PART I

Future Earth and Planetary Issues

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Edited by Tom Beer , Jianping Li , Keith Alverson
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International Drivers to Study Climatic and Environmental Change: A Challenge to Scientific Unions

Tom Beer

1.1 Climatic Change

An English language purist will point out that the word ‘climate’ is a noun whereas the adjective from this word is ‘climatic’ so that the correct term for what is popularly called ‘climate change’ is actually ‘climatic change’. The Springer scientific journal *Climatic Change*[1] uses correct English. Thus, even though this chapter will deal with climatic change and environmental change, the term climate change is synonymous, and will be used interchangeably, with climatic change.

Though the term climate change has become standard usage, there is less standardisation in relation to the term that is used to cover the *effects* of climate change on the ambient and social environment, generally through studies of impacts, adaptation and vulnerability. This chapter will use the term ‘environmental change’ but the international research community also uses the term ‘global change’ or ‘global environmental change’ for the same phenomenon.

Climatic change as a scientific discipline includes studies of processes, detection and attribution (which in this context means separating out the influences of climatic variability from the influences of climatic change) and projections of climatic change into the future and its effects on sea level and on coasts. Climatic change research can also involve detailed measurement or modelling of the greenhouse gas (GHG) in the atmosphere. In this context, the phrase ‘detection and attribution’ is used to determine the nations or industries responsible for the emissions of particular gases.

This chapter will examine the international political drivers in relation to climate change, the international inter-governmental drivers, the international scientific response and the role of scientific unions focussing on sustainability and then determine where the organisational and research gaps lie.

1.2 International Political Drivers in Relation to Climate Change

The General Assembly of the United Nations called for a Framework Convention on Climate Change (UNFCCC) in 1990, a call that was supported at the Second World Climate Conference in 1990 so that the convention was finally adopted in New York in May 1992. It was opened for signatures at the Intergovernmental Conference on Sustainable Development, held in Rio de Janeiro in 1992. More than 175 countries have ratified the UNFCCC. It is called a ‘framework’ convention because it leaves the details of implementation to be worked out later, by a series of protocols or other legal devices or agreements to be adopted by the member countries at the Conference of Parties (COP).

The first of these was the 1997 Kyoto Protocol in which, for the period from 2008 to 2012, greenhouse gas reduction measures were agreed. The scope of the protocol was extended until 2020 with the Doha Amendment to that protocol in 2012.[2]

The objective of the UNFCCC is stated in Article 2 to be:

> the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to all ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

The UNFCCC contained no binding commitments on emissions levels, but it did lay down some general principles and objectives to shape future negotiations on these commitments. Pittock (2009) notes that these included that

- developed countries (most members of the Organisation for Economic Cooperation and

Development, OECD), plus many former communist states undergoing transition to a market economy), should take the lead with abatement measures;
- the climate and economic vulnerabilities of developing states should be recognised;
- abatement should be consistent with sustainable development and not infringe the goals of an open and supportive international economy.

These provisions, and negotiations towards their implementation, led to argument between member countries (termed 'parties' to the Convention), especially over the contents and implementation of the Kyoto Protocol adopted in 1997. These debates were originally clouded by uncertainties as to the actual risk from climate change, and uncertainties regarding the costs of impacts and of abatement measures. By the time of the 2015 COP in Paris there was general agreement that a global mean temperature rise of 2 degrees Celsius (°C) would lead to unacceptable warming so that the Paris Agreement[3] (French: *L'accord de Paris*) was an agreement to set a goal of limiting global warming to less than 2 degrees Celsius (°C) compared to pre-industrial levels. The agreement calls for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the twenty-first century. In the final adopted version of the Paris Agreement, the parties will also 'pursue efforts to' limit the temperature increase to 1.5 °C. The 1.5 °C goal will require zero emission sometime between 2030 and 2050. However, no detailed timetable or country-specific goals for emissions were incorporated into the Paris Agreement – as opposed to the previous Kyoto Protocol.

1.3 International Inter-Governmental Drivers

How does one set up a formal process to incorporate scientific advice into the international political process? This question came to the fore in relation to the Montreal Protocol. From the previous information about the UNFCCC it is apparent that in the UN system a protocol relates to a convention. One of the most successful, if not *the* most successful, scientific protocols was the Montreal Protocol on Substances That Deplete the Ozone Layer,[4] which is a protocol to the Vienna Convention for the Protection of the Ozone Layer, an international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion. It was agreed on 16 September 1987.

Due to its widespread adoption and implementation the Montreal Protocol been hailed as an example of exceptional international co-operation, with UN Secretary-General Kofi Annan, in his presentation to the Millennium Assembly of the United Nations in September 2000, saying that 'perhaps the single most successful international agreement to date has been the Montreal Protocol'. In comparison, effective burden sharing and solution proposals mitigating regional conflicts of interest have been among the success factors for the ozone depletion challenge, where global regulation based on the Kyoto Protocol has failed to be. The two ozone treaties (the Vienna Convention and the Montreal Protocol) have been ratified by 197 parties, which includes 196 states and the European Union, making them the first universally ratified treaties in United Nations history.

In the case of the ozone layer it took only thirteen years for science to be incorporated into international policy. The science that led to the Montreal Protocol (Molina and Rowland, 1974) was published in 1974, after the discovery that chlorofluorocarbon (CFC) molecules were stable enough to remain in the atmosphere until they were transported into the middle of the stratosphere, where they would finally (after an average of 50–100 years for two common CFCs) be broken down by ultraviolet radiation, releasing a chlorine atom, which would then react with the ozone in the stratosphere

Then, Farman et al. (1985) noted abnormally low ozone concentrations above Halley Bay near the South Pole. They speculated that this was connected to increased levels of CFCs in the atmosphere. Subsequent work confirmed the reality of the Antarctic losses and established them to be significant. The impact of these studies, the metaphor 'ozone hole', and the colourful visual representation in a time lapse animation proved shocking enough for negotiators in Montreal to take the issue seriously.

The science in relation to climate change was less clear-cut, and some climate change sceptics would claim that it is still less clear-cut. Because of this the bodies responsible for administration of the UNFCCC – the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) – established the Intergovernmental Panel on Climate Change (IPCC) to assess scientific, technical and socio-economic information concerning climate change, its potential effects and options for adaptation and mitigation.

1.3.1 The Work of the IPCC

As implied previously, the major task of the IPCC[5] is to produce assessments. These provide a scientific basis for governments at all levels to develop climate-related

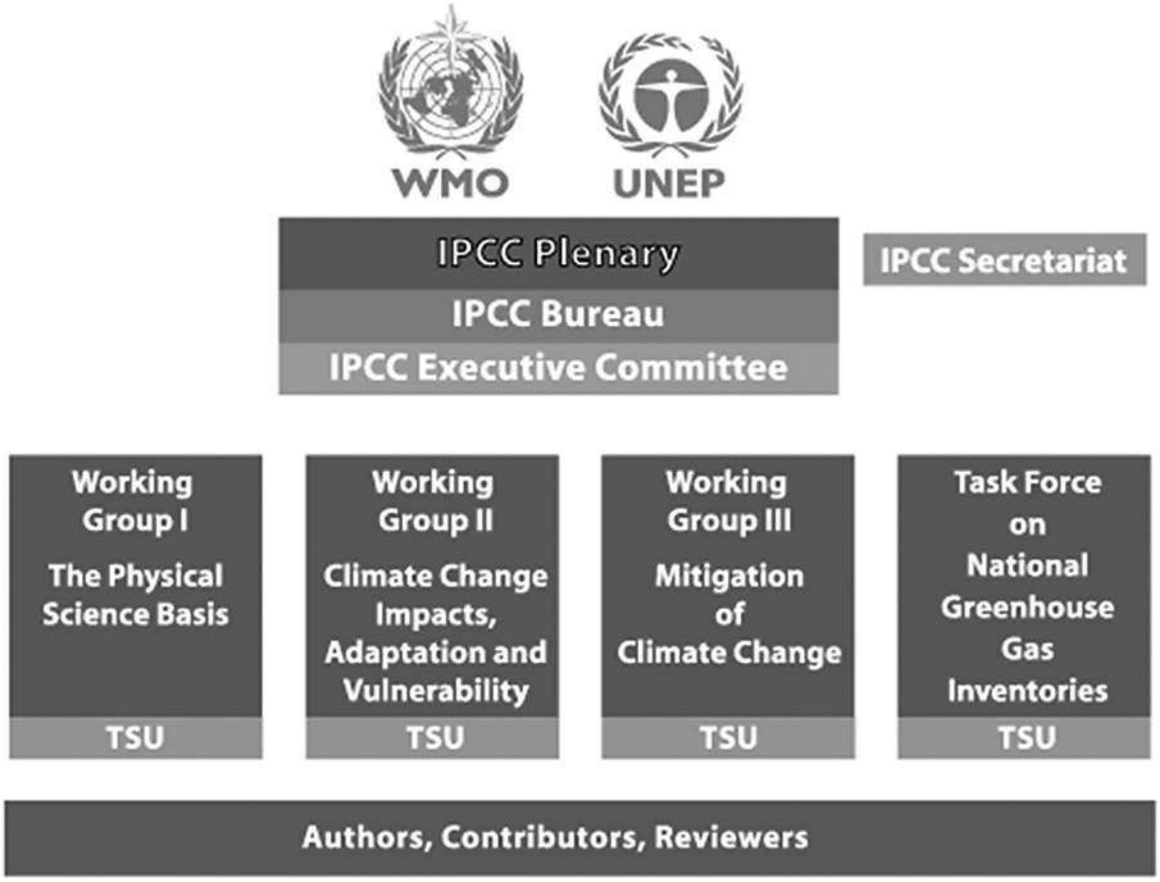

Figure 1.1 Diagram illustrating the structure of the Intergovernmental Panel on Climate Change (reproduced from www.ipcc.ch/organization/organization_structure.shtml with permission of the IPCC).

policies, and the IPCC assessments underlie negotiations at the various UNFCCC conferences. The assessments are policy-relevant but not policy-prescriptive: they may present projections of future climate change based on different scenarios and the risks that climate change poses and discuss the implications of response options, but they do not tell policymakers what actions to take.

According to Article 14 of the Paris Agreement, Nationally Determined Contributions (NDCs) will be revised on a five-year basis through a global stocktaking mechanism established under the UNFCCC, which will start in 2023. The IPCC sixth assessment report, known as AR6, is to be finished by 2022; hence, all elements of the AR6 will be available for consideration by the global stocktake in 2023, and the IPCC will be in a position to provide the policy-relevant scientific input to the global stocktaking.

The IPCC also produces special reports, which are an assessment on a specific issue, and methodology reports that provide practical guidelines for the preparation of greenhouse gas inventories.

The IPCC scientific work is currently organized by three working groups and a task force (Figure 1.1). They are assisted by technical support units (TSUs), which are hosted and financially supported by the government of the developed country co-chair of that working group or task force. Working Group I deals with The Physical Science Basis of Climate Change, Working Group II with Climate Change Impacts, Adaptation and Vulnerability and Working Group III with Mitigation of Climate Change. The main objective of the Task Force on National Greenhouse Gas Inventories is to develop and refine a methodology for the calculation and reporting of national greenhouse gas emissions and removals.

1.3.1.1 Special Reports

The IPCC has produced various special reports and continues to do so. During the Sixth Assessment Report (AR6) cycle there will be three special reports: one on the impacts of global warming of 1.5 °C above pre-industrial levels, a second on climate change and oceans and the cryosphereand a third on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems. Recently completed special reports include the *Special Report on Renewable Energy Sources and Climate Change Mitigation* (SRREN) and the *Special Report on Managing Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX).

The work of the IPCC provides an outstanding example of risk assessment in action. Beer (1997) noted that

> the IPCC process is an ongoing risk assessment of the consequences of climate change. But the noteworthy aspect of it is that, for a problem of such global scale and long temporal duration, the appropriate assessment involves: international cooperation; the involvement of numerous scientists, technologists, environmentalists, economists, politicians, lawyers and other groupings, and as a result takes time and money. Yet there is no doubt that a quick assessment undertaken by a small focused group would fail to win the consensus support that concerted action requires and fail to spread ownership of the consensus across a sufficiently wide cross-section of the community.

From the political perspective, the IPCC process has been a great success that was acknowledged in 2007 when the Nobel Committee awarded one-half of the Nobel Prize in peace to the IPCC. However, from the scientific perspective, and especially from the viewpoint of an individual scientist, it is constrained by its inter-governmental nature. The various IPCC assessment reports are reviews of the scientific literature. The IPCC process does not exist to generate the scientific literature but to review and assess it.

1.4 Other International Drivers

The year 2015 was an important one. The Paris agreement has already been mentioned. In addition, two other relevant international agreements were achieved. In terms of disaster risk reduction, assembled delegates approved the Sendai Framework for Disaster Risk Reduction,[6] whereas in terms of sustainability, at a UN summit in September 2015 world leaders adopted the Sustainable Development Goals,[7] discussed in more detail later on, which officially came into force on 1 January 2016. Over the next fifteen years, with these new goals that universally apply to all, countries will mobilize efforts to end all forms of poverty, fight inequalities and tackle climate change, while ensuring that no one is left behind.

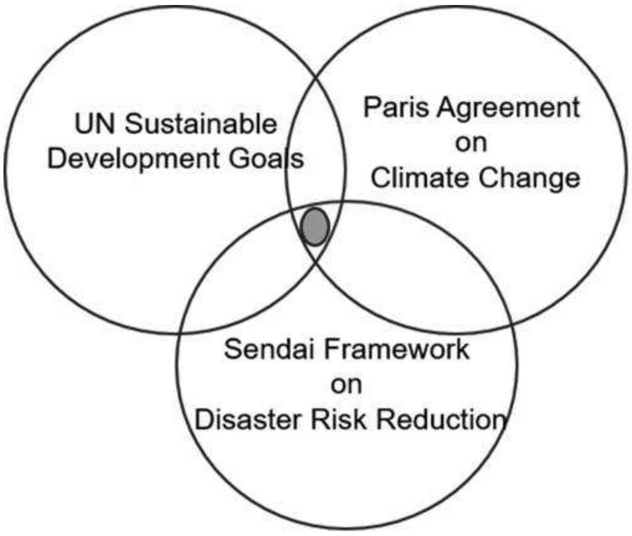

Figure 1.2 Relations between the major international drivers. The spot at the intersection of the three circles is meant to indicate that the greatest research potential for scientific unions is to be found at this point.

This chapter, and indeed this whole volume, is predicated on the assumption that international scientific union members of the International Council for Science (ICSU) can produce worthwhile and significant achievements if they collaborate in areas that span two or more of these international agreements, as illustrated diagrammatically in Figure 1.2. ICSU itself has felt that the best way to meet the existing and future challenges facing science and society is to merge with the International Social Sciences Council (ISSC). In October 2017 the membership of ICSU agreed to such a merger.

1.5 The International Scientific Response

The international process that has been established to assist researchers to generate the scientific literature is the World Climate Research Programme (WCRP),[8] an international scientific research programme jointly sponsored by the World Meteorological Organization (WMO), the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

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The WCRP mission is to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. The two overarching objectives of the WCRP are

- to determine the predictability of climate, and
- to determine the effect of human activities on climate.

Recent progress in the understanding of climate system variability and change makes it possible to gauge its predictability, and to use this predictive knowledge in developing adaptation and mitigation strategies. Such strategies assist global communities in responding to the impacts of climate variability and change on major social and economic sectors including food security, energy and transport, environment, health and water resources.

The main foci of WCRP research are:

- observing changes in the components of the Earth system (atmosphere, oceans, land and cryosphere) and in the interfaces between these components;
- improving our knowledge and understanding of global and regional climate variability and change, and of the mechanisms responsible for this change;
- assessing and attributing significant trends in global and regional climates;
- developing and improving numerical models that are capable of simulating and assessing the climate system for a wide range of space and time scales and
- investigating the sensitivity of the climate system to natural and human-induced forcing and estimating the changes resulting from specific disturbing influences.

In actual fact, WCRP was established in 1980 – a testament to the prescience of the scientific community. Its mandate is to study the climate, rather than climate change in particular. Accordingly, once it became apparent to the scientific community that what was needed was scientific research targeted at the science, effects, impacts and human response to climate change, then-new scientific programmes were established. The International Geosphere Biosphere Programme (IGBP) was set up in 1986 to study the total Earth system, the changes that are occurring and the manner in which changes are influenced by human actions. The International Human Dimensions Programme (IHDP) was set up in 1996 to address the coupled human-natural system in the context of global environmental change (GEC) and to examine ways in which individuals and societies

- contribute to global environmental change,
- are influenced by global environmental change and mitigate and adapt to global environmental change.

A fourth programme, DIVERSITAS, established in 1991, belongs to a family of four global change programmes (IGBP, WCRP, IHDP and DIVERSITAS) that have ICSU as a common sponsor. DIVERSITAS existed to promote integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge and to provide the scientific basis for an understanding of biodiversity loss, and to draw out the implications for policies for conservation and sustainable use of biodiversity.

At the end of 2014, the projects under IGBP, IHDP and DIVERSITAS were all transferred into the new global change research programme Future Earth,[9] that aims to study – along with WCRP – the Anthropocene. 'Anthropocene' is a term (Crutzen and Stoermer, 2000) coined in relation to humans affecting the Earth and its geology. Conversely – or perhaps in cyclical tandem – changes in our Earth and its geology affect humans, physically and emotionally.

All of these initiatives entrained many working scientists into research programmes and projects to examine global change and provided an impetus for many national governments to become involved with such research. Nevertheless, one could argue that the initiatives really occurred at a level above that of the normal researcher. The programmes were initiatives of the International Council for Science (ICSU), which is a body to which most scientists do not feel any attachment. Scientists feel attachment to their own scientific union. Chemists identify with the International Union of Pure and Applied Chemistry. Physicists identify with the International Union of Pure and Applied Physics. Earth Scientists identify with the International Union of Geodesy and Geophysics. This is normal. The national and international analogy is with the United Nations. Citizens identify with their own country, even if they happen to be involved in a programme for one of the United Nations agencies.

1.6 The Role of Scientific Unions

The upsurge of interest in global change issues strengthened the resolve of the ICSU Unions involved in the sciences that study the Earth to work together. They formed an alliance (Figure 1.3) known as the GeoUnions,[10] involving the International Astronomical Union (IAU), the International Geographical Union (IGU), the International Union for Quaternary Research (INQUA), the International Society for Photogrammetry and Remote Sensing (ISPRS), the International Union of Geodesy and Geophysics

Figure 1.3 ICSU GeoUnions (reprinted from the ICSU GeoUnions website (with permission from A. Ismail-Zadeh)).

(IUGG), the International Union of Geological Sciences (IUGS), the International Union of Soil Sciences (IUSS), the International Union of Radio Science (URSI) and a later member, the International Cartographic Association (ICA).

One of the issues for the GeoUnions, separately and collectively, is how to respond to the international activity that has been generated by initiation of Future Earth. The reason is that by combining the existing programmes[11] of IGBP, IHDP and DIVERSITAS there was no obvious niche for the establishment of new research programmes.

In a document addressing this issue, De Mulder et al. (2015) note that ‘as Future Earth is intended to be a “global research platform designed to provide knowledge needed to support transformations towards sustainability” all four spheres of System Earth should be included, the atmosphere, the hydrosphere, the biosphere and the geosphere. In Future Earth priorities as given in Future Earth’s Strategic Research Agenda, the authors observe a distinct lack of attention to the geosphere and its processes.’

Since then, Future Earth developed a mechanism to incorporate new activities in the form of Knowledge Action Networks,[12] with the following eight topics: Water–Energy–Food Nexus, Oceans, Transformations, Natural Assets, Sustainable Development Goals, Cities, Health and Finance & Economics.

Even though it may be difficult for the GeoUnions, as a collective, to find a niche in Future Earth, various initiatives of the individual unions are either already part of Future Earth or were established to foster such interaction. For example, The International Global Atmospheric Chemistry (IGAC) project[13] is a non-profit organisation created in the late 1980s to address growing international concerns over rapid changes observed in Earth’s atmosphere.

IGAC developed under joint sponsorship of the Commission on Atmospheric Chemistry and Global Pollution (CACGP) of the International Association of Meteorology and Atmospheric Sciences (IAMAS) and the International Geosphere-Biosphere Programme (IGBP) and became part of Future Earth when IGBP was incorporated into Future Earth. IAMAS is one of the eight constituent scientific associations of IUGG.

Within IUGG, there are two separate commissions that exist to deal with climate change. Within IAMAS itself there exists the International Commission on Climate (ICCL[14]), a group with a long history of bringing together physical scientists who study climate. In 2012, IUGG established a union commission – the Commission on Climatic and Environmental Change (CCEC [15]) to

a build scientific capacity for responsibly addressing the broad, multi-disciplinary issues involved in climatic and environmental change;
b provide useful information, understanding and support to the public and governmental organisations;
c interact and cooperate with outside activities that would benefit from the capabilities and resources of the IUGG Associations; and
d strengthen links across the scientific associations within IUGG, to build new external links to organisations outside IUGG, to strengthen existing links to external organisations and to promote IUGG’s contribution to global change research.

Figure 1.4 Illustration of the seventeen UN Sustainable Development Goals.

1.7 Sustainability

Sustainable development ('sustainability' for short) has been defined in many ways; the most frequently quoted definition is from Our Common Future, also known as the Brundtland Report: 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' The report continues: 'It contains within it two key concepts: the concept of "needs", in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs'.

The United Nations has entered a fifteen-year development goal package, from 2016 to 2030, known as the 17 Sustainable Development Goals (SDGs), that are illustrated in Figure 1.4. These show an understanding of the bi-directional impacts between humans and Earth. The original MDGs were included, goals relating to the environment were better defined and the importance of globally shared and delegated roles and responsibilities was further highlighted. The December 2015 Paris Agreement includes also acknowledgement 'that climate change is a common concern of humankind' and of an 'intrinsic relationship' between climatic change and poverty, hunger, equality, health, education, etc.

The scientific community has, to date

- Undertaken a review of the targets (ICSU, ISSC 2015). There are 17 Goals but 169 targets;
- Produced a working paper on a framework for SDG interactions, with a commentary that was published in *Nature*[16] (Nilsson et al., 2016);
- Produced a report (International Council for Science, 2017) on SDG interactions focussing on the detailed interactions for Goals 2 (Hunger), 3 (Health), 7 (Energy) and 14 (Water).

1.7.1 Quantifying Sustainability

The ecological footprint is probably the best known way of quantifying sustainability. The method measures the biologically productive land and water area required to produce the resources consumed and to assimilate the wastes generated using prevailing technology. This area, called the Ecological Footprint, represents the fraction of the biosphere necessary to maintain the current material throughput of the human economy under current management and production practices (Wackernagel et al. 2002; Amekudzi et al. 2015).

These calculations indicate that at present humanity uses the equivalent of 1.6 planets to provide the resources we use and absorb our waste. This means it now takes the Earth one year and six months to

Table 1.1 *How the International Scientific Association That Comprises the International Union of Geodesy and Geophysics (IUGG) Can Assist in Analysis of the Sustainable Development Goals*

Mapping IUGG/Associatious to the UN Sustainable Development Goals

Goal	IUGG	IACS	IAG	IAGA	IAHS	IAMAS	IAPSO	IASPEI	IAVCEI
1.5	CCEC, GRC	x	x	x	x	x	x	x	x
2.4	CCEC, GRC	x	x		x	x	x	x	x
3.9					x	x			
4.7	x	x	x	x	x	x	x	x	x
4.b	x	x	x	x	x	x	x	x	x
5.5	x	x	x	x	x	x	x	x	x
6.3–6.7		x				x			
7.a					x	x	x	x	x
9.5–9.6	x	x	x	x	x	x	x	x	x
9.6	x	x	x	x	x	x	x	x	x
11.5	GRC	x	x	x	x	x	x	x	x
11.6	CCEC					x			
11.b	GRC	x	x	x	x	x	x	x	x
13.1	CCEC, GRC	x	x	x	x	x	x	x	x
13.3	CCEC	x			x	x	x		
14.1–14.3							x		
14.a, 14.c							x		
15.1		x			x	x		x	
15.3	GRC				x	x			
16.6–16.7	x	x	x	x	x	x	x	x	x
17.6	x	x	x	x	x	x	x	x	x
17.16	x								
17.18	UCDI		x	x			x		

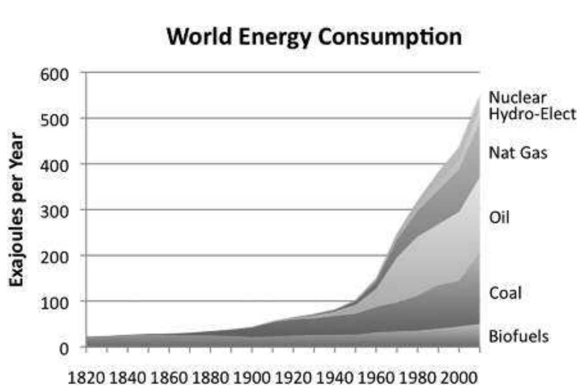

Figure 1.5 World Energy Consumption (from https://ourfiniteworld.com/2012/03/12/world-energy-consumption-since-1820-in-charts/).

regenerate what we use in a year.[17] If we re-examine this issue from an energetic perspective, in 2008 the world consumed, through fossil fuel burning, 48.5×10^{19} J. Over a year the sun radiates 40.24×10^{23} J on the Earth's surface. If we assume that 1 per cent of this is available for photosynthesis, then in energetic terms the fossil fuel consumption is 1 per cent of the energy available for photosynthesis. However if energy consumption continues to grow as shown in Figure 1.5, then eventually it will exceed available. Haberl et al. (2007) introduced the concept of 'human appropriation of the world's net primary productivity (HANPP)', as an indicator of the amount and intensity of land use by humans. It is measured as a percentage of total potential vegetation, which in turn is a measure of the incoming solar radiation and has been estimated to have been between 23 and 45 per cent around the year 2000.

Hall et al. (2014) show that the energy return on energy invested in fossil fuel production is declining, indicating that more and more effort is required to extract the fossil fuel needed by the world.

1.7.2 The Role of Geodesists and Geophysicists

Table 1.1 shows how the international geophysical community can assist in analysis of the Sustainable Development Goals. The particular goals and targets that bring together climatic and environmental change (shown as CCEC in Table 1.1) are: