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# Introduction<sup>1</sup>

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## 1. THE ROLE OF ECONOMICS IN ADDRESSING CLIMATE CHANGE

Political efforts to address climate change have developed greatly in the last 20 years. In 1992, at the Rio Summit, the UN Framework Convention on Climate Change (UNFCCC) was established. Then, in 1997, despite its flaws, the Kyoto Protocol set targets to curb greenhouse gas emissions on a number of industrialized countries emissions between 2008 and 2012. These developments have been driven by advances in the natural and social sciences over the last 30 years, coupled with more recent media attention and NGO campaigns. They have also coincided with a rising public awareness of the existence of climate change and its physical and economic threats (Whitmarsh, 2011), creating a broader demand for climate stability.

While natural scientists identified the relationship between greenhouse gas concentrations and climate change, and highlighted many of the threats, social scientists and particularly economists have played a crucial role in developing strategies for mitigating climate change (Nordhaus, 1977, 1991; Cline, 1992; IPCC, 2007). Economists have been influential in arguing that the costs of mitigation may not be as great as many industrialists claimed (Porter, 1991; Fischer and Newell, 2008) and that there may be substantial benefits (Stern, 2006; Sterner and Persson, 2008). They have also proposed mechanisms for trading responsibilities and credits related to greenhouse gas emission reductions, which have been a central tool in agreements on targets related to the Kyoto Protocol and certain national climate policies (Dales, 1968; Atkinson and Tietenberg, 1991; Stavins, 1995). At a national level, many governments have introduced taxes to discourage the consumption of high-carbon energy sources (Pearce, 1991; Newbery, 1992; Oates, 1995; Parry and Small, 2005; Nordhaus, 2007; Sterner, 2007). In other words, economists have become highly influential in the global efforts to achieve climate stability.

Yet, to me, this apparent success hides a potential problem. One of the impressions I have formed from talks at conferences, working papers and journal articles over the last decade is that the shift has been associated with a perceived decline in the number of new ideas being presented – intellectual ‘blockbusters’ that ‘challenge or influence the boundaries of knowledge and . . . change the way we think about problems’ (Brouthers et al., 2012, p. 960). The hypotheses proposed here, which will be considered more fully in this chapter, are that (i) during the 1990s, there was a growth in research originality in the economics of energy and climate change, (ii) during the 2000s, there was a rapid growth in research production in this field, and (iii) in the last five to seven years, either the originality of research has declined or the originality relative to the quantity has declined.

This may be an inevitable process (Hargadon and Sutton, 1997). After a period of great ideas, which created several new ‘research fronts’ at the intersection of energy and environmental economics (Upham and Small, 2010), economists are in a phase of

refining and applying them. This is a crucial aspect of developing research and converting economic ideas into useable tools for policy makers, and can be responsible for a large research output. However, eventually, declining marginal returns (from using and developing these ideas) tend to set in. In time, new 'research fronts' need to be developed for the discipline to generate new knowledge and be of long-term value (Hall et al., 2005).

Indeed, despite the successes of economic analysis in this field, it is clear that many energy and climate change problems remain that economists (and other social and natural scientists) are not managing to fully resolve. Thus it is proposed that economists investigating energy and climate change issues need to develop new 'research fronts'.

So, with this in mind, this handbook has been constructed around the objectives of displaying some of the best of current thinking in the economics of energy and climate change, and encouraging the formulation of new questions and the development of new ideas. Before outlining the chapters in the handbook, this introduction will briefly highlight some of the most influential ideas in the literature on the economics of energy and climate change – that is, the 'blockbusters' that have created new 'research fronts' and changed the way we think about these issues. This introduction will use bibliometric evidence to examine the trends in related research over the last 40 years, identify and analyse the explosion in energy and climate change research in the last ten years, and consider the validity of this hypothesized rise in original ideas in the literature and then decline (or relative decline) since the explosion in research output.

## 2. THE ORIGINS OF THE ECONOMICS OF ENERGY AND CLIMATE CHANGE

Economists' current approach to energy and environmental problems has its roots in the seminal ideas produced between the 1960s and the 1990s that were, no doubt, driven by a broader consciousness about environmental and resource issues (Pearce, 2002). While this is not the place to offer a review of the economics of energy and climate change, it is worth commenting on a few salient 'research fronts' that are so important today (see, e.g., Kula, 1998; Stevens, 2000; Pearce, 2002 for broad reviews of the literature).

In the 1960s, energy economics was driven by an empirical approach to questions, exemplified by the Resources for the Future (RFF) studies of long-run energy consumption and prices (Schurr and Netschert, 1960; Potter and Christy, 1962; Barnett and Morse, 1963; Adelman, 1972). Long before them, Jevons (1865) had considered the economics of coal and Hotelling (1931) had brought some theoretical grounding to possible non-renewable resource price trends. Nevertheless, it was this growing awareness of the economic importance of energy during and after the Second World War, and particularly the oil shock in 1973 (Fisher and Ward, 2000), that led more economists to analyse the role of energy in the economy (Nordhaus, 1980; Hamilton, 1983; Bohi, 1989), the demand for energy (Christensen et al., 1973; Hudson and Jorgensen, 1974; Berndt and Wood, 1975; Griffin and Gregory, 1976; Pindyck, 1979; Dubin and McFadden, 1984; Bhatia, 1987; Griffin, 1993), resource production and its costs (Gordon, 1967; Pindyck, 1978; Dasgupta and Heal, 1979; Slade, 1982; Arrow and Chang, 1982; Krautkraemer, 1998), and energy markets (Penrose, 1957; Nordhaus, 1973; Gately, 1984; Adelman, 1986).

From the 1980s, a number of new issues came to the forefront: energy policy and particularly the liberalization–privatization debate (Joskow and Schmalensee, 1983; Joskow, 1987; Helm et al., 1988; Green and Newbery, 1992; Newbery and Pollitt, 1997; see also Pollitt, 2012), developing economy energy markets (Bhatia, 1987; Pearce and Webb, 1987; Pearson and Stevens, 1987; Asafu-Adjaye, 1999; Soytas and Sari, 2003); the role of technology and efficiency improvements in energy consumption (Khazzoom, 1980; Goldemberg et al., 1985; Jaffe and Stavins, 1994; Nordhaus, 1996; Unruh, 2002; Sorrell and Dimitropoulos, 2008; Fouquet and Pearson, 2012); the potential development of markets for renewable energy technologies and sources, incentivized by feed-in tariffs (Menanteau et al., 2003; Meyer, 2003), competitive tender (Mitchell, 2000), renewable portfolio standards (Wiser et al., 1998; Fischer and Newell, 2008) or a demand for low-polluting energy sources (Fouquet, 1998; Roe et al., 2001; Scarpa and Willis, 2010); and, of course, concerns about the environmental damage associated with energy consumption (Nordhaus, 1977; Shafik and Bandyopadhyay, 1992; Newbery, 1994).

This last issue required the fusion of two disparate literatures and approaches to economic analysis. No doubt because of the lack of data, environmental economics had begun from a more theoretical perspective. The starting points for much of the energy-related environmental economics literature were Pigou (1920), explaining the need to internalize external costs in order to improve market efficiency, and Coase (1960), arguing for the need to ensure well-defined property rights to allow exchanges between polluters and victims.

In the 1960s and 1970s, the analysis of and arguments for market-based instruments to regulate environmental pollution, such as taxes and tradable permits, were developed (Dales, 1968; Baumol and Oates, 1971; Montgomery, 1972; Sandmo, 1975). Weitzman (1974) raised the question about which instrument to use when faced with uncertainty. This was a crucial start to a large literature on the comparative advantages of different instruments – frequently supporting the theoretical virtues of taxation over other instruments (Goulder et al., 1999; Pizer, 1999, 2002; Aldy et al., 2010).

The details of optimal and second-best environmental taxation (which sought to discourage environmentally damaging behaviour rather than simply using taxes as a source of raising revenue (Pearce, 1991; Newbery, 1992; Oates, 1995)) began to be explored in the 1990s, such as the distortionary effects of environmental taxation (Bovenberg and de Mooij, 1995) and possible double dividends (Bovenberg and van der Ploeg, 1994; Parry, 1995; Bovenberg and Goulder, 1996; Allcott et al., 2011).

Meanwhile, the argument for introducing tradable permits was persuading politicians to introduce flexible mechanisms to reduce pollution (Hahn, 1984; Stavins, 1995; Rubin, 1996). In the 1990s, the introduction of the US sulphur dioxide tradable permit scheme was a crucial natural experiment in environmental markets (Stavins, 1998; Schmalensee et al., 1998; Ellerman et al., 2000). This experience has been crucial for the creation of the EU Emissions Trading Scheme, both in convincing politicians of its benefits and in its development (Ellerman et al., 2010; Chevallier, 2012). This understanding is also important for other forms of carbon credit trading, such as the Clean Development Mechanism.

The traditional view of environmental regulation (whether market-based instruments or other policies) had been that requiring firms to reduce pollution externalities would lower their options and profits. Porter (1991) and Porter and van de Linde

(1995) controversially proposed that environmental regulation could actually enhance competitiveness. While the debate continues 20 years later, Jaffe et al. (1995) provided important evidence that environmental regulation did not necessarily harm industrial competitiveness.

Simultaneously, the debate surrounding the environmental Kuznets curve (EKC), which proposed that environmental degradation first increased with economic development and then declined beyond a threshold, was important because it brought a great deal of additional empirical evidence to environmental economics and linked environmental damage with economic growth (Selden and Song, 1992; Stern et al., 1996; Stern, 2004).

Another important strand of empirical environmental economics was the valuation literature, which developed creative methods for getting around the lack of data to estimate and understand the demand for environmental quality (Hanemann et al., 1991; Cropper and Oates, 1992). The development of valuation techniques, as well as refinements in cost–benefit analysis (Barbier et al., 1990; Palmer et al., 1995), have been crucial for measuring the impacts of climate change (Mendelsohn et al., 1994; Manne et al., 1995) and estimating the social cost of carbon (Hope et al., 1993; Tol, 1994, 2005). When linked to the mitigation costs, these can offer long-term strategies related to climate policy (Nordhaus, 1991; Nordhaus and Yang, 1996; Stern, 2006; Weitzman, 2007; Nordhaus, 2008). These articles have also tackled the philosophical, moral and empirical question about discounting future generations (Schelling, 1995; Lind, 1995; Azar and Sterner, 1996; Weitzman, 1998; Groom et al., 2005). This debate has run in parallel with the more game-theoretical literature on environmental agreements (Maler, 1989; Barrett, 1990, 1994; Hoel, 1991; Carraro and Siniscalco, 1993; Nordhaus and Yang, 1996).

Following Tol and Weyant (2006), and other bibliometric studies, Table I.1 provides an insight into the most cited energy and energy-related environmental economics articles in mainstream economic journals (which were found in an extensive search of the ISI/Web of Knowledge (1 March 2012)). Although far from a complete list, it acts as a crude indicator of the most influential articles in this field. Other relevant articles with more than 200 citations in mainstream economic journals include Bovenberg and de Mooij (1995), Palmer et al. (1995), Stern et al. (1996), Carraro and Siniscalco (1993), and Nordhaus and Yang (1996). Naturally, this ignores many highly influential chapters in books, such as Watkins (1992) or Nordhaus (1996), or books, such as Barnett and Morse (1963), Dales (1968), Darmstadter et al. (1971), Baumol and Oates (1975), Pearce et al. (1989), Cline (1992), Nordhaus (1994, 2008), Stern (2006) and IPCC (2007), or books by economists that might influence public attitudes, such as Kahn (2010) and Wagner (2011).

As an example of further key articles in the economics of energy and climate change, Table I.2 presents the most cited relevant articles (again based on ISI/Web of Knowledge) in energy and energy-related environmental economics journals (*Energy Economics* (*EE*), *The Energy Journal* (*EnJ*), *Resource and Energy Economics* (*REE*), *Energy Policy* (*EnPol*), and relevant articles in the *Journal of Environmental Economics and Management* (*JEEM*), *Environmental and Resource Economics* (*ERE*), and the *Review of Environmental Economics and Policy* (*REEP*)). It should be noted that, although no articles from the journals *EE*, *EnJ* and *REE* appear in this short list, they were close behind, with articles featuring in the top 20 or 30 most cited, and *REEP* already has some articles with impressive numbers of citations given that it has only been in existence for the last five years.

*Table I.1 Most cited energy and energy-relevant environmental economics articles in mainstream economic journals*

Article	Journal	General topic	Citations
Weitzman (1974)	<i>RES</i>	Market-based instruments	554
Jaffe et al. (1995)	<i>JEL</i>	Environmental policy	419
Green and Newbery (1992)	<i>JPE</i>	Electricity liberalization	385
Hamilton (1983)	<i>JPE</i>	Oil prices effects	368
Nordhaus (1991)	<i>EcJ</i>	Climate policy	358
Montgomery (1972)	<i>JET</i>	Tradable permits	296
Joskow (1987)	<i>AER</i>	Coal markets	279
Mendelsohn et al. (1994)	<i>AER</i>	Carbon impacts	272
Stern (2004)	<i>WDev</i>	EKC	247
Baumol and Oates (1971)	<i>SwJE</i>	Environmental policy	229

Source: ISI/Web of Knowledge (1 March 2012).

*Table I.2 Most cited articles in energy and energy-related environmental economics journals*

Article	Journal	General topic	Citations
Selden and Song (1992)	<i>JEEM</i>	EKC	432
Unruh (2000)	<i>EnPol</i>	Carbon lock-in	202
Stavins (1995)	<i>JEEM</i>	Emissions trading	198
McDonald and Schrattenholzer (1999)	<i>EnPol</i>	Energy technology	192
Manne et al. (1995)	<i>EnPol</i>	CO <sub>2</sub> emissions	181
Weitzman (1998)	<i>JEEM</i>	Discounting	163
Greening et al. (2000)	<i>EnPol</i>	Rebound effect	159
Tol (2005)	<i>EnPol</i>	Carbon impacts	152
Dincer (2002)	<i>EnPol</i>	Energy policy	152
Tol (2002)	<i>ERE</i>	Carbon impacts	143

Source: ISI/Web of Knowledge (1 March 2012).

Naturally, apart from a few cases in Table I.2, it is too early to identify the seminal pieces in the twenty-first century. This is partly because of this crude bibliometric approach. However, this approach will become even more helpful for identifying seminal articles in the future, as the research output on the subject grows.

### 3. RECENT TRENDS IN ENERGY AND CLIMATE CHANGE RESEARCH

This recent phase that seemed to me to be a period of refinement and application of original ideas, rather than appearing to produce a relatively large number of new ideas, was, if one looks at the statistics, a golden age for the economics of energy

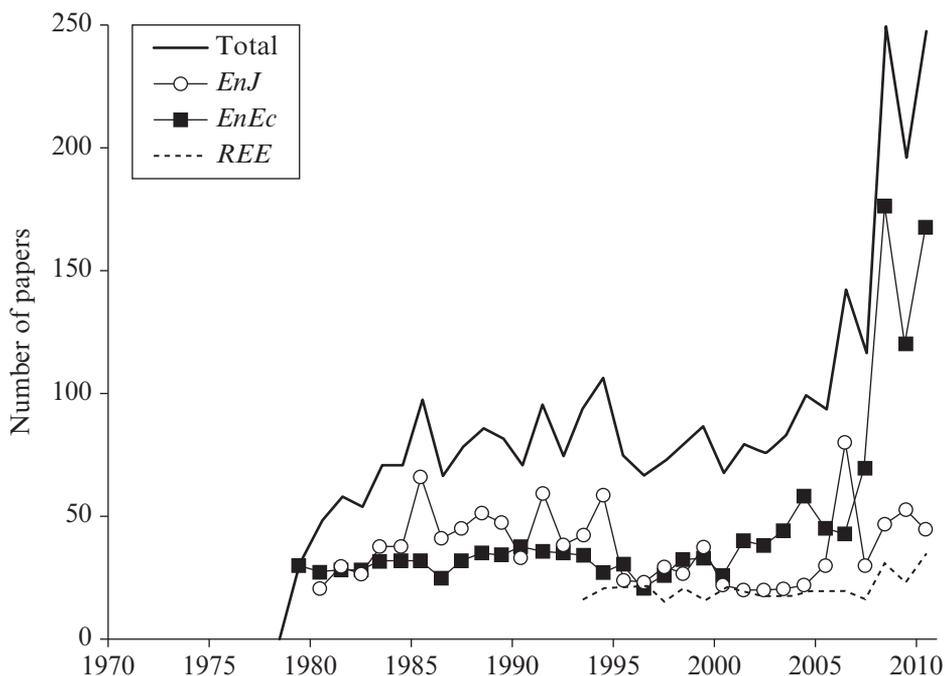


Figure I.1 Trend in energy economics articles (1979–2010)

and climate change. The first decade of the twenty-first century saw a dramatic increase in the production of research related to energy and climate change issues. The number of energy economics academic articles took off in 2005 (see Figure I.1). Before that year, a little under 100 articles were published in the main energy economics journals (*Energy Economics* (*EnEc*), *The Energy Journal* (*EnJ*) and *Resource and Energy Economics* (*REE*)). By the end of the decade, the average was closer to 250 – much of the increase due to the expansion of the journal *Energy Economics*. There are naturally many more energy economics articles, since some get published in mainstream economics journals (for now, it is unclear whether the number of energy economics articles in mainstream journals increased or decreased), and in broader environmental and resource journals (such as *Journal of Environmental Economics and Management*, *Environmental and Resource Economics*, *Ecological Economics* and more recently *Review of Environmental Economics and Policy*, and *Economics of Energy and Environmental Policy*).

Table I.3 shows the total number of articles in these journals, plus those published in *Energy Policy*, which was founded by energy economists and provides an important forum for the more policy-related analysis – as shown in Table I.2. These journals published three times more articles in the period 2006–10 than in 2001–05, and 13 times more than in 1976–80.

Figure I.2 shows the *Energy Economics* articles (*EnEcon*, the total from Figure I.1), those published in the journal *Energy Policy* (*EnPol*), and working papers that appeared

Table I.3 Annual average number of articles in energy economics and policy journals (1973–2010)

Years	Total	Years	Total	Years	Total	Years	Total
1973–75	25	1981–85	110	1991–95	185	2001–05	228
1976–80	54	1986–90	128	1996–2000	165	2006–10	722

Source: Journal websites.

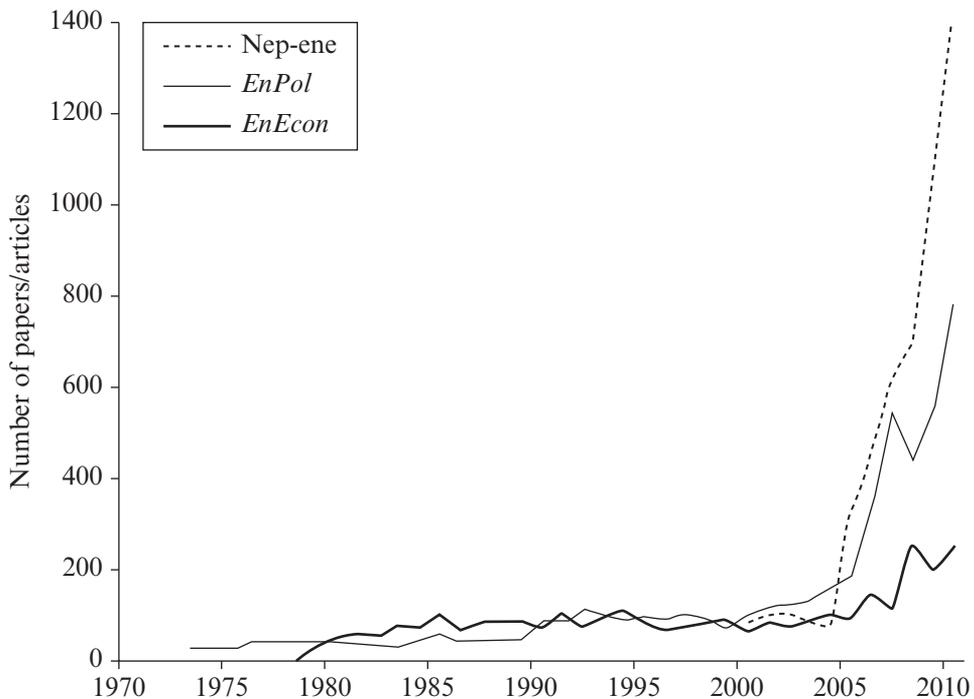


Figure I.2 Trend in energy-related papers and articles (1973–2010)

in the weekly nep-ene reports, the list of New Economic Papers dedicated broadly to energy economics. While there was a 3.5-fold increase in articles in specifically energy economics journals in the first decade of the twenty-first century, a ten-fold increase was measured in the broader literature on energy and climate change issues (see Figure I.2). In this period, the number of articles published in the journal *Energy Policy* leapt – rising eight-fold between 2000 and 2010.

Also shown in Figure I.2 are working papers listed in the energy economics report of the New Economic Papers, nep-ene (<http://ideas.repec.org/n/nep-ene/>), which are new additions to RePEc, the world's largest virtual repository of economic working papers. These working papers went from being one-third of the total articles and papers in 2000–04 to 50 per cent–58 per cent in 2006–10. So, in part, this simply reflects that more

working papers are being included in this virtual repository. This is certainly true: more institutions are linked to the RePEc (Research Papers in Economics); thus economics working papers in all sub-disciplines have increased during this decade. However, before 2007, the number of working papers appearing in the energy economics report (nep-ene) was less than 3 per cent of the total working papers (nep-all). This increased to 3.2 per cent in 2007, 3.8 per cent in 2008, 4.7 per cent in 2009 and 6.1 per cent in 2010, without any change in the selection criteria for including working papers in nep-ene. Thus economists are increasingly attracted to producing research related to energy and climate change.

It is important to stress that whereas the first two categories (*EnEcon* and *EnPol*) are peer-reviewed, nep-ene is not – as the reports include mostly working papers by academic and research institutions. Also, a number of the articles in the journals appear as working papers in nep-ene first. Thus there is some double-counting. At the same time, it provides an indicator of the crude amount of research on the economic, social and policy aspects of energy and climate change. So, while many articles or papers are left out, and there is some double-counting, nevertheless, Figure I.2 reflects the spectacular increase that has occurred from 2005.

It is also interesting to identify whether certain issues are becoming more or less topical. Table I.4 shows the breakdown of working papers in nep-ene according to the main subject of the paper between 2000 and 2010. For longer-run studies of trends in subjects for environmental, resource and ecological economics, it is worth consulting Fisher and Ward (2000) and Silva and Teixeira (2011). It seems that oil (averaging 18 per cent between 2006 and 2010) and natural gas (averaging 4 per cent) became more important in the second half of the decade, while electricity was less covered (falling from more than 24 per cent between 2002 and 2005, averaging 13 per cent in the second half of the decade). Renewable electricity and biofuels became more important, averaging 9 per cent – biofuels on its own became a hot topic in 2008, reaching 10 per cent of the total working papers. It is interesting to note that, given the potential roles renewable electricity and nuclear power might play in a low-carbon economy, the former (excluding the biofuel papers) has never reached 5 per cent and the latter never more than 1 per cent of the total papers in any year.

Conversely, the environmental Kuznets curve (EKC), and the relationship with growth, which was a hot topic at the beginning of the decade, has become less important. General environmental policies have also been covered less. This had been replaced by a greater focus on climate change policies and agreements. This subsection includes issues not directly related to energy, such as carbon sequestration, and climate change impacts and adaptation – these topics are included as they are seen as some of the external costs of energy use. Environmental and carbon taxes were popular in 2002–03, declining substantially since then. Emissions trading, which also peaked in those years, has maintained an important share of the total. Interestingly, this corresponds with the beginning of the EU Emissions Trading Scheme. There was then a new peak in 2008–10 reflecting analysis of this scheme.

Overall, though, the share of energy working papers (rather than predominantly about the environment or climate change) in nep-ene has increased from under 50 per cent in the first half of the decade to an average of 57 per cent in the second half of the decade. Thus the dramatic overall increase in articles and papers from 2005 signals a rising

Table I.4 Average shares (%) of different topics in nep-ene reports (2000–10)

	Energy (modelling, forecasts, policies)	Coal	Oil	Gas	Electricity	Renewables & biofuels	Techn. & efficiency	Growth & EKC	Env. policies	Env. & carbon taxes	Emissions trading	Climate policies (incl. sequestration, adaptation)
2000	1.3	0.0	11.3	0.0	17.5	3.8	2.5	7.5	27.5	6.3	3.8	18.8
2001	3.1	0.0	18.6	2.1	10.3	2.1	4.1	7.2	29.9	4.1	3.1	14.4
2002	5.8	0.0	10.6	1.9	35.6	1.9	3.8	2.9	16.3	8.7	3.8	8.7
2003	2.3	0.0	8.1	2.3	23.3	2.3	8.1	2.3	16.3	12.8	10.5	11.6
2004	1.3	1.3	8.9	0.0	25.3	3.8	7.6	2.5	16.5	1.3	12.7	19.0
2005	5.2	0.6	18.5	1.5	24.0	1.2	8.0	6.5	15.4	3.4	5.2	9.8
2006	5.3	0.2	20.8	4.2	18.6	4.7	5.3	4.0	13.1	2.7	7.1	12.9
2007	5.7	1.6	19.9	5.8	13.8	7.1	5.2	3.1	6.2	3.2	6.5	21.7
2008	7.1	1.1	16.9	4.0	13.7	13.8	4.3	2.8	4.4	2.7	9.2	19.8
2009	5.2	0.9	18.4	2.1	9.7	12.4	7.0	2.6	4.3	2.3	8.8	25.7
2010	8.2	0.5	14.8	3.0	10.3	8.9	6.4	4.8	6.2	3.1	9.3	24.0

Source: nep-ene archives (<http://ideas.repec.org/n/nep-ene/>).

interest in oil issues (especially related to resource scarcity and price hikes) and renewables, as well as in climate change.

#### 4. THE CAUSES OF THE EXPLOSION IN ENERGY ECONOMICS RESEARCH

It is worth dwelling on the causes of the explosion in energy and climate change research. There are general academic trends. Total economic working papers, including those in nep-all, increased from 2700 in 2000 to 23 500 in 2010.

Obviously, as mentioned before, there has been a growth in the use of this system as a virtual repository of research output. While, in 2000, only a fraction of economic institutions were linked to RePEc (which provides the list of new working papers for nep-all), today most working papers written in English (and other European languages) from economic departments and research centres around the world are now included in nep-all, and accessible through New Economic Papers and RePEc.

Also, the knowledge economy has been benefiting from greater investment in research and development (R&D), including economic, social and political knowledge (Jaffe and Trajtenberg, 2005). On the supply side, thanks to computers and the Internet, researchers find it easier to produce a working paper today than in the twentieth century. There is also more pressure for academics to publish than 20 years ago (De Rond and Miller, 2005), although there may be signs that the use of bibliometric indices is reversing the trend towards researchers publishing fewer, more cited articles (Weightman, 2011).

However, the specific growth (indicated by the increasing share of energy and climate change issues in economics working papers) reflects a demand for a better understanding of energy markets and policies, and the many dimensions of climate change. Research funding agencies and private organizations are using their constrained budgets to answer related questions. Academics independent of funding may also be drawn to these topics. So energy economists are in demand for many of the old issues and equally for the environmental angle.

Probably the growth reflects in part the boom years up to 2008. One could say that the income elasticity of demand for energy and climate change research was positive. It seems that it was also greater than one. Certainly the 'research intensity' (i.e. the research output relative to GDP) has risen in the twenty-first century (see Table I.5).

Yet this research intensity indicator associated with energy economics has not always risen and, at times, has fallen. Using a very crude indicator, in 1975, four articles were produced on energy issues per trillion (2010) dollars of global GDP (see Table I.5). This peaked at more than 12 articles per trillion dollars in 1985, following the oil shocks. It then fell back in the 1990s, before reaching 13 articles (and papers) in 2005. This increased rapidly in the second half of the 2000s to almost 40 articles per trillion dollars of GDP.

The variation in this crude research intensity indicator shows that research output (and, no doubt, funding) reflects critical periods in the history of energy rather than more general economic output. The growth from 1975 to 1985 was clearly driven by funding agencies' and researchers' reaction to the oil shocks. This interest slumped with the oil

Table I.5 *Energy economics' research intensity (1975–2010)*

Year	Research intensity	Year	Research intensity	Year	Research intensity
1975	4.7	1990	7.1	2005	13.2
1980	8.3	1995	5.8	2010	38.9
1985	12.2	2000	7.6		

Sources: Figure I.2, and World Bank (2011).

price in the early 1990s. It took off again with the climate change debate and then more recently the new hike in oil and other energy prices.

At present, crucial for many reading this handbook is whether, when the economy starts growing again, this research output and intensity will begin to rise once more. Indeed, it is very possible that the research output related to energy and climate change issues will plateau at 2010 levels or even start to drop. The decline in the 1990s hints that 2005–10 may have been a golden period for energy economists.

If, on the other hand, energy prices rise further and climate-change-related damage intensifies, the business of energy economics is likely to be rosy. If so, research output will continue to grow in absolute terms and even relative to GDP, and this should generate a great deal of new understanding of energy and climate change issues.

## 5. A COMMENT ON RESEARCH ORIGINALITY

The discussion has focused on the quantity of research output measured by the number of articles published, and working papers available on a specific website. This was crude, but the trend seems to be clear: around 2005, research output focusing on energy and energy-related environmental articles and working papers exploded.

However, this tells us nothing about the quality<sup>2</sup> of the research output. At the beginning of the chapter, I proposed that there was a period of growth in the originality of the research related to the economics of energy and climate change during the 1990s, and then, following an explosion in research output, perhaps a decline in the number of original ideas being presented and new ‘research fronts’ developed (Upham and Small, 2010). Of course, it would be absurd to suggest that there have not been important and even seminal ideas produced since this explosion, around 2005. No doubt there have been, in absolute terms, more new ideas in the last decade than before. However, because of the explosion in papers on the subject, they might be a smaller percentage of the overall total. Thus the researcher attending conferences or flicking (or clicking, now) through journals or working paper lists in search of inspiring new thoughts may be looking in the proverbial haystack.

It would be interesting to consider: (i) did the economics of energy and climate change experience a period of great originality, when many new ‘research fronts’ were developed and the associated publications were especially ‘influential’ during the 1990s? (ii) Around 2005, was there a decline in relative ‘originality’? A more general set of questions is: (iii) Is there any correlation between resource quantity and originality? (iv) Are

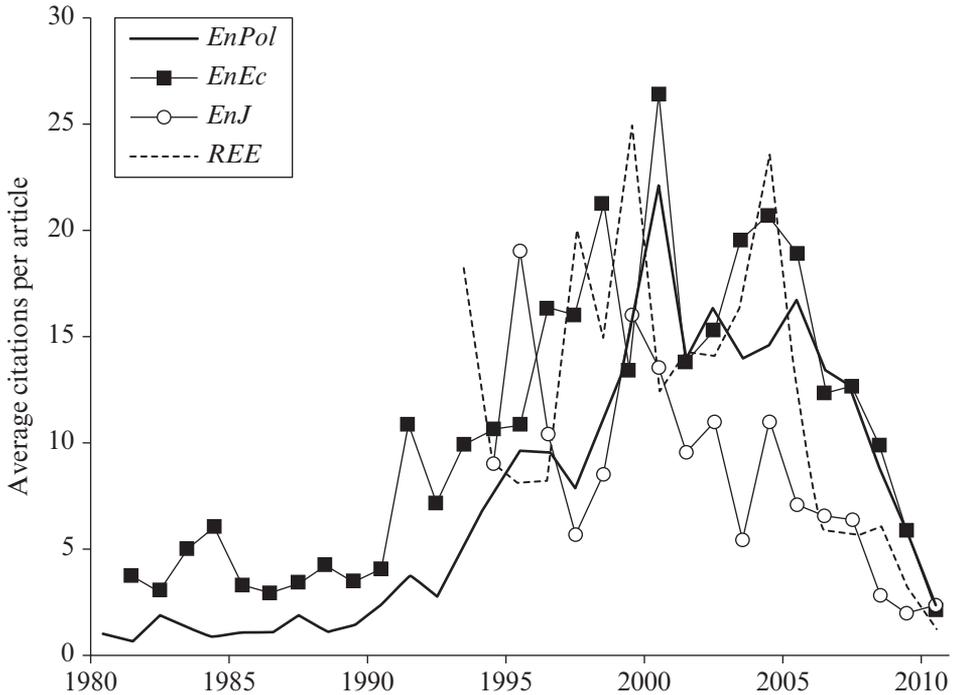


Figure I.3 Trend in annual average citations per article in energy economics and policy journals (1980–2010)

they positively or negatively correlated? (v) Does a rise in originality precede a rise in quantity?

Clearly, these are hard questions to answer. Again, despite the limitations of bibliometric analysis, they might offer some information on the subject. Figure I.3 presents the trends in average citations per article in each year for specific energy-related journals. The journals presented are the same as above (*Energy Economics* (*EnEc*), *The Energy Journal* (*EnJ*), *Resource and Energy Economics* (*REE*) and *Energy Policy* (*EnPol*)). The trends suggest a peak around 2000–2001 with another lower peak in 2005. However, one should be very careful before concluding that hypotheses (i) and (ii) are supported by the evidence.

First, this is a very crude metric of research originality and even influence. There are a number of different possible indicators, such as the impact factor (citations for the journal in the last two years) or five-year impact factor, eigenfactor, h-index for journals, all quite flawed.<sup>3</sup> Also, in each journal, the number of ‘blockbuster’ articles and their distribution in relation to standard ones varies greatly and, therefore, affects the average citations in each journal (Brouthers et al., 2012).

Second, the older the article, the more time has passed for it to be cited. So, all other things being equal, the oldest articles might be expected to be the most cited. This is not the case. Other factors must also be at work.

Third, present articles build on past ones, and if a growing number of articles is pub-

lished, the ratio between present and past increases, meaning that past articles will be cited more often. When the growth is especially rapid, such as between 2005 and 2010, the difference between past and present articles is especially pronounced, implying many citations for past articles. So the total number of citations should be expected to increase. However, with each year that passes the total number of past articles to be cited increases. So, all other things being equal, in periods when the growth rate in research output increases, average citations in the preceding period probably increase, and, when the growth rate falls, average citations in preceding periods probably fall.

Fourth, the advent of computers and access to journal articles on the Internet has meant that today's researchers are probably citing more than in the past. So the Internet is helping to increase average citations.

Fifth, except for classic or 'blockbuster' articles, researchers are likely to prefer the use of recent publications with the most up-to-date information and methods of analysis. So, given all this growth (in research output and in the use of the Internet), we might expect the peak to be in 2010.

Sixth, however, articles do not get cited immediately. They take a while to be read, digested, discussed and considered useful. In fact, the peak number of citations for articles in any year seems to be between seven and ten years after publication. The articles published in 2000 for the *Energy Journal* and *Resource and Energy Economics* received the maximum number of citations in 2007, for *Energy Policy* in 2009 and for *Energy Economics* in 2010. Beyond this peak, the number of citations in each year declines, but still adds to the total and average number of citations for any year of publication. So, given that 2011 is the last year for which data are available, a peak around 2000 might be expected (looking at the data from a 2012 perspective).

So, in light of the many caveats, all that can be said is that there has been a growth in the number of citations per article from the early 1990s, which peaked between 2001 and 2005. Let each reader judge whether there was indeed an important rise in research originality from 1995.

Future research might be able to answer this more thoroughly, offering greater insight into research influence, originality and maybe even quality. Over the next ten years it might be interesting to follow the trend in average citations per article in any year. If average citations between 2006 and 2010 do not catch up with those between 2000 and 2005, then one might suspect (although, very tentatively, since there are so many other factors involved and it is a very crude indicator) that the growth in research output coincided with a decline in originality, and that there was a rise in originality preceding the growth in research output.

If this is confirmed, then the discussion and these hypotheses hint at a possible causality between the two variables, and a narrative: driven by a change in general concern for resource and environmental issues, between the 1960s and the early 1990s, mainstream economists applied their expertise to energy and environmental issues (see Table I.1). In response to the oil shocks, energy economics became a specific sub-discipline of economics, with dedicated journals. Inspired by these and more basic ideas from mainstream economists, the growing interest in issues related to developing economies, energy policy, efficiency and environmental concerns led, during the 1990s, to a great deal of original research among more specialized energy and environmental economists. In the language of students of science, new research fronts opened up, with a relatively large number

of 'blockbuster' articles produced (Upham and Small, 2010; Brouters et al., 2012). Although still to be confirmed, the level of 'originality' among energy and environmental economists may have peaked between 1995 and 2005. After this period, the focus was probably on using and applying these ideas, and it generated a great deal of funding and research output.

## 6. NEW DIRECTIONS IN THE ECONOMICS OF ENERGY AND CLIMATE CHANGE

Two issues stand out. First, since 2005, we may have entered a growth phase (of research output) that coincides with an emphasis on refinement rather than original thinking. This is a concern because energy security, supply and prices, and of course climate change mitigation and adaptation, are still serious problems that require original ideas to solve them.

Second, for the energy economists seeking new ideas, one challenge is how to find seminal working papers and articles (Brouters et al., 2012). It is a challenge that is likely to continue and, depending on oil prices and climate change, and the ensuing supply of energy economics, may become even greater. There will be a need to find a way to approach this challenge, such as by bringing these ideas together. Thus, in this handbook, I have taken the responsibility of inviting (what are in my view) creative and controversial thinkers to contribute.

That is certainly not to claim that all the chapters offer or address radically new ideas. Instead they might be providing important overviews or reviews of topics. This handbook is simply an invitation to researchers to present some stimulating thought and debate. Nevertheless, it is hoped that the reader will find here a high concentration of stimulating ideas and, on reading individual chapters, will discover new windows onto possible solutions to energy and climate change problems to have opened up.

The handbook is divided into seven parts: fossil fuel markets, electricity markets, energy policy, climate agreements, carbon mitigation policies, low-carbon behaviour and low-carbon growth.

The chapters in Part I address aspects of the various fossil fuel markets. Hamilton, in the first chapter, provides a long-run perspective on global oil production and prices, and their relationship with economic growth. He indicates that, historically, global oil production has kept up with the growth in demand by finding new geographical areas. In the periods before production had adjusted, prices inevitably rose, with substantial impacts on the global economy. There is evidence that these impacts have become weaker through time, but that there may be less potential for energy production to grow by finding new geographical areas.

In Chapter 2, Stevens presents the history of natural gas markets and considers the role of gas in the global primary energy mix. He discusses the reasons for the rapid growth in natural gas in the last two decades, emphasizing the important role that declining LNG (liquefied natural gas) transport costs have played. He then reviews the markets in different regions, and the important role Russia has and will continue to play in a number of the regional markets. He also discusses the potential impact of advances in shale gas production on future global markets. In Chapter 3, the potential implica-

tions of an OPEC-style natural gas cartel are considered by Gabriel et al. They find that, in the foreseeable future, the problems of coordination are too high and the gains from production cuts among GECF (Gas Exporting Countries Forum) members too low (especially for Russia) to develop a genuine natural gas cartel. They do suggest, however, that a more subtle form of supply infrastructure coordination may develop as a result of Russia's strategic interests.

In Chapter 4, Haftendorn et al. warn us of the continued expansion of world demand for coal, and its potential for large carbon dioxide emissions. They suggest that there will probably be a move towards India and Asia. They compare the impacts of different climate policies on the coal trade, and find that global climate policies will be crucial for minimizing carbon dioxide emissions related to coal consumption.

Part II covers different issues related to the market for electricity. Jacoby et al. in Chapter 5 investigate how the future electricity grid in the USA and more generally is likely to evolve, presenting the institutional issues and incentives facing the industry. They identify the key factors that will determine the evolution of the electricity transmission and distribution systems. They present some of the technological developments under way, such as smart meters, and some of the associated threats, including cyber privacy.

In Chapter 6, Johnstone and Haščič focus on the drivers of past R&D into energy storage and grid management. Both for the future of electricity markets and especially given the intermittency associated with some renewable energy sources, energy storage and grid management are seen as important enablers of renewable electricity sources. Also, there is a major role for the public support of such R&D projects because of the difficulty of the innovators capturing the benefits from these advances; the problem of picking winners among the generating technologies is also avoided. In Chapter 7, Lee and Lovellette consider the factors, in the USA and internationally, that will promote the use of electric vehicles. They highlight the huge uncertainties associated with the potential uptake of electric cars. The key variables are trends in oil prices, the extent of biofuels expansion, electricity infrastructure, technological developments, such as battery performance, and consumer expectations about car attributes. They also indicate that these factors vary greatly across countries, and that, in some countries, the factors might all combine to encourage their uptake.

Part III considers the involvement of government in these fossil fuel and electricity markets. Despite their potential for reducing carbon dioxide emissions, barriers to energy efficiency, and the higher costs of renewable energy and nuclear power compared with fossil-fuel-generated electricity, these are central parts of today's energy and climate policy. Evans et al. in Chapter 8 present an original method for identifying macro-level improvements in energy efficiency. They provide new evidence on energy efficiency improvements for a range of different economies, and the potential of efficiency in meeting carbon dioxide emission targets. The chapter also acts as a valuable reminder that trends in energy intensity are frequently not a good indicator of energy efficiency improvements in an economy.

In Chapter 9, van Kooten reviews the current policies in place to promote the development of renewable energy technologies and sources, with a detailed discussion of feed-in tariff (FIT) programmes. He discusses these tariffs in theory and in practice, indicating their widespread adoption across the world and the level of tariffs in different countries

for wind power and solar photovoltaic. He argues that feed-in tariffs as an energy and climate policy are inefficient compared to other instruments, and suggests that the higher costs of the tariffs and associated rising electricity prices are starting to reduce their popularity among a number of populations and electorates. In Chapter 10, Jefferson questions the potential contribution that renewable energy sources can make to future (medium-term) energy requirements. He suggests that the rising concern about climate change is giving energy supply industries, especially the nuclear and renewable industries, an opportunity to develop a strong rhetoric (which might involve stretching the truth, and using expert advice and scientific reports to their advantage), which is affecting the public's and government's perception of their potential expansion. He proposes that their potential expansion in the medium term is far more limited than is generally perceived, and places doubt on the ability of the electricity supply industries to achieve renewable energy growth targets.

Robinson, in Chapter 11, reviews the evolution of energy policies and identifies where they might go in the future. In particular, the role of government in energy markets appears to have increased in the mid-twentieth century and declined at the end of the century. He argues that the increased concern about climate change is an important factor reviving government involvement in energy markets.

Part IV is about climate agreements. Hendry and Pretis in Chapter 12 offer new evidence on the first and potentially most important agreement, the general consensus among scientists and even politicians that climate change is affected by anthropogenic activities. They combine long-term and seasonal data to show that, while natural factors are important for seasonal fluctuations, fossil-fuel-related carbon dioxide emissions are crucial for explaining air temperature trends.

In Chapter 13, Holtmark discusses some of the main reasons why it is difficult to gain broad international support for an effective climate agreement. He also proposes that a set of regional agreements, which has been proposed as a solution to the problem, might lead to inefficiently small emission reductions. He also argues that unilateral pledges by individual or groups of countries to make deep cuts in emissions may in fact make it more difficult, not easier, to achieve an effective international climate agreement. In turn, Tol in Chapter 14 proposes that the Kyoto Protocol may be a satisfactory framework for achieving major reductions in global carbon dioxide emissions. He argues that all the requirements necessary for international climate policy are in place (electoral demand for action, international monitoring of emissions data, a forum to pledge domestic action and review progress, and international flexibility in emissions reduction) and that future Conferences of the Parties (COP) meetings should focus on refining the existing agreements.

Aldy, in Chapter 15, discusses some of the key conditions that will be necessary to achieve a successful post-2012 international climate regime. Three issues he raises are the need to enhance the legitimacy of multilateral climate policy efforts, promote best policy practices, and channel financing for investments in climate change risk mitigation activities in developing countries. He emphasizes the importance of transparency and surveillance to enhance the credibility of international agreements. For instance, this surveillance and individual country legitimacy may also be used to justify financing in that country, ultimately increasing support for carbon finance more generally. Aldy proposes a Bretton Woods-style institution to act as the central architecture for

addressing these issues and coordinating international climate change agreements and developments.

Part V discusses different policies for encouraging reductions in carbon dioxide emissions. Given the agreement to raise \$100 billion per year by 2020 for financing climate mitigation and adaptation projects in developing countries, Parry in Chapter 16 discusses how the revenue to fund such projects might be raised. He compares the features of different approaches to raising revenue: the effectiveness, revenue raised, cost-effectiveness, cross-country distribution of revenues, and impacts on energy prices. He offers the rationale for carbon pricing, ways of dealing with the opposition to carbon pricing (such as pulling back environmentally less effective taxes) and alternatives to carbon taxes, such as ‘feebates’ that combine fees and rebates to incentivize less polluting consumption.

In Chapter 17, Hope seeks to identify how high a tax related to climate change might reach. He outlines the role of integrated assessment models in estimating the social costs of carbon. He shows that estimates of the social costs of carbon tend to be based on a subsample of the results, which excludes extreme results. However, given the great uncertainty about climate change, when extreme results are incorporated, estimates of the social costs of carbon increase substantially. Based on a fuller subsample of results, he proposes that a tax related to climate change should probably be well over \$100 per tonne. In Chapter 18, McKittrick proposes a state-contingent (i.e. temperature) pricing mechanism for carbon dioxide emissions. One of the purposes of the idea is to find a compromise for two opposing sides – those that fear climate change and, therefore, believe that associated taxes are under-predicted, and those that believe they are over-predicted. It is also an interesting proposal because it creates incentives for future climate change to be predicted with greater accuracy.

In Chapter 19, Gago et al. focus on energy consumption and related emissions in buildings. They argue that conventional policy instruments may not achieve the desired outcomes unless they are packaged together to tackle the existing problems of information, split incentives among agents, uncertainty and access to capital. They propose a policy package based around energy certification of buildings, the use of flexible building codes, smart metering and a new tax on energy inefficiency. In Chapter 20, Gennaioli et al. offer a methodological introduction to the econometric analysis of climate policies and a review of the evidence to date with the objective of providing more robust evaluation of instruments. They suggest that a race between ‘hard’ incentives (such as forms of carbon pricing) and more ‘soft’ interventions (such as energy reports, free energy advice or voluntary agreement) is under way. Evidence indicates that either type of policies can achieve reductions in carbon dioxide emissions. Nevertheless, they question whether soft interventions can be a substitute for the typically less popular hard interventions.

In Chapter 21, Chevallier reviews the main characteristics of tradable permits markets, with specific emphasis on the two largest cap-and-trade systems to date: the EU Emissions Trading Scheme (ETS) and the Kyoto Protocol’s Clean Development Mechanism. He considers the distortionary effects of allocative mechanisms, identifies the factors determining permit prices and links market fluctuations with broader macro-economic forces. He also considers the potential unification of regional carbon market initiatives into a ‘world’ carbon market. In Chapter 22, Kverndokk examines some of

the barriers to the introduction of tradable permits. He presents evidence on the public's ethical concern about such schemes. This barrier implies that concerned individuals are likely to impede the progress of environmental legislation and may be responsible for greater emissions than otherwise.

In Chapter 23, de Perthuis and Trotignon consider the transition to the next phase (2013–20) of the EU carbon dioxide emissions trading scheme. They analyse proposed reforms to the scheme, including setting a reserve auction price, allowing for set-asides and extending the phase until 2030. A key message of the analysis is that policy clarity will be crucial to the effectiveness of the long-run development of the EU tradable permit market. Finally, they discuss the formation of a carbon regulating authority, similar to central banks, independent of any short-term political pressures, to manage the permit market to achieve emission reductions while minimizing price volatility and promoting market efficiency.

Part VI explores some of the behavioural limitations to a low-carbon economy. Pollitt and Shaorshadze in Chapter 24 review the literature on behavioural economics in the context of energy and low-carbon policies. They focus on consumption and habits, investment in energy efficiency, and the provision of public goods and support for pro-environmental behaviour. The large-scale deployment of smart meters and appliances will be particularly relevant for the application of behavioural economics to energy issues. They propose that a key role this approach can offer is in influencing public perceptions about the affordability of climate policy and in facilitating the creation of a more responsive energy demand.

In Chapter 25, Gowdy argues that the unique social characteristics of the human species can be used to address climate change. In particular, he reviews the fascinating anthropological and neurobiological literature on the sociality of human decision-making and links this economic behaviour related to energy and climate change. In Chapter 26, O'Garra outlines the moral dimensions of polluting behaviour related to climate change. She identifies features that make framing climate change as a moral issue currently problematic, and discusses how they might be re-cast within the structure of the archetypal moral problem, so that individuals may start to perceive climate change as a moral issue. She argues that, as long as the public fails to perceive climate change as a moral issue, the demand for climate stabilization will be weak and little progress will be made towards a low-carbon economy.

In Chapter 27, Eyre explores the need for a decentralized governance structure to achieve certain aspects of a low-carbon transition. He emphasizes that many of the carbon mitigation strategies will involve the involvement of an increasing number of decentralized players, whether households, social collectives or small businesses, investing in and running projects related to energy efficiency improvements or the provision of small-scale and intermittent renewable energy. He proposes that the nature of energy and climate policy may have to adapt to meet the changing dynamics between players, including a greater involvement of local government. Barbier, in Chapter 28, draws on institutional and historical perspectives to explain the continuing policy stalemate related to climate change, proposing that there is a policy failure on a massive scale. With this in mind, he asks whether a global crisis will be required to break the existing institutional structure and introduce new ones that are more suited for preventing climate change.

Part VII considers the longer-term perspective associated with low-carbon economic growth. Hepburn and Bowen, in Chapter 29, provide a conceptual and synthetic analysis of the relationship between economic growth and environmental limits, including those imposed by climate change. They propose that continued economic growth is feasible and desirable, although not without significant changes in its characteristics. These changes need to involve ultimately the reduction of the rate of material output, with continued growth in value being generated by expansion in the 'intellectual economy'. In Chapter 30, Llavador et al. refocus the debate about optimal climate strategies by asking which characteristics, such as consumption, knowledge or education, are desirable and should be promoted when seeking economic growth. Their message (as well as that of the authors of the preceding chapter) is that by broadening the set of values, policy makers might help to lead the economy towards activities that are less energy- and carbon-intensive.

In Chapter 31, Chevallier explores whether a low-carbon transition is possible in China. Given that China is responsible for about one-fifth of global carbon dioxide emissions at present, future climate change will be affected by the economy's ability to stabilize and reduce emissions. Similarly, because it is becoming a global economic leader, its path will have a very large impact on the behaviour of other economies. Furthermore, as a centrally planned economy, its approach may offer new lessons for achieving a transition to a low-carbon economy. Chevallier concludes that, given its industry structure, current energy mix and potential for technological development in renewables, a transition towards a low-carbon economy in China is necessary, and feasible with a possibility of developing domestic emissions trading and joining a future global carbon market

Given the concerns about climate change, on the one hand, and those about the economic implications of a transition to a low-carbon economy on the other, Fouquet, in Chapter 32, offers a speculative discussion about the problems and possibilities created by a climate-changed and low-carbon economy. Taking account of future population growth and economic development, he presents three extreme scenarios of the world during the twenty-first century that focus on, first, climate adaptation, second, an all-nuclear economy and, finally, an all-renewable economy. He highlights that each outcome implies specific constraints and major implications (some positive, some negative) for the future energy system and for the wider economy and even society. He warns against a blind objective of achieving a low-carbon transition at any cost, and instead encourages care about the outcome sought and, thus, the path chosen.

This handbook is far from an exhaustive survey of the issues related to energy and climate change. For one, it has focused on the economic aspects rather than approaching the issues from more technical or other social angles. Naturally, it tries to focus on the interaction between energy and climate change, and accompanies similar endeavours that focus on either energy or climate change (Evans and Hunt, 2009; Dinar and Mendelsohn, 2011; Dryzek et al., 2011). Finally, certain topics have not received the attention of a whole chapter dedicated to them, including: the specifics of energy production, distribution and use in developing economies (see, e.g., Wolfram et al., 2012), nuclear power (see, e.g., Davis, 2012 or Joskow and Parsons, 2012), the Clean Development Mechanism (see, e.g., Popp, 2012) and carbon capture and sequestration

(see, e.g., von Hirschhausen et al., 2012). This handbook tries only to offer some insights into where the literature has reached – after the concerns in the 1960s about the long-run relationship between economic growth and resource scarcity, to the many new ‘research fronts’ created from the 1970s and to the 1990s, to the explosion in research output since 2005 – and where it might be going.

## NOTES

1. I would like to thank Peter Pearson for his valuable comments and Claire Fitzgerald for collecting some of the data related to this chapter.
2. Research quality takes on several dimensions – as well as the development of new knowledge and influence on other research, it might include the theoretical and empirical analytical rigour of the research (Tol and Weyant, 2006; Frey and Rost, 2010; Brouthers et al., 2012).
3. For instance, the standard impact factor uses only the citations in the two years after publication, although, below, it will be shown that the peak for average citations occurs with a lag of seven to ten years after publication. Meanwhile, the eigenfactor identifies all the citations in a journal, weighting them according to the ‘ranking’ of the journal in which the citation occurred, but naturally depends on the ranking methodology. Finally, the h-index favours journals with a large number of issues (Seglen, 1997; Bornmann and Daniel, 2005; Chang and McAleer, 2011).

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