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ORIGINAL PAPER

Eco-innovation for environmental sustainability: concepts, progress and policies

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Abstract There is increasing scientific evidence that natural systems are now at a level of stress globally that could have profound negative effects on human societies worldwide. In order to avoid these effects, one, or a number of technological transitions will need to take place through transforming processes of eco-innovation, which have complex political, institutional and cultural, in addition to technological and economic, dimensions. Measurement systems need to be devised that can assess to what extent eco-innovation is taking place. Environmental and eco-innovation have already led in a number of European countries to the establishment of substantial eco-industries, but, because of the general absence of environmental considerations in markets, these industries are very largely the result of environmental public policies, the nature and effectiveness of which have now been assessed through a number of reviews and case studies. The paper concludes that such policies will need to become much more stringent if eco-innovation is to drive an adequately far-reaching technological transition to resolve pressing environmental challenges. Crucial in the political economy of this change will be that eco-industries, supported by public opinion, are able to counter the resistance of established industries which will lose out from the transition, in a reformed global context where international treaties and co-operation prevent the relocation of environmentally destructive industries and encourage their transformation.

Keywords Eco-innovation · Environmental sustainability · Technological transitions · Eco-industries · Innovation policies

1 Introduction

Given the scale of contemporary environment and resource challenges in relation to climate change, energy and other resources, and biodiversity, it is common to hear

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international bodies and policy makers at both international and national levels call for major changes in most aspects of contemporary resource use and interactions with the natural environment. To give just one example, in 2005 the Synthesis Report of the Millennium Ecosystem Assessment (MEA) concluded: "The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services ... involve significant changes in policies, institutions, and practices that are not currently under way." (MEA 2005, p.1)

The scale of the changes that seem to be envisaged goes well beyond individual technologies and artefacts, and involves system innovation through what the literature calls 'a technological transition'. However, clearly it is not just any technological transition that is being advocated in response to these challenges, but one that greatly reduces both environmental impacts and the use of natural resources. The innovation that could lead to such a transition has been variously called environmental or eco-innovation, with a key role for environmental technologies. The European Union has adopted an Environmental Technologies Action Plan (ETAP),[1] and in May 2007 the European Commission published a report (CEC 2007) on trends and developments in eco-innovation in the European Union, which confirmed the strong growth of environmentally related industries, also called eco-industries, while emphasising that the state of the environment and climate change call for the take-up of clean and environmentally-friendly innovation "on a massive scale",[2] and proposing "a number of priorities and actions that will raise demand for environmental technologies and eco-innovation". Similarly, the Background Statement for the OECD Global Forum on Environment on Eco-innovation[3] in November 2009 declares: "Most OECD countries consider eco-innovation as an important part of the response to contemporary challenges, including climate change and energy security. In addition, many countries consider that eco-innovation could be a source of competitive advantages in the fast-growing environmental goods and services sector." Similarly the goal of ETAP was explicitly to achieve a reduction in resource use and pollution from economic activity while underpinning economic growth. This linkage between environmental challenge and economic opportunity recurs throughout discussion of eco-innovation. Section 2 considers both the nature of eco-innovation, while Section 3 discusses how it might be measured. Section 4 looks at some developments in the eco-industries in Europe.

The development of eco-industries is driven by public policies. Section 5 looks at the kinds of environmental policies that have been implemented and presents some evidence as to which have been most effective. What is clear is that the introduction of such policies has been and continues to be contested. However, it is also the case that there is little to be gained environmentally if such policies simply result in the relocation of such industries to parts of the world that do not introduce them. This illustrates the importance of global agreements if countries are to be able to stimulate environmental innovation without loss of competitive advantage.

[1] See the ETAP website at http://ec.europa.eu/environment/etap/actionplan_en.htm.

[2] See http://ec.europa.eu/environment/news/brief/2007_04/index_en.htm#ecoinnovation.

[3] See http://www.oecd.org/document/48/0,3343,en_2649_34333_42430704_1_1_1_37465,00.html.

2 A technological transition through eco-innovation

Technologies do not exist, and new industries and technologies are not developed, in a vacuum. They are a product of the social and economic context in which they were developed and which they subsequently help to shape. The idea of a technological transition therefore implies more than the substitution of one artefact for another. It implies a change from one techno-socio-economic system (or 'socio-technical configuration' as it is called below) to another, in a complex and pervasive series of processes that may leave little of society unaffected.

There is now an enormous literature on technological change and the broader concept of technological transition, ranging from relatively simple descriptions of the way technologies are developed and diffused in society in terms of 'technology-push/market-pull' (e.g. Foxon 2003; Carbon Trust 2002), to theories that emphasise transition management and the co-evolution of socio-economic systems (e.g. Freeman and Louça 2001; Bleischwitz 2004, 2007; Nill and Kemp 2009) and multi-level interactions between technological niches and socio-technical regimes and landscapes (Geels 2002a, b). These theories are discussed in some detail in Ekins 2010 (forthcoming), and see the papers by Kemp and Walz (this issue).

However such changes are conceptualised, to achieve the radical improvements in environmental performance that are required they will need to be driven by processes of innovation that emphasise the environmental dimension, which have variously been called eco-, or environmental, innovation.

Innovation is about change. Moreover, in the economics literature it always means positive change, change which results in some defined economic improvement. Similarly, in respect of the environment, environmental innovation means changes that benefit the environment in some way. In the ECODRIVE project (Huppes et al. 2008) the now much-used term 'eco-innovation' was defined as a sub-class of innovation, the intersection between economic and environmental innovation, i.e. "eco-innovation is a change in economic activities that improves both the economic performance and the environmental performance of society" (Huppes et al. 2008, p.29). In other words,

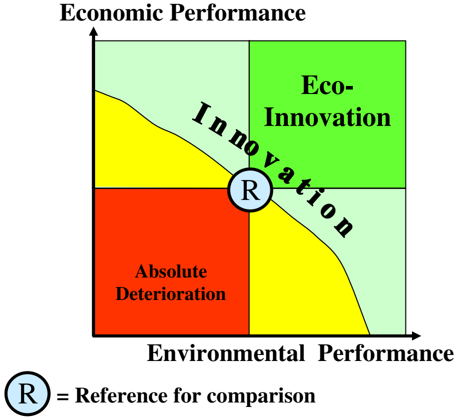


Fig. 1 Eco-innovation as a sub-class of innovation

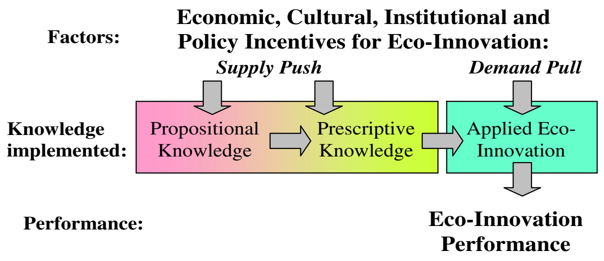


Fig. 2 Knowledge creation and eco-innovation performance. Source: Huppes et al. 2008, p.23

whether or not eco-innovation has taken place can only be judged on the basis of improved economic and environmental performance.

This is illustrated in Fig. 1. Innovation (compared to the reference technology R, which defines the current economy-environment trade-off along the curved line) that improves the environment, (environmental innovation) is to the right of the vertical line through R and the curved line. The lighter shaded area shows where improved environmental performance has been accompanied by deteriorating economic performance. Similarly, economic innovation is above the horizontal line through R and above the curved line. The lighter shaded area in this case shows where improved economic performance has been accompanied by environmental deterioration. Eco-innovation is the darker shaded area where performance along both axes has improved. Figure 2 relates this conception to the two kinds of knowledge—propositional and prescriptive—identified by Mokyr (2002), illustrating how this knowledge is pushed and pulled through to eco-innovation performance by the economic, cultural, institutional and policy incentives supplied by markets and governments.

Another approach to conceptualising eco-innovation was taken by the so-called MEI European Framework 6 research project.[4] This adopted a different definition of eco-innovation from the ECODRIVE project, defining it as "the production, application or exploitation of a good, service, production process, organisational structure, or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resources use (including energy use) compared to relevant alternatives." (Kemp and Foxon 2007, p.4). Close inspection of this definition reveals that the only difference between this and the ECODRIVE definition is that it does not insist on improved economic as well as improved environmental performance. In other words, it is what is called above 'environmental innovation', the light as well as the darker shaded areas in Fig. 1 to the right of the vertical line through R and the curved line (the 'relevant alternative'). Both ECODRIVE and MEI identify that a requisite of eco-innovation is improved environmental performance or results. For the concepts to be operational, it is necessary to be able to measure the extent to which eco- or environmental innovation are being achieved.

[4] See http://www.merit.unu.edu/MEI/.

3 Measuring eco-innovation

There are now well developed frameworks for the measurement of innovation in general, such as the European Innovation Scoreboard,[5] which is reported on an annual basis. The same is not true for environmental or eco-innovation, although the OECD now has in hand a programme of work in this area, described in OECD (2009), which seeks to develop "indicators of innovation and transfer in environmentally sound technologies (EST)", and concludes that the most promising approach in both areas is the use of suitably selected and structured patent data. Some of its early work on patents as an indicator of environmental innovation is reported in OECD (2008).

The MEI project derived a list of possible indicators of eco-innovation (using the MEI terminology), which cover a wide area, including products, firms, skills, attitudes, costs and policies (Kemp and Pearson 2008, pp.14–15). However, the proposed indicators actually focus on the predisposing conditions for environmental improvement rather than on whether the environmental improvement has actually taken place. There are no indicators of environmental performance *per se*. There is presumably an assumption that the areas covered are likely to have a positive relationship with environmental performance. Many of the areas derive from or are closely related to measures of environmental policy, the implications of which for eco-innovation are discussed in Section 4. In line with MEI's exclusively environmental definition of eco-innovation, its list of proposed indicators gives no attention to economic performance or results at all.

As noted above, the ECODRIVE project proceeded in contrast from the perception that eco-innovation needs to deliver improvements in both economic and environmental performance and therefore sought to determine how this joint outcome could be indicated. The project came up with numerous suggestions for how economic and environmental performance could be measured, at different economic and spatial levels. In principle, the methodologies for the measurement of environmental performance are now quite well developed, and were discussed in detail in Huppes et al. (2008, pp.64ff.) and will not be further considered here. Economic performance, however, is another matter.

The purpose of economic activity is to deliver functionalities that meet human needs and wants, at a cost consumers (which may be individuals or businesses) are prepared to pay. In Fig. 3 the functionalities are delivered by processes and products (including services) produced by firms, which may be classified as belonging to economic sectors, and which have supply chains consisting of firms which may belong to different sectors. The sectors will belong to a national economy.

The most basic measure of improved economic performance for products and processes is therefore one which can show that greater functionality is being delivered for the same cost, or the same functionality is being delivered for reduced cost. The basic measure is therefore Functionality/Cost, where functionality may be measured in a wide variety of different ways, depending on the product or process under consideration.

[5] See http://www.proinno-europe.eu/index.cfm?fuseaction=page.display&topicID=5&parentID=51.

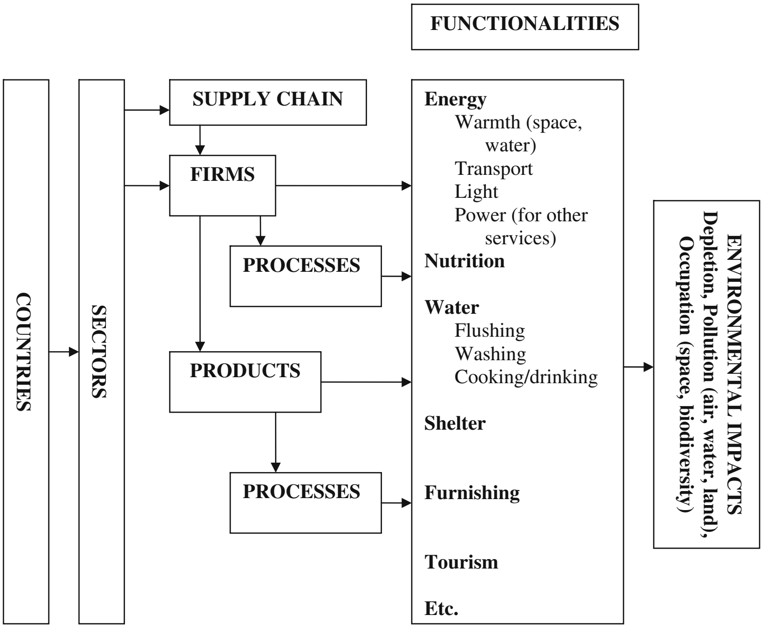


Fig. 3 The delivery of functionality in an economy. Source: Huppes et al. 2008, p.53

For example, in the case of transport, the unit of functionality may be (vehicle-km), and the cost to the owner will be the life-cycle cost of acquiring, operating and disposing of the vehicle over the period of ownership. However, it should be borne in mind that many products have multiple functionalities, so that in comparing the functionalities of different products, one must be careful to compare like with like. For example, cars have many functionalities apart from the delivery of vehicle-km (an obvious one is conferring status, or making a social statement), so that it is important when comparing products like cars that they are as similar as possible in terms of other functionalities. The 'eco-innovative product or process' will then be one which delivers greater functionality per unit cost and improves environmental performance.

Products and processes are produced or operated by firms. Clearly a firm may have different products and processes, delivering different functionalities, so a complete view of its performance will require some aggregation across these different outputs. Normally this aggregate is expressed in money terms, so that measures of a firm's performance will often be some measure of economic (money) output compared with economic inputs (e.g. value added, profitability, labour productivity), sometimes compared with other firms (e.g. market share). The 'eco-innovative firm' will then be one which improves its economic performance while also improving its environmental performance. Firms are conventionally grouped into economic sectors, obviously introducing a higher level of aggregation. Many of the measures of sectoral economic performance are the same as for firms and will consist of an aggregate, or average, of the sectors' firms' performance. And then sectors are aggregated into national economic statistics.

One critical issue in the consideration of economic performance is time. Economies are inherently dynamic, and the consideration of timescale will be crucially important to a judgement as to whether or not economic performance has improved. Many new technologies, and new firms, are not 'economic' to begin with (i.e. they deliver lower functionality per unit cost than incumbents). There is always a risk in investment that it will not pay off, and different investments pay off, when they do, over different periods of time. In any evaluation of economic performance, the timescale over which the evaluation has been conducted should therefore be made explicit.

An example may be renewable energy, and the 'feed-in' tariffs which a number of countries have introduced to promote it. At present most such energy is not economic (i.e. it is more expensive per kWh delivered than a non-renewable alternative). That is why it needs the subsidy of a feed-in tariff. In the short term, therefore, it does not deliver enhanced economic performance and therefore, despite its enhanced environmental performance, it is an environmental innovation, rather than an eco-innovation, as the terms are used here.

However, this situation may change. Mass deployment of renewable energy technologies through feed-in tariffs may engender learning by doing or economies of scale, reducing unit costs (see Fig. 9 below for PV). The costs of competitors (e.g. the price of fossil fuels) may rise. Other countries may decide to deploy these technologies, generating export markets. All these developments are likely to take time. Provided that economic performance is computed over that time, it may well be that an environmentally-improving new technology (i.e. an environmental innovation) which in the short term was an economic cost actually turns out to deliver enhanced economic performance, and therefore to be an eco-innovation.

For any product or process which delivers improved environmental performance, there are therefore three possibilities:

- It immediately delivers improved economic performance as well (e.g. compact fluorescent light bulbs, some home insulation), in which case it is unequivocally an eco-innovation
- It does not deliver immediately improved economic performance, in which case it is only a *potential* eco-innovation which
    - Becomes an actual eco-innovation when its economic performance improves and it is widely taken up (a process which may take decades or even centuries)
    - Never becomes an eco-innovation because its economic performance never improves adequately

The boundary within which economic performance is considered is also a relevant consideration. For example, although the feed-tariff is currently a net economic cost for the German economy as a whole (because the energy produced is more expensive than non-renewable energy), for the producers of renewable energy it may result in highly profitable businesses. If the boundary of the calculation of 'economic performance' is just those businesses, clearly the economic performance picture will be positive. If it is the national economy, and the German renewable energy businesses are focused on the German market, a different picture will emerge, and the overall change in economic performance may be negative. If, again, the German renewable energy industries generate significant exports, this may make their overall effect on the German economy positive.

Another example relates to the market boundary being considered. Many markets are highly imperfect and exhibit many market failures, especially in respect of environmental impacts. An economic activity may be highly successful in market terms (i.e. deliver a certain functionality at low cost, and result in profitable businesses), but generate environmental costs which actually exceed the market benefits. Similarly, an environmentally preferable activity may seem to be uneconomic in market terms, but actually be socially desirable because of the environmental benefits it delivers. It is obviously important that analysis takes the full picture (all the market and external costs and benefits) into account, but because of uncertainties in the monetary valuation of external costs and benefits it may not be possible to say definitively whether they change the picture as revealed by markets.

Because of the existence of market failures like environmental externalities, environmental innovations may be socially desirable even if they are not eco-innovations, if the social judgement is that the environmental benefit outweighs their economic cost. For example, it may well be that, because of their reduction in carbon emissions, renewable energy technologies are highly desirable socially, even if at present they are not eco-innovations (though over time they may become so, as discussed above). Eco-innovations are always socially desirable (because they are win-win across the environmental and economic dimensions).

The argument can be extended to incorporate the socio-economic and cultural dimensions, in line with the 'sub-systems' approach of Freeman and Louça (2001), as shown in Fig. 4. This shows that the outcomes of economic activity (processes, products, firms, which are conceived as satisfying consumer demands for services as in Fig. 3) of interest in relation to environmental and eco-innovation are economic and environmental performance. Economic activity is driven by institutions, the framework of laws, norms and habitual practices that define how markets and other economic structures (e.g. public sector, households/families as sources of production) operate. These institutions in turn derive from an interaction between polity and culture. There are multiple feedbacks between the boxes as shown and the whole socio-economic cultural construct should be thought of as a system in dynamic evolution.

The drivers of eco-innovation are in the first place institutions, and in the second place the polity (which produces policies that feed into, or become, institutions) and culture, (e.g. social values), which also feed into or create new institutions. Both polity and culture are affected both by institutions, and by the economic and environmental performance of economic activities. In addition to indicators of economic and environmental performance, the ECODRIVE project also derived

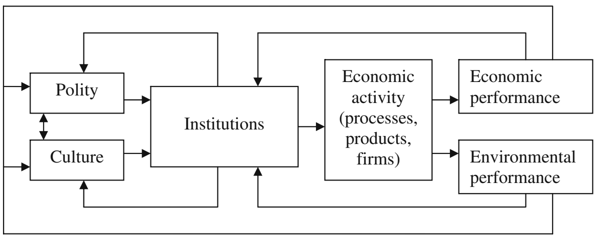


Fig. 4 The socio-economic cultural system in dynamic evolution. Source: Author

predictive institutional, policy and cultural indicators (including those based on societal values) that might be used to show whether eco-innovation was likely to take place (see Huppes et al. 2008). Many of these predictive indicators gives insights into the political economy interactions between the social, political, economic and cultural forces and processes discussed above that will jointly determine whether eco-innovation takes place or not.

Oosterhuis and ten Brink (2006) show that there is widespread agreement in the literature that environmental policies have the potential to exert a strong influence on both the speed and the direction of environmental innovation. Rather than being an autonomous, 'black box' process, technological development is nowadays acknowledged (as illustrated in the previous section), to be the result of a large number of different factors that are amenable to analysis. Environmental policy can be one of these factors, even though its relative importance may differ from case to case. The policies which might promote environmental innovation and eco-innovation are the subject of Section 5.

Of crucial importance to delivering both the improved economic and environmental performance of the ECODRIVE definition of innovation is that sub-set of economic activity shown in Fig. 4 that is explicitly concerned with environmental outcomes, the numerous firms and sectors now grouped under the heading of 'eco-industries', to brief consideration of which this paper now turns.

4 The nature and growth of eco-industries

Eco-industries are likely to come about through a mixture of environmental innovation and eco-innovation.

Classifying 'eco-industries', also called the environmental, or environmental goods and services, industry, is not straightforward. Enterprises engaged in many different types of activities are involved, making it difficult to single out environmental protection products within the standard international classification of industrial activities (ISIC). An OECD/Eurostat Informal Working Group on the Environment Industry was established in 1995 to address the issues and develop a common methodology. The working group agreed on the following definition of the environment industry:

> 'The environmental goods and services industry consists of activities which produce goods and services to measure, prevent, limit, minimise or correct environmental damage to water, air and soil, problems related to waste, noise and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimise pollution and resource use.' (OECD/Eurostat 1999)

Environmental industries thus fall into three main groups[6]:

A. **Pollution management group:** Includes Air pollution control; Wastewater management; Solid waste management; Remediation and clean-up of soil and water; Noise and vibration abatement; Environmental monitoring, analysis and assessment

[6] A more detailed list can be found in Annex 1 and Annex 7 of 'The Environmental Goods and Services Industry: Manual for Data Collection and Analysis' (OECD/ EUROSTAT, 1999).

B. **Cleaner technologies and products group:** Activities which improve, reduce or eliminate environmental impact of technologies, processes and products (e.g. fuel-cell vehicles)
C. **Resource management group**: Prime purpose of activities is not environmental protection but resource efficiency and development of new environmentally preferable resources (e.g. energy saving, renewable energy plant)

A specific feature of environmental technology is the particular mechanism by which the environmental impact is reduced. The following types are often distinguished:

- ‘End-of-pipe’ technology (isolating or neutralizing polluting substances after they have been formed). End-of-pipe technology is often seen as undesirable because it may lead to waste that has to be disposed of.[7]
- ‘Process-integrated’ technology, also known as ‘integrated’ or ‘clean’ technology. This is a general term for changes in processes and production methods (i.e. making things differently) that lead to less pollution, resource and/ or energy use.
- Product innovations, in which (final) products are developed or (re)designed that contain less harmful substances (i.e. making different things), use less energy, produce less waste, etcetera.

Eco-industrial activities have been distributed across many industrial sectors for a number of years. For example, OECD/Eurostat 1999 (Annex 6) showed that in 1992 the environment industry in Germany was significant (in descending order of importance) in the following standard sectors: machinery, instruments and machinery, ceramics, electronics, fabricated metal products, plastics, rubber, textiles, non-metallic mineral products, vehicles, chemicals, pulp and paper, and iron, steel and metals.

4.1 The eco-industries in the European Union

Following the recommendations of the environment industry working group, national statistical classification systems are being revised to include separate items for the environment industry. In the future, this will allow for easier identification and analysis of this cross-cutting industry.

Because of the difficulties involved in classifying the environment industry, only a very limited amount of data on the size of this industry can be retrieved from standard national statistical sources. In recognition of this data gap the European Commission (DG Environment) published a comprehensive study: ‘Eco-industry, its size, employment, perspectives and barriers to growth in an enlarged EU’ (EC 2006). The study is based on data on environmental protection expenditures provided by Eurostat and a number of interviews with representatives of the industry and administration. Jänicke and Zieschank (2010, forthcoming) are among those who have stressed the unsatisfactory nature of current statistical classifications of the

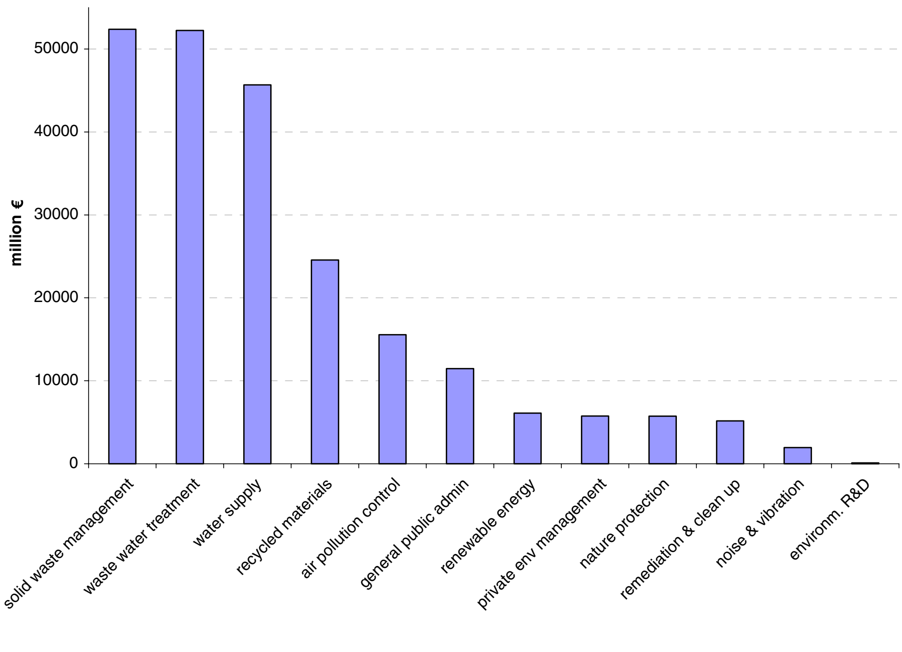
[7] This is not necessarily the case, though. For example, reducing nitrogen oxides at the end of a smokestack or car exhaust produces the harmless substances nitrogen and oxygen, which are natural components of the air (although even then particles from the platinum catalyst from the vehicle’s catalytic converter may cause pollution).

sustainable resource management and environment industries, which tend greatly to underestimate the industries' quantitative significance, and the following numbers need to be interpreted in that light.

The estimated total turnover of eco-industries in 2004 in the EU-25 is €227 billion (Fig. 5). The largest eco-industries are solid waste management and wastewater treatment (both around €52 bio.) and water supply (€45 bio.). The countries with the largest eco-industry sectors are Germany (€66.1 bio.) and France (€45.9 bio.), followed by the UK (€21.2 bio.) and Italy (€19.2 bio.).

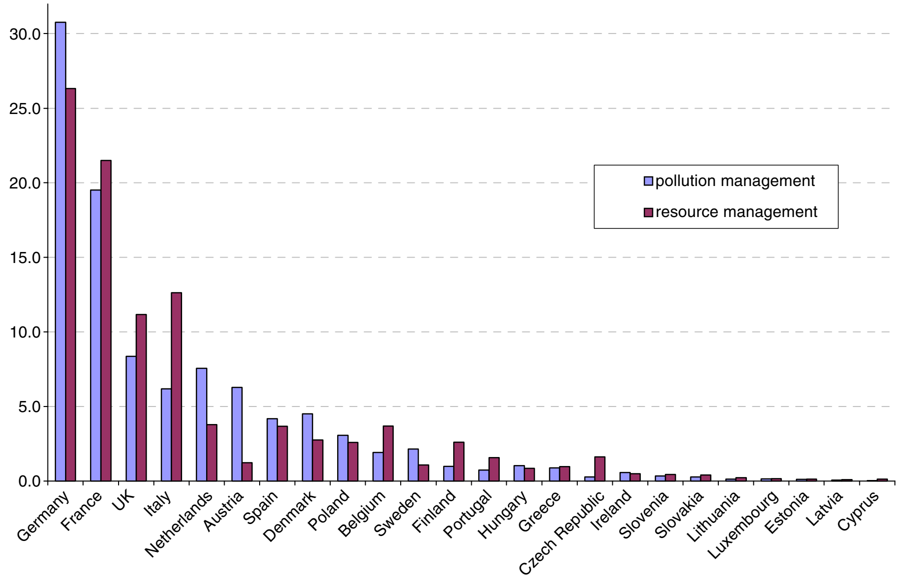
Pollution management activities make up 64% of total turnover in 2004, resource management activities account for the remaining 36%. Figure 6 shows the split between pollution and resource management activities for the EU-25 countries. Germany and France together account for roughly half of both pollution and resource management activities. In the UK a higher proportion of activities fall into the resource management category, 11.2% versus 8.4% pollution management activities.

Across the EU-15 the eco-industry grew by around 7% (constant €) from 1999–2004 (DG Environment 2006, p.33), although the growth rates for different EU countries vary widely. Around 3.4 million jobs (full-time equivalent, direct and indirect employment) are attributed to the eco-industries, over two-thirds of which fall into the pollution management category. Figure 7 shows the distribution of employment across the sectors. The three largest employers are the solid waste management sector accounting for just over 1 million jobs, followed by wastewater treatment (800 thousand) and the water supply sector (500 thousand).



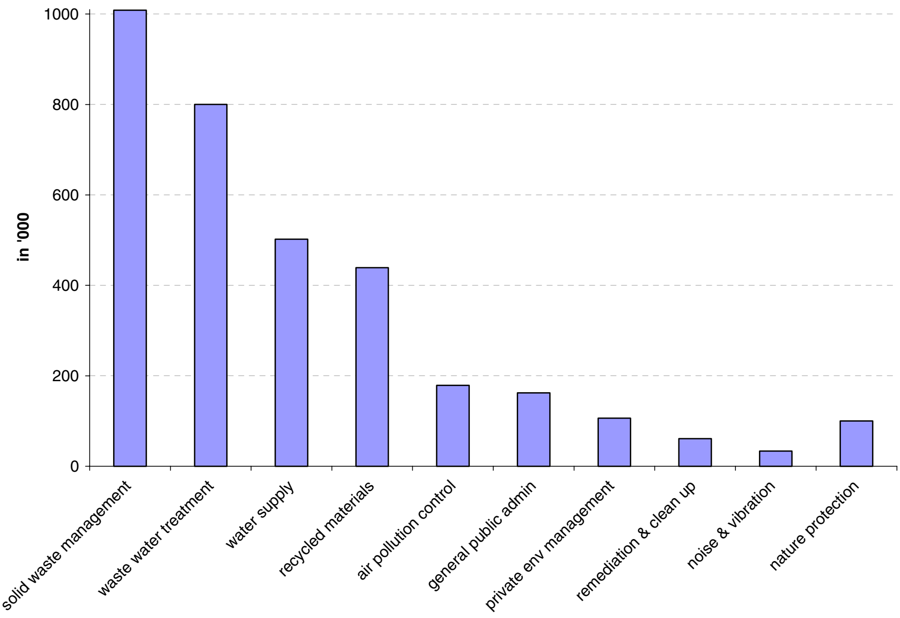
Source: EC 2006

Fig. 5 Eco-industry turnover in 2004, EU-25



Source: EC 2006

Fig. 6 Eco-industry turnover as % of EU-25



Source: EC 2006

Fig. 7 Eco-industry employment in 2004, EU-25

4.2 Eco-industries' diffusion and cost-reduction

Oosterhuis and ten Brink (2006) note that new technologies, when they are successful in being applied and finding their way to the market, often follow a pattern in which the uptake starts at a low speed, then accelerates and slows down again when the level of saturation approaches. This is reflected in the well-known logistic or S-curve (see Fig. 8).

The acceleration in uptake is not only due to the fact that the technology is becoming more widely known, but also to improvements and cost reductions occurring in the course of the diffusion process due to economies of scale and learning effects. Cost reductions as a function of the accumulative production (or sales) of a particular technology can be represented by 'learning curves' or 'experience curves'. Figure 9 shows a learning curve for photovoltaic energy technology. The 'learning rate' (the percentage cost reduction with each doubling of cumulative production or sales) persisted throughout three decades of development of the technology.

IEA (2000) has assessed the potential of experience curves as tools to inform and strengthen energy technology policy. It stresses the importance of measures to encourage niche markets for new technologies as one of the most efficient ways for governments to provide learning opportunities. McDonald and Schrattenholzer (2001) have assembled data on experience accumulation and cost reduction for a number of energy technologies (including wind and solar PV). They estimated learning rates for the resulting 26 data sets, analyzed their variability, and evaluated their usefulness for applications in long-term energy models. Junginger (2005) applied a learning curve approach to investigate the potential cost reductions in renewable electricity production technologies, in particular wind and biomass based. He also addressed a number of methodological issues related to the construction and use of learning curves.

Several studies have been carried out to assess the quantitative relationship between the development of costs of environmental technologies and time. A TME study (1995) pioneered this, and RIVM (2000) further explored the consequences of

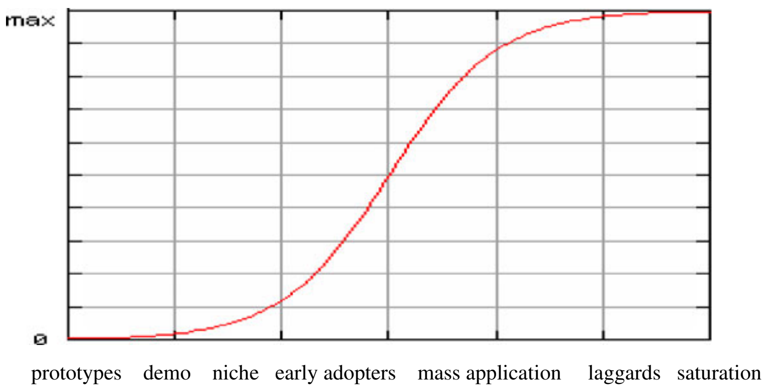
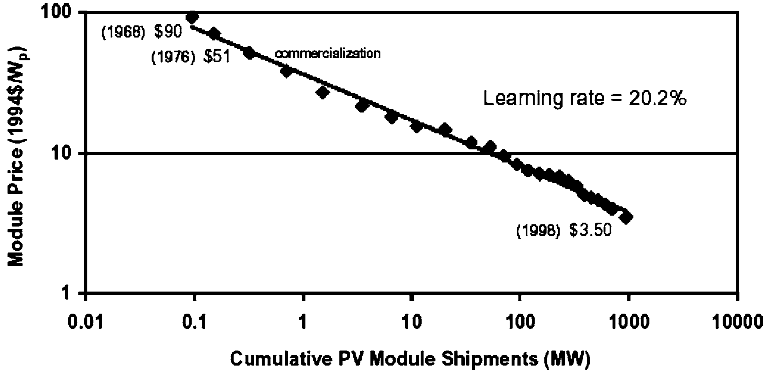


Fig. 8 Stages in the introduction of a new technology; the S-curve



Source: Harmon, 2000

Fig. 9 Learning curve of PV-modules, 1968–1998

this phenomenon. Several other studies address this issue (e.g. Anderson (1999), Touche Ross (1995)).

Both RIVM and TME conclude that the reduction of unit costs of environmental technologies goes faster than the—comparable—technological progress factor that is incorporated in macro-economic models used by the Netherlands Central Planning Bureau. In these models the average factor is about 2% annually. The results of both the RIVM and TME study for the annual cost decrease of environmental technologies are presented in Table 1.

Both studies show comparable results: the annual cost decrease is mostly between 4% and 10%. Therefore, when modelling environmental costs for the longer term, some form of technological progress needs to be taken on board in addition to what is assumed in the macro-economic model.

In the TME and the RIVM study no attempt was made to differentiate between two types of technological progress (see Krozer 2002):

Table 1 Annual decrease in costs of applying environmental technologies

Technology/Cluster	Annual cost decrease		
	Min	Average	Max
Dephosphating sewage	3.8%		6.7%
Desulphurisation of flue gas at power stations	4%		10%
Regulated catalytic converter	9%		10.5%
Industrial low NOx technologies	17%		31%
1. High efficiency central heating		1.4%	
2. Energy related technologies		4.9%	
3. End-of-pipe, large installations		7.6%	
4. End-of-pipe, small installations (catalysts)		9.8%	
5. Agriculture low emission application of manure		9.2%	

TME 1995, p. vi; RIVM 2000, p. 13, cited in Oosterhuis (2006, p.26)

- gradual improvements of already existing technologies (for which Krozer assumes that these will mainly lead to cost-savings and not so much to increased reduction potential);
- innovations (or "leap technologies") for technologies which are new and can compete with existing technologies in both efficiency (lower costs) and effectiveness (larger reduction potential).

This distinction is important, especially concerning the development of the reduction potential, because this will enable in the future a greater reduction in pollution than currently thought.

The anecdotal evidence on waste water treatment and low NOx technologies in industry actually shows both developments:

- increasing reduction potential (to almost 100% theoretical) in a period of about 30 years;
- decreasing unit costs.

So from the empirical point of view both developments are important enough to be separately considered when estimating future costs of environmental technologies.

Because most environmental impacts are external to markets, for eco-innovation to occur it will need to be largely driven by public policy rather than by (free) markets. Aghion et al. (2009a) find that such policy is not yet anything like strong enough to generate the level of eco-innovation that is required to address major environmental problems such as climate change. It is to the nature and effectiveness of the required policies that this paper now turns.

5 Policies for environmental innovation and eco-innovation

While some resources have prices that are considered in market transactions, the great majority of environmental considerations do not enter into the cost calculations of markets, unless government policy causes this to happen through the various kinds of policy instrument. Jordan et al. (2003) categorised them as follows:

- Market/incentive-based (also called economic) instruments (see EEA 2006, for a recent review of European experience).
- Regulatory instruments, which seek to define legal standards in relation to technologies, environmental performance, pressures or outcomes (Kemp 1997 has documented how such standards may bring about innovation).
- Voluntary/self-regulation (also called negotiated) agreements between governments and producing organisations (see ten Brink 2002, for a comprehensive discussion).
- Information/education-based instruments (the main example of which given by Jordan et al. (2003) is eco-labels, but there are others), which may be mandatory or voluntary.

Broadly, the market-based and regulatory instruments may be thought of as 'hard' instruments, because they impose explicit obligations, whereas voluntary and information-based instruments may be thought of as 'soft' instruments, because they rely more on or seek to stimulate discretionary activities. The distinction is not hard-edged, in that the provision of information may be obligatory (e.g. mandatory reporting standards) and voluntary agreements may have ‘hard’ sanctions in the event of non-compliance, so that it might be more accurate to think of these instruments as on a spectrum rather than in discrete categories. The ‘soft’ instruments also include public support for research and development (R&D), which is likely to be a particularly important instrument in relation to the stimulation of eco-innovation. In fact, Aghion et al. (2009a, b) say that the two crucial instruments for low-carbon innovation are a carbon tax and subsidies for low-carbon technologies (both market-based instruments), and public spending on R&D.

It has been increasingly common in more recent times to seek to deploy these instruments in so-called ‘policy packages’ or ‘instrument mixes’ (OECD 2007), which combine them in order to enhance their overall effectiveness across the three (economic, social and environmental) dimensions of sustainable development. One of the main distinguishing characteristics of the eco-industries described in the previous section is that they came about through the prescriptions of public policy, and their growth is almost entirely driven by it.

A literature review by Oosterhuis and ten Brink (2006) discusses what is known about the effects of different types of environmental policy on innovation, noting that the impact of environmental policy on innovations in environmental technology has been studied in various ways, both theoretically (often using models) and empirically. From their review, Oosterhuis and ten Brink (2006) find that the significance of environmental policies in driving eco-innovation is usually confirmed by empirical studies, but they conclude that there is no unanimity about the question as to what kinds of policy instruments are best suited to support the development and diffusion of environmental technology. However, they did feel able to make some general observations:

- Economic instruments (charges, taxes and tradable permits) are often seen as superior to direct regulation (‘command-and-control’), because they provide (if designed properly) an additional and lasting financial incentive to look for ‘greener’ solutions. For example, Jaffe et al. (2002) conclude that market-based instruments are more effective than command-and-control instruments in encouraging cost-effective adoption and diffusion of new technologies. Requate (2005), in a survey and discussion of recent developments on the incentives provided by environmental policy instruments for both adoption and development of advanced abatement technology, concludes that under competitive conditions market-based instruments usually perform better than command and control. Moreover, taxes may provide stronger long term incentives than tradable permits if the regulator is myopic. Johnstone (2005) also presents some arguments from the literature suggesting that taxes are more favourable to environmental innovations than tradable permits.
- Nevertheless, direct regulation was shown to work well in Germany when applying air emissions standards to power plants when the energy sector was still not liberalised and the energy companies had the possibility of passing through the costs. The context was important in having parties accept the required command and control. Evidence suggests that German emissions

reductions fell very quickly due to the instrument and context and faster than countries where economic instruments were used. This gives one counter example to the oft- quoted position that market-based instruments are more effective. Direct regulation may also be a powerful instrument in spurring eco-innovation (provided that the standards set are tight and challenging) because firms may have an interest in developing cleaner technology if they can expect that that technology will become the basis for a future standard (e.g. BAT), so that they can sell it on the market.

- Ashford (2005) argues that a ‘command-and-control’ type of environmental policy is needed to achieve the necessary improvements in eco- and energy efficiency. According to Ashford, the ‘ecological modernization’ approach, with its emphasis on cooperation and dialogue, is not sufficient. Economic instruments may also be less appropriate if the main factor blocking eco-innovation is not a financial one. For instance, simulations with the MEI Energy Model (Elzenga and Ros 2004), which also takes non-economic factors into account, suggest that voluntary agreements and regulations may be more effective than financial instruments (such as charges and subsidies) in stimulating the implementation of energy saving measures with a short payback period.
- Some authors, such as Anderson et al. (2001) stress that ‘standard’ environmental policy instruments are not sufficient to induce eco-innovation, and that direct support for such innovation is also needed. The main reasons for this are the positive externalities of innovation and the long time lag between the implementation of a standard policy and the market penetration of a new technology.
- The appropriateness of particular instruments (or instrument mixes) may depend on the purpose for which they are used (e.g. innovation or diffusion) and the specific context in which they are applied (see e.g. Kemp 2000).
- Finally, the *design* of an instrument may be at least as important as the instrument type. One type of instrument can produce widely different results when applied differently. For example, Birkenfeld et al. (2005) show remarkable differences in the development of trichloroethylene emissions in Sweden and Germany. Both countries used direct regulation, but in Sweden this was done by means of a ban with exemptions, whereas Germany opted for a ‘BAT’ approach. The latter proved to be much more effective in terms of emission reduction.

A study commissioned by DG Environment of the European Commission investigated the innovation dynamics induced by environmental policy through five case studies. The study was reported in Oosterhuis 2006, and its results were summarised by Ekins and Venn (2009). The headline conclusions of the five case studies were:

1. **Automotive industry—**Innovation levels differed greatly between the three countries studied. Japan had incentivised the most innovation, although there was little information about the development of its standards, the USA set standards unambitiously low, and Europe had induced ‘modest’ levels of innovation. In the European case other trends (i.e. dieselisation) had influenced the EU car manufacturing sector more.

2. **Office appliances**—Innovation levels as identified in Japan and the USA were high and directly correlated to the respective policies which were implemented, in both cases strict public procurement policies. In Japan these were combined with increasingly stringent standards. The European case study saw that there was an uneven use of energy efficiency criteria in member states' public ICT tenders. This is coupled with the fact that the EU still tends to shy away from mandatory energy efficient public procurement despite industry support.
3. **Photovoltaics**—This sector has undergone rapid, and innovative, development in recent years. Japan and Germany have both encouraged significant expansion and development of the sector through substantial financial incentives and R&D support. With far lower financial commitment, the UK has not managed to achieve substantial deployment of installed PV capacity.
4. **Pulp and paper**—In Europe there has been innovation with respect to abatement technologies, but the extent to which this has been induced by policy is not clear. Insofar as an effect is discernible, it seems to be more due to the characteristics of the instrument (e.g. its stringency) than to the nature of the instrument itself.
5. **Hazardous chemicals—**In general there has been success in encouraging innovation or diffusion of existing technology. Policy approaches in Sweden, Denmark and Germany have in different ways all been influential in encouraging innovation and reducing environmental impact. There is an interesting contrast between approaches that seek to reduce the use of hazardous substances (Sweden, Denmark) and those that seek to contain them (Germany). It is of note that Sweden and Denmark, the two EU countries applying the substitution principle, also have the highest rate of R&D in their respective chemical industries.

Table 2 categorises the environmental policy instruments used, as revealed by the case studies, in terms of the typology above, and shows whether the type of innovation which seems to have been primarily induced was end-of-pipe, process-integrated or product innovation. It also provides an overall indication of the success of the policy in inducing eco-innovation. Table 2 shows that a wide range of different environmental policies has been used in different countries, ranging in Europe across voluntary approaches, directives, investments, grants, bans, taxes and technical standards. In the USA classic regulation, i.e. command-and-control, appears most common.

Across the case studies there are a number of cross-cutting themes with policy implications.

- **Technological development**—One assumes that most regulatory approaches seek to allow for technological development and increasing efficiencies over a time period. However, the technical expertise required to understand all factors at play in such sectors as the hazardous chemicals sector or the PV sector is formidable, and there are bound to be problems of asymmetric information between industry and the policy maker.
- **Commercial factors—**The extent of innovation is often reflected in commercial learning curves and economies of scale associated with the production and development of new technologies and processes. These developments will rarely

Table 2 Comparison of innovation observed

Case study	Country or area	Policy result in inducing innovation	Policy type				Innovation type experienced		
			Incentive/Market-Based	Classic Regulation	Voluntary	Information Based	End of Pipe	Process Integrated	Product Innovation
1	Europe	*Medium*			X				X
1	USA	*Poor*		X					X
1	Japan	*Good*	X	X		X			X
2	Europe	*Poor*			X[a]				X
2	USA	***Excellent***	X	X					X
2	Japan	***Excellent***	X	X		X			X
3	Germany	*Good*	X						X
3	Japan	***Excellent***	X	X					X
3	UK	*Poor*	X	X					X
4	Various	*Unclear*		X			X	X	
5	Sweden	*Good*		X					X
5	Denmark	*Good*	X						X
5	USA	*Good*		X				X	
5	Germany	***Excellent***		X				X[b]	

[a] Although a Directive is used, and an obligation is present, other considerations supersede obligations making the approach voluntary. The option of mandatory public procurement is being discussed currently by the European Community Energy Star Board.

[b] Although there has been product innovation, a main success of the policy has been the eco-innovation of new processes and capital stock together with a reduction in the use of hazardous chemicals.

be disclosed due to their sensitive commercial nature—making it hard for the policy maker to accurately predict potential rates of innovation, as they will rarely be party to such sensitive information.

- **Standards—**It seems from analysis in case studies 1, 2 and 5 that setting standards for industry can work effectively. An incentivised approach, with technical standards and green procurement plans, allowed firms to approach the target flexibly and innovate to meet it. However, when standards are set low (such as in case study 1—USA) unsurprisingly there is little incentive to exceed the benchmark.
- **Focus—**It is apparent that unless actions are targeted to specific areas and take into account external trends, as they were in Japan with the Top Runner Programme, policies will generally not aid in encouraging innovation. This was seen in the UK PV market where policies both failed to take account of external developments in the global market, and involved low levels of funding, resulting in insignificant levels of innovation or deployment.
- **Historical trends—**There can be historical factors at play which present barriers to innovation in certain sectors or geographical locations. For example in the pulp and paper industry innovation is low due to the mature nature of the industry, and the fact that the median age of paper machines in Europe is 23 years. In the USA the historical setting of low levels for fuel economy improvements in automobiles encouraged a poor performance in the sector.

The headlines lessons learned from the case studies may be summarised as:

- Inducing innovation requires strong policy. Weak policy, whether in terms of weak standards (e.g. 1—USA), or low levels of expenditure (3—UK) will not be likely to achieve it.
- Classic regulation was the single most important type of policy in the case studies where eco-innovation was stimulated, sometimes combined with market-based instruments (especially public purchasing or subsidies). However, an overall conclusion from the case studies was that 'No general statements can be made about the kind of policy instruments that are best suited to support the development and diffusion of environmental technology.' Oosterhuis (p.vi, 2006).
- Regarding learning curves and economies of scale, case studies 2, 3 and 5 all found that when policy, or external factors, encouraged innovation, positive relationships between increases in production and reduction in costs were found. The PV case study noted that it was not merely learning curves of PV which must be taken into account, but also learning curves of associated infrastructural technology.

In terms of the categorisation introduced earlier, Table 2 shows that the great majority of the policy instruments used in the case studies were 'hard' (market-based or regulatory) rather than 'soft'. In fact, with only one exception (and with a Poor result) the latter were really only employed as subsidiary instruments. In such a role, however, they still may help the policy to have a better overall result.

It is also interesting to reflect on the case studies in terms of Fig. 4. In all cases, institutions are important to the implementation of any policy, whether 'hard' or 'soft'. New instruments may require new institutions, or institutional change, but whether or not this is the case strong branding of the policy is likely to help its implementation and contribute to its effectiveness. The branding, however, will be crucially related to the political and cultural context, so that it is difficult to make generalisations across different countries, except to say that the context is likely to find most obvious expression through the 'soft' instruments that are deployed.

6 Conclusions

History shows that innovation is one of the normal characteristics of markets and capitalist economic development, and current innovation rates are, in historical terms, very high. However, normal innovation is driven by a desire for market success, which may have little to do with environmental impacts. In fact, normal innovation may increase or decrease environmental impacts. The environmental policy makers' task is to seek to harness normal innovation forces in order to achieve win-win outcomes, i.e. environmental improvements as well as improvements in products and processes from a market point of view. Because innovation is inherently unpredictable, and there is no methodology that can reliably assess the 'without policy' counterfactual, there is an inherent problem in assessing the results of policy in relation to eco-innovation. However, as shown above, careful case study comparisons can generate insights as to whether and how eco-innovation has been achieved.

Just because policy can achieve eco-innovation does not mean that it will be easy to introduce. As this paper has made clear throughout, there is a political economy of eco-innovation as of any other subject that affects the distribution of resources. Aghion et al. (2009a) present worrying evidence that, despite recent rhetoric on green innovation, not only is this not the dominant direction of innovation, it is even lagging behind the rate of non-directed innovation. This situation will have to change if increasingly serious environmental problems are to be effectively addressed.

The eco-industries, supported by public opinion, need to become crucial actors in the political economy of eco-innovation if such innovation is to become more widespread and transformational, leading to a profound eco-innovatory transition. Such a transition (like all transitions) will adversely affect many well established industries and interests and will be fiercely resisted by those interests. The eco-industries need to become an increasingly effective counter-force to this resistance.

Because eco-innovation will be largely driven by public policy rather than by (free) markets, established industries will do everything they can to prevent or slow the introduction of policies to promote eco-innovation (for example, the campaign by the US fossil fuel industries against the climate policies of President Obama, [Goldenberg 2009]). At the same time, for global environmental problems like climate change, there is little point in imposing policies on firms subject to global competition and industries that are mobile, such that they simply relocate without any overall change to global production or consumption or environmental impacts. Although there is very little evidence to date that such relocation has actually taken place, the possibility is resonant in the political rhetoric around environmental policy and adds to the difficulty of driving eco-innovation in the contemporary global marketplace.

Clearly national policies on eco-innovation need to be underpinned by international agreements that all countries will take action to reduce their environmental impacts. While such agreements now exist (perhaps most importantly the UN Framework Convention on Climate Change), there is a long way to go before they assert a sufficient influence on global market developments for eco-innovation to proceed at the pace identified at the beginning of this paper as scientifically necessary to avoid major disruption to natural systems and human societies.

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