1 Introduction

1.1 Roots

When you open a newspaper, any newspaper, there is a big chance you will encounter the term *sustainable development*. Introduced to a broader public in the 1980s with the publication of the UN's report *Our Common Future*, sustainable development has become common vocabulary. The word 'development' is commonly used to indicate growth, not only in quantity, but primarily in quality. The word 'sustainable' refers to something that can or should last. The idea of sustainable development reflects one of the leading aspirations of humankind in the 21st century, not unlike the idea of socialism in the early 20th century. It has become a modern equivalent of, and complement to, the Declaration of Human Rights, formulated shortly after the devastating Second World War. Civil society organisations have pushed sustainable development forward; respected business and government leaders now hail it as the foremost challenge for the 21st century.

Inevitably, such an aspiration or ideal accommodates a large variety of explanations, objectives and proposals. These are intertwined with personal and collective values and perceptions, which are in turn rooted in millennia of developments shaping human experiences, knowledge, technical skills and social arrangements. Given the human population's continous growth and its use of the planet as a source of resources and a sink of waste, humanity needs an ongoing dialogue that slowly converges to a widely shared vision on the theory and practise of sustainable development.

The word *sustainable* has been known in European languages since the early Middle Ages. It is rooted in the Latin verb *sus-tenere*, *sub* meaning 'up from below' and *tenere* meaning 'to hold'. In the physical sense, the verb *to sustain* is equivalent to bearing, or carrying the weight of something to keep it from falling by support from below. However, early on, the word had a meaning beyond a simple mechanical act, as is already evident in the words of the Roman philosopher Seneca (3 BCE–65 CE): 'The society of man is like a vault of stones, which would fall if the stones did not rest on another; in this way it is sustained'.

One of the oldest and most common connotations of the verb *to sustain* is to keep a person, a community or the spirit from failing or giving way, to keep it at the proper level or standard. It can be active, as 'to support (life)' and being capable

and willing to go on. It can also be passive: 'to undergo' or 'to endure' and is then equivalent to bearable or defensible. Which of the two meanings apply depends on the role, attitude and circumstances of the actor. As he or she may succeed or fail, the verb *to sustain* reflects the human condition: ranging from willpower, duty and pride to fate, pain and suffering. As early as 1290 CE, this connotation was known in the English language.

A closely related connotation stems from the archetypical notion of some force or god, which 'keeps the world running'. In Chinese and Indian cosmology, the forces sustaining the world reflect a dynamic equilibrium between opposites; in Greek cosmology, it is Atlas who kept the earth and the heaven separated. In this sense, the verb *to sustain* gets a transcendent connotation, as in Milton's words:

> *Whatever was created, needs*
> *to be sustained and fed.*

This is even more outspoken in 'sustenance'. The word sustenance has become equivalent to nourishment, food and more generally the means of living or of sustaining life – without any specification of 'that which sustains'. This usage, as in Tennyson's verse:

> *Water is one part,*
> *and that not the least of our sustenance,*

comes close to the ecological meaning, which the word sustainable has acquired in recent times.

An English equivalent of the verb *to sustain* is 'to last', meaning to go on existing or to continue. Interestingly, it used to be associated with performance and duty. The verb 'to endure' is an English equivalent of *to sustain* and is rooted in the Latin verb *durare*. It is common in other European languages. In German, the word *dauerhaft* is the common word for sustainable, with *nachhaltig* as a synonym. The Dutch equivalents are *duurzaam* and *houdbaar*. In French, the word *durable* is most common – and is also used in English as a synonym of lasting or permanent. The words *soutenable* and *viable* are also used in French as synonyms to indicate something that is bearable, can survive or is feasible.

Present-day usage of *sustainable* refers to an act, a process or a situation, which is capable of being upheld, continued, maintained or defended. It has a largely active disposition, in the context of sustainable resource use or management. The word *sustainability* expresses the presence of such a capacity and is a recent coinage. The words rooted in *durare* suggest a more passive connotation than those rooted in *sustenere*.

The word *development* comes from the *des* meaning 'undo' and *veloper* meaning 'to wrap up' in old French and is possibly of Celtic origin. In present-day use, the verb *to develop* means to (help) strengthen and enlarge. In particular, it is a progression from earlier to later stages of a life cycle or a process from simpler to more complex stages of evolution. It is about growing by degrees into a more advanced or mature state. Development is considered to be broader than quantitative growth. It involves maturing, ripening or bringing from latency to or towards fulfilment and fullness. It refers to a dynamic process of (causing to) grow and differentiate along lines natural to its kind, of improving the quality and of (causing to) become more complex or

Box 1.1. *Sustainability science.* 'A new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society . . . . [it] needs to move forward along three pathways. First, there should be wide discussion within the scientific community regarding key questions, appropriate methodologies, and institutional needs . . . Second, science must be connected to the political agenda for sustainable development . . . . [and] third (and most important), research itself must be focused on the character of nature-society interactions, on our ability to guide those interactions along sustainable trajectories, and on ways of promoting the social learning that will be necessary to navigate the transition to sustainability' (Kates *et al.* Science 292(2001) 641–642).

'Sustainability science is not yet an autonomous field or discipline, but rather a vibrant arena that is bringing together scholarship and practice, global and local perspectives from north and south, and disciplines across the natural and social sciences, engineering, and medicine' (Clark and Dickson PNAS 100(2003) 8059–8061). In the same article, the link with a new kind of science is emphasised: 'Post-Normal Science has been developed to deal with complex science related issues. In these, typically facts are uncertain, values in dispute, stakes high, and decisions urgent, and science is applied to them in conditions that are anything but "normal"'.

intricate. Development is an evolution from simple to complex in terms of technical and managerial skills and of social-cultural connections and institutions.

The concept of *sustainable development* supposedly combines the ideas of a process or situation that can be continued and one that is growing in complexity and maturing towards 'natural' fulfilment. Introduced in the 1970s, it was applied initially with reference to an ecological or environmental desire, target situation or state. A measure or indicator of sustainability is then the difference between the actual and the desired situation and the timepath towards it. Often, the desired or target situation is related to some reconstructed preindustrial 'natural' situation and serves as a reference. Practitioners often held the view that 'sustainable development' could thus be given an objective interpretation.

In the 1990s, the interference of social scientists and notably economists made it clear that formulating such a desired or target situation for a sustainable development trajectory cannot be legitimised solely on ecological-environmental criteria. First, which indicators for decision making are chosen? Should not economic and social aspects be included as well? Second, if there is agreement on the choice of indicators, the desired or target indicator levels must be the outcome of a societal negotiation process and be open for renegotiation. Even if a command has to be obeyed under penalty of complete and irreversible loss and, therefore, should be considered an unconditional moral obligation – Kant's categorical imperative – it may still have to be renegotiated in the light of new information, a shift in values or new and other pressing needs.[1] Accordingly, economists argue that the quest for

[1] Examples are an unconditional interdiction of slavery and a complete ban on entering Antarctica.

sustainable development can and should be founded on welfare economics and societal cost-benefit analyses. Other social scientists brought their own and different observations, concepts and theories. In any event, it is now widely acknowledged that the interpretation of sustainable development includes the subjective, value-laden elements that are inherent in the words *sustainable* and *development*. The inputs from a variety of scientific disciplines have led to a flux of ideas, concepts and observations, which together lead to a new branch of science in the making: *sustainability science*.

1.2 Sustainability Science

This book has also the word *science* in the title. The word science comes from the Latin noun *scientia* and the associated verb *scire* meaning 'to know'. Originally, it may have come from the Latin verb *scindere* meaning 'to cut, divide'. Thus, an old connotation related the word already to the act of distinguishing, that is, of dividing in the mind. The word science has undergone a gradual evolution in European history. In the 17th century, it became separated from more practical and artistic knowledge – and practises and skills – then became understood as theoretical truth. Gradually, science got the meaning of a 'body of regular or methodical observations or propositions . . . concerning any subject or speculation'. The overlap with philosophy became smaller, and science evolved into an expanding set of compartments of systematised knowledge about particular objects. When it concerns objects in the physical world and its phenomena, science is natural science – but the word natural is often omitted. The focus is on general truths and laws as well as on particular methods of enquiry. However, the first and common meaning of science still is 'a state of knowing: knowledge as distinguished from ignorance or misunderstanding' (Encyclopedia Britannica).

Connecting sustainable development to science stems from the idea that sustainable development is an aspiration that can and should be realised only on the basis of scientific knowledge. Does it justify the establishment of a new branch of science? Yes, for several reasons. An overriding reason, in our view, is that humanity is confronted at an ever larger scale and rate with the consequences of its own success as a species. The complexities and uncertainties of the human adventure are becoming such that insights from all the sciences are needed to deal with them if we are serious about the aspiration to improve quality of life (development) that endure (sustainable). Understanding and acting upon the causal mechanisms and behavioural responses across several time- and space-scales is a great challenge for an increasingly fragmented science. A transdisciplinary approach is called for, in which the quantitative and the qualitative, the natural and the social and also theory and practise (or science and policy) are reconciled and creatively combined. Such an integrating and synthesising approach deserves the name *sustainability science*.

This new science started with research and education on change processes across all scales in space and time. Known as Global Change Science or Earth System Analysis, the focus is on large clusters of observations and phenomena, and new scientific branches develop along the borders of classical disciplinary sciences. Much of it emanated from the environmental sciences, which branched into many directions such as atmospheric and ocean science, marine biology, human ecology, ecological

economics and so on (Boersema and Reijnders 2009). Gradually, it became clear that there were rather general laws underneath the phenomena in the different fields of study. Also, the emphasis shifted from description of states to understanding changes in states. *System theory* and the methods of system analysis and system dynamics became the most coherent expression of this insight (Bossel 1994). The new field increasingly expanded beyond the environmental sciences. The time has come to reinforce the unified approaches and unifying tendencies in science and to liberate the study of real-world processes from the confines of artificial, 19th-century boundaries between the scientific disciplines. Sustainability science is perhaps the most clear and desirable expression of this endeavour.

What is a meaningful definition and working program for sustainability science? During the last few decades, scientists from different backgrounds have formulated attempts at founding statements. The following are a good start (Kates *et al.* 2001; Clark and Dickson 2003):

- sustainability science is about understanding the dynamics of evolving, coupled *social-ecological systems* (SES);
- sustainability science is *transdisciplinary*: solutions to the problems have to acknowledge that the world is/becomes more integrated, more complex and more uncertain;
- the focus of sustainability science is on the *interactions* between the resource system (earth/life sciences), its users and the governance system (social sciences); and
- sustainability science is *problem-driven* to manage complex coupled SES in order to have them deliver what people value.

This book uses the term *sustainability science* to indicate the efforts from all corners of science to construct a framework for understanding and acting in relation to (un)sustainable development. The aim is to provide foundations for and essential concepts and methods in such a sustainability science.

In sustainability science, human individuals and societies are studied in a biosphere context. The key notion here is that of SES, which are defined as integrated human–nature systems with reciprocal feedbacks and interdependences (www.resalliance.org). It appears to be a 'natural' unit of study. We reflect explicitly on the ways and limitations of a transdisciplinary approach and pay attention to models and the process of modelling. We introduce *system dynamics* and, more broadly, *complex systems science* as one set of methods and techniques ('tools') for integration. As part of the transdisplinarity, we consider explicitly the great variety and richness in people's values and beliefs about the world and about sustainable development. The idea of *worldview pluralism* is applied in various places as a way to deepen personal understanding and engagement.

The problem-driven nature of sustainability science is controversial. If one accepts it as a constitutive element, two questions arise: Which problems should be addressed and where does the overlap begin with practical policy and management insights and skills? Because there are very different appraisals of the problems humanity faces in the 21st century, the first question raises the issue of worldview pluralism. Natural scientists formulate the problem largely in terms of human-induced changes at a planetary scale. Some of these processes have become

well known, such as the ozone layer depletion ('ozone hole') and anthropogenic climate change ('global warming'). Others are still less known but possibly equally serious (Rockström *et al.* 2009). These 'problems' were already addressed one year after human beings set foot on the Moon, in the report *Man's Impact on the Global Environment* (SCEP 1970): 'the concept of the earth as a "spaceship" has provided many people with an awareness of the finite resources and the complex natural relationships on which man depends for his survival . . . Some . . . have warned of both imminent and potential global environmental catastrophe. Theories and speculations of the global effects of pollution have included assertions that the building of CO_2 from fossil fuel combustion might warm up the planet . . . the possibility of . . . particles emitted into the air . . . lower[ing] global temperature . . . the effects on ocean and terrestrial ecosystems of systematically discharging . . . heavy metals, oil, and radioactive substances; or nutrients such as phosphorus'. It was repeated and supported with a system dynamics computer model in the report *Limits to Growth* (Meadows *et al.* 1971) to the Club of Rome. Since then, the world has in terms of population and economic activity largely followed the 'business-as-usual' path in that report (Turner 2008). Nevertheless, there are still widely divergent interpretations and appreciations of what happened during the intermediate forty years.

The second question points to the demarcation between science and technique, επίστημη and τεχνη. Sustainability science differs from sustainably managing SES, although the two have a fruitful and creative connection. Knowledge of how the world works and how we think the world works is only one, and not necessarily an essential or sufficient, ingredient of acting upon the world. This book follows a pragmatic course. First, it considers models of systems important in understanding, assessing and communicating about sustainable development. Therefore, Chapters 2, 8 and 10 deal rather extensively with the construction and use of models and with some analytical and modelling tools. Aware of sometimes large, or even impregnable, limitations of (mathematical) modelling, Chapters 7, 9 and 11–13 present stories and case studies in order to bridge the concrete and the abstract, the data and the theory. Finally, Chapters 6, 10 and 12 introduce other ways of engaging people's insights and participation, such as value surveys, participatory modelling and simulation games. In this way, the scientific insights presented provide a context for action – technical, political or other – without explicit discussion of the myriad options for action.

Box 1.2. *Exactness.* Don't expect a Unified Theory of SES or Social-Ecological Systems. It does not exist. Do not expect exactness either . . . precision is not always what we are looking for:

Joachim went to the famous Museum of Natural History where, he was told, one could see many dinosaurs.

Seeing one of them, the provost standing nearby told him 'This dinosaur is very old, sixty-five million and fifteen years'.

'Very old indeed', replied Joachim, '. . . but how do you know its age with such precision'?

'Well', the man replied, 'when I came here to do this work, it was sixty-five million years old and that was fifteen years ago. . . . '

1.3 Sustainable Development Is About Quality of Life

We have spoken about the roots of the words sustainable and development. But what *is* sustainable development? The word sustainable is used in many different contexts, and not always sensibly: sustainable cities, sustainable traffic, sustainable water, sustainable livelihoods, sustainable banking, sustainable technology – and sustainable growth. The French newspaper *Le Monde* celebrated the start of the 'Semaine du développement durable' in 2005 with a special supplement saying: 'Let's forget the words "sustainable development", because they provoke indifference . . . and, worse, they make people smile. Let's take care of its contents, though: producing what people need without destroying their environment. . . . ' They are not the only ones who give this advice. Yet, this book does not follow the advice and sticks to the notion of sustainable development as the core concept. The objective is to deepen its content both in the abstract and the concrete.

For the moment, we use the most widely known definition of sustainable development, given in the UN's World Commission on Environment and Development (WCED) report *Our Common Future* (1987):

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

Within this definition, the goal of sustainable development expresses a quest for developing and/or sustaining qualities of life. Framing sustainable development in terms of quality of life introduces the subjective and objective dimensions of human well-being and invites a truly transdisciplinary approach. It has an intergenerational and an international dimension: people should act *here and now* in such a way that the conditions for a (decent/high) quality of life *elsewhere and later* are not eroded.

Did we only shift the problem – because: What is quality of life? And which qualities, for whom and for how long? Should these be experienced or imagined qualities of life, for the lucky few or for all, for humans only or for all species, for our children or for the next seven generations or even longer?[2] Another question poses itself: Is it development towards a static situation, a world that can be sustained because there is no change? Such a blueprint approach is seductive, as the many utopias in literature testify (Achterhuis 1998; de Geus 2003). But science tells us that everything is always and everywhere in flux and that development is an evolutionary path of success and failure.

Quality of life is an experience that stretches out over large domains in space and time, in our individual life space (Figure 1.1a,b).[3] In first instance, I as an individual person relate to it in the here and now: material and immaterial well-being. Do I have enough to eat? Do I have shelter? Can I avoid or cure diseases? Can I have sex and experience love? Can I learn or apply skills? Can I communicate and relate? What we experience as quality of life is, through our actions and emotions, our beliefs

[2] Most people will adhere to an anthropocentric view, but some people want to extend it to all life or even the planet as a whole. Such an ecocentric view can in theory be defended – but the defense is, in practise, always by a human being.

[3] Of course, each individual lives in a larger, social-cultural context and the two schemes in Figure 1.1 are flat-world simplifications of a complex reality.

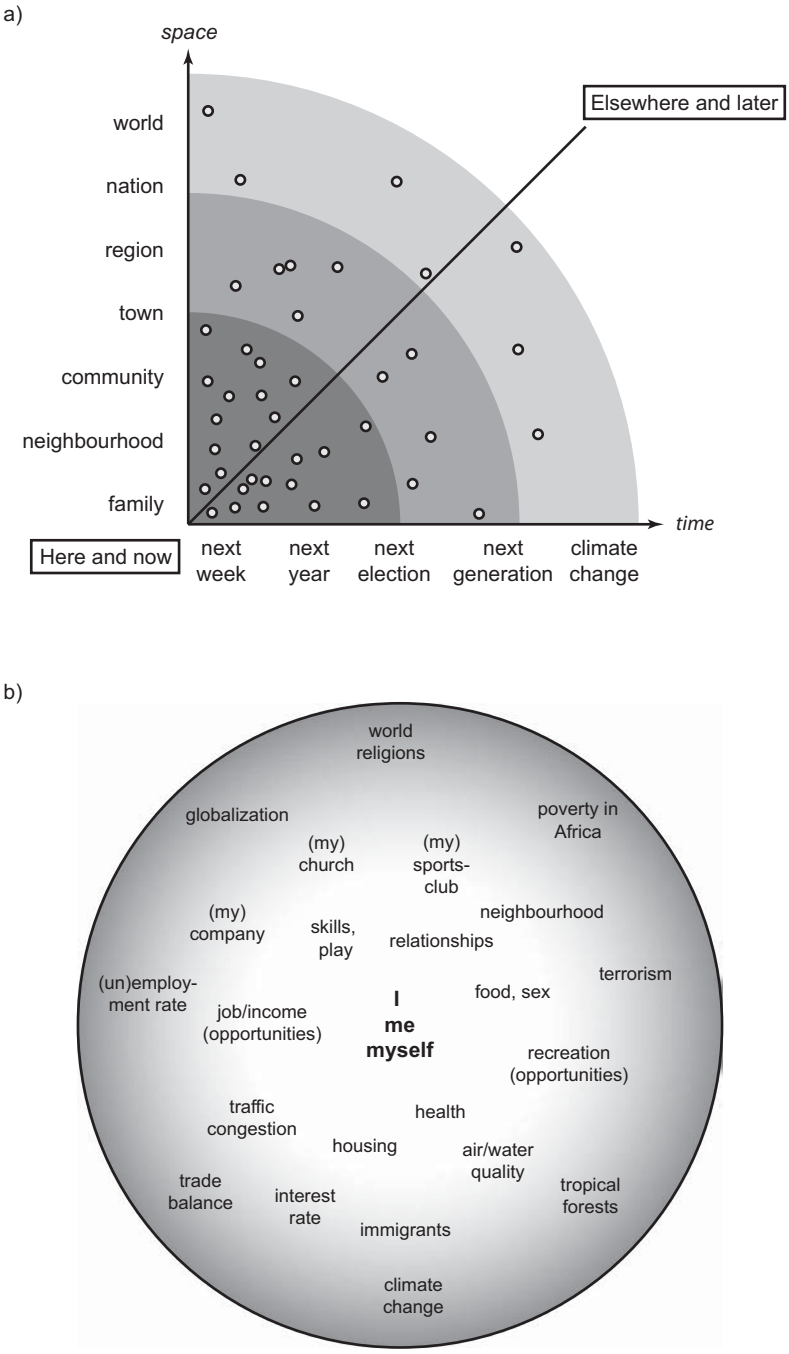

Figure 1.1a,b. Simplified schemes of time and space in the perception of sustainable development issues: (a) the space and time scales in which we experience the world; (b) items in the centre-periphery of our daily consciousness.

and thoughts, also something of others and elsewhere, of past and future (Figure 1.1b). Is there food for the whole family? Can I pay my children's school fees? Will there be riots in town? Will my husband's job disappear next year? Can I still enjoy last week's celebration or forget last year's insult? Will there be a good harvest this

year? Clearly, quality of life is not easily condensed in one or a few quantitative measures.

We have seen that development is growth towards a more complex and mature state. Growing up, maturing as a human individual implies a widening of one's perspective on what life is about and on what 'the good life' can or should be. It can coincide with a deepening of experiences, from the sensate and emotional to the mental and spiritual. Thinking and acting can become more inclusive, with caring for the larger scale and the longer term.The motivation for inclusive thinking can be an expression of biological pragmatism and functionalism or of solidarity with wider kin and of tribal 'commandments' and social norms for the benefit of the group. Perhaps, it arises out of spiritual yearning.

Whatever the motives, in the manifestations of inclusive thinking, the aspiration of sustainable development is recognised as more than a scientific quest: It is an ethical and transcendent endeavour. It challenges us as individuals and groups in how we manage our needs and wants *and* how we organise and manage resource use that goes with it. *Ethics* enters the discourse, with questions about fairness, solidarity, justice, egoism and altruism. *Transcendence* appears when we inquire into the meaning and dignity of human life. I can give many references to books by philosophers, artists and mystics who have struggled with these questions and attempted to express it in words (Elgin 1993). It is probably better if you reflect on your own life to see if it makes sense for you. Subsequent chapters offer openings for such reflections.

In a practical sense, we must link sustainable development to the aspirations of human beings for a good quality of life while respecting the plurality of worldviews. Science can contribute here with adequate beliefs about the world and its workings and with methods and tools to make those beliefs effective in action. It can also teach how to complement intuition with rationality in managing uncertainty. It can inspire feelings of respect and joy in the face of the world's rich diversity, beauty and complexity. And, finally, it invites us to reflect and give knowledge and mind their proper place in our lives.

Immanuel Kant (1724–1804) offered a guide in the search for sustainable development when he summarised his philosophy as the search for an answer to three questions: '*What can I know? What ought I to do? What may I hope for?*' In the present context, these questions can be reinterpreted. What can science tell (and what not)? What, then, is an individual's responsibility and duty? And which dreams and destinies can he or she expect? This book is primarily about Kant's first question: *What can I know?*, but it opens a panorama on answers to the other two questions.

1.4 Guidelines for the Reader

Set up as a textbook and an introductory guide, this book is intrinsically transdisciplinary: The student is not expected to become an expert in a particular domain or method but, instead, is invited to learn about and appreciate the different perspectives on (un)sustainable development. Not only are those perspectives following the different scientific disciplines, but they also reflect the different individual worldviews. In this way, the book prepares the student for an independent yet personal position on ideas and actions regarding sustainable development. The most important

word in this respect is probably *context*. After studying the book, the student should be able to put into context what is read or seen in journals, newspapers, books or on TV or the Internet about ecological, economic and social aspects of sustainable development. Equally important, the reader should feel better equipped to engage with his or her own values and beliefs in the aspiration for a more sustainable world.

There are four threads in this book. The first is a *historical* and *qualitative* description of past developments and civilisations in order to get an idea of 'where we are and what the problem is'. It is based on reconstructions by archaeologists and historians and comprises Chapters 3 and 4. In most chapters, there are also 'relevant (hi)stories'.[4] These are personal accounts of people living through particular events, which illustrate concepts or models discussed in the chapter. Of course, it is merely a selection of the numerous stories about (un)sustainable development around the world.

The second thread centres around the notion of *worldviews* and is the focus of Chapters 5 and 6. I briefly examine the historical background of the concept of sustainable development. Next, I discuss the objective and subjective aspects of needs and capabilities and the variety in value orientations and beliefs that describe and explain the difference in views about sustainable development and quality of life. After this groundwork, I offer a theory and a framework that explore the centrifugal forces behind unsustainable developments, which are applied throughout the book to categorise and understand the different views people have on important issues such as population, resources, technology and economic growth.

The third thread is the *systems* approach and the methods and techniques that have been developed over the years in order to understand a system's behaviour over time. Chapters 2 on system dynamics and the thematic Chapters 7 and 9–14 use simple simulation models to explore basic mechanisms of change. These models are constructed with software packages such as Stella®, Vensim® and NetLogo® (Mathematical details are set apart in the appendices for the interested student). To appreciate the role of mathematical models in sustainability science, there is a brief orientation on the philosophy of science, in particular on the nature of knowledge and models and on uncertainty and complexity.

A fourth thread summarises the major insights and findings of the *scientific disciplines* that shed light on (un)sustainable development. Each scientific discipline contributes to the search for a sustainable world. It may be argued that ecology and geography are the core of sustainability science, but the natural and engineering sciences and the economic and social sciences may be of equal importance. Largely following the reductionist-empiricist paradigm, later chapters survey observations ('facts'), concepts, methods and theories ('laws') in contemporary science with respect to environment and development. What is the input from classical thermodynamics and mechanics and, broader, energy science (Chapter 7)? What insights do we gain from ecologists and demographers who study nature's evolution and species populations and what is the image of man in the economic and social sciences (Chapters 9 and 10)? What does science tell us about the dynamic processes

[4] We will also use the words narratives or, sometimes, case studies or anecdotes. The website www.sustainabilityscience.eu is collecting stories with relevance for sustainability science issues.