7 Economic Approaches to Energy, Environment and Sustainability

Paul Ekins, Paul Drummond and Jim Watson

Abstract

We first present an overview of different conceptual views of the relationship between the economy and the environment, and on the 'sustainability' of the interaction between them, and how this may be measured. We then discuss the components of the '*Energy Trilemma*'; energy security, decarbonization, and energy access and affordability, before examining the policies required for advancing a green, low-carbon economy – including lessons from and priority research areas surrounding EU climate policy. Issues relating to the science-policy 'interface' are then presented, before priorities for research on energy, the environment and sustainability are summarized.

7.1 Introduction

The intertwined topics of energy, environment and sustainability have, perhaps, more than other topics, been treated from a variety of economic perspectives, and in an interdisciplinary way that is outside economics altogether. The structure of this chapter is as follows. Section 7.2 first outlines the different schools of economic thought that influence the way in which the economy, natural resources and the environment are conceptualized and are seen to influence each other. Section 7.3 then explores how these economic approaches have been applied to fashion the core concepts in contemporary environmental and development discourse, of sustainable development, and the distinct but related idea of sustainability. This then leads to considerations of principles of environmental sustainability and, more broadly, of the many different measures that have been applied to assess progress or otherwise towards sustainable development. Section 7.4 focuses on the issues and future requirements concerning the energy system and climate change mitigation, particularly through the lens of the '*energy trilemma*'. Section 7.5 then discusses the policies required to achieve these requirements, and for a broader '*green economy*'. Section 7.6 assesses the interface and interaction between scientific analysis of the issues, and practitioners, policy and policy-makers. Section 7.7 concludes, and summarizes priorities for research in the field.

7.2 Economic Approaches to the Environment

In any general overview of economic literature it is hard to avoid the conclusion that the economics of natural resources and the environment is usually regarded as a relatively unimportant topic. For example, the book by Canterbery (2011), entitled a *Brief History of Economics*, has no entry in the Index for 'resources', 'natural resources', or 'environment', although as Hueting (1980) recognized, natural resources and the environment, and the ecosystem goods and services they produce are scarce goods, they are subject to competition, and they contribute to human welfare. As such, they fall squarely within Robbins's (1935) definition of economics. The two principal schools of economic thought regarding natural resources and the environment (concerning both natural resources and pollution) are '*environmental and resource*' economics and '*ecological*' economics.

7.2.1 Environmental and Resource Economics

Environmental and resource economics broadly adopts the worldview of mainstream neoclassical economics, and considers environmental concerns an aspect of broader economic issues to which the approaches of methodological individualism (general equilibrium models), rationality, marginalism and efficiency may be suitably applied. In this view the focus of economic analysis is overwhelmingly on the economy depicted as a flow of money between firms, households and government. When the environment is considered at all, it is in terms of 'externalities', the phenomenon whereby a third party is affected positively or negatively by the economic activities of others. The most common example of a negative environmental externality is pollution of air, water or land, which affects others who are not part of the economic activity or transaction that created it. The term 'externality' conveys the fact that the impact on the environment is often external to the market or other economic activity that created it, and as a result is not included in the prices of, and is therefore not taken account of in, the relevant transaction or any calculus of the activity's social benefit. Such externalities are characterized as a market failure and the standard environmental economic prescription for the correction of a negative environmental externality is the levying of a '*Pigouvian tax*' at the rate equal to the marginal social cost of the externality at the point where this equals the marginal social benefit of the activity causing it. This prescription indicates a key characteristic and dominant method of welfare analysis applied in environmental and resource economics, namely the conversion of all impacts from the economy, market transactions and externalities, into monetary values so an economic optimum can be computed in a social cost benefit analysis. This analytic method derives from an assumption of 'weak' sustainability, which purports that different forms of capital (discussed in Section 7.3.2) are (often fully) substitutable. Methods for nonmarket valuation of externalities, including key issues raised by such approaches, are also discussed in Section 7.3.2.

7.2.2 Ecological Economics

In contrast to environmental and resource economics, ecological economics considers the human economy as a component of the global ecosystem, and employs '*methodological pluralism*' to assess different aspects of what proponents view as a highly complex, multifaceted human-economy-environment interaction (Venkatachalam, 2007). Ecological economics considers the human economy as subject to the laws of thermodynamics, extracting high-grade energy, materials and ecosystem services from the natural environment, and discharging low-grade energy and wastes back into it, with consequent degradation of the ecosystems that produce the services. As such, as economic activity expands, so too does the throughput of energy and materials (the *physical growth* of the economy). Broadly, ecological economics represents the idea of 'strong' sustainability (discussed in Section 7.3.2), which purports that different forms of capital are not fully (or even widely) substitutable. Another key difference between environmental and ecological economics is their view of human motivation and behaviour. Implicit in much of the environmental economics worldview and literature is the assumption of rational, self-interested, utilitarian behaviour (*homo economicus*), whilst ecological economics largely rejects this model and leans towards the assumption of co-operative actors capable of being motivated by improving their environment (*homo reciprocans*) (Jansen and Jager, 2000). The institutional, evolutionary and behavioural schools of economic thought, discussed in Section 7.2.3, concur with this rejection.

Over time, these different views have matured into 'a new substantive research agenda, straddling resource, environmental and ecological economics', that needs to be tackled in 'a pluralistic and multidisciplinary spirit of tolerance' (Turner, 2002, p. 1003). The agenda included 'questions about sustainability and the substitutability of different forms of capital, including natural capital; macro-environmental scale and thermodynamic limits in source and sink terms; future technological and other changes, together with the problems of novelty and "surprise"; ecosystem resilience, thresholds and chaos'. Other issues were 'more fundamentally contentious', and included 'value systems, philosophy and ethics and related policy prescriptions' (Turner, 2002, p. 1003). Many of these issues are discussed further in the sections that follow.

7.2.3 Institutional, Evolutionary, and Behavioural Economics

These three schools of economics are included here because each is relevant to ongoing efforts to understand how humans interact with the natural environment through the economy, and how these interactions change over time. Each also challenges the core tenets of neoclassical economics, including assumptions of rational, welfare-maximizing behaviour by all economic agents (individuals and firms) according to exogenous preferences, the absence of chronic information problems, complexity and limits to cognitive capacity, and a theoretical focus on movements towards or attained equilibrium states of rest (Hodgson, 1988, p. xviii).

Institutional economics emphasizes the importance of institutions to economic action. Hodgson described economic institutions as 'complexes of habits, roles and conventional behaviour' (Hodgson, 1988, p. 140), whilst John Commons, another early father of institutional economics, conceived of them as 'embodying collective action' (Rutherford, 1983, p. 722), and 'including the state, political parties, courts, unions, firms, churches, and the like . . . [with their] rules, regulations, customs, common practices and laws that regulate the actions of individuals and concerns' (Rutherford, 1983, p. 723). Many institutional economists have paid little attention to the natural environment, and even (Hodgson, 1988, Figure 1.2, p. 16) considers it outside 'the projected domain of institutional economic theory', although many have applied this school of thought to resources and the environment (a recent example of which is Bromley, 2014). Although the terms 'institutional' and 'evolutionary' economics are often used interchangeably, the more ecologically aware version of the latter conceives development as a co-evolutionary process between five dimensions of economic and ecological systems: values, knowledge, organization, technology, and the environment (Norgaard, 2010). Furthermore, many evolutionary economists have focused in particular on the important role of technical change and innovation in markets and in broader long-run changes in economies (e.g., Freeman (1992)).

Behavioural economics focuses on the behaviour of individuals, rather than the nature of the institutions that influence or constrain them. An extensive behavioural economics literature concludes that human behaviour is highly complex, and exhibits characteristics of both *homo economicus* and *homo reciprocans*, espoused by environmental/resource and ecological economics, respectively (Gsottbauer and van den Bergh, 2011). Glasser (2002) explores a number of moral considerations and other factors that can result in actual human behaviour departing from the narrow self-interested and static assumptions of much neoclassical consumer theory. Moreover, people have often been observed to seek equitable outcomes where self-interest would produce higher rewards (Fehr and Schmidt, 1999). While this evidence runs counter to the basic *homo economicus* model, other evidence suggests that the *homo reciprocans* model is unlikely to be broadly applicable either. For example, Dohmen et al. (2006) suggest that cooperation, even when it produces short-term costs to those engaging in it, may be in their long-term self-interest under certain conditions. An ongoing subject for further research is how to integrate such complex behavioural issues into economic-environmental models (An, 2012). Other behavioural economics literature that departs from neoclassical assumptions regarding individual behaviour concern '*satisficing*' and '*bounded*' rationality (where decisions are constrained by cognitive processes and available information), the presence of hyperbolic or '*present-biased*' rather than exponential discount rates (Venkatachalam, 2007), and the practice of '*mental accounting*' (which suggests that the substitution functions between different environmental goods and services is not smooth) (Knetsch, 2005). Additionally, the experiments reported in Kahneman et al. (1982) suggest that under uncertainty people look to heuristics and norms based on notions such as anchoring, availability and representativeness to guide their decisions, and further investigation established that these norms can acquire moral connotations associated with judgements about 'fairness' (Kahneman et al., 1986).

7.3 Sustainability and Sustainable Development

It is common in the literature to see the concepts of 'sustainable development' and 'sustainability' used interchangeably. However the distinction between these two concepts has been developed in some detail in Ekins (2011), and is briefly described in this section. Linguistically, the idea of 'sustainability' denotes the capacity for continuance into the future, and immediately begs the question – continuance of what? That question has a number of answers in the context of the sustainability literature, three of which are sustainability of the environment (environmental sustainability), sustainability of the economy (economic sustainability) and the sustainability of society (social sustainability). The over-arching concept that contains these three ideas is sustainable development; development that has the capacity of continuing into the future.

7.3.1 Sustainable Development

Definitions

Since it was first brought to prominence by the Brundtland Report (World Commission on Environment and Development, WCED, 1987), the concept of sustainable development has achieved and maintained a high international profile. Most recently, in September 2015, the United Nations General Assembly convened to adopt a broad range of Sustainable Development Goals (SDGs), to replace the Millennium Development Goals (MDGs) adopted in 2000. The unanimity of support for sustainable development may give the misleading impression that its meaning and implications are clear. In fact, as early as 1989, Pearce et al. (1989) were able to cite a 'gallery of definitions', and although absolute clarity of meaning remains lacking, progress has been made. For example, (Jacobs 1999, p. 25) lists six ideas that are fundamental to sustainable development: environment-economy integration, futurity, environmental protection, equity, quality of life, and participation. These concepts are repeated in all of the more extended definitions of sustainable development, including that in 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', WCED, 1987, p. 7), which clearly encompasses the first four of the six points above.

However, the scope for controversy increases markedly with attempts to move beyond such definitions, to identify policy objectives. For example, given that 'quality of life' contains many different dimensions, what is the balance to be struck between them in situations where they conflict? And are environmental objectives really compatible with aspirations for indefinite economic growth, to which all countries remain absolutely committed? And, intergenerationally, what is the balance to be struck between present and future generations, between development now and environmental sustainability for the future? These are intractable questions, to which it is unlikely that there are generally accepted answers. Rather, the answers will have to be continually negotiated and renegotiated through political processes, with considerable scope for confusion, misunderstanding and conflict. It may, therefore, justifiably be asked why policy-makers persist with, and have given new importance to, the concept of sustainable development if it is so problematic in practice. To answer this question it is necessary to go back to why the concept of sustainable development was introduced in the first place. This was basically in response to two concerns: the pace and scale of environmental degradation and perceptions of potential limits to economic growth.

Environmental Degradation

The principal cause of the increasing realization that a new path of development had to be found was the growing scientific evidence over the 1970s and 1980s, that has further accumulated since, that the combination of economic and human population growth was inflicting damage on the environment that threatened to disrupt some of the most fundamental natural systems of the biosphere, with incalculable consequences. The most recent evidence of widespread environmental degradation comes from four large-scale reviews. The first, the Millennium Ecosystem Assessment (MEA), was the first comprehensive evaluation of the impact of human activities on the natural environment and the ecosystem functions it provides. It identified three main problems arising from these activities: the degradation or unsustainable use of approximately 60 per cent of the ecosystem services (defined in Section 7.3.2) it examined; evidence that changes being made in ecosystems were increasing the likelihood of nonlinear changes in ecosystems (including accelerating, abrupt, and potentially irreversible changes) that have important consequences for human well-being; and the fact that the negative results of environmental degradation were being borne disproportionately by the poor, 'contributing to growing inequities and disparities across groups of people, and sometimes the principal factor causing poverty and social conflict.' (MEA, 2005, pp. 1–2). Secondly, in 2009, Rockström et al. (2009) developed the concept of '*planetary boundaries*', which defined a '*safe operating space*' for humanity within the environment, and published evidence of human activities in relation to this space across nine environmental issues. Their work suggested that for biodiversity loss, climate change and the nitrogen cycle, human activities were already outside the safe operating space (with the phosphorus cycle fast approaching this condition).

Thirdly, the Fifth Global Environmental Outlook of the United Nations Environment Programme concluded that 'As human pressures within the Earth System increase, several critical thresholds are approaching or have been exceeded, beyond which abrupt and nonlinear changes to the life-support functions of the planet could occur. There is an urgent need to address the underlying drivers of the human pressures on the Earth System' (UNEP, 2012, p. 194). Finally, in 2013 the Intergovernmental Panel on Climate Change (IPCC), in its Fifth Assessment Report, gave its starkest assessment yet on the threats to humanity because of its continuing large-scale emission of greenhouse gases (GHGs), with five 'integrative reasons for concern', namely unique and threatened ecosystems; extreme weather events; distribution of impacts; global aggregate impacts, including extensive biodiversity loss; and large-scale singular events, with risks of '*tipping points*' (IPCC WGII, 2014, p. 12).

Limits to Growth

The first economist to make an unequivocal prognosis of the unsustainable nature of human development was Thomas Malthus (Malthus, 1798). To summarize drastically, he noted that human population had an exponential growth trajectory, that agricultural productivity had a linear growth trajectory, and that fertile land was absolutely limited. From this, he drew the conclusion that human population growth would be brought to a halt by a shortage of food, and that such population as remained would bump along between subsistence and famine, disease and war. He considered that technology might increase the productivity of land, but ruled out the possibility that it could do so sufficiently to negate for long the difference between rates of increase of human populations and agricultural production, which led him to his dismal conclusion. Malthus was wrong, but that does not mean that this basic insight – that the physical resources of the planet are finite, and that the indefinite expansion of human activities that use these resources will lead to catastrophe – will always prove wrong.

The most powerful expression of the Malthusian prognosis in modern times was from Meadows et al. (1972), with the famous Club of Rome report *Limits to Growth*, which concluded that growing population and economic activity would exhaust resources, and that this and the pollution from this activity would result in the '*overshoot and collapse*' of both human population and economic output. In contrast to that of Malthus, this prognosis has not yet been proved wrong, because the authors envisaged this outcome within 100 years – a period that is not yet half way through. Moreover, the same authors have issued periodic updates of their prognosis claiming that their original projections were either essentially on track, or even optimistic, and overshoot and collapse could occur earlier (Meadows et al., 2005). However, the great majority of economists reject these conclusions. They continue to hold to their critique of *Limits to Growth*, which was forcibly expressed at the time, and which held that scarcity would be expressed in markets through rising prices, and would stimulate substitution away from scarce to more abundant resources, while technological progress would continue to make resources more productive and control pollution, well before overshoot and collapse took place. In recent years, the debate between these opposing points has centred on the question of whether it is possible to 'decouple' economic growth from environmental constraints and pressures.

Decoupling and the Environmental Kuznets Curve

Decoupling is the term used to describe a situation in which some environmental pressure (resource depletion or pollution) grows less fast than the economic activity causing it (relative decoupling) or declines while the activity continues to grow (absolute decoupling). The latter concept is reflected by the Environmental Kuznets Curve (EKC) hypothesis. The EKC suggests that the relationship between income and resource depletion and pollution levels follows an 'n'-shaped parabola; resource depletion and pollution levels increase with income until a given level of income is reached, after which environmental pressures decrease, with the reductions driven by, rather than simply inversely correlated to, increasing income. The term is borrowed from the original Kuznets Curve idea, which concerns the relation between income and inequality (Franklin and Ruth, 2012). The EKC aligns with the environmental economics position, but is at odds with the ecological economics standpoint. The former tends to consider growth as neutral or even positive for the environment, as technological innovation and substitution, the level of human capital (discussed in Section 7.3.2) and economies of scale increase efficiency of resource use and reduce environmental impact (including pollution and other wastes). The latter considers population as the 'consuming unit' of natural resources, with growth in population, affluence and technology mutually reinforcing each other to produce a nonlinear negative impact on the environment (through both the use of natural resources and resulting pollution) (Venkatachalam, 2007).

A very substantial body of theoretical and empirical literature has investigated this hypothesis, with no consensus reached on its validity. Studies produce different conclusions for different pollutants into different media (including local, transboundary and global commons pollutants), across different spatial scales, from different sources and in different economies. Additionally, when studies may agree on the existence of the EKC for a given set of conditions, they often disagree on where the peak of the curve lies (Chowdhury and Moran, 2012; Franklin and Ruth, 2012). The first explanation for such varied results is methodological. Data availability and quality is often cited as an issue (Chowdhury and Moran, 2012), along with the high degree of statistical sensitivity of such data to the specific modelling approach employed (Harbaugh et al., 2002). Reduced-form models are often used, linking income and pollution levels directly and reducing the need for data collection on multiple variables, rather than structural equation models that are more able to characterize the nature of the links between these variables. The second explanation is simply that it is unlikely that the EKC hypothesis is applicable as a general theory.

The influence of political and institutional circumstances on the relationship between economic growth and environmental damage is undoubtedly significant. In fact, a common explanatory factor for the EKC, where evidence for it exists, is that with increasing prosperity, citizens pay increasing attention to noneconomic aspects of their living conditions. Such '*vigilance and advocacy*' is then reflected by the introduction of increasingly stringent environmental protection instruments (Torras and Boyce, 1998). However, where an increased vigilance and advocacy is found to exist, the causal relationship between this and the introduction of environmental protection depends on the extent to which public preferences are heard by governing institutions, and whether pressure to act upon them exists. Indeed, evidence suggests that in the long-run, the higher the 'democratic stock' of a nation (i.e., the accumulation and evolution of democratic institutions over time, and thus the representation of and pressure from public opinion), the higher the level of environmental quality with respect to some pollutants (Gallagher and Thacker, 2008), whilst Torras and Boyce (1998) find that political rights and civil liberties (in addition to literacy) have a particularly strong positive effect on environmental quality in low-income countries. In addition, López and Mitra (2000) find that where corruption is found, while it may coexist with an EKC, levels of pollution for any level of income are likely to be above the socially optimal level (including the apex of the EKC).

Generating further insights into the validity or otherwise of the EKC hypothesis will require improved data availability and modelling approaches, including improved characterization of the technological, institutional (and broader political economy), and behavioural phenomena highlighted in Section 7.2.3 (Chowdhury and Moran, 2012). An additional focus on economic and demographic structures, which has thus far received little attention in the EKC literature (Franklin and Ruth, 2012), would also be beneficial, along with further investigation into the Pollution Haven and Porter Hypotheses (discussed in Section 7.5.5). Such research would advance the ongoing search for a more nuanced theory (or theories) regarding the link between economic development and environmental degradation.

7.3.2 Environmental Sustainability

The Concept of Capital

Conceiving of sustainability as the capacity for continuance immediately suggests, to economists at least, its logical connection to the concept of capital, where capital is a stock, or asset, that has the characteristic of producing a flow of goods and services, which contribute to human well-being. In order to maintain or increase welfare, the quantity of capital stock must therefore be maintained or increased. Four different types of capital may be identified. The first is 'manufactured capital' (e.g., built infrastructure), the traditional focus of capital economics. The second is 'human capital' (e.g., knowledge, skills, health), which extends the traditional identification of labour as a factor of production (and is explored further in Chapter 4). The third and fourth categories are relatively new to the concept of capital; 'social capital', which includes insights from institutional economics regarding the importance in economic activity of relationships and institutions, and 'natural capital' (also called environmental or ecological capital). Environmental sustainability is clearly related to natural capital, a broad definition of which might be everything in nature (biotic and abiotic) capable of contributing to human welfare, either through the production process or directly.

Viewed in these terms, what needs to be kept for environmental sustainability to be achieved is the flow of benefits that humans derive from it. Such benefits derive from '*ecosystem services*' that flow from stocks of natural capital. These functions or services may be grouped into three broad kinds: the provision of resources, the absorption and neutralization of wastes, and the generation of services ranging from life-support (such as the maintenance of a stable climate) to amenity and recreation (Pearce and Turner, 1990). These three sets of functions collectively maintain the biosphere, and contribute to the human economy, human health and human welfare. However, as noted above (Section 7.2.1), the economy's use of the environment can impact negatively on the biosphere, and thus on the welfare which other people derive from it, through negative externalities.

Because natural capital has featured regularly in various definitions of sustainability and sustainable development, more attention has been paid to the concept as sustainable development has risen up the public policy agenda. In this context, considerable efforts have been invested in developing and making environmental indicators operational (discussed in Section 7.3.3).

Weak and Strong Sustainability

Environmental economics traditionally considers environmental resource scarcity as a Ricardian 'relative scarcity' issue, where biophysical constraints on economic growth may be overcome by incurring additional cost in the economy in the short-term (through investment in innovative technology) (Venkatachalam, 2007). This derives from a view that human or manufactured capital can substitute almost entirely for natural capital and ecosystem services, leading to the *weak sustainability* conclusion that, as long as the total economic value of all capital stocks (natural, human and man-made) can be maintained in real terms, regardless of the distribution between the different types, sustainability is achieved. An important strand in the sustainability and sustainable development literatures has called these assumptions into question, particularly for natural capital. The idea of *strong sustainability*, more often espoused in ecological economics, considers that certain elements, aspects are characteristics of natural resources and the environment, such as uncertainty and the 'irreversibility' of some phenomena (e.g., an extinct species cannot be recovered) (Pelenc and Ballet, 2015) mean that some kinds of natural capital, which has been called 'critical' natural capital (CNC) (Ekins et al., 2003) makes a unique contribution to welfare or has intrinsic value and therefore cannot be substituted by manufactured or other forms of capital.

Despite the contrasting theoretical positions taken on these issues, there is increasing alignment on them in practice in the environmental and ecological economics literatures. For example, many environmental economists recognize issues of multi-functionality, irreversibility and uncertainties surrounding natural capital, and support the idea of maintaining the natural capital stock independently of man-made capital. Summarizing the literature on the debate between the validity of the weak or strong sustainability approaches, Dietz and Neumayer (2007, p. 619) list four reasons why the strong approach to sustainability may be preferred to the weak: risk and uncertainty, irreversibility, risk aversion and the ethical nonsubstitutability of consumption for natural capital. However, proponents of both paradigms appear to agree that it is unlikely to be possible to conclude which natural capital may be considered 'critical' over an indefinite time horizon (Illge and Schwarze, 2009). A key, long-standing question remains the extent to which these two concepts may be combined, and how, to be useful for policy-makers and other stakeholders. Numerous indicators and indices of sustainability exist, with varied approaches, producing equally varied results (Mayer, 2008). Positions could probably be further aligned through the development of a robust, common indicator for sustainability, or collection of indicators, as discussed in Section 7.3.3.

Principles of Environmental Sustainability

As discussed, environmental sustainability may be conceptualized as requiring the maintenance of benefits derived from environmental functions and the natural capital that generates them. The major factor in the operationalization of this definition is the process for identifying which benefits and associated environmental functions are important to maintain, and to use the terminology introduced above, which natural capital, and at what level of stock, is 'critical' for providing these functions.

de Groot et al. (2003) put forward the criteria of maintenance of human health, avoidance of threat and economic sustainability. On the basis of such criteria, a number of principles of environmental sustainability may be derived. These principles spring from the perception that, in order for the environment to be able to continue to perform its functions, the impacts of human activities on it must be limited in some ways. At the global level it would seem important not to disrupt the climate (discussed further in Section 7.4), deplete the ozone layer or significantly reduce biodiversity. For pollution generally, emissions should not exceed levels at which they cause damage to human health, or the critical loads of receiving ecosystems. Renewable resources should be renewed, and the development of renewable substitutes should accompany the depletion of nonrenewable resources. For each of these, quantitative standards describing the environmental states (e.g., concentrations of pollutants) and pressures (e.g., emissions of pollutants) that are consistent with the criteria defined by de Groot et al. (2003) may be readily derived (though not without a broad range of uncertainty in some cases) from environmental science; for resources, it is depletion (or nonrenewal) of renewable resources that is currently giving most cause for concern, especially with respect to biodiversity, many aspects of which cannot readily be reduced to the idea of 'resources' at all, so that identifying sustainability standards for biodiversity is likely to be especially challenging. Given the great uncertainty attached to many environmental impacts, and the possibility that some of these may give rise to very large costs, the Precautionary Principle should also be used as a sustainability principle.

Valuation of Natural Capital and Ecosystem Services

A major divergence between environmental and ecological economics concerns the view of and approach to the valuation of natural capital and ecosystem services. Environmental economics tends to adopt an anthropocentric, preference-based, 'instrumental' approach based on the calculation of the monetized value of natural resources and services, according to the economic welfare of individuals, and in line with the weak sustainability paradigm. Ecological economics rather promotes the notion of nonmonetized 'intrinsic', rather than monetary value (Venkatachalam, 2007), in line with the strong sustainability perspective. Despite these traditionally opposing views, ecological economists now widely use and promote the monetary valuation of natural capital and ecosystem services (to calculate both instrumental and intrinsic values), possibly driven by pragmatism, leading to monetary valuation as a social convention among researchers (Plumecocq, 2014). There are six primary natural capital and ecosystem service valuation methodologies: *avoided cost* (services that allow society to avoid costs in the absence of those services, such as waste treatment by wetlands avoids heath costs or treatment by artificial means), *replacement cost* (services could be replaced by manmade systems, such as natural waste treatment can be replaced with artificial treatment systems), *factor income* (services provide for the enhancement of incomes, such as water quality improvements increase commercial fisheries catch and incomes of fishermen), *travel cost* (service demand may require travel, whose costs can reflect the implied value of the service, such as recreation areas attract visitors whose value placed on that area must be at least what they were willing to pay to travel to it), *hedonic pricing* (service demand must be reflected in the prices people pay for associated goods, such as housing prices at beaches exceed prices of otherwise identical inland homes without such an amenity), and finally, *contingent valuation* (service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives, such as people would be willing to pay for increased forest cover) (Farber et al., 2002).

Each technique has particular strengths and weaknesses, with the most appropriate approach (or combination of approaches) and specific design based on the stock or service of interest. Valuation methodologies have been applied extensively to land, freshwater and marine resources across the world, including an extensive assessment across the EU's Natura 2000 network, using a combination of the approaches listed above (European Commission, 2013). Four key areas for further research regarding natural capital and ecosystem service valuation present themselves in the literature. The first is how to include or mitigate the effects of behavioural and psychological phenomena, discussed in Section 7.2.3 (Scholte et al., 2015). Such issues contribute to the substantial difference in results produced by techniques that determine '*stated preferences*' and '*revealed preferences*', along with '*willingness to pay*' and '*willingness to accept (compensation)*' approaches (Venkatachalam, 2007). The second surrounds how nonmonetary valuation, such as social-cultural value, may be integrated or made complementary to monetary valuation (Scholte et al., 2015). The third is on how monetary valuation of natural capital and ecosystem services itself impacts behaviour. For example, whether monetary valuation crowds out other forms of valuation (by altering the 'framing' of the good or service) (Neuteleers and Engelen, 2014). The fourth key area, linked to the previous two in particular, is the extent to and nature in which ecosystem service valuation can and does impact decision- and policy-making, and why (Laurans and Mermet, 2014) – including whether 'commodification' in discourse leads to 'commodification' in practice (e.g., via the use of payments for ecosystem services, discussed in Section 7.5.3) (Neuteleers and Engelen, 2014). Additionally, whilst a significant body of literature has been published on the valuation of biodiversity, the majority of studies instead value individual species, habitats or ecosystem services, rather than biodiversity per se, largely due to a lack of consensus on how 'biodiversity' may be defined and measured (Beaumont et al., 2008). Such an issue is also a topic for ongoing research.

Marginal Costs of Environmental Degradation

Linked to the valuation of natural capital and ecosystem services themselves is the marginal social cost of their degradation through resource extraction and pollution. This is a focus particularly in environmental economics, which uses social cost-benefit analysis as a key tool to determine the 'optimal' level between mitigation of such degradation (through policy mechanisms), and maintenance of the degrading activity. However, calculation of these marginal social costs is complex, and highly dependent on the characteristics of the pollution or resource considered and circumstances of its production, release or extraction. Broadly, it may be argued that the difficulty and uncertainty of marginal social cost calculation increases with spatial impacts (e.g., whether the pollutant is largely local, such as PM_{10}, or impacts the global commons, such as CO_2), as the heterogeneity, complexity and dynamic interaction between impacts increases. A broad and expanding base of literature attempting to estimate the marginal cost of CO_2 emissions (or the '*Social Cost of Carbon*', SCC), produces values spanning at least three orders of magnitude (Watkiss and Downing, 2008). Two principal drivers behind such disparity include different assumptions regarding behaviour of economic agents, and monetary valuation of nonmarket entities (including natural capital and ecosystem services, discussed above, but also human health, etc.) (Van den Bergh and Botzen, 2015). As such, continued research into and improvement of nonmarket valuation techniques (both broadly and as related to natural capital and ecosystem services), and the focussed inclusion of behavioural insights into economic modelling would improve the calculation of marginal costs of pollution (at all spatial scales).

Two further essential issues lie behind such a range of estimates. The first is the value of the social discount rate used to compute the present value of costs and benefits experienced in the future. Unfortunately there is little agreement as to what the appropriate discount rate, especially with respect to such long-term issues such as those raised by climate change, should be. This has important implications for intergenerational equity – a high (exponential) discount rate quickly places a low value on the costs and benefits of resource extraction, pollution damage (including climate impacts) and policy interventions impacting future generations. Van den Bergh and Botzen (2015) provide a recent overview of the literature on discounting as applied to SCC calculations, and highlight the specific points of contention. They also highlight the requirement for further research on how to reflect risk aversion and uncertainty (both about the future and about the true value and profile of social discount rates) in discount rates employed in cost-benefit analyses.

The second issue is the specific characteristics of the consequences of CO_2 emissions (i.e., climate change), specifically (a) the likely extent of the damage is very uncertain, but may be very large (even catastrophic), (b) it is likely to affect every aspect of human life: mortality, morbidity, migration, the provision of water, food and energy (which have come to be called the '*resource nexus*'), and cultural and spiritual values, (c) the results will play out over the very long term, and (d) the results may be irreversible. Techniques of environmental economic valuation are unable adequately to reflect such characteristics for a number of reasons, including those discussed in the subsection above, but also the nonmarginal, irreversible nature of the changes, and the lack of knowledge about the probabilities or even full range of possible outcomes. Weitzman (2007) highlighted that the combination of uncertain costs and uncertain probabilities of climate change damage produces '*fat tailed*' distributions, and potential costs that are conceptually infinite, rendering traditional cost-benefit methodologies inapplicable. He termed this his '*Dismal Theorem*'.

Environmental Justice

As noted in Section 7.3.1, it is widely accepted that a core conceptual component of sustainable development is equity, both within and between generations. When applied to environmental issues this idea is often framed in terms of environmental justice (or injustice), which Laurent (2011) conceived as composed of four broad aspects: *exposure and access* (the distribution of environmental quality between individuals and groups, either negative, such as exposure to environmental nuisances, risk and hazard, or positive, such as access to environmental amenities), *policy impact* (the impact of environmental policies between individuals and groups, such as the distributional implications of an environmental tax; this, along with '*exposure and access*', may be classified as '*distributive*' justice), *environmental impact* (the environmental impact of different individuals and groups, related to lifestyle, consumption patterns, etc.), and finally, *representation in policy-making* (the involvement and empowerment of individuals and groups in decisions regarding their (usually immediate) environment; this may be termed '*procedural*' justice).

As with (and linked to) views on other subjects, there are different approaches to inter- and intra-generational equity in the environmental and ecological economics literature. A broad environmental economics view is that income growth and improved resource use efficiency, along with reduced pollution and other wastes (according to the EKC hypothesis) will improve intra-generational equity, as the poorest in society generally exhibit the highest exposure to 'bads' and the least access to 'goods'. At the same time intergenerational equity may be ensured through the maintenance of the total capital stock over time (following the 'weak sustainability' paradigm) (Venkatachalam, 2007). In contrast, many ecological economists view distributional injustice as a driver of environmental deterioration, so that intra-generational equity, as a precondition, makes an important contribution to intergenerational equity (Illge and Schwarze, 2009), in that the transfer of resources to future generations is influenced by the endowment of property rights, income distribution and the preferences of the preceding generations (Venkatachalam, 2007). In this view, the value of social discount rates is also clearly of significant importance for intergenerational equity.

Questions of environmental justice have been largely peripheral to debates surrounding valuation of natural capital and ecosystem services, discussed above, and subsequent policy instrument design and implementation (Matulis, 2014). However, they are becoming increasingly salient (McDermott et al., 2013). In particular, there are disagreements and uncertainties surrounding whether instruments utilizing monetary valuation reduce or exacerbate preexisting economic and social inequalities – particularly at a local level (a question of policy impact) (Matulis, 2014, Cobera, 2015). This is linked to a currently poor understanding of the dynamic interaction between distributional justice and procedural justice, and 'contextual' justice, which considers preexisting conditions (including culture, beliefs, practices and institutions) that limit or facilitate access to decision-making and environmental exposure and access, and therefore receipt of benefits or costs of policy intervention. This is now a key area for future research (McDermott et al., 2013, Cobera, 2015), that may be linked to priority research subjects highlighted in previous sections, surrounding natural capital and ecosystem service valuation methodologies and consequences, and consideration of behavioural and institutional economics. Further understanding of this interaction may allow for the advancement of a sound conceptual basis upon which to further develop and monitor robust indicators of environmental justice in practice, which has proven a continual difficultly thus far, despite several efforts (McDermott et al., 2013). The further development of such indicators aligns to broader efforts for indicators of sustainable development.

7.3.3 Measurement and Indicators of Sustainable Development and Sustainability

Since the UN Conference on Environment and Development in 1992, which established the idea of sustainable development as an overarching policy objective, there has been an explosion of activity to develop sustainable development indicators (SDIs) in order to determine whether sustainable development is actually being achieved. Because the meaning of sustainable development was (and is still) not particularly clear (as discussed in Section 7.3.1), this activity was characterized by much experimentation. Many indicator sets were put forward by different bodies at different levels (international, national, regional, local), and substantial efforts have since been invested in seeking to rationalize these into 'core' sets that can be used for comparison and benchmarking, while the development of particular sets of indicators for specific purposes has continued to flourish.

There are two main approaches to constructing indicators of sustainable development. The first is the 'framework' approach, which sets out a range of indicators intended to cover the main issues and concerns related to sustainable development. In 1996 the UNCSD published its first set of SDIs, comprising 134 economic, social, and environmental indicators (UN, 1996). The indicators were structured in a matrix that related Driving Force, State, and Response indicators to the chapters in Agenda 21. Because not all the indicators were relevant for the European Union, EUROSTAT carried out a study using a subset of 36 of these indicators, publishing the results of the study in 1997 (EUROSTAT, 1997). UNCSD subsequently produced a 'core' set of 59 SDIs based on its original set, and EUROSTAT (2001) produced another study involving 63 indicators, which related closely to the UNCSD core set and showed the very wide range of issues that sustainable development is considered to cover. There are many other frameworks of SDIs. Internationally, one of the best known is that published by the Organisation for Economic Co-operation and Development (OECD) in 2000. This contained a set of 'possible core sustainable development indicators', a number of country case studies on different aspects of sustainable development indicators, and indicators for the major environmentally significant sectors. It also contained a new set of social indicators, with context indicators and structured according to the themes of promoting autonomy (or self-sufficiency), equity, healthy living (or just health), and social cohesion. Within the themes the indicators were grouped according to social status and societal response (OECD, 2000).

The most recent and, arguably, most influential, framework of sustainable development indicators to be constructed is the Sustainable Development Goals (SDGs),[1] which were agreed by the United Nations in September 2015. There are 17 broad goals, spanning the economic, social and environmental dimensions of sustainable development, and underpinned by more than 100 indicators.

A limitation of the framework approach to indicators is that unless all the indicators are moving in the same direction (i.e., all making development more, or less, sustainable), it is not possible to say whether, in total, the objective of sustainable development is being advanced. This limitation is addressed by the second main approach to SDIs, which seeks to express development-related changes in a common unit so that they can be aggregated. A number of such methods have been developed, including *aggregation into environmental themes* (the approach underlying the Netherlands National Environmental Policy Plan process, described in Adriaanse (1993)), *aggregation across environmental themes* (one method of doing this is to weight the different themes according to perceptions of environmental performance, such as in the Eco-points system developed by BRE, 2008), and *aggregating across environmental and other themes* (this may use multi-criteria analysis, or relate the themes to some concept such as Quality of Life or Human Development). Another common aggregation approach is to express the different environmental impacts in monetary form. Examples include the Index of Sustainable Economic Welfare (ISEW), first proposed by Daly and Cobb (1989), which starts from consumer expenditure and then adds various social or environmental impacts. ISEW has been calculated for a number of countries, and has been further developed into the Genuine Progress Indicator (GPI), which has also been calculated for a number of countries, US states, and other subnational entities (see Posner and Costanza (2011) for further discussion). Another influential application is what is now termed '*inclusive wealth accounting*' (UNU-IHDP and UNEP (2014)). The approach remains rooted in weak sustainability, with the issues surrounding nonmarket valuation discussed in Section 7.3.2 coming into play. With this approach, therefore, whilst the indicator may be expressed as a single number, the number may lack credibility.

A third approach, confined to assessing (strong) environmental sustainability, involves establishing standards of environmental sustainability and calculating the 'gap' between current environmental situations and these standards. This gap may be characterized as the '*sustainability gap*' (SGAP) (Ekins and Simon, 1999). The SGAP concept takes explicit account of critical natural capital and indicates, in physical terms, the degree of consumption of natural capital or pollution levels in excess of what is required for environmental sustainability. The concept may also be applied to examine the time required, on present trends, to reach the standards of environmental sustainability ('*Years-to-Sustainability*'). See Ekins and Simon (1999, 2003) for further discussion of the SGAP concept, including how the indicator may be derived. A strong sustainability approach is also taken by the framework developed by the European research project CRITINC, which sets out a classification of natural capital in input-output form, together with the various steps that need to be implemented in order to identify CNC and whether the environmental functions are being sustainably used (Ekins et al., 2003). Over recent years, there has been considerable development of physical I-O tables (PIOT), and environmentally extended input output (EEIO) accounting, to match the monetary I-O tables which are a standard feature of national economic accounting (see, for example, Vaze, 1998, Stahmer et al., 1998 and, for an application of multi-region EEIO, Wiedmann et al., 2013).

7.4 The Energy System and Climate Change Mitigation

Energy is essential to human life, civilization and development. Societies became industrialized through their greatly enhanced use of energy per person, enabled by the discovery of fossil fuels and the development of technologies that enable their exploitation at an increasing scale, from less accessible locations, and with increasing efficiency. They continue to satisfy the great majority of the world's demand for energy, and their use, on current trajectories, is likely to continue to increase to provide energy to drive the continued development of emerging economies and to satisfy the needs and desires of an increasing global population, and to provide modern energy services to the current population of 1.4 billion people without access to electricity and 2.7 billion people who rely on biomass for cooking and heating (GEA, 2012). However, fossil fuels are increasingly associated with problems that are becoming more prominent on the world stage. The first is local air pollution. The old industrial societies have already grappled with, and to a considerable extent resolved, the local air pollutants associated with fossil fuel combustion. Fast-growing emerging economies, especially those that burn a lot of coal, are now struggling with the same problems. To these local air pollution issues arising from fossil fuel use may be added the global problem of CO_2 emissions from fossil fuel combustion, and associated climate change. A link between the two issues is that some actions to address CO_2 emissions from the energy system can also have a beneficial effect in terms of the reduction of both indoor and outdoor local air pollution (GEA, 2012, NCE, 2014).

The multidimensional nature of energy policy is sometimes expressed through the '*Energy Trilemma*' concept, employed by the World Energy Council (WEC) to describe the three objectives that most current energy policies now tend to seek to achieve. The three objectives are energy security, environmental sustainability (defined here as reducing CO_2 emissions), and energy equity (including accessibility and affordability) (WEC, 2015). Each objective is discussed below.

7.4.1 Energy Security

Although without a single definition, '*energy security*' relates to the desire of governments, businesses and citizens to have access to energy services when, where and in the quantity that they need and want – and at an affordable price. The factors that influence energy security may be summarized and grouped in numerous different ways and through a variety of different lenses, depending on the specific definition employed and the purpose of the categorization. However, from a broad perspective, six interrelated dimensions may be described (Mitchell et al., 2013).

The first concerns the *nature of the energy resources* in question. Many oil and gas resources are highly concentrated, leading to security risks that may produce rapid and significant price fluctuations. Relatively short-term changes in demand due to, for example, cold winters, may produce similar effects to constraints on supply. In the long term, the challenge of decarbonization (discussed below, in Section 7.4.2) may have a substantial impact. For fossil fuel exporters, decarbonization may be economically deeply threatening. For importers, this may give an opportunity to diversify away from fossil fuels to renewable energy sources or to nuclear power (both of which have their own, different, implications and challenges), and to increase energy system efficiency, reducing demand for energy in the first place. Indeed, the *technical characteristics* of the energy system comprise the second key dimension of energy security. Whilst energy efficiency measures can reduce energy demand, changes to the availability and relative costs of key technologies may alter the dynamics of the energy resources used to satisfy the demand that remains. For example, the development of low-cost electricity storage could reduce the need for back-up electricity generation capacity (such as natural gas) to maintain adequate supply when intermittent renewables (such as wind and solar) are not sufficient. In the shorter-term, vulnerability to 'common mode' failures (e.g., overheating power station, transmission substation failure) and 'one-off' failures (e.g., oil tanker spillage) may produce substantial effects. Technological and infrastructure vulnerability to natural events such as earthquakes, but also the impacts of climate change, such as threats to coastal sites and the availability of water for cooling in thermal generation, may also be significant (Watson and Scott, 2006).

The third dimension of energy security is the influence of *governance*. This exhibits two broad aspects. The first concerns governance structures. Energy security requires governance at multiple levels of jurisdiction (e.g., local, national and in the case of the EU, supranational), and an important concern is the extent to which responsibilities of and arrangements between each level (and with nongovernmental parties, such as energy suppliers) are clear and appropriate to ensure adequate decision-making for short- and long-term management. This is linked to the second aspect; the presence of appropriate strategy and policy that ensures the stable, secure and efficient operation of the energy system (such as protocols for its automated control), along with instruments and regulations that may be in place to meet health standards, emissions reduction goals and ethical standards that may rule out the use of otherwise available resources (e.g., fossil fuels from particular regions of the world, such as the Arctic).

The fourth dimension of energy security is the effect of *culture, norms and behaviour* of individuals, society, organizations and governments. This dimension is particularly multifaceted. The culture and norms of a society and government may dictate what rules, regulations and other policy instruments are feasible to introduce, and what technologies may be deployed. For example, concerning the EU legislature, a 'consensus reflex' still dominates, despite the formal permissibility of qualified majority voting (Wurzel, 2008, p. 82). In many countries, the acceptability of nuclear power reduced substantially in the wake of the Fukushima disaster in Japan in 2011. Additionally, culture and norms may influence what energy security means in the first place. For example, a primary component for improving energy security in a particular nation may be the reduced dependence on a particular fuel from a particular region (e.g., reducing reliance on Russian natural gas in Eastern and Central Europe). The behaviour of individuals and (nongovernmental) groups may impact energy security both directly and indirectly. For example, domestic activism and terror attacks may have substantial direct impacts on energy supplies. Indirectly, behavioural responses to policy instruments such as carbon pricing, subsidies for renewables and energy efficiency incentives (discussed in Section 7.5), along with nonpolicy influences such as underlying fuel price changes, may have equally substantial impacts (or, alternatively, little impact) on energy security in the longer-term.

The final two dimensions of energy security are particularly cross-cutting. The first of these, the fifth overall, is *time and space*. The dimensions above may influence energy security from a matter of seconds (e.g., terrorist attack or technical failure) to decades (e.g., resource depletion), and may themselves be influenced over such differing timeframes (e.g., particular instruments and market rules may be introduced relatively quickly if conditions permit, whilst altering culture and norms may take a generation). In terms of space, the processes of globalization, both of energy systems but also more broadly, have complex implications for energy security. On the one hand, countries without their own indigenous energy resources are obviously dependent on imports, and the extension and liberalization of energy markets can increase their energy security and provide them with access to lower cost sources of energy. On the other hand, the increasing use of energy encouraged by these open markets may introduce new vulnerabilities (e.g., volatile prices), and a new dependence on their continued and orderly functioning (Wicks, 2009). There is no straightforward relationship between the energy security of a given country and its degree of dependence on imported energy (Mitchell et al., 2013). The sixth and final dimension is *uncertainty*, which permeates all assessments of how the dimensions discussed above may develop into the future, and how such aspects may directly and indirectly influence each other over different timescales. Whilst uncertainty may be reduced by ongoing research into the particular influences of the above dimensions (both individually and in combination), and how the risks they hold for energy security may be mitigated, and benefits they have enhanced, a level of uncertainty will always remain. This must be recognized and understood, with decision-making and policy frameworks taking this into account (discussed in Section 7.5.5).

7.4.2 Reducing CO_2 Emissions

The most recent report of the Intergovernmental Panel on Climate Change (IPCC) concluded that 'anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. [Their effects], together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century' (IPCC WGIII, 2014b, p. 4). They also conclude that 'in recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans' (IPCC WGII, 2014, p. 4). Limiting CO_2-equivalent concentrations in the atmosphere to 450ppm (parts per million) would 'likely' (i.e., with a probability of 66–90%) limit warming to 2°C over the twenty-first century, relative to pre-industrial levels. Such a limit has been broadly accepted, and adopted by the United Nations Framework Convention on Climate Change (UNFCCC), to be the limit at which 'dangerous' climate change may be avoided – although, as discussed under Section 7.3.2, this is by no means certain. However, for the purposes of this Chapter, the 2°C target is assumed to be the '*environmentally sustainable*' limit. Achieving this target would require 40–70 per cent reductions in global anthropogenic GHG emissions by 2050 compared to 2010 levels, with emissions levels near zero in 2100 (IPCC, 2014). However, annual GHG emissions have continued to climb year on year, with recent data suggesting that 2014 may have been the first year in which CO_2 emissions from the energy sector (the principal type and source of anthropogenic GHG emissions) remained stable, rather than growing (IEA, 2015).

7.4.3 Financial Requirements and Affordability

A reduction of CO_2 emissions from the energy system may be delivered through a combination of three things: reduced demand for energy services (e.g., lighting, heating and transport), improved efficiency in delivering these services, and a reduction in the CO_2 intensity of the energy used to satisfy the remaining demand. Each of these may be delivered through a range of technological and behaviour change options, in varied combinations, to deliver the low-carbon objective. A well-known example of an attempt to classify various CO_2

abatement options from each of these three categories in terms of both abatement potential and associated cost per unit of CO_2 reduced is the so-called McKinsey (2007) marginal abatement cost curve (MACC). This curve shows that, globally, $5GtCO_{2e}$ ($\sim$ 15% current CO_2 emissions from the energy system) can be abated at negative net cost, and a further $21GtCO_{2e}$ (65% current CO_2 emissions from the energy system) can be abated at a marginal cost of less than €40/tonCO_{2e}.

Various estimates of the net additional annual investment cost to move from the current global emissions trajectory to one consistent with the 2°C limit exist; however a commonly cited figure is that produced by the IEA (IEA, 2012, p. 137), which calculates the need for an extra US $36 trillion invested in the energy system by 2050 – roughly US $1 trillion per year (a 35% increase from what would be required in the absence of the decarbonization imperative). With global GDP in 2012 at around US $70 trillion, and under the assumption that average annual global economic growth is around 2 per cent, this additional investment is in the order of 1 per cent the global GDP. However, this is not necessarily the same as a 1 per cent cost to GDP, as these additional investments in the energy system contribute to economic activity, and depending on their specific nature, may increase or decrease economic growth. Investment in energy efficiency measures and technologies that are already cost effective would tend to increase GDP (as noted above, McKinsey (2007) suggests that such opportunities are considerable). However, many low-carbon technologies currently cost more, and in some cases significantly more, than their fossil fuel alternatives. Furthermore, apparently cost effective measures such as energy efficiency are seldom implemented at the scale suggested by McKinsey (2007), and often require significant up-front investment. Such investments would tend to reduce GDP. However, it is expected that their large-scale deployment would cause their cost to be reduced. A number of new low-carbon technologies for power generation have indeed experienced significant cost reduction as they have been progressively deployed (Stern, 2007), discussed further in Section 7.5.4.

It is the macroeconomic costs and benefits of such investments that are of interest in calculating the overall economic impacts of CO_2 mitigation. Over the last 20 years, there have been a very large number of macroeconomic modelling analyses of CO_2 abatement. Barker (2008) carried out a meta-analysis of four of the most important such exercises, taking into account hundreds of model runs, using different, but mainly computable general equilibrium (CGE) models, in order to estimate the GDP costs of different levels of decarbonization. The majority of the runs estimated that a 60–80 per cent reduction in CO_2 emissions would cost between 1 per cent and 4 per cent of GDP. The IPCC's Fifth Assessment Report in 2014 arrived at a similar assessment on the basis of more recent published evidence, summarizing thus the costs of mitigation to a rather lower GHG concentration level (450ppm): ‘Most scenario studies collected for this assessment ... estimate that reaching about 450ppm CO_{2eq} by 2100 would entail global consumption losses of 1–4% in 2030 (median of 1.7%), 2–6% in 2050 (median of 3.4%), and 3–11% in 2100 (median of 4.8%) relative to what would happen without mitigation’ (IPCC WGIII, 2014a, Ch.6, pp. 418–419).

It is important to note that none of the baselines in the studies above, with which the mitigation runs were compared, incorporated any projections of significant costs of damage from climate change. That is to say, the baselines simply assumed that, with no attempt to reduce GHG emissions, economic growth would simply continue into the future at historic rates. However, the 2007 Stern Review on the Economics of Climate Change estimated that unabated climate change could produce costs equivalent to reducing annual GDP by 5–20 per cent ‘now, and forever’ (Stern, 2007). Were such costs to be included in baselines for the studies above, then instead of showing costs, the modelled emission reductions would almost certainly result in net benefits to GDP. Although, because of the uncertainties of the extent of environmental impacts from climate change (including ‘fat tailed’ risks, discussed in Section 7.3.2), and the difficulties of modelling these impacts in macroeconomic models, formal analysis and modelling of such issues is still in its infancy.

A recent literature has also emerged concerning the ‘co-benefits’ associated with tackling GHG emissions. A recent example is the New Climate Economy (NCE) Report (NCE, 2014), which reworks the McKinsey marginal abatement cost curve into a marginal abatement benefits curve, considering potential co-benefits of low-carbon investment such as fairer distribution, greater resilience, stronger local communities, improved quality of life, including from reduced air pollution and less commuting, and an enhanced natural environment. The reworked curve suggests that GHG emissions could be reduced by more than 15 $GtCO_{2e}$ by 2030 at net benefit to GDP as conventionally measured, but that if the non-GDP benefits were also included more than 20 $GtCO_{2e}$ may be abated at a net-benefit.

Beyond energy, there are now many studies that suggest that strong actions and investments to increase resource efficiency can generate economic benefits over the short, medium and long terms. One estimate puts these benefits at US$ 2.9 trillion in 2030, of which 70 per cent have an internal rate of return on investment of more than 10 per cent (Dobbs et al., 2011, p. 70). At the European level, MECAMEC and BIO IS (AMEC and BIO IS, 2013, pp. 95–96) estimate that European businesses could reap net benefits from resource efficiency measures based on current prices and technologies of €603 billion. As with GHG emissions reduction, there is almost no evidence that wider policies for environmental sustainability would have a significant negative effect on economic growth rates, still less choke off economic growth altogether.

7.5 Policies for Energy, Climate Change Mitigation and a Green Economy

The literature contains a number of similar, but slightly different definitions of a '*green economy*'. However, the conclusion of Ekins et al. (2014) was that a green economy is more easily characterized than defined: it has very low levels of CO_2 and other emissions to the atmosphere, it does not pollute the land, fresh water or seas, and it delivers high levels of human value (measured in money or other terms), for low throughput of energy and material resources. Thus, the green economy is a description of a whole economy that is characterized by climate stability, resource security and environmental quality, each of which are likely to play an important role in underpinning future prosperity. '*Green growth*', which may also be characterized in many different ways but broadly embodies the 'decoupling' objective described in Section 7.3.1, is required to deliver a green economy (under the assumption that economic growth will remain a key objective of policy-makers). Heading in such a direction requires appropriate policy frameworks. Grubb (2014, p. 69) provides detailed theoretical and empirical foundations of the need for three, simultaneous '*pillars of policy*' in order to achieve a low carbon economy. Each pillar in turn corresponds to three different 'domains' of risk, economic theory and processes, and opportunity.

The three domains in turn broadly correspond to behavioural economics, which stresses limits to individual rational market behaviour, neoclassical economics, which tends to view markets as generally well-functioning, optimizing entities, and institutional/evolutionary economics, which focuses on how economies evolve and transform. The policy approaches, or 'pillars' (as he calls them) most relevant to these domains are respectively; 'standards and engagement' (which include regulation, the provision of information and voluntary agreements), resulting in cost-effective increases in efficiency; 'markets and pricing' (economic instruments), resulting in cleaner products and processes derived from price-induced changes in behaviour and technology; and 'strategic investment in innovation and infrastructure', which causes the economy to shift to a new production possibility frontier, resulting in this context in much lower CO_2 emissions. Both standards and engagement and strategic investment have a medium relevance in the delivery of cleaner products and processes, and markets and prices have some effect on smarter choices and innovation and infrastructure.

Beyond decarbonization, Ekins et al. (2014) consider that a shift to a green economy more broadly requires three major conceptual and practical pillars of public-private cooperation: the provision of information, which is relevant to both market functioning and behaviour change; and innovation and infrastructure (together with the associated investment), which obviously maps closely onto Grubb's third policy 'pillar'. Each of these pillars will now be explored in greater detail.

7.5.1 Standards and Engagement

Standards

Standards may take many forms. However, all act to 'push' a market, product or process to higher levels of efficiency (or lower levels of pollution or resource intensity), through regulation. Such regulations help to overcome market failures such as split-incentives, a prominent example of which is the '*landlord–tenant dilemma*', under which the interests of the landlord and tenants are misaligned. Whilst the installation of energy efficiency measures, for example, would benefit the energy bill-paying tenant, savings do not accrue to the landlord who would generally bear the cost of installing such measures, preventing their introduction. Instead, standards can require their installation, or other measures to induce the same effect. Such standards may be applied with a legal basis, or through the use of voluntary agreements.

7.5.2 Information

It is well recognized that adequate, timely and relevant information is essential for the understanding of the state of an economy and where it is headed. There is a need for a new information infrastructure about material and resource use that enables economic actors and policy-makers to understand and manage the resource and environmental basis of the economy and businesses. Two major extensions of national accounting approaches are required for this. The first is the construction of a system of natural capital accounts (SNCA) to increase understanding as to how and where natural capital should be maintained and augmented, and to act as an interface between the economy and the environment, to facilitate the detailed modelling of the impacts of the economy on the environment and the contribution of the environment, resources and ecosystem goods and services to the economy. The second is the construction of much more detailed material flow accounts for national economies that track the flow of different materials through the economy, to facilitate their retention of value and their appropriate management at the end of product lives, without which policy-makers will not be able to understand how resource use is developing, and how it should be managed.

This information may feed in to engagement processes, mechanisms and instruments for targeted communication and engagement between governments, organizations, communities and individuals, which may help to overcome issues of psychological distancing, motivational issues, split incentives and information asymmetry. Such instruments act to 'pull' the market towards higher efficiency, lower emissions and resource consumption, and greater resilience, and may include training and education campaigns, labelling and certification, public reporting and other information disclosure and transparency measures. All act to provide consumers and investors with information surrounding environmental performance of a product, service, process or organization at the point of use, or across the product lifecycle or organizational operations and supply chain, in order to make informed decisions regarding investments, purchases and other behaviour.

7.5.3 Markets and Pricing

Carbon Pricing

Perhaps the most commonly suggested policy prescription to address climate change is carbon pricing, whether through carbon taxes, tradable permits, or some combination of the two. Contrary to many perceptions, this is a prescription that has actually been implemented in a number of countries. Globally, 40 national and over 20 subnational jurisdictions have implemented carbon pricing, representing almost a quarter of global GHG emissions (with a value of around US $50 billion in 2015) (World Bank, 2015). Goulder and Schein (2013) conducted an assessment of the relative advantages and disadvantages of carbon taxes and emission trading systems. On a number of grounds carbon taxes seem to be preferred, one of the most important of which is that additional climate change mitigation policies do not reduce emissions in a cap-and-trade system (unless the cap is adjusted downwards, which then undermines the principal feature of an emissions trading system, which is that it gives assurance over the quantity of emissions), whereas under a carbon tax additional policies do reduce emissions further. This is an important consideration when policy mixes are employed. However, there are political advantages to emission trading systems, such as the ability to allocate emissions permits for free, which have led to them being introduced more frequently than carbon taxes, despite the theoretical advantages of the latter.

Environmental Tax Reform

The introduction of carbon pricing (or other environmental pricing instruments) may be part of an environmental (or ecological) tax reform (ETR), which is the shifting of taxation from ‘goods’ (like income, profits) to ‘bads’ (like resource use and pollution). ETR is often implemented, and is normally modelled, to be revenue-neutral (i.e., taxes on labour or businesses are reduced in line with the revenues from the environmental taxes, such that there is no change in the overall fiscal balance). The basic hypothesis of ETR is that it can lead to higher human well-being (or welfare) both by improving the environment, and by increasing output and employment, and potentially also by stimulating green innovation (discussed in Section 7.5.4). Andersen and Ekins (2009) present the results of an assessment of environmental and economic effects of ETRs that had been implemented in six EU countries (Denmark, Finland, Germany, Netherlands, Sweden, UK). As would be expected, the modelling suggested that environmental impacts in those countries were reduced, but perhaps more significantly, that these countries experienced slightly faster economic growth than they had without the ETR. Ekins and Speck (2011) present the results of a modelling investigation into the implications of a large-scale ETR in Europe, which used two European macro-econometric models, and explored six scenarios of a varied carbon price (with revenue neutrality achieved by reducing taxes on incomes and employers' social security contributions). Broadly, the study suggests that ETR is a very cost-effective way of reducing CO_2 emissions, with employment increasing in all instances.

Payments for Ecosystem Services

A broader concept than the pricing of negative market externalities is the concept of '*Payments for Ecosystem Services (PES)*', which has received significant attention in the literature in recent years. Although various definitions exist, PES may be broadly defined as a voluntary transaction where ecosystem managers (e.g., land owners), are compensated through conditional payments by ecosystem beneficiaries (often governments, with the public being the beneficiary), for the additional cost of maintaining ecosystem services above legally required levels (or in the absence of such requirements) (Schomers and Matzdorf, 2013). It is clear that effective implementation of PES depends on the possibility of arriving at an agreed valuation of ecosystem services, the difficulties of which are discussed in Section 7.3.2. Despite their growing use around the world, few PES systems have undergone rigorous ex post analysis to determine their effectiveness (Engel et al., 2008). As such, there is scope for further research to evaluate existing PES instruments, particularly surrounding how institutional and governance structures (including property rights, transaction costs and monitoring and enforcement regimes) influence effectiveness, cost-efficiency and distributional impacts in practice (Schomers and Matzdorf, 2013). The conditions under which 'bundling' ecosystem services together in a single instrument (reducing transaction costs and raising price premiums) is beneficial, and which services may be bundled together without producing trade-offs and perverse incentives, is also a topic for further research (Farley and Costanza, 2010).

Environmentally Harmful Subsidies

Economic instruments may only reach their full potential if other market failures and distortions are minimized. Whilst instruments discussed in the other two pillars of policy aim to do this, the presence of environmentally harmful subsidies may continue to inhibit the effectiveness (and cost-efficiency) of a policy mix. Globally, fossil fuels continue to receive substantial subsidies; US $544 billion in 2012, more than five times the level of subsidy paid to renewables (IEA, 2013). Such subsidies distort the market, encourage the consumption of fossil fuels and make the deployment of low-carbon options more expensive in relative terms. As such, fossil fuel subsidies (for both consumption and production) should be reduced and removed where they occur. G20 countries have a commitment from 2009 to phase out 'inefficient' subsidies to fossil fuels in the medium term, but since then such subsidies have grown substantially, and with no definition as yet of the 'medium term', the commitment seems somewhat hollow. While the justification for fossil fuel subsidies is often that they give energy access to low-income households, in fact the IEA (IEA, 2013, pp. 93–98) reports that only 7 per cent of fuel subsidies in low-income countries go to the bottom 20 per cent of households, while 43 per cent go to the wealthiest 20 per cent. As such, removing such subsidies may have positive distributional effects, particularly if the additional revenue (or rather, subsidies foregone) are targeted to directly counter the effects of the increased fuel costs to those most affected (through, for example, energy efficiency measures, or other ETR approaches). Countering negative distributional effects is also essential in wealthy countries. '*Fuel (energy) poverty*', a condition in which individuals must spend a high proportion of their income in order to keep warm or cool, is a substantial (political) issue in many EU Member States. In the UK, for example, over 10 per cent of all households were considered to be in fuel poverty in 2013 (defined as the number of households with required fuel costs above the national required median level, and if they were to spend that amount, would be left with a residual income below the official poverty line) (DECC, 2015).

7.5.4 Strategic Investment

Infrastructure Provision

As has long been recognized, market actors are unwilling and unable to create the infrastructure that underpins national prosperity by themselves. There are important choices to be made in respect of infrastructures of supply and demand, of energy, water, construction and transport, and of the information and communications infrastructure that will to a large extent determine how they are operated. Government and public policy has a crucial role to play in all the important choices in this area if businesses and consumers are not to be locked in to high-carbon, resource-intensive patterns of economic activity that become a growing liability in a world increasingly concerned about, and feeling the effects of, climate change and escalating demands for resources of all kinds. To avoid lock-in to carbon-intensive infrastructure and resource-inefficient infrastructure in general, governments need to adopt a clearer approach to prioritization of low carbon infrastructure, perhaps through a strategic infrastructure plan that sets out the criteria that ensure that infrastructure investments are compatible with long-term green economy objectives. This would enable a prioritization of those infrastructures that are required for a green economy (such as sufficient transmission capacity to incorporate renewable electricity into the power system), '*smarter grids*' to facilitate its management, and materials management facilities to delay or prevent resources from becoming wastes.

A National Infrastructure Bank with green criteria embedded within its mandate, could finance large infrastructure and demonstration projects. In addition, the capacity of local authorities to drive green infrastructure locally could be bolstered by enabling the establishment of green municipal bonds and a collective municipal bond agency owned by participating local authorities.

Innovation

Change in the energy sector since the industrial revolution has been rapid and dramatic, with a huge range of energy demand technologies and associated energy consumption practices being invented, developed and adopted as new, more convenient and versatile energy sources became widely available and cheaper. The extent of cost-reducing innovation is often described through learning or experience curves, and associated 'learning rates', the percentage reduction in unit cost for each doubling of installed cumulative capacity. Azevedo et al. (2013 p. vii) give learning rates for different electric power generation technologies from a literature review of different studies. Nuclear and coal have relatively low learning rates (rates for the former technology have been negative), whilst of the renewables technologies, the narrowest range of estimates is for hydropower. High rates of learning have been estimated for natural gas, onshore wind, solar PV and bio-power. In future, further innovation in low-carbon energy supply technologies, particularly innovation that reduces their costs, will be crucial.

The literature often characterizes innovation as having several distinctive stages – from research and development (R&D) to prototyping, demonstration, commercialization and deployment. Early conceptions of innovation tended to emphasize a linear process of moving through these stages from R&D to deployment. However, this 'linear model' is now regarded as too simplistic. Models of innovation have therefore evolved to reflect empirical observations of innovation processes, including feedback between innovation stages (a process that is sometimes referred to as 'learning by doing'), and the increasingly networked character of innovation (including parallel activities by different functional departments within innovating firms, closer relationships between technology suppliers and customers, and a focus on speed and flexibility of product development to respond to changing needs). This increasingly sophisticated understanding of innovation is further enhanced by a recognition that the scale and scope of innovation varies widely (from '*incremental*' to '*radical*' innovations) (Freeman, 1992), that patterns of innovation are also shaped by national institutions (Freeman, 1987), and that innovation processes vary significantly between sectors (Pavitt, 1984). These and other insights have led to a number of standard rationales for government innovation policies, including financial support. Most of these rationales focus on the existence of market failures, two of which are most prominent in low-carbon innovation. The first is the market externality of CO_2 emissions, distorting the relative economics between high- and low-carbon technologies, and thus the market for the latter. The second is a tendency of the private sector to under-invest in R&D because individual firms cannot fully capture the returns from their investments ('*knowledge externalities*').

Beyond such market failures, an 'innovation systems' perspective also focuses on wider system failures. The adoption of some low-carbon (or enabling) technologies may require both technological and institutional change. Technologies and institutions co-evolve and are closely integrated (Weber and Hemmelskamp, 2005), and many of those that currently exist were designed for a fossil fuel-based energy system. For example, the diffusion of smart metering technology is not just a simple technical challenge but also implies a new approach to information provision to energy consumers and new information technology infrastructure. Others require new links between established but hitherto separate actors within the innovation system. For example, carbon capture and storage (CCS) technologies require new collaborations between utilities, oil and gas companies, and power equipment companies, and can also require amendments to previously-unrelated existing regulations (e.g., those that govern marine pollution or issues around liability).

These insights have informed policies to support innovation in more sustainable technologies in many countries. In many cases, broad 'horizontal' policies have been implemented such as generic tax credits for R&D (Owen, 2012). However, many policies have gone further than this, and have emphasized more tailored policies for particular sectors or technology families that take into account sectoral differences and characteristics. An important area of debate has focused on the extent to which more specific policies for innovation require a different modus operandi for governments. One view is that, rather than implementing generic policies and leaving decisions to market actors, a more 'hands on' approach from governments and their agencies is required. Mazzucato (2011) argued the case for an '*entrepreneurial state*' that works in partnership with the private and third sectors to foster innovation. The aim is to underwrite the specific risks of developing and commercializing new technologies, and to share the rewards. As part of this, she argues that there is a need for much greater emphasis within public institutions on experimentation and learning. Mazzucato cites US institutions such as ARPA-E as successful examples of translating these principles into practice. Issues surrounding innovation in relation to economic growth are further explored in Chapter 1.

Industrial Strategies

As Mazzucato's research suggests, green industrial strategies can guide innovation and strengthen a country's innovation system and secure comparative advantage in key sectors and areas of technology that enhance resource productivity. This can be delivered with both horizontal instruments that give the right incentives right across the economy, and targeted sector-specific policies that focus on the skills and supply chains required for greener products and processes. This would also require a clear approach to the selection of technology priority areas with explicit processes for review, and enhancement of 'mission-driven' R&D agencies, identifying where new ones may be necessary to drive core green economy technologies. Where possible, these should build on existing regional industrial and innovation strengths. Complementary policies can include the development of long-term patient-finance vehicles for green innovation, to invest and hold equity in technology-based firms developing new technologies; better alignment of downstream policies focused on supporting diffusion of core green technologies (i.e., deployment subsidies) with upstream funding support for technological innovation; and support for innovation in business models, including the provision of a small fund for proof-of-concept or feasibility studies for innovative business models. Establishing appropriate financial institutions for such a purpose may be required, such as the Green Investment Bank in the UK.

7.5.5 EU Energy and Climate Change Policy: Lessons and Priorities for Research

The evidence suggests that the climate policy mix in the EU has had a relatively significant impact on CO_2 emissions in recent years, although nonclimate policy and nonpolicy factors (such as the 2008 financial crisis) have also been highly influential (Drummond, 2014).

The EU Emissions Trading System

The EU Emissions Trading System (EU ETS), a cap-and-trade system applicable to the power and heavy industry sector across EU Member States (plus Norway, Iceland and Lichtenstein), is the cornerstone of the EU's climate policy landscape, and covers around 55 per cent of total CO_2 emissions. Although the primary objective of the EU ETS (i.e., to maintain obligated emissions under the level of the cap) has been and continues to be achieved, it is unlikely that the EU ETS has been a significant driver of CO_2 abatement. A primary factor for this is permit oversupply and consequential low carbon prices, first as a result of initial overestimation of CO_2 emissions from obligated sectors due to lack of prior data (in Phase 1, 2005–2007), and subsequently due to the reduced demand for electricity and industrial products stemming from the 2008 financial crisis (in Phase 2 (2008–2012), and continuing into Phase 3 (2013–2020)). Instead, parallel (largely regulatory) instruments such as renewable deployment targets for Member States (implemented most commonly through feed-in tariffs), CO_2-intensity regulation for cars and minimum energy performance standards for energy-using products have driven the majority of abatement attributable to climate policy in the EU (Drummond, 2014).

Carbon Leakage and the Pollution Haven Hypothesis

Prior to its introduction, much analysis projected that the EU ETS would induce ‘carbon leakage’, the CO_2-specific manifestation of the Pollution Haven Hypothesis (PHH). The PHH contends that increasing environmental regulation will raise costs for pollution-intensive industries and encourage their migration to regions without such costs to achieve a comparative advantage. This raises the possibility that the (absolute) decoupling of income from environmental degradation, where evidence for it exists, may be driven by the export of such activities, rather than genuine pollution abatement (Kearsley and Riddel, 2010). Thus far however, no evidence of a loss of competitiveness and ‘operational’ leakage (an induced shift in the use of existing production capacities from within to outside the EU ETS’ jurisdiction) exists for key industry sectors as a result of the EU ETS (Kuik et al., 2013). However, there is not yet sufficient evidence to determine whether ‘investment’ leakage – an induced change in relative production capacities – has been induced (Branger and Quirion, 2013). Indeed, despite substantial research over recent years, largely focussed on inward foreign direct investment (FDI) and net imports to the USA, the empirical validity of the PHH continues to be a highly contentious issue, with some studies demonstrating small or insignificant impact from environmental regulations on trade flows, and others finding a more substantial relationship. Where supporting evidence for the PHH is found, it is ‘footloose’ rather than the most pollution-intensive industries, that appear most at risk (Kellenberg, 2009). Additionally, it often appears that other factors such as capital availability, labour force qualification, proximity to customers and infrastructure quality may be more significant factors in location decisions than the presence of environmental regulations. There is also evidence that enforcement of environmental regulation is a more important factor than stringency (Cole, 2004, Kellenberg, 2009, Kuik et al., 2013). Further work is required in order to determine the relative strength and characteristics of these different factors in determining the potential for migration for different industries (Cole (2004)), and to produce empirical evidence from a wider geographic range. Additionally, the literature does not sufficiently address the impact of a regulatory approach; the difference between market-based or command-and-control, or poor or well designed instruments (Ambec et al., 2013). Such insights would be highly valuable for policy-makers.

The Porter Hypothesis

Contrary to the PHH, the Porter Hypothesis suggests that 'properly designed environmental standards can trigger innovation that may partially or more than fully offset the costs of complying with them [and] can even lead to absolute advantages over firms in foreign countries not subject to similar regulations' (Porter and van der Linde, 1995). Jaffe and Palmer (1997) disaggregate this hypothesis into 'weak', 'strong' and 'narrow' versions. The 'weak' version states that properly designed environmental regulation may spur innovation. The 'strong' version states that in many cases such innovation more than offsets any additional regulatory costs, leading to an increase in competitiveness. The 'narrow' version states that flexible regulatory instruments (market-based instruments) give firms greater incentive to innovate, and are thus preferable to prescriptive regulation (command-and-control instruments) (Ambec et al., 2013). Ambec et al. (2013) find that the 'weak' version has relatively strong empirical support, whilst empirical evidence for the 'strong' version (at firm- and industry-level) is largely negative (evidence for the 'narrow' version is not addressed here, as evidence for this significantly pre-dates the Porter Hypothesis). However, the vast majority of studies reviewed employ cross-sectional (one-period) or two-period models. Longitudinal studies may generate new insights into the issue. Moreover, substantial issues surrounding data availability and quality, and methodological approaches (including the use of compliance cost as a proxy for regulatory stringency), make robust conclusions and comparisons between studies difficult. Further research to address and refine these issues, for example through regular structural surveys to collect time series data at the micro (e.g., firm), meso (e.g., sector) and macro (e.g., national) levels, would be beneficial (Ambec et al., 2013). However, the administrative feasibility of such a data collection exercise may require a more targeted approach.

Policy Mixes

Meyer and Meyer (2013) found that the combination of the EU ETS and renewable energy targets (and instruments deployed to achieve them), along with ETR measures in some Member States (discussed in Section 7.5.3), likely increased both GDP and employment at the EU level against the counterfactual, although much analysis suggests that many climate policy instruments (such as the EU ETS and feed-in tariffs) may have had negative distributional impacts (Branger et al., 2015). However, such analysis often examines the impact of one or two instruments, rather than an instrument mix as a whole. Further research is required to understand the impacts of individual instrument design, and how multiple instruments may interact in an instrument mix, before comprehensive conclusions on the effects of climate and energy policy, particularly on issues of competitiveness and distributional impacts, may be drawn. Such lessons would help inform, and be informed by, improved modelling techniques and characterization that take into account existing and improved insight into behavioural and institutional economics (discussed under Section 7.2.3), innovation processes (discussed in Section 7.5.4), discount rates (discussed in Section 7.3.2), and the components and associated value of marginal social costs of carbon (particularly impacts on human health).

Improved knowledge and analytical techniques would also allow for improved understanding of complex issues, such as the energy trilemma (discussed under Section 7.4), and policy mixes that may effectively enhance synergies and reduce trade-offs between the three aspects of the trilemma; for example, how support for the different stages of innovation (from basic research to deployment) may be balanced, how the micro and macroeconomic costs of CO_2 emission mitigation actions may be minimized and equitably distributed, or even how such actions may most effectively increase prosperity and equity. Such questions have yet to be given adequate attention in the literature (Falkner, 2014).

The identification of ‘win–win’ actions and instruments, those that advance more than one aspect of the trilemma (without inhibiting the other), should be a priority. A classic example of a ‘win–win’ strategy is that of increasing energy efficiency, although continued robust investigation is required to further define where and how such action, along with the instrument mix required to achieve it, is most (cost-) effectively targeted (Mitchell et al., 2013).

Living with the Trilemma

However, the energy trilemma is a ‘*wicked problem*’.[2] Efforts to improve the situation in respect of one component of the trilemma may make the others better or worse, in multidimensional ways that are hard to predict. As such, successfully negotiating it will prove extremely difficult. Additionally, even if apparently suitable pathways and approaches are found, efforts to implement them in a long term, consistent strategy may flounder against political, institutional and decision-making realities. In practice, the three components of the energy trilemma may be hierarchical in priority to decision-makers, and may rapidly change in response to short-term events and ‘shocks’. For example, the EU ‘Energy Union’, as initially proposed in response to increasing fears over dependence on Russian gas in the wake of the conflict in Ukraine in April 2014, focused on (fossil fuel) energy security – arguably at the expense of the ‘decarbonization’ element of the trilemma (in particular). However, the concept has since evolved and broadened to explicitly refer to the three aspects of the trilemma, with the objective of 'ensur[ing] that Europe has secure, affordable and climate-friendly energy' (European Commission, 2015). Further research should be conducted to determine how the concept of the Energy Union may evolve over time to negotiate the elements of the trilemma, and remain robust in the face of potentially abrupt changes in EU and Member State level priorities (which are, and are likely to continue to be, substantially different).

A key element of the energy trilemma, as discussed in Section 7.4.1, is uncertainty. Decision-makers must plan, invest and introduce policy instruments to satisfy the energy trilemma in the face of a raft of unpredictable developments that may occur over subsequent years and decades (e.g., technological development, economic pressures, energy resource scarcity and prices, public preferences, etc.). Whilst some of these uncertainties may be reduced, others are likely to remain. Policies, policy mixes and strategies must therefore be flexible and able to deal with uncertainties when they arise, as far as they are able to, to prevent abrupt changes and maintain long-term credibility. Examples of flexibility mechanisms are the forthcoming '*Market Stability Reserve*' for the EU ETS (intended to reduce existing and reduce the risk of future permit oversupply), and 'degression' mechanisms for renewables' subsidies (i.e., an automatic change in subsidy levels based on deployment rates) to prevent unacceptably high costs. However, the occurrence of some uncertain or unexpected events may be beneficial. For example, the rapid fall in oil prices that began in August 2014 has facilitated the reduction of fossil fuel subsidies in many countries around the world (IEA, 2015), and if it continues, may facilitate the continued introduction of robust carbon pricing. This helps reduce market distortions and the relative cost of low-carbon alternatives, and thus subsidies for their deployment. The research priorities identified above would contribute to the continued identification of appropriate approaches for policy flexibility and resilience, and key options for reform that may be introduced when the political economy allows.

7.6 The Science-Policy Interface

Economic analysis of policies to address energy, environment and sustainability challenges plays a central role in the development and implementation of such policies in many countries – including in the European Union and EU Member States. This chapter has demonstrated that a number of different schools of economic thought tend to frame the relationship between the environment, energy and the economy differently. They also emphasize different theoretical frameworks and methods. As a result, there are often conflicting views in answer to important policy questions, such as the most cost-effective strategy for reducing GHG emissions in the EU. Additionally, many of the key questions faced by policy communities working in these fields require an interdisciplinary approach. Economic perspectives therefore need to be combined with perspectives from other disciplines, including engineering, physical sciences, natural sciences and other social sciences.

The Role of Scientific Advice

The interface between science and policy is often populated by a range of institutions that are designed to inform government policies and strategies. Wilsdon and Doubleday (2015) emphasize the diversity of approaches used in different countries, but nevertheless they identify four common approaches of 'high-level advisory councils', more specialist 'scientific advisory committees', 'chief scientific advisers' and 'national academies and learned societies'. They note that in many countries more than one of these approaches is used in parallel, and that countries differ significantly in the extent to which scientific advice is sought formally or informally. They also argue that scientific advice systems need to deal with the fundamental differences between the science and policy worlds: 'debates about scientific advice often focus on the "supply-side" of the science-policy interface. But the "demand-side" is equally important: advisory bodies need a sophisticated understanding of how policy-making processes work, and the pressures and constraints under which politicians, officials and decision makers operate' (Wilsdon and Doubleday, 2015). Whilst these institutions are largely populated by natural scientists and engineers, this is not exclusively the case, with economic expertise included in some scientific advisory structures. However, it is important to remember that economics expertise is already embedded in policy-making in a much broader way. This includes the use of specific bodies that are set up to provide economic advice – either inside government or independent from it. Perhaps more importantly, economics has a central role in government departments in many countries. The civil service often includes large numbers of economists, and economic tools such as cost benefit analysis are used routinely to support decision-making. These tools tend to be rooted in traditional neoclassical economics, and this extends to their treatment of environmental impacts and natural resources (see Section 7.2). It is less common for economic ideas from outside mainstream neoclassical economics to be represented and used, however there are some exceptions to this. For example, the UK government's Cabinet Office established a '*behavioural insights team*' (known more popularly as the 'Nudge Unit') in 2010, which applies behavioural economics to a range of policy questions, including how to improve the adoption of energy efficiency measures.

Scientific Advice Structures in the EU

The European Governance White Paper (2001) called for a number of reforms that aimed to make European institutions more responsive and accountable (European Commission, 2001). These included proposed reforms to the use and networking of expert advice, which the Commission argued had a tendency to be nationally oriented. This Communication was followed in 2002 by a more specific publication outlining approaches to the collection and use of expertise.[3] This issue has also been a focus of attention more recently, in 2005 and 2006, including the establishment of a register of the expert groups used by the Commission and the publication of guidelines for these groups. According to Metz (2013), the number of expert groups to the Commission grew steadily until the mid-2000s when there were well over a thousand in existence. She attributes their rise to an increase in Commission competencies and regulations–though many expert groups cover areas where competencies are shared between the Commission and Member States. She also observes that numbers have fallen since the mid-2000s, partly as a result of the new guidelines and register, and partly due to pressure for more transparency. A similar trend occurred in the US, where the number of expert committees has reduced from 3000 in the 1970s to around 1000 in recent years.

Metz (2013) also identifies three distinctive roles for expert groups: problem solving (in areas where the Commission uses external expertise to develop policies and regulations); substantiating (where expert positions are used to support Commission positions); and consensus building (for areas where there are significant areas of controversy). In the area of research and innovation policy, she argues that the second substantiating role has been particularly significant. Of particular relevance for this chapter are the advisory groups on research priorities under Horizon 2020. These groups tend to be technologically focused, but their remits also extend to societal issues, and therefore sometimes incorporate some social science and economics expertise. There are currently groups focusing on energy, climate change and transport. There have also been ad-hoc committees formed to advise on overall strategy. One notable example is a committee formed to advise the Commissioner on Energy on the EU Energy Roadmap to 2050 (European Commission, 2011). The committee included a number of prominent energy economists. In addition to expert groups, the Commission's Joint Research Centre (JRC) provides in-house research capabilities, with the status of a Directorate General. The JRC includes significant research capabilities in energy, environment and sustainability – much of which is technical in nature. However, there is also substantial economics expertise in relation to these fields. For example, the Institute for Prospective Technological Studies (IPTS) has expertise in the economic analysis of energy, transport and climate change. It also includes a science area on innovation and growth. The most recent addition to European Commission institutions at the science-policy interface was the creation in 2012 of a new position of chief scientific adviser to the President (Wilsdon and Doubleday, 2015). However, this position has not been renewed since the completion of the first incumbent's three-year term. In May 2015, the Commission announced that a new scientific advisory panel will be appointed instead of a single chief scientific adviser. At the time of writing, the plan is for a seven-member group that could include at least one social scientist and/or economist.

The system of scientific advice in the US has some similarities with the European system and some EU Member States. The US government has a chief scientific adviser who is also head of the Office of Science and Technology Policy in the White House. In addition to this, the US National Academies have a formal role in providing advice to the US government on science, engineering and medicine. In the US, it is also common for senior scientists to be appointed as government ministers, with recent appointments including academics from Stanford University and MIT.

7.7 Conclusions and Research Priorities

It is clear that whilst the application of economic thought and methodological approaches has advanced our understanding of interactions within and between the human and natural world, many important areas of further theoretical, empirical and methodological research remain. These areas may be broadly delineated into three interrelated themes; (i) the basic characteristics of the economy-environment interaction, including how the state of this interaction and changes to it can be measured, (ii) the 'natural' (nonpolicy) drivers of this change (both from economic activity on the environment, and environmental degradation on the economy), and (iii) the impact and design of policy interventions.

The first theme largely concerns the opposing notions of weak and strong sustainability, and associated concepts and approaches. Central to the operationalization of the weak sustainability approach is the valuation of natural capital and ecosystem services. Four areas for particular further research have been identified. The first is the ongoing question of how to include or mitigate the impact of behavioural and cognitive complexities on values elucidated. Such issues are well known and expressed in the literature, but remain a key methodological issue (particularly for stated preference approaches). The second is how nonmonetary valuation approaches, such as social and cultural value, may be integrated with or made complementary to monetary valuation. A clear avenue for research concerning both these issues is the continued development of multi-criteria analysis methodologies. The third area is whether monetary valuation, by framing the good or service in such terms, crowds out other forms of valuation. The fourth concerns the extent to and nature in which monetary valuation can and does impact decision- and policy-making (including the drivers and barriers involved), and leads to the introduction of instruments based upon the values derived. Alongside methodological improvements and assessment of the impact such approaches have, further research into how they may be applied to biodiversity, rather than individual species, habitats or ecosystem services, is required. This also includes the construction of a commonly accepted, functional definition of the term. Such research will also provide a more robust basis for the use of biodiversity offsets, the focus of increasing policy attention.

An ongoing area of strong sustainability research is the refinement of robust approaches to identifying critical natural capital, in order to further define environmental limits, in respect of which monetary valuation is inappropriate, too expensive or impossible. Advances in the natural sciences will contribute to improving knowledge in this area. Research into the above issues would advance the development and quality of indicators for sustainability, in respect of both strong and weak interpretations – an important area for continued research.

The second theme, on nonpolicy drivers of change, contains two principal longstanding questions. The first concerns the validity of the EKC hypothesis. Whilst a large body of literature has attempted to address this question, no consensus has been reached. Further research using structural equations, rather than reduced-form econometric models, is required, along with an increased focus on the influence of economic and demographic structures, and the political economy. However, this requires additional efforts in the generation and collection of the required data, and improvements to modelling techniques, discussed below. The second long-standing question surrounds the calculation of marginal social costs of pollution, and of CO_2 in particular. Continued research in the natural sciences on the impact of climate change will help advance this question, although in the economics sphere, alongside improvements to the valuation of natural capital and ecosystem services (in addition to valuation of human health and comfort, etc.), debates around discount rates are dominant. Whilst this topic is a key broad area for continued research, specific efforts may focus on how to reflect risk aversion, uncertainty and time variation in respect of the discount rate.

The third theme, on the impact of policy interventions and their design, contains four principal, interrelated topics for further research. The first concerns the cost for firms of environmental, energy and climate policies, and the effect this has on competitiveness. As with other subjects, the contentious Pollution Haven and Porter Hypotheses have received significant attention in the literature, but with consensus yet to emerge. For the former, two principal areas of recommended research arise. Firstly, determining the relative strength and characteristics of nonregulatory cost factors, such as capital availability, labour force qualification and infrastructure quality in determining the potential for migration for different industries. Secondly, the impact of specific regulatory approaches, such as the difference between market-based and direct regulatory instruments, and the specific design of instruments therein (including 'well'- and 'poorly'-designed instruments), both individually and in a policy mix, including through longitudinal studies is required. However, such research requires empirical evidence from a broader geographical scope as well as the availability (or production) of high-quality data for analysis, an issue that already presents a substantial challenge.

These issues (particularly the Porter Hypothesis) link directly with the second topic, which concerns issues of innovation. The development of robust approaches to measurement, and the development of indicators for innovation, is one particular area of ongoing research and policy interest. Another, broadly, surrounds the process, drivers and barriers of innovation and diffusion of innovations – including technological, organizational, social and institutional innovation – including the appropriate combinations of incentives and policy instruments, framework conditions and context, and the role of institutions and governance arrangements.

This leads to the third topic, which concerns the role, nature and impact of institutions and behaviour more broadly in policy choice, design and impact. Knowledge about the interaction between governance institutions and resource users and managers on institutional choices, and on the role of each in enhancing or preventing institutional change, is relatively sparse, and potentially a rich avenue for further research. This links to the selection of appropriate policy instruments, and how effective and cost-efficient they may be in practice (e.g., the presence of appropriate property rights, the information available to actors, the scale of transaction costs, etc.), particularly concerning the use of payments for ecosystem services.

In terms of the '*energy trilemma*', continued research into the availability of 'win–win' options, and options for reducing the risks surrounding inherent uncertainty of future developments, would also be of substantial benefit in maximizing achievements as far as the political economy allows.

The fourth topic concerns environmental justice and distributional impacts. For example, uncertainty surrounds whether instruments utilizing monetary valuation of natural capital and ecosystem services reduce or exacerbate pre-existing economic and social inequalities, particularly at the local level. This is linked to a currently poor understanding of the dynamic interaction between distributional justice, procedural justice and contextual justice (with includes institutional arrangements, but also culture, beliefs and practices). Further research into this interaction would help shape our understanding of environmental justice and policy interventions. As with the impact on competitiveness, further research is also required to determine the distributional impacts of policy instruments and their specific design, both individually and in a policy mix.

A research agenda that would advance knowledge in each of the above themes would allow for improved characterization of the relationships that operate within and across the economy–environment interface, and provide the basis for such characterization to be adapted into computational models. However, much of the existing state of knowledge surrounding the above topics is often not incorporated into such models as currently designed and employed, for various reasons, the most important of which is the predominantly qualitative nature of this knowledge. This in itself may act to inhibit research into many of the above topics. One conclusion is that theoretical, empirical and methodological research approaches must continue in parallel and inform each other in order to achieve effective progression.

Most models employed to assess the impact of environmental policy (or the absence of it) tend to focus on a particular component of the environmental-economic system. For example, energy system models deeply characterize technologies and costs, macroeconomic models characterize the complex dynamics of economic processes and interactions, whilst yet others characterize environmental systems and interactions. Numerous Integrated Assessment Models (IAMs) attempt to link (at least two of) these domains and their interactions. However, such dynamic links are usually characterized relatively basically. Further research and efforts should be directed at improving the interaction between domains in IAMs. This allows for improved assessment both of the impact of policy interventions, and the projection of appropriate baselines against which such assessments may be made. These need to include increasingly robust research into the micro and macroeconomic costs of local environmental degradation (such as local air pollution), which in turn allows for increasingly robust assessments of the macroeconomic costs and benefits of climate change and climate change policy interventions (coupled with advances in knowledge and methodological considerations provided by the above research themes). However, such improvements also rely on improvements to the individual components of such models. For example, integration of the insights provided by behavioural and institutional economics in macroeconomic models is often poor, meaning that processes of structural transformation and innovation and diffusion, along with nonrational, nonwelfare maximizing choices made by individual economic actors, are not well represented. The improved incorporation of such dynamics into economic-environmental models should hold a high priority on the research agenda. In addition to this, more emphasis should be placed on other, complementary modelling frameworks (e.g., simulation or agent based models) that do not rely as much on assumptions made in many energy and economic models such as rational decision making and perfect foresight. To some extent, existing optimization models can be adapted or further developed to address the shortcomings of such assumptions, for example to explore the impact of uncertainty.

Advancing the research frontiers above would enhance policy-makers' ability to tackle 'wicked' environmental problems, such as the energy trilemma. It would also contribute to and allow for further research into how to combine the three '*pillars of policy*' to encourage a low-carbon, and broader green economy, an increasingly pressing priority in a world of growing environmental and resource pressures, and their effects on the economy. European researchers have made many important contributions to this research agenda, and are well placed to make more, through national and especially European research programmes. There is some urgency, however, to make faster progress on the answers, especially in respect of climate change, if they are to be relevant to the task of trying to keep within the 2°C average global warming limit.

Notes

1. The SDGs may be viewed at https://sustainabledevelopment.un.org/?menu=1300.
2. '*Wicked problems*' are characterized by incomplete or contradictory knowledge, different opinions, which may be based on different value systems, held by large numbers of people, substantial economic implications, and complexity, both internally and in their relationship with other issues. Such problems are not amenable to definitive solution, although some resolutions of them may be judged better than others.
3. http://ec.europa.eu/governance/docs/comm_expertise_en.pdf.

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