Institute of Technology, Newark, USA. maurie.cohen@njit.edu

Dr. Herman E. Daly is an ecological economist and professor at the School of Public Policy of University of Maryland, College Park, USA. hdaly@umd.edu

Dr. H. J. M. (Bert) de Vries is senior scientist at the Netherlands Environmental Assessment Agency (MNP) Bilthoven and professor of Global Change and Energy at the Copernicus Institute Utrecht University, The Netherlands. bert.devries@pbl.nl

Dr. Craig Dilworth is reader in theoretical philosophy at Uppsala University, Sweden. Craig.Dilworth@comhem.se

Dr. Jan Eberg is a lecturer of Politics and Social Sciences at the Institute of Safety and Security Management, *Hogeschool* of Utrecht, The Netherlands. jan.eberg@casema.nl

Dr. Paul Ekins is professor of Sustainable Development at the University of Westminster and head of the environmental group at the Policy Studies Institute, London, UK. p.ekins@psi.org.uk

Dr. Anita Engels is professor of Sociology at the Centrum für Globalisierung und Governance Fakultät für Wirtschafts- und Sozialwissenschaften Universität Hamburg, Germany. sofv001@sozialwiss.uni-hamburg.de

Dr. Reinout Heijungs is an assistant professor at the Institute of Environmental Sciences at Leiden University (CML), The Netherlands. heijungs@cml.leidenuniv.nl

Dr. Ignas M. A. Heitkönig is lecturer at the Resource Ecology Group of Wageningen University, The Netherlands. ignas.heitkonig@wur.nl

Dr. Jean-Paul Hettelingh directs the Coordination Centre for Effects at the Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands. jean-paul.hettelingh@pbl.nl

Dr. Matthijs Hisschemöller is assistant professor Environmental Policy Analysis at the Institute for Environmental Studies (IVM) at the VU University Amsterdam, The Netherlands. Matthijs.hisschemöller@ivm.vu.nl

Dr. Leen Hordijk is director of the International Institute for Applied Systems Analysis (IIASA) at Laxenburg, Austria. hordijk@iiasa.ac.at

Dr. Roefie Hueting is an economist and retired as head of the Department of Environmental Statistics at the Central Bureau of Statistics (CBS), The Hague, The Netherlands. rhig@hetnet.nl

Dr. Gjalt Huppes is head of the Department of Industrial Ecology, Institute of Environmental Sciences at Leiden University (CML), The Netherlands. huppes@cml.leidenuniv.nl

Dr. A. M. Mannion is a senior lecturer in Geography at the University of Reading, UK. a.m.mannion@reading.ac.uk

Dr.ir. Karel Mulder is senior lecturer in Technology Dynamics & Sustainable Development at the Faculty of Technology, Policy & Management of Delft University of Technology, The Netherlands. k.f.mulder@tudelft.nl

Dr. P. H. (Piet) Nienhuis is professor emeritus of Environmental Science at the Department of Environmental Science, Institute for Wetland and Water Research, Radboud University Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands. p.nienhuis@science.ru.nl

Dr. David Pimentel is professor emeritus of Ecology and Agriculture at Cornell University, Ithaca, USA. dp18@cornell.edu

Clive Ponting served as a reader in the Department of Politics and International Relations at the University of Wales, Swansea, until his retirement in 2004. He now lives in Greece.

Dr. Herbert H. T. Prins is professor and chair of Resource Ecology at Wageningen University, The Netherlands. herbert.prins@wur.nl

Dr. Lucas Reijnders is professor of Environmental Science(s) at the University of Ámsterdam and the Open University of the Netherlands, The Netherlands. l.reijnders@uva.nl

Dr. Udo E. Simonis is professor emeritus of Environmental Policy at the Wissenschaftscentrum für Sozialforschung, Berlin, Germany. simonis@wzb.eu

Dr. Linda Steg is a senior lecturer in Environmental Psychology at the Faculty of Behavioural and Social Sciences, University of Groningen, The Netherlands. E.M.Steg@rug.nl

Dr. Helias A. Udo de Haes is professor emeritus of Environmental Sciences at the Institute of Environmental Sciences at Leiden University (CML), The Netherlands. udodehaes@cml.leidenuniv.nl

Dr. Petra J. E. M. van Dam is a senior investigator and lecturer in Environmental History at the Amsterdam Institute for Heritage and Society at the VU University Amsterdam, The Netherlands. pjem.van.dam@let.vu.nl

Dr. Richard van der Wurff is associate professor at the Department of Communication and the Amsterdam School of Communications Research *ASCoR*, University of Amsterdam, The Netherlands. R.J.W.vanderWurff@uva.nl

Ir. Klaas van Egmond is professor of Earth and Sustainability at the faculty of Geoscience Utrecht University and was director of the Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands. nd.van.egmond@wxs.nl

Dr. S. W. (Wybren) Verstegen is lecturer in Economic, Social and Environmental History at the VU University Amsterdam, The Netherlands. sw.verstegen@let.vu.nl

Dr. Charles Vlek is professor emeritus of Environmental Psychology and Behavioural Decision Research at the University of Groningen, The Netherlands. c.a.j.vlek@rug.nl

Dr. Konrad von Moltke (†) was director of the Institute for European Environmental Policy in Bonn, Germany and Senior Fellow at the International Institute for Sustainable Development in Canada. He passed away in 2005.

Anna J. Wieczorek, M.Sc. is an executive officer of the Industrial Transformation project of the International Human Dimensions Programme on Global Environmental Change hosted by the Institute for Environmental Studies (IVM), VU University Amsterdam, The Netherlands. anna.wieczorek@ivm.vu.nl

Dr. Bastiaan Zoeteman is professor of Sustainable Policies in International Perspective at the Faculty for Economics and Business Administration at Tilburg University and active at Telos, Brabants Centre for Sustainability Issues, Tilburg, The Netherlands. zoeteman@uvt.nl

Part I
Stating the Problem

Chapter 1
Environmental Sciences, Sustainability, and Quality

Jan J. Boersema

Contents

1.1 Introduction

This chapter examines the contribution of environmental sciences and scientists to the finding to solutions to environmental problems. It defines and describes important concepts, highlights methods used to analyse human impacts on the environment, and it discusses the ways in which sustainability can be measured. The chapter is subdivided into three sections:

J.J. Boersema (✉)
Environmental Sciences and Worldviews at the Institute for Environmental Studies (IVM) VU University Amsterdam, The Netherlands.
e-mail: jan.boersema@ivm.vu.nl

1.2 Concepts, definitions, and delineation
1.3 Environmental problems and solutions in context and
1.4 Measuring human impact on the environment

1.2 Concepts, Definitions, and Delineation

1.2.1 Environment

The term *environment* in environmental sciences is derived from the science of ecology. The term ecology or *oekologie* was coined by the German biologist Ernst Haeckel in 1866, when he defined it as 'the comprehensive science of the relationship of the organism to the environment'. In the environmental sciences these organisms are humans. This explains why the term *human ecology* is used sometimes as a synonym for environmental sciences. By using the latter term we want to avoid that humans are only seen as biological beings and to emphasise that we consider them primarily as social beings and as members of a society. A further restriction is placed on the use of *environment*: the social environment is excluded as an object for study. The focus is on the physical (living and not living) environment: air, water, land, and all the biota that grows and live therein. Environmental scientists are not concerned with angry neighbours, although they may well be interested in noisy traffic, the fate of cod and smokestacks (at least nowadays).

Therefore, the environment is to be defined as: *the physical, non-living and living, surrounding of a society with which it has a reciprocal relationship*.

In this definition, the living world is included and the relationship with society explicitly mentioned, contrary to the more narrow definitions of 'environment'. An example of such a narrow definition is for instance, the definition of environment used in the UK Environmental Protection Act 1990: 'consists of all, or any, of the following media, namely, the air, water and land' (Porteous 2000: 217). In the narrow sense, the term environment can also be equivalent to the term 'nature', which is defined as comprising all biota. Combinations were later made, like *the natural environment*, as opposed to the social environment. Use of the term 'environment' in the broad sense, as is done in this textbook, reflects the growing understanding of the interrelationship between both the non-living and the living world.

1.2.2 Environmental Quality

To properly assess and value the actual state of the environment, we need to have an idea of what that state could or should be; it requires the setting of a norm or adopting a reference. The difference between actual state and reference points to the concept of quality, being somehow a valuation of the gap between 'is' and 'ought'. Following the German philosopher Schopenhauer (1848) we consider quality to be a *relational* as well as *relative* concept. The quality of a specific entity always depends on the needs of a 'user'. Surface water with very low oxygen content may be of poor quality for a pike while it is up to the mark for an anaerobic. Besides being relational, quality is also relative, since it has no absolute size. Something can only have (more or less) quality with respect to a chosen or given reference. For instance, the counterpart of quality in a different field would not be 'income' but rather 'prosperity'. One's annual income can, as a rule, be measured objectively and amounts to a certain number of euros or dollars per year. Whether this can be seen as prosperous is dependent on the outcome of the comparison with a subjectively chosen reference, like the average of a given country or your neighbour's income, or what you think you deserve.

A definition which would do justice to what has been postulated above, may be the following: *quality is the level at which a quantity satisfies the function which it is expected to satisfy*. Applied to the environment and to users of the environment this has led to the listing of a whole catalogue of environmental functions, or parts thereof (Groot 1992). Once the function is known, it is easier to set a standard. A standard is defined as the state of (parts of) the environment in which or by which the function is e.g. fully or sufficiently satisfied. The more accurate the user and the function are defined and the more we understand about causal relations and other relevant mechanisms, the more precise the standards that can be set.

Quality can then be assessed by comparing the actual (or expected) state of the environment with the standard. It is noted that the actual state of (parts of) the environment can change due to either human interventions or to 'natural' fluctuations, and the emphasis here is on the human induced or enhanced changes. If people in a given society view the differences or the expected changes as negative effects, then we are referring to environmental problems. As we will see in Section 1.3 science plays an important role in this process of awareness and valuation. Environmental problems vary largely in scale and gravity (Chapter 6). On a higher level, as environmental problems can be considered a deterioration of the relationship between a society and the environment, the relationship is deemed to be unsustainable (this will be elaborated in Section 1.3.3).

1.2.3 Environmental Sciences

Environmental science(s) can now be defined as *the study of man-made environmental problems*. In the title of this book we use the plural *sciences* to acknowledge the fact that many sciences take part in these studies, ranging from natural sciences and the social sciences to the humanities. All have their distinctive language, methods and approaches (set out in the first chapters of Part II of this book). This is not to deny or undervalue the need to employ multidisciplinary and interdisciplinary approaches to analyse and solve the often intricate and complex environmental problems: it is to emphasise the interdependences and complementarities of the scientific efforts in this field. Interdisciplinary builds on disciplinary.

It is important to recognise the limits of science and scientists while trying to solve problems that are ultimately societal problems. When it comes to analysing causes, science may be argued to have a virtual monopoly but efforts required to solve environmental problems may involve factors beyond science; like funding, political will, or the cooperation of stakeholders. Most complex problems require a thorough scientific analysis to understand their root causes and underlying mechanisms but this knowledge does not always translate easily into action.

1.3 Environmental Problems and Solutions in Context

1.3.1 Whose Problems?

Environmental problems, the main subject of the environmental sciences, are currently important for society. Surveys have shown that they have now been on the public and political agenda for nearly 40 years (Dunlap 1991, 2002). At the same time, surveys do not always provide a clear idea of what people understand by environmental 'problems' or how important environmental problems are considered to be. People are generally asked what they consider to be major social issues, or they are asked to assign priorities to a number of issues specified in no further detail ('criminality', 'unemployment', 'the' environment, etc.). In either case, the result is a hierarchical listing of the issues as perceived by society at that particular instance in time. When asked to characterise environmental problems in greater detail, it makes a world of difference whether people are questioned about matters confronting them in their own everyday environment or about environmental problems in general. Such a discrepancy is to be expected, because not every general environmental problem is experienced as a problem in one's own living environment. Being aware of problems is not the same as experiencing them.

1.3.2 Science and Society

There may also be differences between the general problems cited by the public and the issues discussed in academic textbooks, journals, and reference works, or in government documents. This can be explained in a variety of ways. A given environmental problem may be quite familiar to a broad section of the public, but still only rarely cited spontaneously in surveys (e.g. the CFC refrigeration fluids causing the well known 'hole' in the ozone layer). It may also be the case that although a problem is deemed of vital importance, as well as topical interest, by policy-makers and public alike, it has little appeal as a scientific problem, i.e. worthy of research (like dog excrement in the public domain). Yet other problems may not have fully permeated the public consciousness, even though scientists and policy-makers may already have been wrestling with them for some time, an example being the worldwide loss of biological diversity (now usually termed biodiversity). However, due caution should be exercised here, as there may simply be a lack of public familiarity with the specific terminology employed; i.e. the public are familiar with the loss of certain species, like the Panda, but are less aware of the more general problem of biodiversity decline. Finally, there are also problems that are recognized by some sections of the scientific community but are yet to be acknowledged by other scientists, policy-makers and the general public (like the release of methane out of methane clathrates resulting from the warming of the permafrost or oceans). Whether such recognition indeed follows depends partly on the robustness of the data brought forward as evidence, and partly on how the problem is picked up by policy-makers and society at large. A relatively recent example of an issue becoming a recognized problem is 'hormonal pollution' by endocrine disrupters (substances acting like hormones and adversely affecting animals and humans) described by Colborn et al. (1996). If such recognition is not forthcoming, then by definition the issue at hand does not constitute an environmental problem in the sense of something requiring public attention, for public recognition, and acceptance of the problematical nature of the issue is a *sine qua non* in this respect. Of course, facts exist whether or not they are acknowledged – social constructivists seem to miss this point – but in order to turn facts into an environmental problem there needs to be some recognition on the societal level. The question, though, is this: when does a change in the environment materialise into an environmental problem? With many environmental problems, in retrospect we frequently see a shifting of public concern with time.

The social scientist Anthony Downs (1972) introduced the compelling idea of an 'issue attention cycle', later reflected in the 'policy cycle' approach of the former Dutch minister of the environment Pieter Winsemius. They identified a general pattern whereby every environmental problem goes through successive policy phases, each associated with a different degree of attention on the part of the various actors involved. The approach taken by Downs and Winsemius is a good reflection of how environmental problems always have both a factual and a perceptual side. These two aspects stand in complex relation to one another. Problems may well 'drop out of the picture', as it were, while still remaining just as topical as real-world phenomena. Facts can also be interpreted differently. Certain issues may draw massive public attention even though 'objectively speaking' there is little reason for such a sharp rise in interest. The 'oil crisis' of 1973 is a case in point. At the time there was little if any physical scarcity, and the economic scarcity (resulting from the price rise) was modest, when compared with later rises at the end of the 1970s and in the early 1980s. However the modest scale of the problem was not reflected in the massive attention it received from the politicians and the public.

Considered over a longer time span, too, there may be major changes in both public and political awareness of the issues at hand. In just a few decades the smokestack underwent a metamorphosis from a symbol of progress and reconstruction to one of environmental pollution; an emission source to be controlled. The writer and former president of the Czech Republic Václav Havel (1989) goes further, and holds the smokestack that 'fouls the heavens' to be 'a symbol of a civilization that renounces the absolute, denies the natural world and despises her imperatives'.

We also see national and cultural differences in how environmental problems are perceived and described. Such differences may be due to material circumstances, but cultural perception is also generally involved. The sentiment voiced by Havel is not as likely to be heard in contemporary China, say, and even less likely to be voiced in the same way by China's political leaders. This cannot be explained from the physical conditions, for in some regions of contemporary China the number of smokestacks is considerably greater than in the Czech Republic and the heavens at least as heavily fouled.

What can be said of environmental problems holds also true of solutions: the context is important. The case studies described in the Chapters 20–22 reveal differences between countries with respect to the way they solve their waste problems, make use of their natural resources or try to reach agreement on measures to be taken to curb emissions of greenhouse gases. In these cases there were no major differences in problem perception; nevertheless, the chosen solutions and the approach were different and these differences were – to a considerable extent – culturally determined.

There is every reason, then, to include the cultural-historical background of environmental problems and their perception within the domain of environmental research. In the next paragraph, we will do so in order to explain the emergence of the concepts of sustainability and sustainable development.

1.3.3 Solutions in Context

Human beings live in an intensive relationship with their natural surroundings. This relationship, described so aptly as 'metabolism' by Marx, forms the basis of every human society. From time immemorial, humans have made use of the natural environment to satisfy their basic needs for food, clothing, shelter, warmth, security and transport. In this respect, human beings are in principle no different from other creatures. In addition, though, humanity makes claims to the natural environment to satisfy what Maslow terms 'social needs' and 'the need for self-actualisation' (Maslow 1954).

This process of metabolism has had a severe impact; human beings have in fact radically altered the face of the earth (Marsh 1864; Thomas 1956; Simmons 1990). Even in their early stages of development, human societies were confronted with the consequences of their actions, in the form of soil salinisation and exhaustion, erosion and desertification. The extinction of plant and animal species also has a long history, going back to the Pleistocene (>10,000 BCE) according to some scholars. At a later date, but still centuries old, is local pollution of the soil, water and air with toxic substances. Clive Ponting in Chapter 5 provides a concise overview of this environmental history.

The fact that we can nevertheless speak of environmental degradation as a modern problem, despite its ultimately long history, is partly due to the global scale that humanity's environmental impacts have assumed in our era and also to our vastly expanded knowledge of the nature of that impact. But that is not all. Just as important, if not more so, is that it is now also increasingly seen as a structural problem of societies. This somewhat remarkable reversal of attitude cannot be explained by the fact that people were previously blind to the negative impacts of human action: for the most evident forms of environmental pollution, protest is almost as old as the pollution itself (Brimblecombe and Pfister 1990; Simmons 1993). The change in thinking is due mainly to the fact that today, far more so than in former times, we have become aware of the inter-relatedness, scale and scope of environmental problems, no longer categorising them as being nasty but unavoidable side-effects of our social evolution.

This process has occurred gradually over the past few decades. In the early stages, publications like *Silent Spring* by Rachel Carson (1962) and *The Limits to Growth*, the first report to the Club of Rome (Meadows et al. 1972), played a major role. Carson's work described graphically how persistent toxic chemicals were being transported through food webs around the globe, wreaking havoc with animal populations often far distant from pollution sources. *The Limits to Growth* focused minds on the inescapably finite nature of non-renewable resources and the well-nigh-impossible marriage of exponential growth (of resource use and population, for example) and sustainability in a finite world. With the United Nations' conference on the human environment in Stockholm in 1972, for the first time the environment issue was placed squarely on the international political agenda.

The growing concern worldwide in the 1970s about the global character of the emerging environmental problems did not result in any coherent strategy or 'solution' at the global level, however. Although an important initial step had been taken, the issue was by no means universally recognised and neither was there any common analysis of the problems involved. For example, in the centrally planned economies of Central and Eastern Europe authorities focused on the toxicity of substances in the workplace, while virtually ignoring the pollution outside the factory gates or the issue of natural resource depletion (Komarov 1980). In the industrialised western nations, technological cleanup was seen as the ultimate solution. At the same time, the core message of *The Limits to Growth* also met with resistance from certain quarters. For most developing nations, as well as for dominant liberal and socialist political currents in the developed world, the Club of Rome's report exuded an 'anti-growth' ideology. There was major apprehension that this would hold back growth of gross domestic product (GDP), which was deemed absolutely vital.

At the regional level in most developed countries, though, this period saw a growing focus on tackling concrete environmental problems, using an increasingly sophisticated institutional and legislative toolkit. By the end of the 1970s, most developed countries had national environmental legislation in place to control soil, water and air pollution. 'Environmental affairs' were situated within the apparatus of government, with new ministries and policy departments being established worldwide. Standards were set for many toxic substances, and filters and other technologies were installed to reduce both indoor and outdoor pollution. Economic instruments were also introduced, based on the *polluter pays principle*. Some of these measures proved very effective. By introducing levies on emissions into the atmosphere and surface waters, a shift was effectuated from end-of-the-pipe measures to process-integrated strategies. Frequently, the latter approach benefits not only the environment but also business results. Coal-burning by households was largely phased out. The results gradually became apparent within the natural environment: in rivers like the Thames and the Rhine fish stocks began recovering and in many major Western cities the 'London smog' became a thing of the past.

In some areas, though, progress was not quite as straightforward. It became increasingly apparent that e.g. over-fishing, and landscape fragmentation were leading to an overall decline in the quality of the world's ecosystems. These problems, it was realised, are related very intimately to the functioning of many of the essential sectors of today's economy: industry, transport, agriculture, fisheries and households. To control the environmental impacts of these sectors requires an integrated strategy designed for each specific sector, employing such instruments as the Environmental Impact Statement, the Environmental Audit and Life Cycle Assessment (see Chapters 11–13 and 17A). The compartmentalised strategy of the 1970s was no longer effective, and the first long-term cross-sectoral and cross-media environmental masterplans were drawn up. At the end of the 1980s, the result is paradoxical. With the environment now a fully-fledged 'issue', understood in far greater detail and depth, a realisation begins to dawn of the fundamentally unsustainable nature of much of modern humanity's interaction with the natural environment. Climate change, land degradation through erosion, declining fish catches through over-harvesting and biological extinction on a massive scale through habitat destruction are the most convincing and best-documented examples of man's unsustainable use of the natural environment. Many countries adopt the objective of reversing these broader trends and *sustainability* becomes not only a policy goal but is also seen as an important precondition for the long term viability of socio-economic and socio-cultural development (IUCN 1980; Clark and Munn 1986).

It is in this climate that the UN Commission on Environment and Development, chaired by Mrs. Gro Harlem Brundtland, embarked on its mission. The commission acknowledged and further substantiated the gravity of the world's environmental problems. Humanity's treatment of its natural environment was described as threatening not only the environment itself but also the legitimate economic and social needs of the present and, above all, future generations. The fact that many countries still faced poverty and hardship and viewed strong, sustained economic growth as their only way forward, formed an important motive for the commission to identify development as an essential objective. Moreover, to a certain extent poverty and environmental degradation prove to be positively correlated.

This explains why, in its final report, the commission recommended that the goal of sustainable development be adopted worldwide. In many countries, the ideas embodied in the Brundtland Report (WCED 1987) were subsequently adopted as a basis for government policy. For the first time, the relationship between the environment and the economy and the implications for future generations featured prominently on the international agenda.

Acceptance of sustainable development as an overall guiding framework (a solution in context) led to an explosion of studies and publications in which the concept was critically analysed and fleshed out in increasing detail. Once the aforementioned tension between sustainability and development is taken seriously, the key question becomes how prosperity can be increased while at the same time reducing environmental pressure (see Chapters 23–26).

1.3.4 Two Positions for Environmental Scientists

The considerations discussed in the foregoing section lead to two basic positions. Both relate to academic environmental research and environmental scientists.

First, environmental scientists should not align themselves too much with short-term perceptions of problems in society, nor with the problem definitions currently in sway in policy circles. The environmental scientist should seek to lay bare the underlying, more fundamental problems and unravel the relationships between them. This quest may (temporarily) lead the researcher away from the current, often whimsical, public debate, but it is essential: not only because it is the only avenue by which to arrive at more readily practicable answers to familiar problems, but above all because it holds out greater prospects for identifying as yet unknown problems and solutions. Science has a role in the disinterested definition and analysis of problems. Scientists can endeavour to present a clear picture of the situation, what positions have been and might be adopted, and where – scientifically speaking – the important and researchable problems lie. This may obviously include pronouncements on the nature, scale and relative gravity of the problems concerned.

Secondly, environmental scientists should perhaps be less pretentious about their ability to resolve social issues. Two arguments can be given for greater modesty in this respect. One, in many fields there is too little scientific knowledge available to expect 100% reliable recommendations for solutions from this quarter. Indeed, in some fields (human behaviour; complex ecosystems; the effects of climate change) this will probably remain the case in the foreseeable future. Scientists should not lay claim to unassailable knowledge. Two, although scientists may well succeed in carefully dissecting the problem at hand, as well as all the associated dilemmas, they are rarely able to resolve those dilemmas on purely scientific grounds. Conscientious scientists return the ball of these dilemmas into the court of society, or to the party commissioning the research. Less scrupulous scientists – when challenged or otherwise – may champion their own personal choices as scientific solutions. Although the first approach may leave the researcher dissatisfied, the latter also has its drawbacks. It involves a twofold risk: the solutions pursued may prove erroneous, for the scientist's expertise is not generally in the realm where the ultimate decision is to be taken; and democratic transparency may be lost, with those responsible for decisions hiding behind science or scientists. Scientists should clearly indicate when they are speaking as professionals and when they are participating in a debate as engaged citizens.

This position thus advocates a more social debate on how to resolve environmental problems and a more transparent role for science and scientists and scientific books and journals in that debate. This line of reasoning underpins the approach chosen in this textbook.

1.4 Measuring Human Impact on the Environment

1.4.1 *Measuring and Indicators*

Measuring is at the heart of science and the environmental sciences are no exception to that rule. Over the last decades a wide range of metrics and indicators has been developed (Adriaanse 1993; OECD 1998). Indicators can be used at national and international levels in state-of-the-environment reporting, measurement of environmental performance and in reporting on progress towards sustainable development. Once a set of environmental indicators has been established and measured there will be a tendency to integrate these measurements into one overarching indicator (see Chapter 16). To do this quantitatively requires a common denominator like hectares (the ecological footprint) or kilograms (the MIPS). Qualitative comparison requires an overall reference system (AMOEBA). In Section 1.4.3 three of these integrative indicators will be discussed. Since the Brundtland Report we have also seen many attempts to develop indicators for sustainable development (SD) (Kuik and Verbruggen 1991; Bell and Morse 2003), and there is a growing consensus on what can be considered a suitable indicator. The concept of SD links economic, environmental, and some social aspects and an important question is how far these essential dimensions can be integrated. It seems logical to develop indicators for each dimension, with further integration being envisaged in a subsequent phase (see Chapter 28). In the last section we will discuss some of the methods used to track progress towards a better environmental quality and to SD, but we will start with an analytical framework for analysing the human impact.

1.4.2 *The IPAT-Equation*

In the early 1970s, Paul Ehrlich and John Holdren were fighting a full-scale academic war with Barry Commoner over the question of what contributes most to environmental problems. Ehrlich and Holdren pointed to (over) population as being the worst for the planet, while Commoner argued that technology is the dominant reason for environmental degradation in modern societies (Ehrlich and Holdren 1971, 1972; Commoner 1971, 1972).

Ehrlich was not the first to blame population size and growth. The idea that population growth affects natural resources and human welfare is perhaps as old as written history itself. The Greek historian Herodotus (484–ca. 425 BCE) already noted how the population of the Lydians had outpaced (food) production, which led to a prolonged famine (*The Histories* Book I) and the Latin author Seneca the Younger (ca. 4 BCE–AD 65), living in Rome, noted a connection between population and pollution in his *Naturales Quaestiones*. Of a more recent date is Malthus' famous *Essay on the Principle of Population* (1798) in which he posed the question: 'what effect does population growth have on the availability of resources needed for human welfare'. Malthus' answer was that 'geometric' growth (exponential growth as we call it now) would eventually outstrip 'arithmetic' (linear) growth in the means of subsistence. He concluded that population growth has to be controlled. If not, the inevitable outcome will be misery and poverty. This Malthusian message was echoed clearly in Paul Ehrlich's bestseller *The Population Bomb* published in 1968 and repeated in many publications that follow thereafter (1971, 1972, 1990). The first formula presented by Ehrlich and his collaborators was intended to refute the notion that population was a minor contributor to the environmental crisis. It reads:

$$I = P \times F$$

I is the total Impact, P the population size and F the impact per capita.

Commoner had fewer predecessors to follow. In his popular book *The Closing Circle* (1971) he was concerned with measuring the amount of pollution resulting from economic growth in the United States. However, just measuring economic growth was not enough. 'The fact that the economy has grown – that GNP has increased – tells us very little about the possible environmental consequences. For that we need to know *how* the economy has grown' (Commoner 1971: 129). The economy had followed a 'counter-ecological pattern of growth' in which productive technologies with intense impacts on the environment have displaced less destructive ones' (Commoner 1971: 175). For that reason he felt that we have to include a specific factor to measure the impact per unit of economic production. 'Impact' he defines as pollution. The equation he published in 1972 reflected this view:

I = Population × (Economic Good/Population) × (Pollutant/Economic Good)

Population was used to express the size of the (US) population in a given year or the change in population over a defined period. Economic good (referred to as Affluence) was used to express the amount of a particular good produced or consumed during a given year or the change over a defined period. Pollutant refers to the amount of a specific pollutant released per economic good and reflecting the nature of the productive technology.

After cancelling out the identical factors what remains is: I = Pollutant. By defining the factors more rigorously Commoner became the first to apply the IPAT concept in a quantitative way.

Both combatants try to prove themselves as correct by adapting and applying 'their' equation to specific processes and/or products. Over the years of their dialogue the equation grew into the following form:

$$I = P \times A \times T$$

With P being the population or population growth, A being a measure of individual or collective welfare (GDP, goods or services per capita) and T the environmental impact per unit of A, reflecting the technological performance.

The use of the IPAT equation has been met with criticism. The criticism concerned especially the supposed independence of the three factors and the truncation of Technology. Is it possible to consider the technology as being fully independent or is there a mutual dependence? Most likely there is a reciprocal relationship and it is quite possible that Boserup (1981) is partially right in stating that it is precisely the population growth which is the driving force for new technological development and innovations, thereby increasing the affluence. Maybe Julian Simon, who believes that increasing population and wealth together evokes new technologies, deserves some credit (Simon 1980, 1981). And finally we have the so called Kuznets curve, a nuanced relationship between A and I, such that an environmental emission might rise as income increases until a particular level is reached, at which point emission levels begin to fall (Arrow et al. 1995).

The value of the equation in providing conclusive answers to the question raised by Ehrlich and Commoner may be overstated. In this book, we will not elaborate on this but instead refer the reader to the literature: for instance, to the thoughtful reviews made about the history and various interpretations of the IPAT equation by Dietz and Rosa (1994) and by Chertow (2000).

Now we would like to illustrate the use of the equation as an analytic framework with an example taken from Amory Lovins. It concerns the environmental impact of a coffee mug in connection with its use of energy (see Fig. 1.1).

Itemising the separate factors A and T clarifies where each environmental pressure is created and what the possibilities of reducing it are at that detailed level, what the estimated size of it is and what time scales we have to keep in mind in that connection. The figure shows in 'Window-like scrolls', as it were, what is hidden behind the aggregated factors P, A and T. This creates a useful framework for research strategies and policy measures. According to Chertow this kind of application has proven to be the most valuable. He writes 'the use of the IPAT equation in research related to climate change, specifically energy-related carbon emission studies, may be the most enduring legacy of IPAT' (Chertow 2000: 19; see also Chapter 6.1 for a similar use of IPAT).

Whereas Commoner introduced the factor T because he considered technology to be the largest contributor to pollution, since a few years we notice that this is reversed, which leads to a remarkable optimism whereby technological improvements are regarded as an essential part of the *solution* (Heaton et al. 1991). This technological optimism is also apparent in approaches that use the IPAT concept for future oriented programs, setting goals for research and policy alike. Based on the same IPAT concept the emphasis now has been placed on the need to substantially reduce

Energy-related environmental impact =

$$\text{population} \times \text{affluence} \times \text{impact} =$$

$$\text{population} \times \left[\frac{\text{stock}}{\text{person}} \times \frac{\text{throughput}}{\text{stock}}\right] \times \left[\frac{\text{energy}}{\text{throughput}} \times \frac{\text{impact}}{\text{energy}}\right]$$

Example

$$\text{population} \times \frac{\text{cups}}{\text{person}} \times \frac{\text{plastic/y, ceramics/y,...}}{\text{cup maintained}} \times \frac{\text{GJ, kW-h,...}}{\text{kg material/y}} \times \frac{CO_2,\ NO_x,\ \text{land-use,...}}{\text{GJ, kW-h,...}}$$

Applicable tools				
family planning female literacy social welfare role of women land tenure	values prices full costing what do we want? how much is enough?	product longevity materials choice minimum-materials design near-net-shape mfg. recycle, reuse, remfg. scrap recovery	end-use efficiency conversion efficiency distribution efficiency system integration process redesign	benign sources scale siting technical mitigation offsets
Approximate scope for long-term change				
~ 2x	?	~ 3-10x	~ 5-10x	~ 10^2-10^3x
Timescale of major change				
~ 50-100 y	~ 0-50 y	~ 0-20 y	~ 0-30 y	~ 0-50 y

Fig. 1.1 IPAT applied to the energy related impact of a coffee mug
Source: After Amory Lovins personal communication 1996

global material flows or on completely re-usable materials (McDonough and Braungart 2002). The Factor 10 club for instance has advocated that the current productivity of resources must be increased by an average of a factor ten during the next decades (Schmidt-Bleek 1998). Von Weizsäcker et al. (1997) state in their book Factor Four that the amount of wealth extracted from a unit of natural resources can quadruple by doubling the A while halving the T factor. They define technological progress overall as ecoefficiency, a gain in productivity of resources. For an overview of this 'Factor X debate' see Reijnders (1998).

1.4.3 Ecological Footprint and MIPS

In order to determine the total human impact on the environment the separate impacts have to be joined together. To this end, in principle two courses are available. The first course is a quantitative one. It involves reducing the impacts to a common denominator which then may be added up. The best known and most developed methods are the ecological footprint and the Material Intensity per Service unit (MIPS).

The *ecological footprint* became known in particular by the work of Wackernagel and Rees (1996) and since then has continuously been developed further. It is defined by the authors as follows: 'Ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area' (Wackernagel and Rees 1996: 20) Recently, internationally there has been an attempt at attaining a generally accepted methodology (www.footprintnetwork.org). For the purpose of calculating the footprint, the human consumptive activities are being converted to the use of land which is required for making those activities possible. Our food requires agricultural and pastureland, our houses require land for building etc. For energy consumption another conversion takes place. At the end, a footprint per person, per city or country may be determined (see Box 1.1).

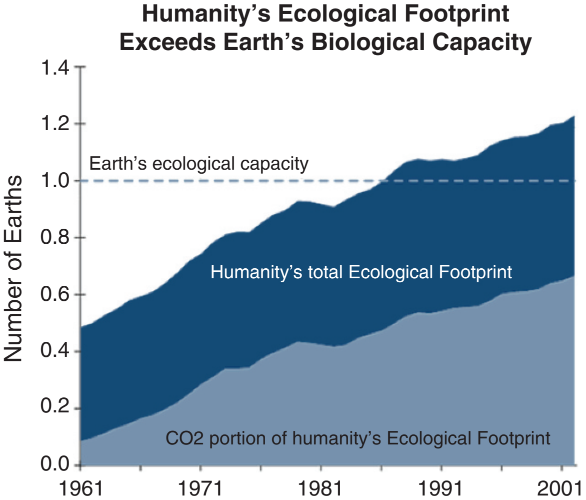
Box 1.1 The ecological footprint: tracking human demand on nature

Ecological Footprint comparisons of human demand on nature with nature's regenerative capacity are updated each year. Recent calculations, available on the website of the European Environment Agency, show that the average Canadian required, in 2002, over 7.5 global hectares (or 18.5 *acres*) to provide for his or her consumption. The average Italian lived on a footprint almost half that size (4.0 global hectares or 10 *acres*). The average Mexican occupied 2.4 global hectares (6 *acres*), the average Indian lived on 0.7 global hectares (1.7 *acres*). Average demand globally was 2.2 ha per person (5.4 *acres*).

In contrast, globally there were 1.8 ha (4.5 *acres*) of biologically productive land and sea area available per person in 2002. Maintenance of biodiversity also depends on this area.

Comparison of supply and demand shows that humanity's Ecological Footprint exceeded the Earth's biocapacity by over 20% (2.2/1.8 ha = 1.2). In other words, it took 1 year and more than 2 months to regenerate the resources humanity consumed in 2002.

The Ecological Footprint can be applied at scales from single products to households, organizations, cities, regions, nations, and humanity as a whole.



Such calculations show large differences between countries which eat up space and countries which are within or even below the 'norm'. In this way, it has been calculated for the earth as a whole that actually the hectares which are needed are 1.2 times the earth if all our consumptive needs are to be met. From the global perspective we are living beyond our means.

The ecological footprint has turned out to be a powerful means of communication with which to express that most likely with our production and consumption we are exceeding the earth's supporting power. Some researchers (Bergh and Verbruggen 1999) have expressed criticism at the reliability and especially the use of lower-scale levels. The method discriminates, for instance, too little with regard to differences in quality of the land use, whereas the impact of man on the biodiversity cannot be included properly in the calculations either.

The metaphor of *ecological backpack* was introduced by Schmidt-Bleek (1994) in order to illustrate the concept of material intensity of a product or a service per unit (*MIPS*). This MIPS is the amount of material which is required for the production and use of certain goods and products. The calculation is carried out on the whole life cycle of a good, including all the emissions and flows of waste. Goods are supposed to provide services. A car, for instance, provides 'transportation kilometers'. In order to make a comparison with other modalities of transportation the backpack may be calculated per 'unit of service' i.e. transportation kilometer. That way the effect of recycling and a lengthening of the life span becomes visible as well. For the production of a golden ring, for instance, which may weigh some 20 g, several tons of minerals have been transmuted. Lignite, too, has a backpack which is ten times as heavy as the weight of lignite itself.

Although the ecological backpack may be considered to be an appealing metaphor, the conversion into kilograms has not become a widespread method with which to determine integrally the pressure on the environment.

In addition, there are integration methods which do require quantification, but where the indicators are not reduced to a common denominator and added. The so-called *AMOEBA* approach is in this category. It is a visualisation in which the actual situation of a certain system such as for instance the North Sea, is compared with a reference after having been measured in a number of indicators (for an example see Chapter 10, Fig. 10.3). It is a *distance to target* (*DTT*) method that can

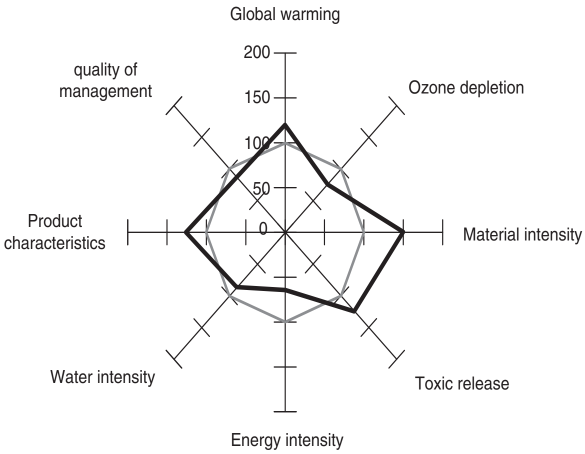


Fig. 1.2 AMOEBA applied to a firm

be applied to many systems. The reference values are put to 100% and the observed values are represented as a percentage of the reference. The general idea is made visible in Fig. 1.2.

The advantage of this approach is that at a single glance the differences in the diverging surface become clear. The method has taken its name from the often fanciful patterns which may form, for the organism amoebe may take many shapes as well. Another advantage is the wide applicability. The system and the indicators may be chosen freely and may be absorbed in any dimension in the same figure. If the crucial parameters of a certain system are known, they may be represented as indicators in relation to the reference. This reference may be the desired ideal as well. In addition, some points of criticism may be mentioned. First of all, the method is very sensitive to the choice of reference and this may not always be made objectively. The method gives little insight into the meaning of the visualized differences. The indicators included in the model may be very heterogeneous and therefore measured in totally different metrics. It is a first approach after which further analysis needs to be done.

1.4.4 Measuring Sustainable Development

As explained above, the concept of SD links economic and environmental aspects. However most indicators discussed so far point to the environment and are therefore sometimes referred to as indicators of 'environmental sustainability' (see Chapter 28). If the quality of the environment is to be integrated into the economic indicators we have to look at the most dominant indicator for economic growth: Gross Domestic Product (GDP). This gave rise to the so called 'greening of GDP'. By incorporating external effects into the determinants of growth this figure is corrected in order to better reflect the 'real' growth (Darmstadter 2000). However, it is unclear to what extent this aim can be duly achieved and how far this process will bring us towards sustainability. New alleys were explored and within the economic domain one of the most promising as well as far reaching proposals of greening growth is the Index of Sustainable Welfare (Daly 1996).

Inspired by John Elkingtons book *Cannibals with Forks* (1998) – written for the business community – it became fashionable to define sustainability as having three dimensions of equal importance. He included the social dimension as a separate third pillar or corner in a triangle. 'Sustainability is the principle of ensuring that our actions do not limit the range of economic, social and environmental options open to future generations' (Elkington 1998: 20). Following this definition sustainability might turn into a mixture of three types of sustainabilities, a trade-of in a triangle. Viewing sustainability as an important precondition for the long term viability of socio-economic and socio-cultural development (as is done in this chapter) emphasise the environmental sustainability to be a prerequisite. Which social indicators should be integrated and how this could be done is by and large unknown.

Zoeteman, in Chapter 28, is navigating such uncharted waters when he calculates the sustainability of nations by combining indicators taken from three domains. For the social domain he uses indicators from the human development index (UNDP 2001).

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Chapter 2
Biogeochemical Cycles

Lucas Reijnders

Contents

It is now often assumed that life first appeared on planet Earth about 3,500 million years ago. Since then 'our' Sun has changed considerably. While the flux of solar energy to the Earth has increased by about 30% over this period, though, this has not led to a corresponding increase in the Earth's temperature or the amount of ultraviolet radiation reaching the planet's surface.

The main reason for the absence of any major change in the Earth's temperature over this extended period is that the concentrations of so-called greenhouse gases – i.e. gases transparent to visible light but absorbing infrared radiation – such as carbon dioxide (CO_2) and methane (CH_4) have fallen dramatically. Ultraviolet irradiation of the Earth's surface has in all probability declined substantially since life's first origins, a crucial development because DNA and other vital cell components are easily damaged by ultraviolet radiation. The decrease in the UV radiation striking the Earth's surface is due to the presence of an 'ozone layer' in the stratosphere, the section of the atmosphere 15–50 km above the Earth's surface containing about 90% of atmospheric ozone. The ozone in this layer is a strong absorber of UV radiation. This long-term decline in atmospheric levels of greenhouse gases and the formation of the ozone layer are intimately linked to the development of life on Earth.

The decrease in concentrations of CO_2 and CH_4 is due largely to the biogeochemical 'carbon cycle'. This cycle, involving both biotic and abiotic processes, transfers carbon within and between four major reservoirs: the lithosphere (the solid outer crust), the hydrosphere (the aqueous envelope, i.e. water bodies), the atmosphere and the biosphere. The carbon cycle is not and has never been a perfect cycle. It has led, rather, to burial in the lithosphere of large amounts of carbon originally present in the atmosphere. The White Cliffs of Dover, the oil reserves of the Middle East and coalmines of China are all places where carbon was buried in the remote past. Figure 2.1 shows the carbon cycle as it is at present. One of the notable aspects of the situation today is the man-made transfer of carbon from the lithosphere to the atmosphere, increasing the temperature of the lowest part, the troposphere.

The genesis of the Earth's ozone layer is closely bound up with the emergence and development of photosynthesis: the conversion of atmospheric CO_2 into organic matter by plants, a process known as carbon fixation and driven by the energy provided by sunlight. Photosynthesis is accompanied by the emission of oxygen (O_2), which can in turn be converted to ozone (O_3), a process occurring mainly in the stratosphere and driven energetically by ultraviolet radiation. Through its capacity to absorb damaging UV, the ozone layer vastly increased the capacity of life-forms to colonise the land and the upper layer of the hydrosphere.

More generally, photosynthetic production of oxygen has increased the atmospheric concentration of this gas from mere traces to its current level of 21%. This permitted development of relatively complex and warm-blooded animals such as mammals, which need a large amount of energy to maintain their bodily processes; with insufficient atmospheric oxygen, the energy generated by the metabolic conversion of food is inadequate.

On the other hand, there are also limits to the amount by which the oxygen concentration of the atmosphere can safely rise. Under an 'over-oxygenated' atmo-

L. Reijnders (✉)
Environmental Science(s) University of Amsterdam and the Open University of the Netherlands, The Netherlands
e-mail: 1.reijnders@uva.nl

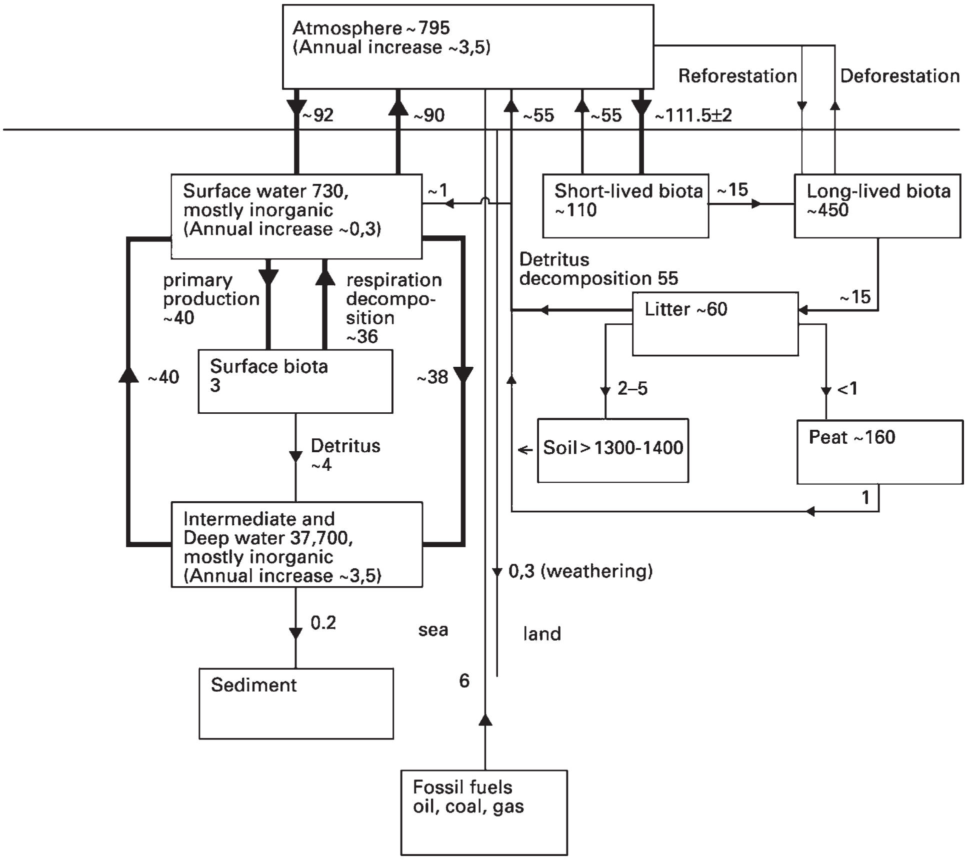

Fig. 2.1 Reservoirs and fluxes, in units of 10^{12} kg C, for the part of the current global carbon cycle that has a turnover time of less than 1,000 years
Source: Adapted from Bolin and Cook (1983)

sphere, biomass would be more often subject to fire. As fire converts biomass carbon to CO_2, however, oxygen levels would be lowered once more.

Current atmospheric levels of oxygen and carbon dioxide are just two of the aspects of our environment that have been shaped by biogeochemical cycles. In fact, many elements undergo transferral between the atmosphere, hydrosphere, lithosphere and biosphere as a result of biotic and abiotic processes. Several of these biogeochemical cycles, including the chlorine, sulphur and nitrogen cycles, which are e.g. important determinants of the concentrations of atmospheric trace gases such as N_2O, CH_3Cl and dimethyl sulfide, will be discussed in Chapter 6.

The remarkable long-term stability of the Earth's surface temperature and the decrease in ultraviolet irradiation of the biosphere were also noted several decades ago by the British scientist James Lovelock and were instrumental in development of his 'Gaia theory'. This theory (Lovelock 1989), named after the Greek Earth goddess Gaia, suggests that the planet is essentially a 'super-organism', characterised by homeostasis: the tendency for organisms to maintain a fairly constant internal environment, as in the case of temperature control in the human body, which is likewise regulated by means of 'negative feedback'. As we have already glimpsed in the case of spontaneous biomass combustion in an over-oxygenated atmosphere and its subsequent 'correction', our planet is clearly susceptible to such feedback mechanisms. Another example is the intensification of photosynthesis with rising atmospheric levels of CO_2 (in the absence of other limiting factors), with an attendant increase in carbon fixation and oxygen production.

However, there are also cases of *positive* feedback that tend to accelerate processes of environmental change. All else remaining equal, a rise in atmospheric CO_2 levels will be mirrored in a temperature rise, promoting microbial respiration of the carbon present in soils, in turn for instance leading to elevated soil emissions of CO_2 from arable soils (Ogle et al. 2005). Other examples of positive feedback are encountered in the context of the Ice Ages of the past 3 million years, discussed in more detail in the next chapter. These Ice Ages were triggered by the so-called Milankovitch cycles associated with peculiarities of the Earth's movement around the Sun (see Fig. 3.1). During recent Ice Ages, however, following the initial cooling brought on by this cycle, photosynthesis in the oceans increased, thereby reinforcing the cooling trend. When the Milankovitch cycle triggers atmospheric warming, there is probably also positive feedback, as the huge, frozen reservoirs of methane 'ice' accumulating in tundra soils and in oceans in the course of the previous Ice Age begin to melt, releasing gaseous methane into the atmosphere. As methane is a greenhouse gas, this reinforces global warming. Thus, the Earth is characterised by both positive and negative feedbacks involving the biosphere in many ways. This means that it is not certain that perturbations will have a homeostatic outcome.

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Chapter 3
Reconstructing Environmental Changes over the Last 3 Million Years

A.M. Mannion

Contents

3.1 Background

Ever since the Earth's creation, some 5 billion years ago, environmental change has been a defining characteristic of our planet. At first these changes were purely inorganic in nature: weathering and erosion of the Earth's surface, and tectonic processes beneath the crust. As life forms began to develop, though, a new, organic influence came to be exerted on the planetary environment. These abiotic and biotic influences continue to this day and are reciprocally related through the various biogeochemical cycles that transport chemical elements within and between the atmosphere, hydrosphere, lithosphere and biosphere. In addition to these 'internal' planetary characteristics and mechanisms, external factors also exert a degree of control over processes of environmental change, the most important of which is the periodicity of the Earth's movement around the Sun, defined by so-called Milankovitch cycles, as shown in Fig. 3.1.

Over the last 200 years our understanding of the Earth's dynamics and evolution has improved enormously. One major early contributor was undoubtedly James Hutton, who in the late 1700s first proposed the theory that parts of the Earth had in the distant past experienced an extended period of glaciation. Other important landmarks include Charles Darwin's work in the mid-1800s, *The Geographical Cycle*, published by William Morris Davis in 1899, and Alfred Wegener's ideas on Continental Drift, published in 1915. More recently, further conceptual elements of a dynamic Earth were introduced by Sir Arthur Tansley's ecosystem theory of the 1930s, the plate tectonics proposed by J. Tuzo Wilson in the 1960s, a time when the systems approach was being adopted in the Earth and Environmental Sciences, and the 'Gaia hypothesis' advanced by James Lovelock in the early 1970s. Equally important is the role of ice and sedimentary archives whose gas and fossil content (pollen, insect remains etc. see below) respectively has facilitated environmental reconstruction and drawn attention to the significant environmental impact of humans during the Holocene. This issue has recently been revisited by Ruddiman (2003) who has suggested, controversially, that human impact on the atmosphere can be detected as far back as 8,000 years ago due to carbon dioxide release following deforestation for expanding agriculture. His opinion is based on a comparison of interglacial and Holocene ice-core carbon dioxide and methane trends though others (e.g. Claussen et al. 2005) indicate that anomalous trends might be expected due to a non-linear response of the carbon cycle to external factors such as insolation. Thus Ruddiman's observations may be due to natural variation rather than land-cover change by humans.

It is also important to signal the role of contemporary environmental issues in bringing the reality of a rapidly changing environment to the attention of the general public. Increasing travel and tourism and especially the rapid growth in media focus and access (notably television) have highlighted such issues as deforestation, loss of biodiversity, acidification, stratospheric ozone depletion and global warming. This has not only made individuals aware of their role in

A.M. Mannion (✉)
University of Reading, U.K
e.mail: a.m.mannion@reading.ac.uk

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