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Economics of Energy and Climate Change: Origins, Developments and Growth

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Economics of Energy and Climate Change:
Origins, Developments and Growth

Roger Fouquet[1][2][3]

This paper briefly highlights some of the most influential ideas in the literature on the economics of energy and (energy-related) climate change. This paper will use bibliometric evidence to examine the trends in related research over the last forty years, and analyse the explosion in energy and climate change research in the last ten years. It will also, more controversially, consider the validity of the hypothesised rise in original ideas in the literature (during the 1990s) and then decline (or relative decline) since the explosion in research output (since 2005). This paper proposes that if economists are going to make an equally important and constructive contribution as they did up to 2012, then their ideas will need to move forward and evolve, offering exciting and stimulating new solutions for the post-Kyoto era.

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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 twenty 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 industrialised countries emissions between 2008 and 2012. These developments have been driven by advances in the natural and social sciences over the last thirty 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, Nordhaus 1991, Cline 1992, IPCC 2007). Economists have been influential in arguing that the cost 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 to 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" (Brouther et al. 2012 p.960). The hypotheses proposed here, and that will be considered more fully in this paper, is 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 (Hagardon and Sutton 1997). After a period of great ideas, that 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, which 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 still remain, which 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 paper will briefly highlight some of the most influential ideas in the literature on the economics of energy and (energy-related) climate change – that is, the 'blockbusters' that have created new 'research fronts' and changed the way we think about these issues. This paper will use bibliometric evidence to examine the trends in related research over the last forty years, identify and analyse the explosion in energy and climate change research in the last ten years, and consider the validity of this *hypothesised* 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 it 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, for instance, Kula 1998, Stevens 2000, Pearce 2005 for broad reviews of the literature).

In the 1960s, energy economics was driven by an empirical approach to questions, exemplified by the Resource for the Future (RFF) studies of long run energy consumption and prices (Schurr and Netschert 1960, Potter and Christy 1962, Barnett and Morse 1963, and 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 their 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 liberalisation-privatisation debate (Joskow and Schmalensee 1983, Joskow 1987, Helm et al. 1988, Green and Newbery 1992, 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 on energy consumption (Khazzoom 1980, Goldemberg et al. 1984, Jaffe and Stavins 1994, Nordhaus 1996, Unruh 2000, Sorrell and Dimitropoulos 2007, Fouquet and Pearson 2012); the potential development of markets for renewable energy technologies and sources, incentivised 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 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 of the need to internalise 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, such as taxes and tradable permits, to regulate environmental pollution 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, Pizer 2002, Aldy et al. 2010).

The details of optimal and second-best environmental taxation (that 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 1994) and possible double dividends (Bovenberg and van der Ploeg 1994, Parry 1995, Bovenberg and Goulder 1996, Alcott 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 emission 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 twenty 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 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 1994, 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), estimating the social cost of carbon (Hope et al 1993, Tol 1994, Tol 2005). When linked to the mitigation costs, these can offer long term strategies related to climate policy (Nordhaus 1991, Nordhaus and Yang 1996, Stern et al. 2006, Weitzman 2007, Nordhaus 2008). The latter has 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, Hoel 1991, Carraro and Siniscalco 1993, Barrett 1994, Nordhaus and Yang 1996).

Following Tol and Weyant (2006), and other bibliometric studies, Table 1 provides an insight into the most cited energy and energy-related environmental economics articles in mainstream economic journals (that 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 Bovernberg and de Mooij (1994), 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), Baumol and Oates (1975), Pearce et al (1989), Cline (1992), Nordhaus (1994, 2008), Stern et al. (2006) and IPCC (2007), or books by economists that might influence public attitudes, such as Kahn (2010) and Wagner (2011) .

Table 1. Most Cited Articles in Energy and Energy-Relevant Environmental Economics Articles in Mainstream Economic Journals

Article	Journal	General Topic	Citations
Weitzman (1974)	RES	Market-Based Instruments	554
Jaffe et al. (1995)	JEL	Environmental Policy	419
Green and Newbery (1992)	JPE	Electricity Liberalisation	385
Hamilton (1983)	JPE	Oil Prices Effects	368
Nordhaus (1991)	EcJ	Climate Policy	358
Montgomery (1972)	JET	Tradable Permits	296
Joskow (1987)	AER	Coal Markets	279
Mendelsohn et al. (1994)	AER	Carbon Impacts	272
Stern (2004)	WDev	EKC	247
Baumol and Oates (1971)	SwJE	Environmental Policy	229

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

As an example of further key articles in the economics of energy and climate change, Table 2 presents the most cited relevant articles (again based on ISI/Web of Knowledge) in energy and 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 & 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 2. Most Cited Articles in Energy and Energy-Related Environmental Economics Journals

Article	Journal	General Topic	Citations
Seldon and Song (1994)	JEEM	EKC	432
Unruh (2000)	EnPol	Carbon lock-in	202
Stavins (1995)	JEEM	Emissions trading	198
McDonald and Schrattenholzer (2001)	EnPol	Energy technology	192
Manne et al. (1995)	EnPol	CO2 emissions	181
Weitzman (1998)	JEEM	Discounting	163
Greening et al. (2000)	EnPol	Rebound effect	159
Tol (2005)	EnPol	Carbon impacts	152
Dincer (2002)	EnPol	Energy policy	152
Tol (2002)	ERE	Carbon impacts	143

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

Naturally, apart from a few cases in Table 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 you look at the statistics, a golden age for the economics of energy 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 1). Prior to that year, a little under 100 articles were published in the main energy economics journals (Energy Economics (EnEc), The Energy Journal (EnJ) and Resource & 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 & Management, Environmental & Resource Economics, Ecological Economics and more recently Review of Environmental Economics & Policy, and Economics of Energy and Environmental Policy).

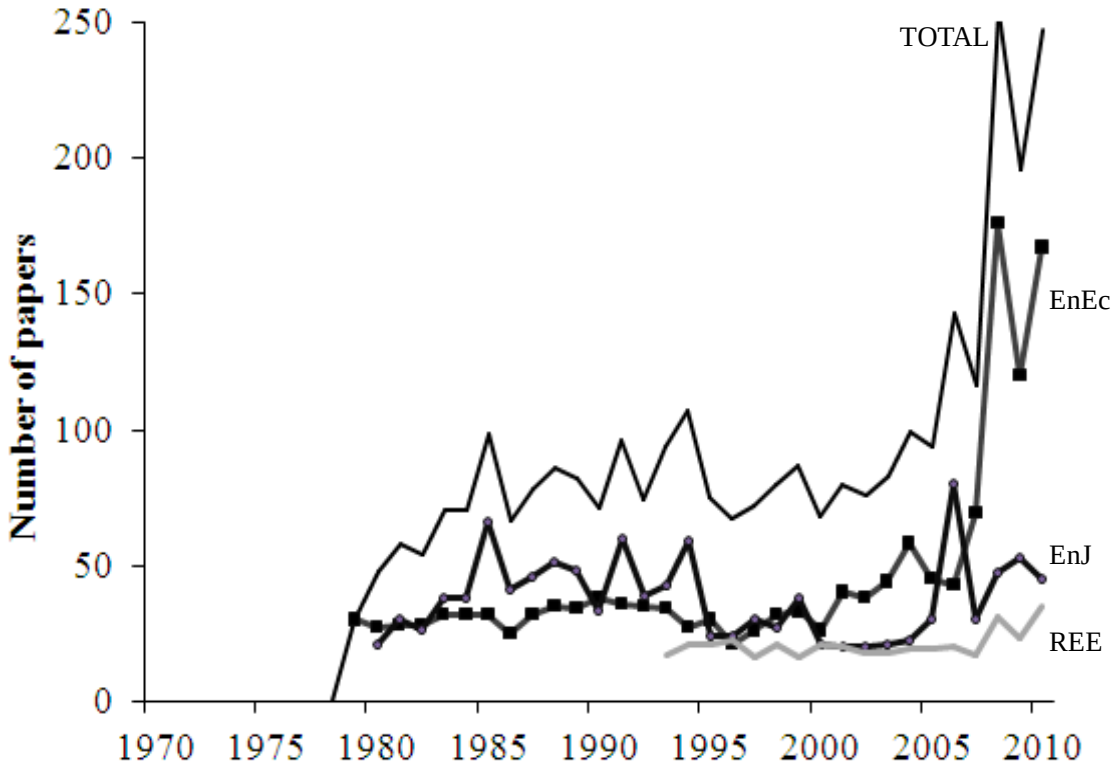

Figure 1. Trend in Energy Economics Articles (1979-2010)

Table 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 2. These journals published three times more articles in the period 2006-2010 than 2001-2005, and thirteen times more than 1976-1980.

Table 3. Annual Average Number of Articles in Energy Economics and Policy Journals (1973-2010)

Years	Total	Years	Total	Years	Total	Years	Total
1973-1975	25	1981-1985	110	1991-1995	185	2001-2005	228
1976-1980	54	1986-1990	128	1996-2000	165	2006-2010	722

Source: Journal websites.

Figure 2 shows the energy economics articles (EnEcon, the total from Figure 1), those published in the journal Energy Policy (EnPol), and working papers that appeared 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 3). In this period, the number of articles published in the journal Energy Policy leapt – rising eight-fold between 2000 and 2010.

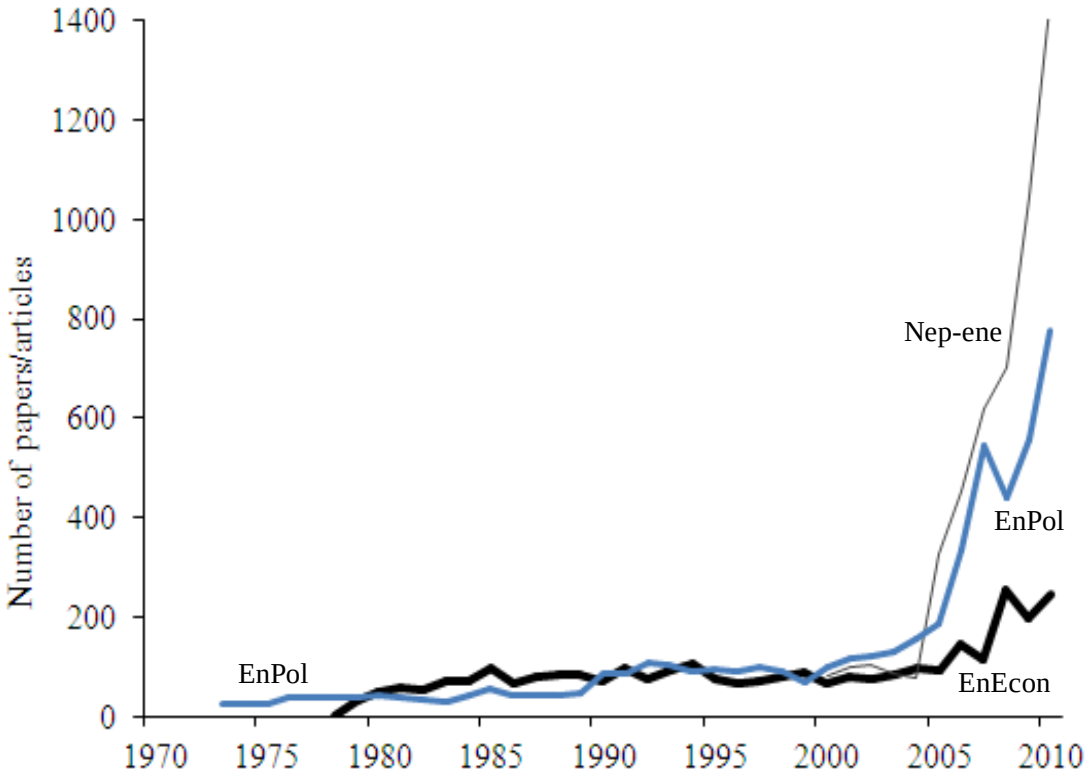

Figure 2. Trend in Energy-Related Papers and Articles (1973-2010)

Also shown in Figure 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 2000-2004 to 50%-58% in 2006-2010. 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, 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% of the total working papers (nep-all). This increased to 3.2% in 2007, 3.8% in 2008, 4.7% in 2009 and 6.1% 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 where as 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 3 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 4 shows the break-down of working papers in nep-ene according 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% between 2006 and 2010) and natural gas (averaging 4%) have became more important in the second-half of the decade, while electricity was less covered (falling from more than 24% between 2002 and 2005, averaging 13% in the second-half of the decade). Renewable electricity and biofuels became more important, averaging 9% - biofuels on its own became a hot topic in 2008, reaching 10% 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% and the latter never more than 1% of the total papers in any year.

Table 4. Average Shares of Different Topics in Nep-Ene Reports (2000-2010)

	Energy (Modelling, Forecasts, Policies)	Coal	Oil	Gas	Electricity	Renewables & Biofuels	Techn. & Efficiency	Growth & EKC	Env. Policies	Env & Carbon Taxes	Emission 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: see nep-ene archives (http://ideas.repec.org/n/nep-ene/).

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 sub-section 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 2002-2003, declining substantially since then. Emissions trading, which also peaked in those years, have maintained an important share of the total. Interestingly, this corresponds with the beginning of the

EU emission trading scheme. There was then a new peak in 2008-2010 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% in the first half of the decade to an average of 57% in the second half of the decade. Thus, the dramatic overall increase in articles and papers from 2005 signals a rising interest in oil issues (especially related to resource scarcity and prices 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 in nep-all, increased from 2,700 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 (Research Papers in Economics, 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 benefitting from greater investment in research and development, 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 twenty 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 organisations 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 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, 4 articles were produced on energy issues per trillion (2010) dollars of global GDP (see Table 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.

Table 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		

Source: see Figure 2, and World Bank (2011).

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 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.

When the economy starts growing again, it is questionable whether this research output and intensity will start rising again. Indeed, it is very possible that the research output related to energy and climate changes issues will plateau at 2010 levels or even start to drop. The decline in the 1990s hints that 2005-2010 may have been a golden period for energy economists.

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

5. A Comment on Research Originality

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

However, this tells us nothing about the quality[4] of the research output. At the beginning of the paper, 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, in absolute terms, there have been more new ideas in the last decade than before. However, because of the explosion in papers

[4] 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 Rosl 2010, Brouther et al. 2012).

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 hay stack.

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 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 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 & Energy Economics (REE), and Energy Policy (EnPol)). The trends suggest a peak around 2000-1 with another lower peak in 2005. However, one should be very careful before concluding that hypotheses (i) and (ii) are supported by the evidence.

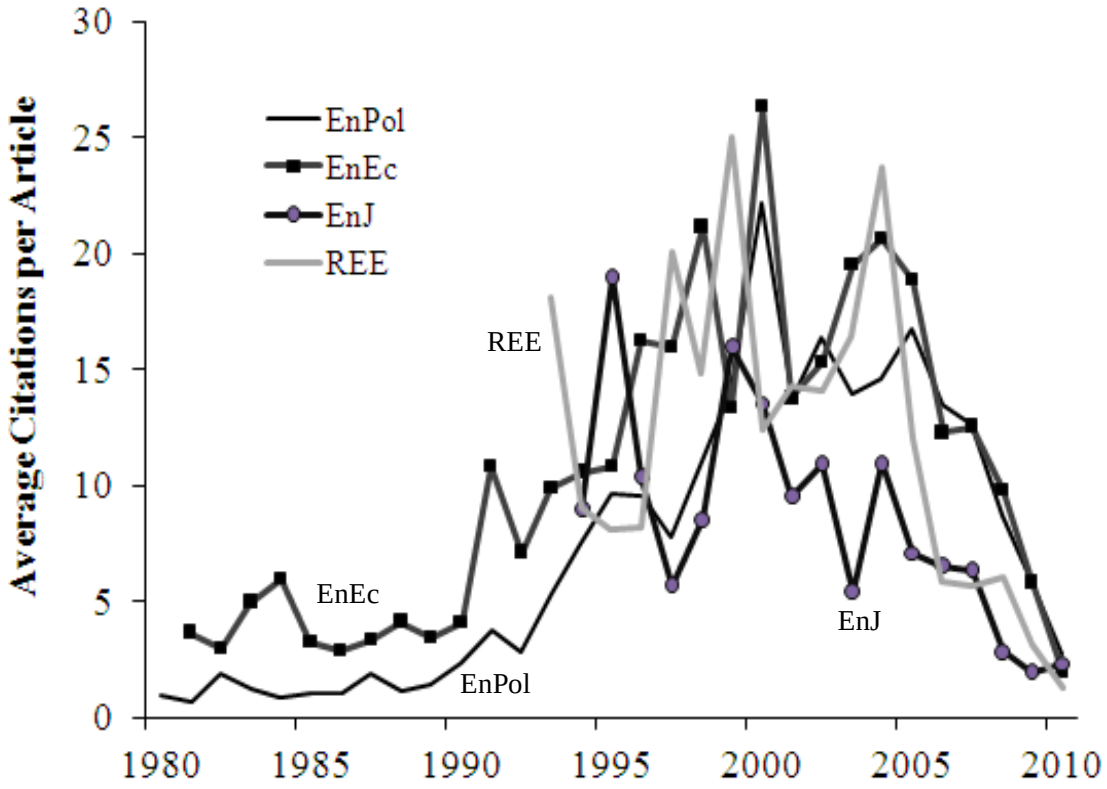

Figure 3. Trend in Annual Average Citations per Article in Energy Economics and Policy Journals (1980-2010)

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 5-year impact factor, eigenfactor, h-index for journals, all quite flawed[5]. 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 (Brouther 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 there is a growing number of articles published, 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, then average citations in the preceding period probably increases, and, when growth rate falls, average citations in preceding periods probably falls.

Fourth, the advent of computer and access to journal articles on the internet has meant that today´s researcher 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 7 to 10 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 is 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

[5] For instance, the standard impact factor uses only the citations in the two years after the publication, although, below, it will be shown that the peak for average citations occurs with a lag of 7 to 10 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 methodlogy. Finally, the h-index favours journal with a large number of issues (Seglen 1997, Bornmann and Daniel 2005 Chang and McAleer 2011).

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 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 amongst more specialised 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, Brouthers et al 2012). Although still to be confirmed, the level of 'originality' amongst 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. Concluding Remarks

This paper used bibliometric information to investigate the trends in the research into the economics of energy and (energy-related) climate change over the last forty years. It also sought to identify and analyse the explosion in energy and climate change research in the last ten years. Finally, it also tried to consider the validity of the *hypothesised* rise in original ideas in the literature and then decline (or relative decline) since the explosion in research output.

Despite all the conflicting interpretations about bibliometric data, one might accept that there was an increase in new ideas in the discipline in the 1990s. Also, since 2005, we have clearly entered a growth phase (of research output). The growth phase coincided with the increased concern about oil prices and about climate change.

More tentatively, this growth phase may have coincided 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.

Furthermore, for the energy economists seeking new ideas, one challenge is how to find seminal working papers and articles (Brouthers 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.

Addressing this challenge should include encouraging the production of new ideas and making it easier for users to identify these innovative ideas. One way is to develop mechanisms to heighten the incentives from producing original research. This might include creating prizes or awards for the most innovative publications in the field of the economics of energy and climate change. Another approach is by bringing together researchers renowned for their originality, as the Handbook of Energy and Climate Change will try to do (Fouquet 2013). These are only a couple of examples of the possible

ways to help stakeholders produce and use innovative research, and hopefully readers will propose their own ways.

In the past, economists have been particularly successful in offering solutions to energy and climate change mitigation issues. This has led to an explosion in this sub-field of economics since 2005, leading to an increasing share of economists focussing on these issues – perhaps reflecting expanding research budgets, urgent demands from policy-makers and greater media attention.

Nevertheless, success can breed a more risk-averse thinking amongst some researchers. As suggested at the beginning of this paper, this might be an inevitable (and possibly desirable) phase. However, this needs to give way to a new wave of original thinking amongst economists. Key issues related to energy and climate change remain unresolved. Thus, if economists are going to make an equally important and constructive contribution as they did up to 2012, then their ideas will need to move forward and evolve, offering exciting and stimulating new solutions for the post-Kyoto era.

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