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Sectoral Innovation Systems in Europe: Monitoring, Analysing Trends and Identifying Challenges

The Energy Sector – Final report

Aris Kaloudis and Trond Einar Pedersen (eds.)

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Preface

This report presents a state of the art analysis of the Innovation system in the Energy production sector. As a part of the Innovation Watch – SYSTEMATIC project (2006–2008), this report contains analytical results from all work packages covered by the *Sectoral Innovation Watch – SYSTEMATIC*-project regarding the energy sector. This implies that the report is written by NIFU STEP (Aris Kaloudis and Trond Einar Pedersen) but relies on substantial contributions from all the partners in the Systematic consortium, which includes WIFO (Austria), NIFU STEP, SPRU at the University of Sussex (UK), Technopolis (Belgium), UNU-MERIT (The Netherlands), LABEIN (Spain), Logotech (Greece), and ZEW (Germany).

The authors are thanking all the partners of the project – and especially the project co-ordinator Dr. Hannes Leo, Dr. Michael Böheim, Dr. Andreas Reinstaller and Kristin Smeral at WIFO – for fruitful and constructive meetings and collaborative work. We are also thanking DG Enterprise in the European Commission for funding this research.

The Sectoral Innovation Watch – SYSTEMATIC-project investigates in detail innovation performance within 11 different sectors of the European economy. These sectors are:

- Biotechnology
- Food/Drink,
- Machinery/Equipment,
- Textiles,
- Chemicals,
- ICT/Electrical/Optical,
- Space and Aeronautics,
- Automotive,
- Energy production
- Eco-innovation and
- Gazelles (fast growing SMEs).

Sectoral Innovation Watch provides policy makers and stakeholders with a comprehensive, holistic understanding of both sectoral innovation performance and challenges across the EU25. The project has produced a number of outputs throughout its period of activity from November 2005 till May 2008. The analysis presented in this report is, hence, complemented by in-depth reports for each sector on policy mapping and analysis on innovation performance, leading innovators, innovation challenges, national sectoral profiles, barriers and drivers of innovation and the innovation environment, as well as, a number of reports covering cross-cutting topics which complete the palette of deliverables for this initiative. All deliverables and background papers from the project are published on the Europe Innova website (http://www.europe-innova.org).

Oslo, October 2008

Per Hetland
Director

Helge Godø
Head of Research Area

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Executive Summary

As a part of the Innovation Watch – SYSTEMATIC project (2006–2008), this report contains analytical results from all work packages covered by the project regarding the energy sector. The report constitutes the final deliverable for the Energy sector.

The aim of this sector report is to provide policy-makers and stakeholders in the energy sector with a comprehensive and as complete as possible understanding of the sectoral *innovation* performance and innovation challenges throughout the EU-25 Member States. In this respect, the core question to be asked – and answered – is to what extent sector-specific policy measures and instruments can be employed to foster innovative performance, competitiveness and sustainability of energy firms in the EU Member States.

The energy sector in this project comprises the following sub-sector (NACE) groups:

Statistical definition of the energy sector
NACE 10: Mining of coal and lignite; extraction of peat;
NACE 11: Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying;
NACE 12: Mining of uranium and thorium ores;
NACE 23: Manufacturing of coke, petroleum products and nuclear fuel;
NACE 40: Electricity, gas, steam and hot water supply.

The delimitation of the energy production sector applied in this report is based on a statistical demarcation of the sector with emphasis on energy production. The approach employing NACE sectors excludes upstream R&D, technology and supply. This means that our analysis may not fully capture the significance of suppliers' R&D-activities, technology transfer and machinery and equipment for the type and magnitude of the innovation efforts within the energy sector. Having said that, we present in this report the most complete data sets on and analysis of market (input-output) interactions and knowledge interactions between the energy sector and the rest of the national EU economies ever made for this sector.

Competitiveness of the European energy sector
There has been a steady growth in EU-15 labour productivity over most of the period 1979–2003 in the energy sector. At the beginning of the period, the EU lagged behind both Japan and the US, but consistently higher growth rates enabled the EU to catch up with the US, even forging ahead towards the end of the period. Moreover, the EU gap with Japan has also narrowed throughout the entire period. The results for EU performance in total factor productivity are even better. Indeed, during the period EU total factor productivity has reached levels very similar to Japan and even higher than the US. During the 1980s, the EU matched the Japanese productivity performance and during 90s total factor productivity has clearly been more dynamic in the EU than in Japan. The US total factor productivity index on

the other hand, commenced lower but has grown faster resulting in some catching-up with Japan and the EU.

Environmental impact

The main driver of innovation - in particular radical innovations - in the energy sector is the expressed social demand and the international commitments to reduce the use of fossil fuels in the future. The Kyoto Protocol was the basis for this process, but has now been taken over by the so-called *20 20 by 2020 policy, Europe's climate change opportunity* (EC, 2008). The path towards fulfilling these commitments provides us *de facto* with a relevant innovation efficiency indicator, that is, the greenhouse gas emissions, an indicator which has been monitored for many years now. Our EU-25 data on greenhouse gas (GHG) emissions from the energy sector shows a remarkably stable *proportion* of total GHG emissions from the energy sector from 1990 and up until 2003 of around 30 per cent of total GHG emissions in EU.

In terms of *absolute* emissions the trend showed a slight reduction from around 1600 million tonnes/ CO^2 equivalent in 1991, stabilised between 1400 and 1500 million tonnes CO^2 equivalent in the 1990s before starting to climb again at the start of the new millennium. This upswing is an issue of increasing policy concern throughout Europe, and a factor that should imply a boost investment and innovation in renewable energy and cleaning technologies.

Another indicator of innovation performance in the sector is motivated by the overall '20 20 by 2020' target policies, that is, the contribution of electricity from renewable energy sources in absolute numbers and as a share of total electricity consumption. While EU-25 as a whole was at a 12 per cent level in 2004, the target of 20 per cent electricity production from renewable energy sources is supposed to be reached by 2010. As the EU currently comprises 27 Member States, some of them have already reached the 20 per cent target (basically due to traditional hydroelectric power sources), others will have to struggle to reach it.

Thus, we may conclude that the present level (and perhaps types) of R&D and innovation activities in the sector does not suffice for achieving the ambitious environmental goals which are set by and for the EU and which in most direct manner concern the firms in the energy sector.

Innovators versus non-innovators in the energy sector

Innovation activity in the energy sector needs to be described and assessed with caution. The sector is special in more than one ways. The most important output in the energy sector is electricity and energy in other carriers (hot water, gas, etc.) and that is basically a standardised product and service. Of the firms in the energy sector, 36.2 per cent have reported that they are innovative (see (Chapter 3.1). This compels us to ask how this piece of information can be interpreted and how the 63.8% of the (non-innovative) firms in the sector meet innovation challenges.

The Europe Innova panel experts for the energy sector emphasised the fact that there is a constant effort of improvement in the European energy sector, and as such the panel experts consider that this sector is more innovative than the share of non-innovative firms in the sector suggests. First, in all parts of the sector, there are expectations of technological improvements related to environmental concerns. Second, the national energy markets in Europe are becoming increasingly more competitive (liberalised). Competition in markets of standardised products or services stimulates incremental process innovation aiming at higher productivity performance. Third, we know that (see Chapter 2, Figures 2.1 - 2.4 in this report) the energy sector in EU is competitive and thriving both in terms of employment, value added and labour productivity.

Hence, the picture of energy sector innovation that has be drawn in Chapter 3 of this report based on innovation data, though more complete and detailed than ever before, only sheds light on a limited part of how development and economic change occurs in the sector. The energy sector panellists have argued that non-R&D based innovation activity may not necessarily be conceived as innovation by firms and their representatives. One reason for this may be that this type of innovation is not project-oriented, and perhaps found infrequently in firms' budget. Consequently, this type of innovation may often not be reported and, hence, it is difficult to capture and measure.

The picture portrayed by the Community Innovation Survey (CIS) of non-innovating firms in the energy sector is that they are significantly smaller than innovative energy firms; they are nevertheless almost equal in size to the average innovative manufacturing firm. Moreover, labour productivity in innovative energy firms is virtually twice that of non-innovators while the related indicator for *employment development* shows a 3 per cent decrease in non-innovating energy firms compared to a 4 per cent decrease for energy sector innovators.

Turnover growth is significantly higher in innovating energy firms, but it is interesting to observe that the level of competence (measured as the proportion of employees with higher education) is approximately the same in non-innovating and innovating energy firms. In terms of methods of intellectual property protection, non-innovating energy firms are little active. However, concerning the variables *implementation of strategic and organisational change in the firm*, a relatively high proportion of non-innovative energy firms implement these types of softer change processes. (The proportion for innovative energy firms is higher but not radically so).

Innovative companies' innovation modes
Innovation is a diverse activity. Firms can use a wide range of methods to innovate, ranging from intensive investment in in-house R&D, to purchasing new production equipment or product components 'off-the-shelf'. Chapter 3.2 uses CIS-data to explore innovation modes in the energy sector. For the firms in the CIS-sample which report innovation activity four modes of innovation are identified: strategic innovators, intermittent innovators, technology modifiers and technology adopters.

- ***Strategic innovators*** have introduced a product or process innovation, at least partly developed in-house; they perform R&D on a continuous basis; they have introduced at least one product that is new to their market; they are active in national or international markets. These firms are the source of many innovative products and processes that are adopted by other firms throughout their domestic economy and internationally.
- ***Intermittent innovators*** have developed innovations at least partly in-house, and have introduced new-to-market innovations. However, they are unlikely to develop innovations that diffuse to other firms.
- ***Technology modifiers*** have developed an innovation at least partly in-house, but none of these perform R&D. They differ from the final group of technology adopters by having some in-house innovative activities. If they are active in national or international markets, they have not introduced a new-to-market innovation (otherwise they would be classified as an intermittent innovator). If they are active in local and regional markets, they may have introduced a new-to-market innovation and have slightly modified it for this market. Many firms that are essentially process innovators that innovate through production engineering probably fall within this group.
- ***Technology adopters*** have innovated, but are dependent on adopting innovations developed by other firms. These firms innovate through diffusion.

Technology modifiers (11% of all firms in the sector), technology adopters (11%) and intermittent innovators (12%) are the dominant innovation modes within the energy sector (Table A1 in the Annex). Only 3 percent of all firms in the sector are strategic innovators. Hence, the typical innovating firm in the energy sector innovate by buying advanced machinery and equipment and by training personnel for innovation activities. It does not perform intramural R&D on a continuous basis. Not many innovators in the sector receive public funding, in particular from local or regional authorities. The technology adopters hardly make use of formal methods to protect their new inventions or innovations. Almost 80 per cent of energy innovators use some form of non-technological change; the implementation of advanced management techniques and new organisational structures is a feature of most firms.

Heterogeneity in the energy sector

There can be large differences between the sub-sectors within the energy sector (see Figure 3.3). Labour productivity for NACE 23 (Manufacturing of coke, petroleum products and nuclear fuel) is 10 times as high as that for NACE 10-12 (Mining of coal and lignite; extraction of peat, extraction of crude petroleum and natural gas, service activities incidental to oil and gas extraction, mining of uranium and thorium ores). Turnover and employment growth are both positive in NACE 40 (electricity, gas, steam and hot water supply) but negative in NACE 10-12. The sales share of new-to-firm or new-to-market products is only 5 per cent in NACE 10-12.

The typical innovation strategy also differs between the sub-sectors. The share of the innovation budget spent on acquiring other external knowledge is small in both NACE 10-12 and NACE 23 but as high as 20 per cent in NACE 40. There are also large differences in intellectual property protection behaviour. Compared to other energy sub-sectors, strategic innovators in NACE 40 make less use of patents, registration of design patterns and trademarks but more than 70 per cent use copyrights to protect their inventions and innovations. Moreover, the low proportion of strategic innovators in NACE 40 seems to be in line with the importance of buying advanced machinery and acquiring external knowledge; apparently firms in NACE 40 do not need to have much in-house R&D to adopt technologies from external sources.

Skills

The Europe Innova energy sector panel experts emphasised that the shortage of engineers and relevant skills and competencies is a clear threat to innovation and growth for all kinds of energy production. Because innovation processes depend on this type of expertise in large utilities, the panellists highlighted that innovation policy should pursue the issue of skills needs in the sector in a more coherent manner. Fewer people tend indeed to be interested in studying technology and natural sciences. The sector needs ICT experts in particular as well as other technical personnel. Furthermore, the workforce has to develop new skills adopted to the changing technologies. The more disruptive the new technologies, the greater the need for continuous life-long learning investment as well as more frequent adjustments of tuition programs and curricula in the educational system. Since there are considerable differences throughout EU in terms of quality of education at lower skill-levels, focus should not only be on skills in tertiary education, but also at lower levels; it is the complementary and balanced mix of skilled labour that is important in the energy sector, not just the quality of the high end of formal skills.

Interaction – input-output

With the input-output analysis in Chapter 3.5 we capture pecuniary interrelationships between sectors in the national economies, that is forward and backward linkages of the energy sub-sectors for the Euro Zone average, the United Kingdom and the United States.

Almost all of the key industries related to the mining sub-sector (NACE 10-12) are services, except for – as expected - forward linkages to the production of electricity, gas and water supply (NACE 40-41). The backward linkage from the production of electricity, gas and water supply to mining is also clear, just as the forward linkages in this industry are to the service industries. Mining is also a key backward linkage to the production of coke, and refined petroleum products (NACE 23), and certain services plus construction are key forward industries. Services play a prominent role in the input-output analysis mainly because they make up a very large proportion of value added.

Finance

The energy sector has strong financial power if we look at the indicator ‘operating surplus and cash flow’ as a percentage of production (Chapter 4.1.1). This probably relates to the fact that large mature multinational energy companies dominate in the data. On the other hand, small and medium-sized firms within new technologies (renewable) seem to be the financially weak risk-takers.

Taxation and regulation
Taxation and regulation (see Chapter 4.1.2) is generally considered as a barrier to innovation, but in the energy sector it is the other way around. Authorities' taxation and regulation regimes, largely motivated by environmental policy targets, represent the most important driving force for R&D and innovation on alternative forms of renewable technologies in the energy sector innovation (radical types of innovation in the sector). However, they may inhibit incremental process innovations aiming at production efficiency improvements in firms operating within mature fossil fuel technology regimes.

Socio-cultural factors and innovation in the energy sector
Socio-cultural factors, i.e. public opinion and individual behaviour, are significant factors in shaping innovation behaviour in the energy sector. The following concrete policy issues related to the sociocultural domain are identified as important:

– Consumer willingness to pay for environmental friendly products and services opens market opportunities for renewable technology firms. Increasing prices of energy – which is the single most important factor stimulating research and innovation on renewable energy sources – may further increase consumers' willingness to pay for renewable energy solutions which in long run seem profitable to the consumer.

– It was suggested that the EU should support research on technologies with an indirect but considerable environmental impact, most notably ICT. Technologies for monitoring energy management in households could be another area for further inquiry with a potential for innovative solutions for reducing energy waste.

– More research on incentives for attitude and behavioural change is an area for innovation policies. Energy consumption is intrinsically related to lifestyle. Consequently, policy planning must take into account changes in consumer behaviour and public awareness related to energy consumption.

– The shortage of engineers and technicians with relevant skills and competencies is a clear threat to innovation and growth for all kinds of energy production. Since there are considerable differences throughout the world in terms of the quality of education at lower skill-levels, one should not only focus on skills in tertiary education but also at lower levels; it is the complementary and balanced combination of skilled labour that would be important, not just the quality of the high end of formal skills.

– The experts also agreed on the point that mobility of researchers is currently below the optimal level. EU research and innovation policies should therefore stimulate public–private mobility flows of human resources in science and technology.

– The panel was very supportive of further research on sociocultural factors shaping innovation in the sector, and advised the EC to focus more research funding on these issues.

Conclusions and policy recommendations

The prospective innovation challenges in the energy sector are linked to the broader challenges related to global climatic change and EUs energy policy targets. The energy sector faces three basic challenges: sustainability, security of supply and competitiveness. It has been argued that these challenges or policy objectives are partly contradictory. In particular, there is some concern on how it is possible to meet targets of security of supply and sustainability, given the dominant role of fossil fuels in Europe. Cleaning fossil fuels is costly and has yet to benefit from technological innovation has not come far. It is difficult to see how policy targets of sustainability are to be reached without fundamental changes in energy consumption patterns in European countries in the foreseeable future. This depends largely on development and innovation in the energy sector, and represents a prospective innovation challenge with relevance to the demand side and the markets of the energy sector.

As a conclusion, a realistic European innovation policy strategy for the energy sector could be:

1) providing incentives for development and the adoption of advanced cleaning technologies, an area where Europe could develop a know-how and a technological advantage;

2) increasing public and private R&D in renewable energy sources at national and EU-levels , since public R&D-support is below the level one would expect based on the centrality of the issue in later policy rhetoric (see Pedersen, Kaloudis 2006);

3) supporting and stimulating energy efficiency and saving technologies as well as consciously develop competitive advantages for Europe in eco-innovation and green product industries. Energy saving technologies will contribute to lower levels of consumption of fossil-based energy sources, to the slowing-down energy demand increases and, hence, to the containing of energy supply risks for EU (this argument is more developed in the eco-innovation final sectoral report);

4) introducing incentives and standards which encourage the take-up of efficient renewable technologies;

5) keeping the focus on developing a European energy market with a pricing system which ensure that the beneficiaries pay full costs, including environmental costs.

6) investigating and experimenting how innovation activities in the energy sector may directly and be shaped by socio-cultural parameters, mark-up margins the public is willing to pay for cleaner energy sources, public awareness, public acceptance of new energy sources, etc. This is a clearly unexplored policy area of a great potential impact.

1 Introduction

1.1 Aim of the paper

This paper is the sector report for the Energy sector studied as a part of the Innovation Watch – SYSTEMATIC project. It contains analytical results from all work packages covered by the project. This report constitutes the final deliverable for the Energy sector.

The aim of this sector report is to provide policy-makers and stakeholders in the energy sector with a comprehensive and holistic understanding of the sectoral innovation performance and innovation challenges throughout the EU-25 member states. Since different sectors have highly specific characteristics, it is the crucial objective of the project to identify main policy implications and to formulate well-tailored and relevant policy recommendations that can promote development of the European energy sector. In this respect, the core question to be asked – and answered – is to what extent sector specific policy measures and instruments can be employed to foster innovative performance, competitiveness and sustainability of energy firms in the EU Member States.

1.2 Statistical Definition of the Sector

A comprehensive classification of the energy sector is required to include the following activities:

- Extraction
- transformation/conversion/processing
- transport
- storage
- consumption
- waste management.

Such a broad definition of the energy sector would, however, be too comprehensive for the purposes of the SYSTEMATIC project; that is, the analysis of the sectoral innovation system of the sector ‘Energy production’. Therefore, we define the sector of energy production in this report as comprising the two upper parts of the energy life cycle, i.e. primary production of energy, and the transformation, conversion and processing of energy.

In statistical terms, this definition means that we limit our analysis to the following NACE industrial activities: NACE 10, NACE 11, NACE 12 and NACE 40. NACE 23 (Manufacturing of coke, petroleum products and nuclear fuel) is related to the two first types of energy production activities (extraction, transformation/conversion/processing), but, also to storage of energy. We choose, therefore, to include NACE 23 within the definition of the energy production sector. An even more comprehensive definition of the energy sector would have to include economic activities related to energy transport and energy supply. It could, for example, include NACE 60 (Transport in relation to pipelines 60.3) and NACE 61 (Marine transport in relation to transportation of crude oil from wells to refineries).

Statistical definition of the energy sector
NACE 10: Mining of coal and lignite; extraction of peat;
NACE 11: Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying;
NACE 12: Mining of uranium and thorium ores;
NACE 23: Manufacturing of coke, petroleum products and nuclear fuel;
NACE 40: Electricity, gas, steam and hot water supply.

Important analytical limitations in our approach
The delimitation of the energy production sector that we apply in this report is based on a statistical demarcation of the sector with emphasis on energy production. As point of departure the NACE sectors exclude upstream R&D, technology and supply. This means that our indicators fail to capture the significance of suppliers in sectors which depend crucially on the supply of R&D, technology and machinery and equipment in their innovation efforts. For example, we know from studies of innovation in the oil and gas extraction industry (which is dominated by large scale oil companies) that innovation is largely carried out in mechanical engineering workshops and engineering consulting firms. In NACE 11, extraction of crude petroleum and natural gas suppliers carry out product innovation which is transformed into process innovation when installed and implemented on the extraction plant. One of the major challenges in the present context, and in studies of sectoral innovation systems in general, is to capture the non-pecuniary knowledge and technology spill-overs (innovation dynamics) emerging from the network of interactions of companies within the sector, and between energy production and other sectors.

Some aspects of such external knowledge interaction shaping the internal organisation of the sectoral innovation system in energy production may be captured by tracing transaction flows between energy production sectors and other sectors in the national accounts statistics (input-output analysis). A rigorous analysis of sectoral input-output interactions, not only for energy production but also for nine other economic sectors, is an important part of the quantitative analysis of this project.

Furthermore, there are many other types of (non-pecuniary) R&D and innovation spillovers that we may not capture if we focus only on knowledge development strictly within the sector as defined above. In the course of the Innovation Watch project, such questions have inevitably been launched and discussed, in particular in the energy panel meetings which asswembled experts with broad knowledge of the activities and operations of different types of energy companies. The recurring argument is that the data presented to the energy panel had failed to capture significant parts of development activities in the energy sector. The experts in the energy panel are continuously referring to the ‘less-explicit-than-R&D projects’ way of working with innovation that is dominant in energy companies. This is a fundamental limitation that has affected the project's ability to fulfil one of the most important conditions when the objective is to develop sector specific policy, namely relevance.

1.3 Structure and Content of the report

The structure of the sector report is as follows. Chapter 2 gives an overview of the general economic performance of the energy sector. Chapter 3 is a description and analysis of the sectoral innovation performance in which the relationships between innovative activity, innovative performance, productivity, skills and competition are investigated. Moreover, different modes of innovation in the sector as well as national sectoral profiles are highlighted. Chapter 4 gives an account of the sectoral innovation barriers, drivers and challenges. Drivers and barriers comprise factors such as financing of innovation, taxation, competition, demand and regulation. Innovation challenges focus on technologies, markets and human capital. Chapter 5 deals with innovation champions, i.e. those firms with an extraordinary innovation performance. Consideration is given to what actually makes an innovation champion and which firms may be identified as innovation champions in the energy sector. Chapter 6 focuses on aspects of innovation policy and gives an overview of sectoral innovation policy programs, outlining what may be regarded as good innovation policy practices. The final chapter formulates conclusions and policy recommendations.

2 General Economic Performance

This chapter gives an overview of general economic performance as may be measured by available statistics. As addressed in the introductory chapter the sector of Energy production comprises the primary production of energy, and the transformation, conversion and processing of energy.

2.1 Economic performance

In the period between 1996 and 2004 energy sector employment in EU-25 increased by more than 50 per cent. Between 1996 and 2004, the number of employed persons in the sector increased from 1,233,000 to almost 1900,000. In terms of number of companies, the increase was roughly 80 per cent in the same period, from 11,600 in 1996 to more than 21,000 in 2004.

In total, value added in the EU-25 energy production sector in 2004 amounted to more than 233 billion euro. This was almost 15 per cent of the manufacturing value added in EU-25 in 2004. These statistics are based on the division of the energy sector into extraction, processing and distribution. Extraction (mining and extraction of energy products NACE 10 to 14) generated around 21 per cent of EU-25 value-added in the energy production sector in 2003, compared with 33 per cent in the USA and just 2 per cent in Japan. Mining of hard coal (NACE 10) is of greater importance in the new Member States compared to EU-15.

Fuel processing (NACE 23) accounted for almost 14 per cent of value-added in the 2003 EU-25 energy sector. The network supply of electricity, gas, steam and hot water (NACE 40–41) was the largest segment within the energy sector, generating 64.7 per cent of value added in energy production in 2003 in the EU-25. The corresponding shares were 57 per cent in the USA and 71 per cent in Japan.

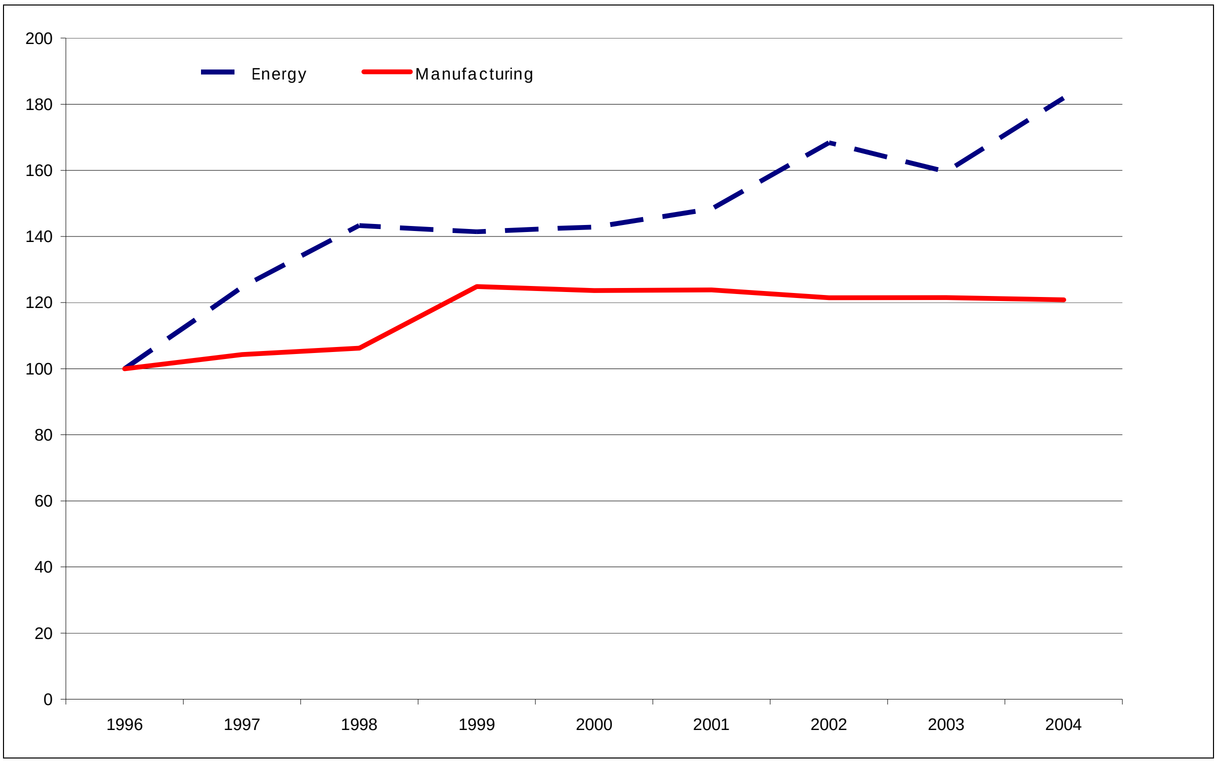
The share of NACE 40–41 was about the same in EU-25 as in EU-15 in 2003. The share of energy production (as a whole) of total value-added declined in the period 1979–2003 for the USA and the EU-15 while it increased slightly in Japan.

In terms of employment, the dominance of the network distribution activities in the energy production sector was even more conspicuous. NACE 40 accounted for about 67.5 per cent of employment in the EU-25 energy production sector with 1.1 million persons employed in 2003. The processing of energy products (NACE 23) accounted for 9 per cent of employment in the energy sector, considerably less than the 21 per cent employment share in mining and extraction of energy producing materials (NACE 10–12).

The electricity, gas and water supply sector in the EU-25 shows also an above average labour productivity after 1995 compared to a below-average labour productivity in coke, refined petroleum products and nuclear fuel.

Focusing on trends of economic performance our data captures the period 1996–2004. We start by focusing on the trend lines of manufacturing as a whole, and the energy sector in particular. Even though the latest developments are not revealed, the data indicate the development of the energy sector relative to manufacturing as a whole. Figure 2.1 displays the development in the number of enterprises during this period. While the number of enterprises in manufacturing as a whole has increased about 20 per cent between 1996 and 2004, the number of enterprises in the energy sector experienced a much stronger increase during the same period with around 80 per cent more enterprises in 2004 than in 1996.

Figure 2.1 Number of enterprises in the energy sector and in manufacturing as a whole, indexed development 1996–2004



The corresponding picture in terms of value added development is shown in Figure 2.2. Manufacturing as a whole experienced an increase in value added by about 25 per cent up until 1999/2000. During the same period the energy sector had doubled its value added by 1999. After some fluctuation in e period 1999 to 2004, the situation in the latter year reflected a level in value added almost 150 per cent higher than in 1996.

Figure 2.3 shows the development of the number of employees in energy compared to manufacturing. Figure 2.3 shows a strong increase in the number of employees up until 1998, corresponding to the increase in the number of enterprises seen in Figure 2.1. The levelling-off of the number of enterprises between 1998 and 2001 is accompanied by an abrupt fall in the number of employees between 1998 and 1999. This seems to relates to a rise in the productivity, visible in Figure 2.4, commencing in 2000 and peaking in 2002, subsequently declining in the following years.

Figure 2.2 Value added at factor cost in the energy sector and in manufacturing as a whole, indexed development 1996–2004

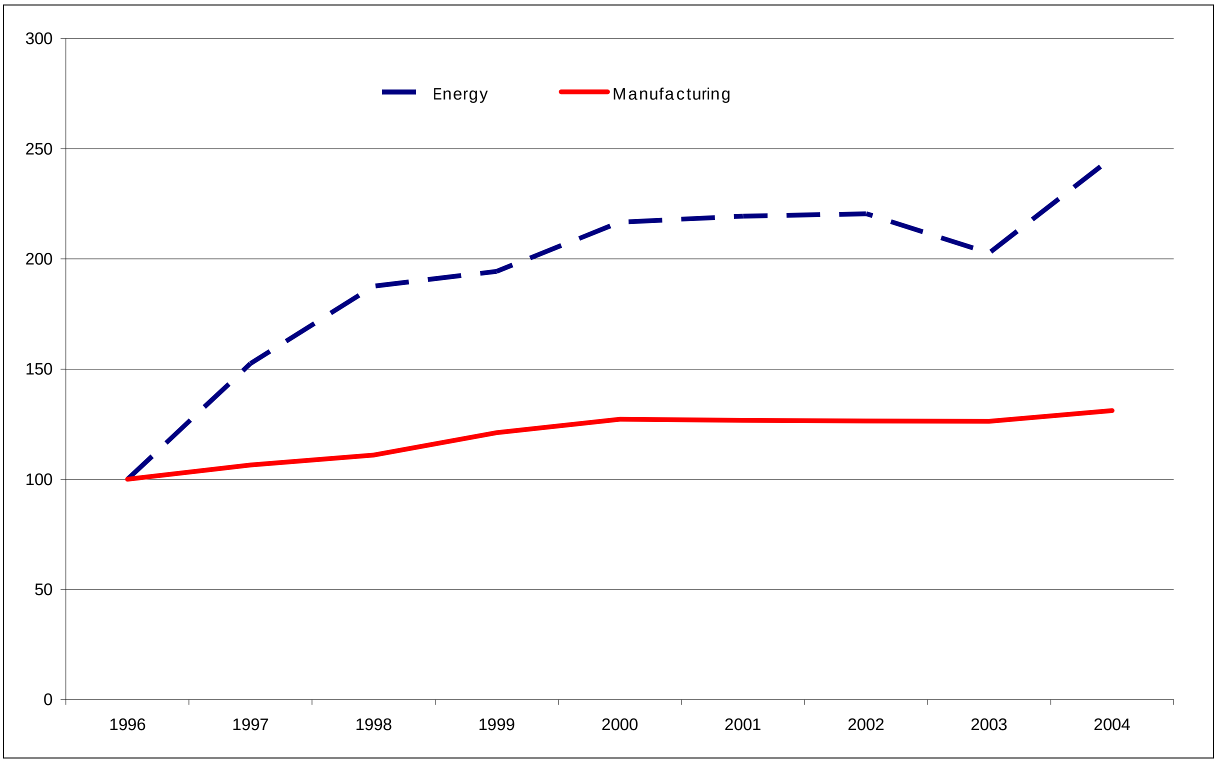
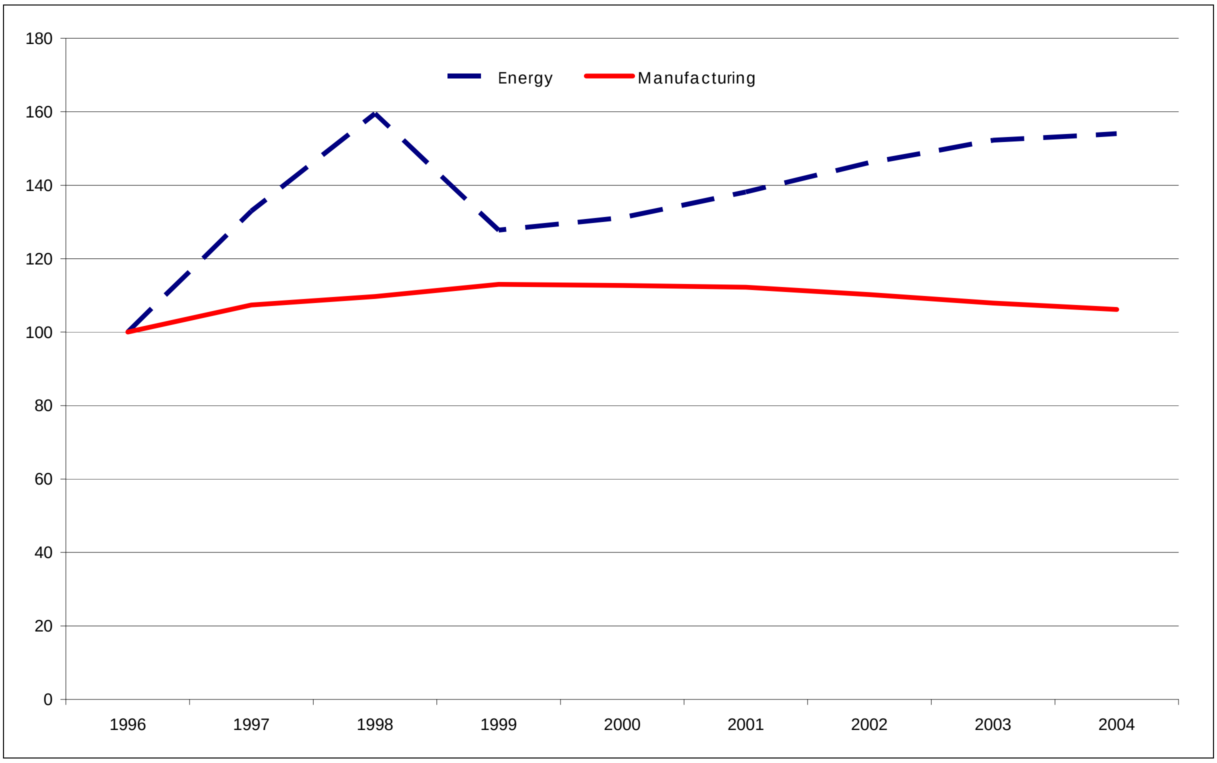
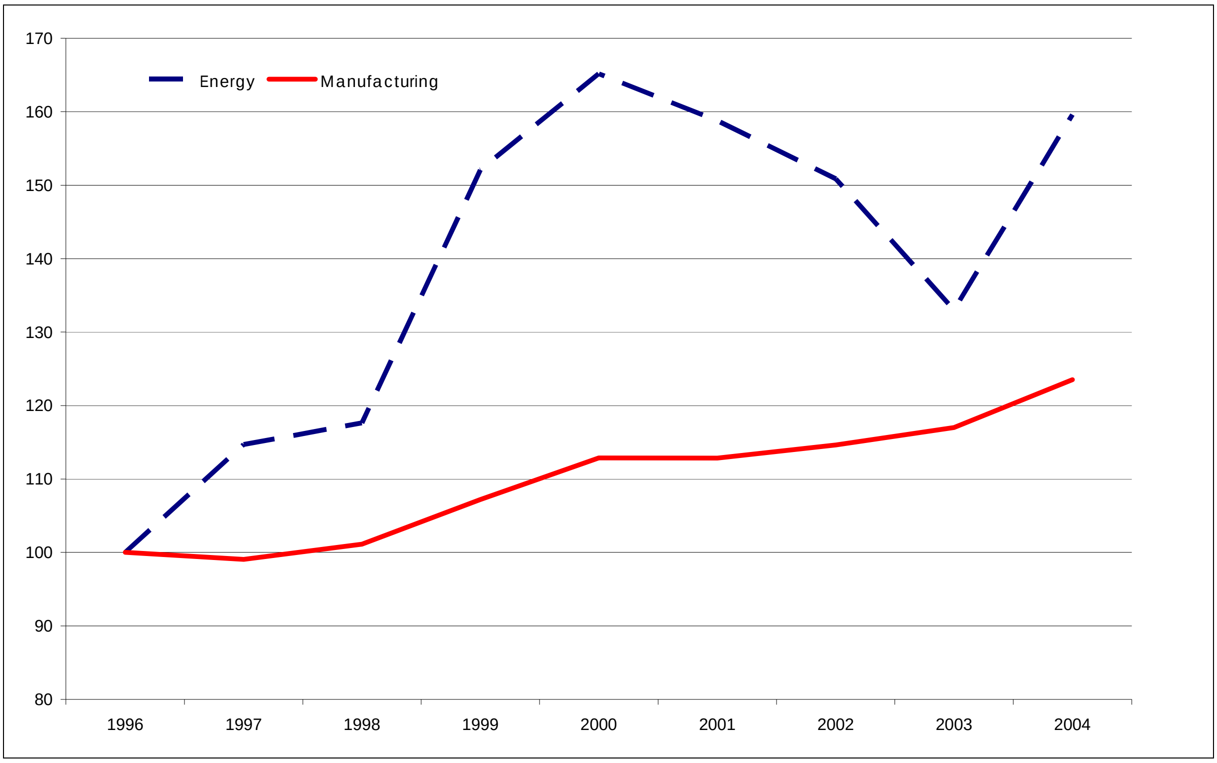


Figure 2.3 Number of persons employed in the energy sector and in manufacturing as a whole, indexed development 1996–2003



In summary, the basic statistics presented here show an impressive period of rise in productivity in the energy sector measured as gross value added per employee, and which reached its peak in 2000. This trend reversed abruptly, however, in 2003, rising again in 2004 when it ending up about 35–40 percentage -points above the productivity level for manufacturing as a whole.

Figure 2.4 Gross value added per employee in the energy sector and in manufacturing as a whole, indexed development 1996–2004



2.2 Other important indicators of economic performance and impact on society

Greenhouse gas emissions

One of the major problems faced by the energy sector is its own impact on the environment in addition to that arising from the use of its products. The main concern with the use of fossil fuels is atmospheric emissions. The Kyoto Protocol was the basis for the commitments but this has now been taken over by the so-called *20 20 by 2020 policy. Europe's climate change opportunity* (EC, 2008). The path towards fulfilling these commitments provides us de facto with a new and highly relevant innovation indicator. Greenhouse gas emissions have been monitored for many years now. Our EU-25 data on greenhouse gas (GHG) emissions by energy industries is provided by the European Commission and its Panorama of the European Union, European Business, Facts and Figures (EC, 2005). These show that the trend from 1990 and up until 2003 is remarkably stable concerning the proportion of total GHG emissions by energy industries. This amounts to about 30 per cent of total GHG emissions. In terms of absolute emissions, there was a slight decline from around 1600 million tonnes/CO^2 equivalent in 1991, stabilising between 1400 and 1500 in the 1990s before commencing to climb again at the start of the new millennium. There is obviously need for more recent data here but as long as there is no abrupt change in the way energy is produced and the efforts to invest and implement CO^2-cleaning technologies have not succeeded, there is no reason to expect a decline in GHG emissions. It is however a matter of growing concern all over Europe, and a factor that may be able to boost investment and innovation in renewable energy technology and cleaning technologies.

Another indicator that may contribute to monitor how the overall 20 20 by 2020 targets are reached is the contribution of electricity from renewable energy sources. The European Panorama provides a figure in which the status in 2004 and the target for 2010 is shown for the European countries. While the EU-25 as a whole was at a 12 per cent level in 2004, the target of 20 per cent electricity production from renewable energy sources is to be reached by 2010. For the critical reader, if the 2010 target in the report from 2005 is compared to the new target (20 20 by 2020) from 2008, the new objective can hardly be called ambitious concerning the share of renewable energy sources in electricity production. On the other hand, as the EU currently comprises 27 countries where even though many countries are already above the 20 per cent target, others will have to struggle to reach it.

3 Sectoral Innovation Characteristics

Innovation activity in the energy sector needs to be described with caution. The sector is special in more ways than one. The most important output in the energy sector can be considered a peculiar product. Energy in the form of electricity and energy in other carriers (hot water, gas, etc.) are relatively standardised products. Basically, it is a service considered as a fundamental good in human welfare.

The concept of *product innovation* in relation to this understanding of energy production and energy supply is less relevant as an innovation measure. Descriptions of energy sector innovation depend very much on what type of data we utilise, depending basically on the perspective we adopt towards innovation. This is particularly relevant here as due to data limitations, the Innovation Watch/Systematic project applies the same focus on product and process which is so solid and fundamental in innovation research based on quantitative data. This definitely affects our measurement of innovation. Hence, we need to take this perspective into account in the analysis.

3.1 General Innovation Performance

3.1.1 How does innovation occur in the energy sector? The view of energy sector experts

In general, innovation is a highly diverse activity. This applies to most sectors in society. Firms can use a wide range of methods to innovate, ranging from well-organised, project-based investment in in-house R&D, via purchasing new production equipment or product components, either customised or 'off-the-shelf', to working with non-project based incremental improvements of products and processes.

If we depart from the picture that the Community Innovation Survey draws about innovation in the energy sector, the message is that about 36 per cent of energy sector firms are innovative (see Table 3.1). The fact that only slightly more than one-third of energy sector firms are innovative is 'a fact' that has been subject to debate and criticism in the energy sector panel of the Innovation Watch Systematic project. The energy panel has gathered participants from energy firms and supporting institutions – persons that have long-standing experience and knowledge from what energy firms do strategically and on a day-to-day basis. The concern we emphasise is based on the fact that none of the participants in the energy panel have experience from energy firms that *are not* working with improvements in their operations. Put another way, the energy panel participants state that innovation is a pervasive and continuous activity in firms in the sector. The statement is rooted in the panellists' deep knowledge about how these actors act in an increasingly competitive market. There is a constant effort to reduce costs in order to be competitive. This kind of activity is part of the operation and daily life of firms.

Our concern can be summarised by the following statement:

> *It is problematic that the picture of energy sector innovation that can be drawn from quantitative data is by and large rejected by qualitative information about the extent to which development and innovation occurs.*

How can this be the case? The energy sector panellists argue that this type of innovation activity is not necessarily conceived as innovation by the employees or actors in the sector. One reason for this may be that this type of innovation is less project- oriented, and not often to be found in the firms' budgets. Consequently, this type of innovation is not easy to measure using ordinary innovation indicators. It is argued the the Community Innovation Survey (CIS) does not seem to be adapted to what is going on in the energy sector. It does not seem to capture important processes of development and innovation; neither does it capture what is produced in the sector. As one of the so-called low-tech sectors, with an average R&D percentage share of value added well below the manufacturing average, the energy sector obviously relies less on direct R&D and more on knowledge, competence and R&D embodied in other types of inputs. Some of the evidence for this is given in the section 3.6.According to the discussions in the energy panel, there is a constant effort of improvement in the energy sector, through knowledge exploration and knowledge exploitation and use, and as such, the panel means that this sector is highly innovative. Innovation is not necessarily a novel product but an innovative way of doing things – progressive work for the sake of improvement. Within the energy sector today, every actor is looking for new and better solutions both concerning the use of energy, the elimination of waste, and energy saving efforts – factors that put pressure on the innovative efforts in the sector. In all parts of the sector there is pressure with regard to environmental concerns and improvement of technology. The markets are very competitive, there is a constant pressure on renewable energy – all indicating that energy sector firms and their suppliers are making an effort to develop, either by being very intensive in R&D, or by working with other types of innovation.

Table 3.1 shows the CIS measurement of energy sector innovation where 36.2 per cent of energy sector firms report that they are innovative. The fact that the share of 'process only innovator' is higher than for all sectors, especially when innovators are concerned (31.6% vs. 24.7%), is in line with the remarks made above on the relevance of product innovation as a measure of innovation activity in the energy sector. But the information from our experts makes it important to consider the remaining 63.8 per cent firms in the sector when we discuss how the quantitative data can be interpreted. We need to take non-innovators into consideration and analyse their performance as well.

Table 3.1 Innovation in the energy sector compared to all sectors (highlighted) CIS-3 for 18 countries

	All firms		**Non-innovators**		**Innovators**	
FIRM CHARACTERISTICS	Energy	All sectors	Energy	All sectors	Energy	All sectors
Share of innovative firms			63.8	62.9	36.2	37.1
Product only innovator (% share)	11.8	11.9	0	0	32.5	32.1
Product and process innovator (% share)	13	16	0	0	35.9	43.1
Process only innovator (% share)	11.4	9.1	0	0	31.6	24.7
Average firm size (employees)	421	140	193	49	824	294

3.1.2 Non-innovators in the energy sector

We have described energy sector output and innovation as something special compared to other manufacturing sectors. It is, however, a fact that innovation in the energy sector, as measured by the Community Innovation Survey, is approximately equal to the manufacturing sector average . Now the average is, of course, made up of the individual sectors' scores – in this case the proportion of firms in the sector informing that they have innovated by introducing new products or processes over the last three years. Some sectors have lower-than-average scores, typically the food processing sector and the textiles sector. Other sectors have far above average scores, typically the machinery and electrical machinery sectors and the biotechnology sector. The point being made here is that every sector has their specific configuration of operation and innovation. This is, of course, the observation that shapes the background for the sector approach taken in the Innovation Watch/Systematic project.[1]

Firm size

Table 3.2 provides some key numbers of innovators and non-innovators in the energy sector. The highlighted numbers show the average for all manufacturing industry. If we look at firm size, we see that the average innovative energy sector firm has as many as 824 employees. In comparison, the average non-innovating energy sector firm has 193 employees. The averages for the manufacturing sectors as a whole are 294 for innovative firms, and 49 for non-innovative firms.

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[1] Malerba, F. (2004) Sectoral Systems of Innovation, Cambridge University Press, Hirsch-Kreinsen H. Jacobson D., Laestadius S. (2005) Low-Tech Innovation in the Knowledge Economy, P.Lang

Labour productivity and employment development
In terms of labour productivity, energy sector innovators are about twice as efficient as non-innovative energy sector firms (448 000 € compared to 226 000 €). But, non-innovators in the energy sector have almost the same labour productivity as the manufacturing sector average. The high labour productivity may also be linked to the development of employment, which in this table is shown as decreasing by 4 per cent and 3 per cent for innovators and non-innovators respectively in the energy sector.

Turnover growth
Concerning growth in turnover, the CIS data indicates that innovating energy sector firms are more profitable than non-innovating firms. The turnover growth is more than 8 per cent for innovative firms in the energy sector and 5 per cent for non-innovative energy sector firms.

Strong competence in non-innovating energy firms
It is interesting to observe that the level of competence as measured by the share of employees with higher education, is actually higher in non-innovating than in innovating energy sector firms. This pattern is not present if we look at the manufacturing average where innovative firms clearly have a more competent work force than non-innovative firms. This is arguably an indication that other absolutely competence-demanding development activities are present in non-innovative energy sector firms, but these activities are not registered as innovation by the Community Innovation Survey.

Table 3.2 Innovators and non-innovators in the energy sector compared to all sectors (highlighted) CIS-3 for 18 countries

	All firms		**Non-innovators**		**Innovators**	
FIRM CHARACTERISTICS						
Share of all firms			63.8	62.9	36.2	37.1
Share of innovative firms						
Product only innovator (% share)	11.8	11.9			32.5	32.1
Product and process innovator (% share)	13.0	16.0			35.9	43.1
Process only innovator (% share)	11.4	9.1			31.6	24.7
Average firm size (employee)	421	140	193	49	824	294
Labour productivity (1000's euros per employee)	383	239	226	178	448	256
Turnover growth (%-point)	7.55	6.53	4.99	5.19	8.12	6.80
Employment growth (%-point)	-3.80	1.86	-3.36	0.76	-3.98	2.18
Share of employees with higher education	15.0	14.2	15.2	10.9	14.9	15.1

Intellectual property protection

There are distinct differences concerning how innovators in the energy sector protect their intellectual property compared to non-innovators (Table 3.3) The shares of innovating energy firms are generally much higher when it comes to formal methods of protection, such as patent applications, the use of registered design patterns, the use of trademarks and the use of copyright. This is arguably easy to explain because innovative firms, having developed a robust (identifiable) innovation should have more to protect. But the pattern of how innovators and non-innovators use other methods of protection, such as the use of secrecy and complexity of design, is roughly the same. A marginal share (secrecy 4.3 per cent and complexity of design 0.8 per cent) of the non-innovators report the use of these methods. And a much higher share (secrecy 28 per cent and complexity of design 9.2 per cent) of the innovators report that they use these methods.

Strategic or organisational change

The Community Innovation Survey has been developed to include questions about whether firms have implemented strategic or organisational change. These are questions that attempt to go beyond the focus on product and process innovation by asking about softer types of change.

In Table 3.3, a comparison is made of the extent to which innovating and non-innovating energy sector firms implement strategic and organisational change. The data show that the shares of non-innovating energy firms' use of strategic and organisational change is high, in fact distinctly higher than the share of non-innovating firms in manufacturing on the whole. Of non-innovating energy sector firms, 32.4 per cent have implemented new or significantly changed corporate strategies. The corresponding share for innovative energy firms is 40.2 per cent. This pattern is also present for the variables implemented advanced management techniques (29.7 % for non-innovators and 52.8 % for innovators) and implemented new or significantly changed organisational structures (36.7 % for non-innovators and 46.4 % for innovators), and changed marketing concepts/strategies (25 % for non-innovators and 36.8 % for innovators).

Table 3.3 Innovators and non-innovators in the energy sector compared to all sectors (highlighted), Intellectual Property Protection, Strategic and Organisational Change CIS-3 for 18 countries

	All firms		**Non-innovators**		**Innovators**	
FIRM CHARACTERISTICS						
Share of all firms			63.8	62.9	36.2	37.1
INTELLECTUAL PROPERTY PROTECTION						
FORMAL METHODS						
Applied for patent	7.8	6.2	0.7	1.7	20.2	14.0
Used registration of design patterns	3.3	5.6	0.5	1.8	8.1	12.2
Used trademarks	7.1	9.9	2.4	5.2	15.3	18.0
Used copyright	1.8	2.7	0.4	1.1	4.2	5.4
STRATEGIC METHODS						
Used secrecy	12.9	12.8	4.3	4.8	28.0	26.3
Used complexity of design	3.9	7.7	0.8	2.4	9.2	16.7
Used lead-time advantage on competitors	9.5	15.7	4.1	5.9	19.2	32.4
STRATEGIC OR ORGANISATIONAL CHANGE	64.8	56.5	56.8	43.0	79.0	79.6
Implemented new or significantly changed corporate strategies	35.2	26.5	32.4	16.4	40.2	43.7
Implemented advanced management techniques	38.1	24.3	29.7	15.7	52.8	38.9
Implemented new or significantly changes organisational structures	40.2	35.1	36.7	23.8	46.4	54.2
Changed marketing concepts/strategies	29.3	25.8	25.0	17.3	36.8	40.3
Changed aesthetic appearance or design of products	17.1	29.6	11.1	19.3	27.5	47.1

Summing up, the picture that CIS gives us of non-innovating firms in the energy sector is that they are significantly smaller than innovative energy firms, although still almost as large as the average of innovative manufacturing firms. Moreover, innovative energy firms can refer to labour productivity which is twice that of non-innovators. Nevertheless, the related indicator employment development shows that non-innovating energy firms are decreasing by 3 per cent compared to 4 per cent for energy sector innovators. Turnover growth is significantly higher in innovating energy firms although the level of competence (measured as the proportion of employees with higher education) is roughly the same in non-innovating and innovating energy firms. In terms of methods of intellectual property protection, non-innovating energy firms are hardly ever active. However, looking at the last set of variables, strategic and organisational change, a high share of non-innovative energy firms implement these types of changes.

3.2 Focus on the observed innovative firms and their modes of innovation

Innovation is a highly diverse activity. Firms can use a wide range of methods to innovate, ranging from intensive investment in in-house R&D, to purchasing new production equipment or product components ‘off-the-shelf’. In each case, the capabilities required by the firm to innovate are very different. Consequently, simple aggregate indicators of the percentage of ‘innovative’ firms provide very little information of value to policy. For example, a much higher percentage of firms in the new Member States of the European Union largely innovate through adopting new-to-firm products and processes. By contrast, a much higher percentage of firms in Finland, Sweden and Germany innovate through creative, R&D based activities. Similar problems apply across sectors. Innovation indicators need to differentiate between styles or modes of innovation in order to provide a clear picture of the structure of innovation capabilities within individual sectors (or countries).

Table 3.4 Number of observations/firms per sector (rounded numbers)

	NUMBER OF OBSERVATIONS	
	UNWEIGHTED	WEIGHTED
AEROSPACE	79	129
AUTOMOTIVE	1025	3893
BIOTECH	--	--
CHEMICALS	1984	7690
ECO-INNOVATION	6702	50094
ENERGY	1465	5041
FOOD	6337	33487
GAZELLES	4599	17717
ICT	4635	22685
MACHINERY	3471	27465
TEXTILES	7231	37679
TOTAL – SYSTEMATIC SECTORS	37528	205880
TOTAL – ALL SECTORS	71477	469996

We address these issues by using the results of the third European Community Innovation Survey (CIS-3) for 18 countries to identify different groups of firms according to how they innovate. The approach builds on the seminal work by Pavitt on differences in how firms innovate across sectors, but provides results at the firm level rather than the sector level. It also extends our previous work which classified the innovative manufacturing firms in Europe into four categories: strategic innovators, intermittent innovators, technology modifiers and technology adopters. The classification is conducted through combining CIS-3 data on whether or not firms introduced product and process innovations, conducted in-house R&D, developed new-to-market products, targeted national or international markets, or carried out continuous or occasional R&D.

For all countries and sectors combined, there are more than 70,000 observations; for the 11 sectors listed in Table 3.4 there are more than 37,500 observations (Table 3.4). For each observation, a weight is included in the database. These weights differ between sectors and countries taking into account how well the survey sample represented the total population of firms in each sector and country. The weighted number of observations for all sectors is almost 470,000, and for the 10 systematic sectors the weighted number of observations is almost 206,000. For Food, Machinery, Textiles, ICT and Eco-innovation, average data availability is good with at least 20,000 observations for each sector. For Chemicals, Energy, Automotive and Gazelles, available data is more limited with almost 7700 observations for Chemicals and only 3900 observations for Automotive. Data availability for Aerospace is poor and most results for this sector are suppressed in the remainder of this report due to problems of data confidentiality.

3.2.1 Energy

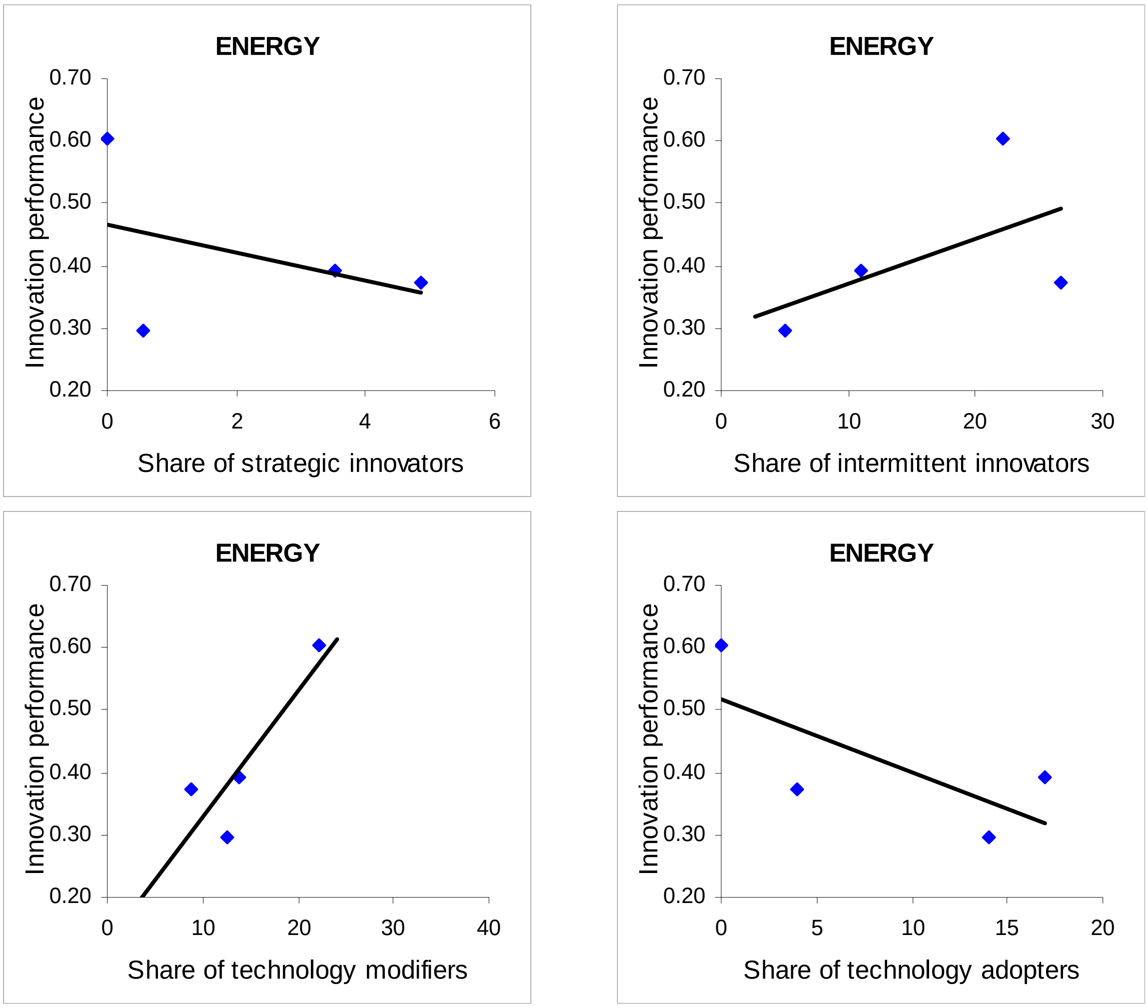
Sectors with higher shares of strategic and intermittent innovators also have higher innovation performance as measured by the ISI. Within the energy sector, countries with higher shares of intermittent innovators within their energy industry also show higher innovation performance as measured by the ISI (Figure 3.1), but countries with higher shares of strategic innovators show lower innovation performance. Also Technology modifiers seem to drive innovation performance in the energy sector. The number of countries for which both ISI scores and data for innovation modes are available is limited to only four, but the results shown in Figure 3.2 are statistically significant for the share of technology modifiers at the 0.05 level.

Diffusion (22%) and intermittent innovators (12%) are the dominant innovation modes within the energy sector (Table A2 in the Annex). Average labour productivity is above that of the average firm. Labour productivity is highest for strategic innovators at 527,000 euros per employee. Firms in the energy sector also employ more people than the average firm. Strategic innovators employ more than 6400 employees and are almost seven times larger than the average strategic innovators and more than 12 times larger than the intermittent innovators in the Energy sector. Turnover growth is highest for strategic innovators, while employment and export growth is highest for intermittent innovators. Employment growth is negative for the average energy firm.

Firms in the energy sector innovate by buying advanced machinery and equipment, by performing intramural R&D, and by training personnel for innovation activities. Less energy innovators receive public funding, in particular from local or regional authorities. Secrecy, patents, lead-time advantage on competitors and trademarks are used most by energy firms to protect their new inventions or innovations. The diffusion innovators hardly make use of formal methods to protect their new inventions or innovations. Almost 80% of energy innovators use some form of non-technological change; implementing advanced management techniques and new organisational structures are used by most firms.

Compared to the average strategic innovator, strategic innovators in the energy industry have an above-average share of turnover due to new-to-market products (12% vs. 10%) but a below average share of new-to-firm products (10% vs. 20%). Firms are more active on the national market. The proportion of firms that receive public funding are below average except for EU funding where twice as many strategic innovators receive funding from this source. Use of both formal and informal IP is above average, with lead-time advantage on competitors (83%), secrecy (82%) and patents (69%) used most often. Strategic innovators make more use of non-technological change, in particular by implementing new organisational structures (92% vs. 69%).

Figure 3.1 Innovation modes and innovation performance in Energy[2]



Compared to the average intermittent innovator, intermittent innovators in the energy industry have below average shares of turnover due to new-to-firm and new-to-market products. Energy firms are less often active on the international market (12% vs. 27%). Energy intermittent innovators innovate more by perform intramural R&D (91% vs. 77%) and acquiring extramural R&D (56% vs. 23%) and less by training personnel (26% vs. 40%). The share of firms receivong funding from local or regional authorities is below average, but relatively more firms receive funds from central government and the EU. Use of IP to protect new inventions or innovations is above average, with secrecy (52%) and patents (42%) used most often. Intermittent innovators make more use of non-technological innovations by implementing advanced management techniques (60% vs. 41%), but implementing new organisational structures (39% vs. 56%) changing the aesthetic appearance or design of products (23% vs. 50%) are less used.

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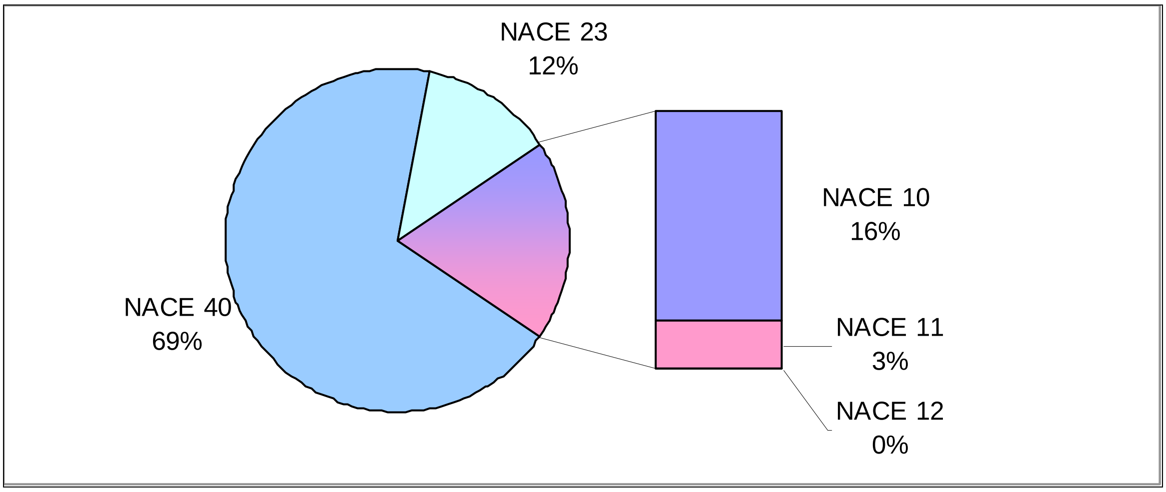
[2] Energy was not covered in the 2005 sectoral innovation scoreboards (Arundel and Hollanders, op. cit.). The ISI scores are based on own calculations.

Intra-sectoral differences

For the energy sector, we have seen that 3 per cent of firms are strategic innovators, 12 per cent are intermittent innovators, 11 per cent are technology modifiers, and 11 per cent are technology adopters. But the energy sector is not a homogenous sector as it is composed of five different industries. The statistical definition of the energy sector includes the following industries defined at the NACE 2-digit level:[3]

NACE 10–12: Mining and quarrying of energy-producing materials
NACE 10: Mining of coal and lignite; extraction of peat;
NACE 11: Extraction of crude petroleum and natural gas; and gas extraction, excluding surveying;
NACE 12: Mining of uranium and thorium ores;
NACE 23: Manufacturing of coke, petroleum products and
NACE 40: Electricity, gas, steam and hot water supply.

Figure 3.2 Distribution of Energy industries



The number of observations in the database for NACE 11 and 12 is small (Figure 3.2) and these industries are grouped together with NACE 10 in Mining and quarrying. The distribution of innovation modes within the energy industries is quite different from the general pattern (Figure 3.3). For Mining and quarrying, the distribution is similar to that of energy, but the share of intermittent innovators is four percentage points below the average. For Electricity, gas, steam and hot water, the distribution is similar to that of energy, but the share of strategic innovators is 2 percentage points below average. For Coke, refined petroleum and nuclear fuel, the distribution is quite different as the share of innovators within this industry is significantly higher than that of the aggregated energy sector. Within Coke, refined petroleum and nuclear fuel almost 60 per cent of the firms are innovative, and 19 per

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[3] Kaloudis, A. and T. E. Pedersen, 2006, *Energy Production, Scoping Paper.* Research report commissioned by the European Commission in Innovation Watch – Systematic, Oslo.

cent are intermittent innovators, 15 per cent are technology modifiers, 12 per cent are strategic innovators and 12 per cent are technology adopters. The share of innovators in NACE 13 is equal to that in Chemicals and the share of strategic and intermittent innovators is comparable, but smaller, to that in Automotive.

Figure 3.3 Innovation modes within energy

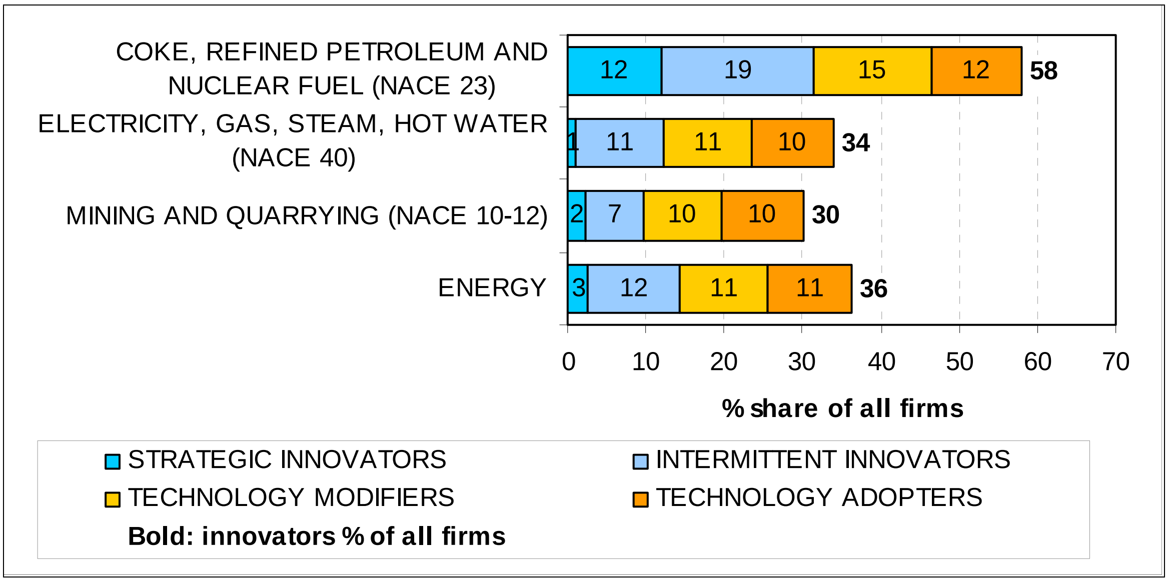


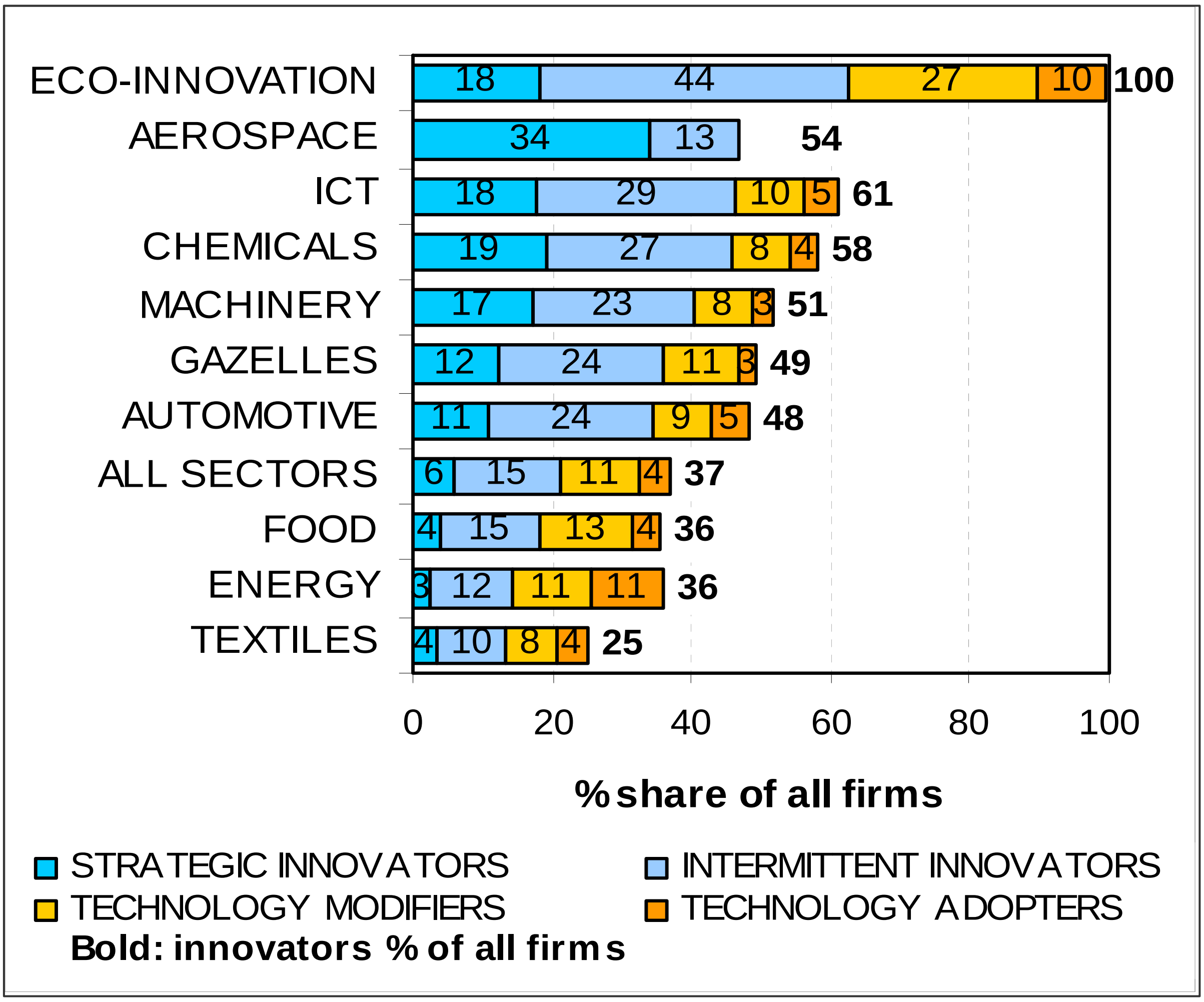
Table A2 in the Annex highlights the fact that there can be large differences between the industries within a sector. Labour productivity for NACE 23 is 10 times as high as that for NACE 10-12. Turnover and employment growth are both positive in NACE 40 but negative in NACE 10–12. The sales share of new-to-firm or new-to-market products is only 5 per cent in NACE 10–12. The innovation strategy also differs between the industries. The share of strategic innovators purchasing advanced machinery and equipment is as high as 90 per cent in NACE 40 but only 36 per cent in NACE 23. The share of the innovation budget spent on acquiring other external knowledge is small in both NACE 10–12 and NACE 23 but as high as 20 per cent in NACE 40. There are also large differences in IP behaviour. Compared to the other energy industries, strategic innovators in NACE 40 make less use of patents, registration of design patterns and trademarks but more than 70 per cent use copyrights to protect their inventions and innovations. Moreover, the low share of strategic innovators in NACE 40 seems in line with the importance of buying advanced machinery and acquiring external knowledge; apparently firms in NACE 40 do not need to have much in-house R&D to adopt technologies from external sources.

3.2.2 Summary of results

Innovation is a highly diverse activity. Firms can use a wide range of methods to innovate, ranging from intensive investment in in-house R&D, to purchasing new production equipment or product components ‘off-the-shelf’. In each case, the capabilities required by the firm to innovate are very different. Consequently, simple aggregate indicators of the percentage of ‘innovative’ firms provide very little information of value to policy. For example, a much higher percentage of firms in the new Member States of the European Union largely innovate through adopting new-to-firm products and processes, whereas a much higher percentage of firms in F, Sweden and Germany innovate through creative, R&D based activities. Similar problems apply across sectors. Innovation indicators need to differentiate between styles or modes of innovation in order to provide a clear picture of the structure of innovation capabilities within individual sectors (or countries). In this section we have assigned each innovative firm to one of four mutually-exclusive modes:

- ***Strategic innovators*** have introduced a product or process innovation that they developed at least partly in-house; they perform R&D on a continuous basis; they have introduced at least one product that is new to their market, and they are active in national or international markets. These firms are the source of many innovative products and processes that are adopted by other firms
- ***Intermittent innovators*** have developed innovations, at least in part in-house, and have introduced new-to-market innovations. But they are unlikely to develop innovations that diffuse to other firms. The class includes three sub-groups:
    - Firms that meet the identical requirements of the strategic innovators except that they only perform R&D on an occasional basis. This group includes firms that innovate in-house intermittently when required by a new product line.
    - Continuous R&D performers which are only active in local or regional markets. These firms probably make only minor adjustments to products or processes that are largely acquired from other firms.
    - Firms that do not perform R&D but which have introduced new-to-market innovations to a national or international market. The novelty of their innovations is likely to be at least as high as the first two categories since the innovation must compete in a larger market.
- ***Technology modifiers*** have developed an innovation at least in part in-house but none of them perform R&D. They differ from the final group of technology adopters by having some in-house innovative activities. If they are active on national or international markets, they have not introduced a new to market innovation (otherwise they would be classified as an intermittent innovator). If they are active in local and regional markets, they may have introduced a new to market innovation and have slightly modified it for this market. Many firms that are essentially process innovators that innovate through production engineering probably fall within this group.
- ***Technology adopters*** have innovated, but depend on adopting innovations developed by other firms. These firms innovate through diffusion.

Figure 3.4 Industrial sectors and modes of innovation



Of all innovators across all industries, 6 per cent are strategic innovators, 15 per cent are intermittent innovators, 11 per cent are technology modifiers and 5 per cent are technology adopters. The highest shares of strategic innovators are found in Aerospace, Chemicals, ICT, Eco-innovation and Machinery. Eco-innovation, ICT, Chemicals, Automotive, Gazelles and Machinery have the highest shares of intermittent innovators. Eco-innovation, Food, energy, Gazelles and ICT, have the highest shares of technology modifiers. Energy and Eco-innovation have the highest shares of technology adopters. Figure 3.4 gives the overview. We have found statistical evidence that sectors with higher shares of strategic and intermittent innovators have higher shares of innovative firms. We have also found statistical evidence that sectors with higher shares of strategic and intermittent innovators have higher levels of innovation performance, and those sectors with higher shares of technology modifiers and technology adopters have lower levels of innovation performance. However, as energy sector experts have stated, it might not be appropriate to refer to higher or lower levels of innovation performance, but rather to different modes of innovation.

For the different sectors, statistical evidence is weak due to a small number of observations within each sector, but we have found some evidence that higher shares of strategic innovators drive innovation performance in Automotive, Chemicals, Food, ICT, Machinery and Textiles. Higher shares of intermittent innovators seem to drive innovation performance in Automotive, Energy, Food, ICT, Machinery and Textiles. But we have seen that innovation performance is driven by higher shares of technology modifiers in Energy, and by higher shares of technology adopters in Automotive, Chemicals, Food and Textiles. In other words, a higher share of strategic innovators in the energy sector would not lead to more innovation performance, but a higher share of technology modifiers would do so. Higher shares of strategic innovators also appear to have an adverse effect on innovation performance in Energy, and higher shares of intermittent innovators appear to have an adverse effect on innovation performance in Chemicals. The pattern linking differences in shares of innovation modes between countries within a sector can thus be different from the observed overall pattern linking differences in shares of innovation modes between sectors across all countries. This illustrates the problem of a sector-across-countries approach versus a sector-within-country approach. In terms of policy implications, it seems meaningful to argue that the energy sector should not attempt to copy the sectors where strategic innovators are most important. The energy sector needs policies aimed at activating technology modifiers and technology adopters. However, this applies only to those firms considered innovative by the Community Innovation Survey. In elucidation of the main message from the sector experts in the energy panel, it is still an open question what would drive innovation performance in firms that are non-innovators (62.8 per cent).

Table 3.5 'Performance' of each innovation mode observed in the energy sector compared to the average performance of that mode over all industries

	Strategic innovators	**Intermittent innovators**	**Technology modifiers + Technology adopters**
Share of innovative firms	-	-	+
Turnover of new-to-firm products	--	-	-
Turnover of new-to-market products	+	-	-
Firm size	++	++	++
Turnover growth	+	+	-
Employment growth	--	-	--
Labour productivity	++	+	0
Innovation activities (top 3 used by most firms)	- own R&D - buying advanced machinery - design preparations	- own R&D - buying advanced machinery - training personnel	- buying advanced machinery - training personnel - design preparation
Innovation expenditures (top 3 highest spending shares)	- own R&D (47%) - buying advanced machinery (32%) - buying external R&D (14%)	- own R&D (47%) - buying advanced machinery (30%) - purchased other external knowledge (17%)	- buying advanced machinery (47%) - buying other external knowledge (36%) - buying external R&D (9%)
Public funding - national - EU	 - ++	 - +	 - -
Use of formal IP (most used)	++ (patents)	++ (patents)	- (trademarks)
Use of non-formal IP (used by most firms)	++ (lead-time advantage)	+ (secrecy)	-- (secrecy)
Use of non-technological change (used by most firms)	+ (new organisational structures)	+ (advanced management) techniques)	+ (advanced management techniques)

The share of novel innovators (36%) in the energy industry is just below average. The combined share of Technology modifiers and Technology adopters is relatively large (22%), and most firms in the energy industry innovate through diffusion-based innovative activities. Moreover, the importance of these two modes of technology modifying and adopting is also apparent in the performance of the energy firms in this mode, compared to firms in the same mode for other sectors.

Table A1 in the Annex summarises the 'performance' of each innovation mode compared to the average performance of that mode over all industries, and shows that the share of innovating firms among the technology modifiers and adaptors is higher in the energy sector than in other sectors.

3.3 Basic features of human capital in the energy sector

According to the European Commission (2006), the network supply part of the energy sector dominates in employment terms as it accounted for 67.5 per cent of employment in the EU25 energy sector in 2003. The processing of energy products accounted for 9.9 per cent of the workforce, less than half the 22.6 per cent share of Mining and extraction of energy products.

As emphasized by Grubb (2004), each stage in the energy innovation chain can take a decade, and diffusion is equally slow. The economic, environmental and national security benefits of energy innovation are potentially large but lie largely in the future. To date, according to the OECD (2006), most of the benefits of innovation in fuel cell technology have been knowledge benefits, either codified in papers and patents, or not codified/tacit in the minds of fuel cell researchers.

The Europe Innova Energy Sector Panel underlined that the shortage of engineers and relevant skills and competencies is a clear threat to innovation and growth for all kinds of energy production. Because innovation processes depend on this type of expertise in large utilities innovation policies should address the issue of skills needs in the sector in a more coherent manner. Fewer people tend indeed to be interested in studying technology and natural sciences. The sector needs ICT experts in particular, and other technical personnel. With competition and deregulation, the workforce has furthermore to build new skills with changing technologies.

The more disruptive the new technologies are, the greater the need for continuous life-long learning investments as well as more frequent adjustments of tuition programs and curricula in the educational system. Since, there are considerable differences across the world in terms of the quality of education at lower skill-levels, one should not only focus on skills in tertiary education, but also at lower levels; it is the complementary and balanced mix of skilled labour that would be important, not just the quality of the high end of the formal skills. Age distribution of the workers in the sector is also an important issue in the sector that may hinder change. According to the Labour Force Survey, the proportion of employees aged less than 30 in 2005 was just 13.9 per cent, slightly less than two thirds the average share for the rest of the economy (21.4%). As a result, older workers, particularly those aged 50 and above, accounted for more than one quarter (25.8 %) of the workforce.

The experts also agreed on the point that mobility of researchers is currently below the optimal level. EU research and innovation policies should therefore stimulate public–private mobility flows of human resources in science and technology. Furthermore, in 2005, according to Labour Force Survey data, 81.5 per cent of employees in this sector in the EU25 were male, which is higher than for the whole industrial economy (77, 2%). The proportion of full-time workers was 95.6 per cent (92,4% on average for the whole of the industrial economy).

3.4 Innovation, Productivity and Competition

This section addresses three sets of issues related to productivity growth and its relationship with the availability of skills in the energy sector. The determinants of knowledge production in the sector are examined by linking an observable innovative output – patents – to observable inputs. Finally, some new empirical evidence on the relationship between competition and innovation is provided. Most previous studies addressing these issues have used aggregate data; the underlying rationale here is to focus on a particular industrial sector, namely the energy sector.

Observed differences in measured productivity (and productivity growth) across countries have received increasing policy attention in the last twenty years. Numerous studies have examined the factors underlying such differences, ranging from expenditures on R&D, purchases of new equipment, to organisational and managerial factors. At the same time, a number of recent analyses have emphasised that the level and composition of skills (or human capital) in an economy also has an important bearing on differences in levels and growth of productivity in the OECD countries. Here, we examine the evolution of both labour and total factor productivity in the energy sector and its relationship to the levels of skills. We make a distinction between skills that are necessary for innovative activities, (i.e. activities aimed at pushing the world technological frontier) and those necessary for activities aimed at ‘catching-up’.

The second issue addressed here relates to *knowledge accumulation* (or knowledge generation) in the energy sector. It has now become a part of conventional wisdom that OECD economies are *knowledge-based economies*, characterised by the increased influence of knowledge creating activities on economic growth. New theories now include knowledge more directly as input for economic growth (Griliches, 1979), because investments in knowledge, embodied in people and technology, increase the productivity of labour and capital and result in new products and processes. In this report, we analyse the determinants of knowledge generation, by linking an observable innovative output – patents – to observable inputs for the energy sector. While patents are an imperfect measure of knowledge generation, they have been used in a range of influential studies (e.g. Porter and Stern (2000); Furman, Porter and Stern (2002), Jaummotte and Pain (2005). Here, we begin by examining the dynamics of national patterns of knowledge accumulation within the EU, the USA and Japan. Moreover, we analyse some of the determinants of knowledge accumulation. In particular three types of variables are considered: i) private R&D investments, ii) the existing stock of accumulated knowledge at a given point in time, and iii) the efficiency of the research process in converting inputs into research outputs.

The third theme in this section is the relationship between innovation and competition – an issue that has been of interest in many studies since the pioneering work of Schumpeter (1943). This has been the subject of renewed attention in the last few years with the emergence of new models suggesting an inverted U-shaped relationship between competition and innovation. Such models argue that competition has a positive effect on innovative activities up to a certain point, beyond which competition decreases the innovative efforts (Aghion, et al. 2005). Here, we analyse the actual shape of the relationship between competition and innovation in the energy sector. Additionally, we examine the interaction between innovation, competition and the technological gap. The underlying rationale is that the relationship between innovation and competition in a particular country is dependent on whether that country is a technological leader or is some way away from the world technological frontier. In other words, we want to determine whether the impact of competition on innovation declines (or grows) with the technology gap.

3.4.1 Skills and Productivity

We begin this section by presenting trends in productivity growth within the energy sector. In general, two alternative definitions of productivity are available: labour productivity and total factor productivity. Labour productivity is measured as value added per hour worked. This is the simplest productivity index and it gives an idea about how efficient labour is for the generation of added value. The problem with this measure is that labour is not the only factor of production(or even the most important). The input of capital (plant, equipment, machinery etc..) also needs to be taken into consideration. This is the underlying rationale for calculating total factor productivity. It is increasingly accepted that from a conceptual point of view, total factor productivity is a preferred measure of productivity compared to labour productivity and is more closely aligned to the idea of innovation. However, its calculation requires strong assumptions, including data on capital stocks, which are prone to measurement errors. In this report we present data on both productivity indices.

The underlying data for our analysis come from several different sources. The economic variables are from the OECD STAN database, which contains data on sectoral output, employment, imports, exports and gross fixed capital formation. We also use information from the Groningen industrial database, from EUROSTAT, and the World Bank (World Development Indicators).

The following countries are included in our analysis: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, United Kingdom and the USA. For all countries, except the transition economies, data are available from 1979 until 2003. For the transition economies, data coverage begins in 1993.

Table 3.6 shows the growth rates of both labour productivity and total factor productivity for the energy sector in the period 1979 to 2003. For all countries, combined labour productivity has been growing at a median rate of 3.8 per cent p.a. On the other hand, median growth of total factor productivity has been just 1.1 per cent p.a.[4] In order to compare the energy sector with other systematic sectors, the bottom row in Table 1 presents the productivity growth rates for the aggregation of the eight systematic sectors.[5] Overall, we see that while the evolution of labour productivity in the energy sector matches very closely the aggregate values, total factor productivity has evolved below the aggregate values, suggesting that growth in capital intensity has been a major driver of labour productivity growth.

Table 3.6 *Labour Productivity Growth (ΔQL) and Total Factor Productivity Growth (ΔTFP) in the energy Sector (1979–2003).*

	ΔQL			ΔTFP		
	Median (1)	Mean (2)	SD (3)	Median (4)	Mean (5)	SD (6)
Energy	3.8	3.4	8.8	1.1	1.0	5.8
Pooled	3.7	4.1	12.5	1.9	2.5	10.1

NOTE: For the Energy, Textile and ICT sectors that comprise several sub-branches, we show the weighted average across the sub-branches where the weights are based on value added. The last column is the ratio between the median ΔTFP and the median ΔQL.

Aggregate figures can conceal large differences between countries. Here we investigate whether there are patterns of catching up, leapfrogging or lagging behind among the different countries considered in our sample. In order to obtain an overall view, we have classified countries into three regions: USA, Japan, and the EU-15 (plus Norway). For each region, we have computed both labour and total factor productivity.

Figure 3.5 shows the evolution of labour productivity in the energy sector in the period 1979 to 2003. For almost the whole period, Japan has been the world leader. However this leadership is being challenged by the USA which has consistently been catching-up with Japan during the whole period. There are some signs of a deterioration in the USA performance since 1996.

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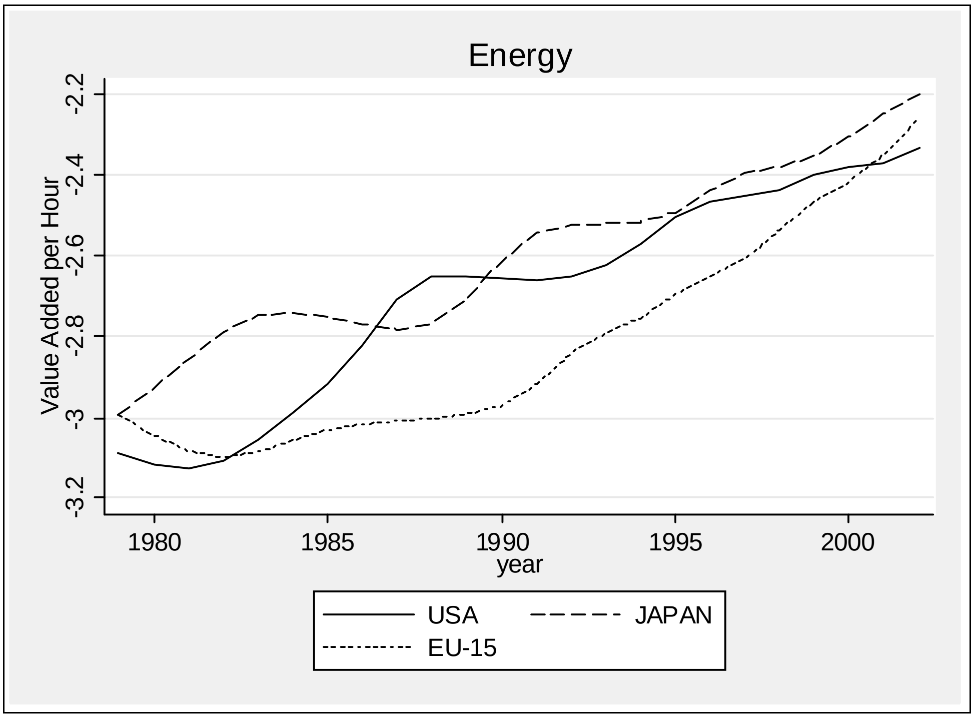
[4] The lower value of TFP growth is due to the fact that we are subtracting from labour productivity growth that fraction that is explained by the growth in capital/labour intensity.

[5] Energy, Food, Textiles, Chemicals, Machinery, ICT, Automotive and Aerospace.

Figure 3.5 Labour Productivity (Value Added per hour)



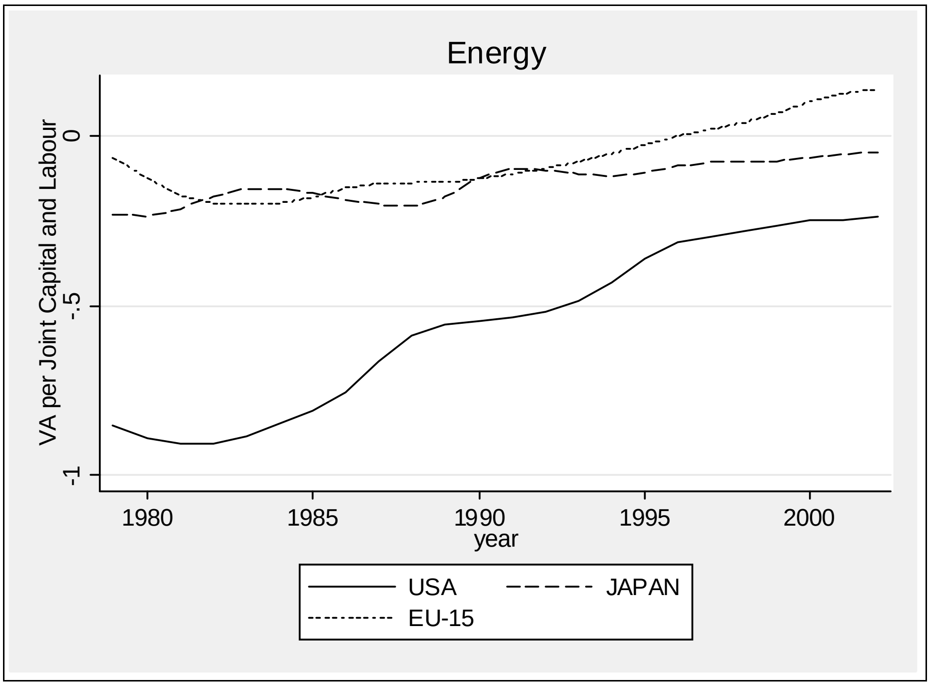
Note: Value Added per Hours worked is in logarithmic scale.

There has been a steady growth in EU-15 labour productivity throughout most of the period under consideration. The EU began the period lagging behind both Japan and the USA, but consistently higher growth rates led to a catching-up with the USA and even forging ahead towards the end of the time frame. Moreover, the EU gap with Japan has also narrowed over the whole period.

The results for total factor productivity are shown in Figure 3.6. Here, the EU performance is much better. Indeed, EU total factor productivity throughout the whole period has reached levels very similar to Japan and even higher than the USA. During the 1980s, the EU matched the Japanese productivity performance and during 1990s total factor productivity has clearly been more dynamic in the EU than in Japan. The USA total factor productivity index, on the other hand, started from lower values but has grown faster over the period leading to some catching-up with Japan and the EU.

An interesting question worth exploring is which factors underly the contrast between labour productivity and TFP performances between the different regions. Is this due only to very large differences in capital intensities and investment across the regions (e.g. is the USA energy industry persistently more capital intensive than Japan and EU)? Alternatively, is the European leadership a result of the deregulation and pro-competition reforms introduced during the 1980s and early 1990s?

Figure 3.6 Total Factor Productivity



Note: Value Added per joint Capital and Labour is in logarithmic scale

In the remaining part of this section we explore the extent to which the levels and changes in the skills composition of the workforce could explain these differences in productivity trends in the energy sector. The measurement of skills is not a trivial issue. Only observable characteristics of skills (such as education, type of occupation and professions) can be extracted from international data sources. And even in this case the information is not normally available for all countries, sectors and time-periods that we aim to cover in this project.

The skills indicators used here are as follows. The first indicator is based on educational attainment data from Barro and Lee (2000) data set.[6] The variable is the percentage of adult population (25+ years old) with a higher education degree. This is a country-level measure only and is available for the period 1960–2003.

We also use data on Human Resources for Science and Technology (HRST), training, technicians, managers and ICT professionals taken from the Community Labour Force Survey (EUROSTAT). The corresponding information for the USA was taken from the Bureau of Census Current Population Surveys (CPS). In all these cases, information is available at sector level for the period 1993–2003. Information for Japan was not accessible at all.

The indicators for HRST are based on the OECD Canberra Manual. The first (HRST-Occ) is based on an *occupational* definition and is the number of people employed as professionals

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[6] Available at http://www.cid.harvard.edu/cidwp/042.htm

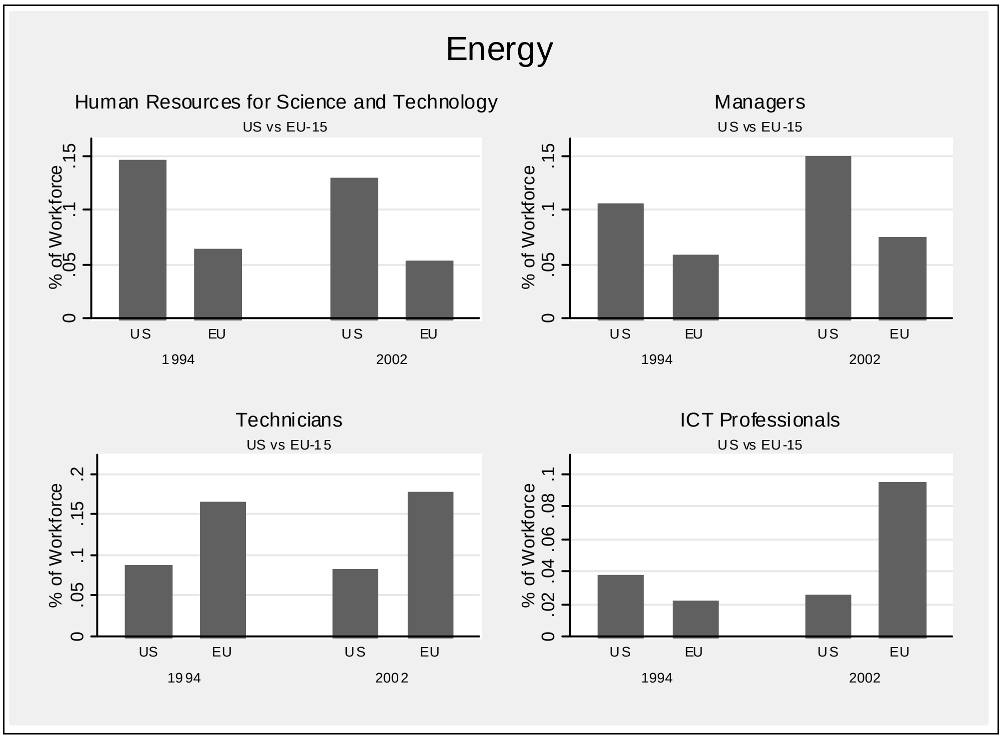
and managers (ISCO groups 1 and 2). The second (HRST-Qual) is based on *qualifications* and is the number of people with high-level qualifications (ISCED97 levels 5 and 6). The third (HRST-Core) is a combination of these two, i.e. people with high-level qualifications employed as professionals and managers. These indicators are defined as a percentage of the work force in the energy sector.

Additionally, we have indicators based on the following categories: *Managers* (ISCO Major Group 1), *Technicians* (and associated professionals) defined in terms of ISCO major group 3, and *ICT Occupations*, an aggregation of various occupational classifications (ISCO 213 (computing professionals); ISCO 312 (computer associate professionals); ISCO 313 (optical and electronic equipment operators) and ISCO 724 (electrical and electronic equipment mechanics and fitters)). The last is a proxy for the importance of ICT skills in the energy sector. Finally, we also use information on *Training* from the Labour Force Survey. As before, all these indicators are defined as a percentage of the sector workforce.

Figure 3.7 shows the levels and trends of four of the skills indicators, comparing the EU countries with the USA (data for Japan are not available) for the energy sector. The indicators are HRST-Core (Occupation and High-level Qualifications combined), Managers, Technicians and ICT professionals. The top left panel shows that in terms of HRST-Core (the indicator closest to the idea of R&D personnel), the EU lags behind the USA in the period 1994–2002. The proportion of workforce in the HRST category has declined slightly in the EU while the decline is even stronger in the USA, resulting in a narrowing of the gap between the two regions.

The top right panel shows the results when the skills indicator refers to managers. Here the USA also has some advantage over the EU countries, and this advantage grows over time as the proportion of managers in the USA grows faster than in the EU. The bottom left panel of the figure compares the proportion of technicians in the workforce, and shows that this proportion is higher in the EU than in the USA.

Figure 3.7 Skills indicators (percentage of sector workforce): EU-15 and USA



The bottom right panel shows ICT professionals as a proportion of the workforce in the EU and the USA in the energy sector. It shows the most dramatic change in the relative position of the two regions in the period 1994–2002. Here, we observe a small gap in favour of the USA in 1994, but by 2002 the gap has been reversed. This change is due to two factors: a decrease in the index for the USA and a significant increase in the index for the EU.

In summary, Figure 3.7 indicates that the EU has performed relatively well in accumulating skills in the energy sector in the period since 1994 (relative to the USA). As discussed above, the relative performance of the EU in terms of TFP during this period has also improved substantially. An important question is the extent to which the improvement in TFP performance by the EU energy sector can be linked to improvements in the skills of the labour force employed in the sector. We turn to this question in the next section.

Relationship between TFP growth and Skills

In this section we report the results of exploring the relationship between total factor productivity *growth* and skills based on econometric techniques. In the modelling, we make a distinction between skills that are necessary for *innovative activities*, (i.e. those aimed at pushing the world technological frontier), and those necessary for activities aimed at '*catching-up*'. The underlying rationale is that some skills can be seen as an input for R&D and other activities (design, marketing, organisational change, etc.) needed for *innovation*. Other skills can be considered as key components of the *absorptive capacity* needed to search and assimilate knowledge accessed through technology *diffusion*. Thus, in our modelling we assume that the impact of skills differs according to whether a country is a technological leader or a follower.

Table 3.7 shows the results of our model for the energy sector. The impact of each skill variable discussed above is assessed separately, and in the table we indicate whether the impact is positive or negative, and the statistical significance of the impact.[7] Overall, the results are quite weak and do not suggest any systematic correlation between total factor productivity growth and skills. In five of the eight cases the coefficient for *innovation* was negative. In the remaining three cases, the coefficient for innovation was positive but only statistically significant for ICT professionals. In the case of *diffusion,* five of the eight estimated parameters were negative and three were positive but none of them was statistically different from zero. In general, it seems that skills are not a major determinant of total factor productivity growth in this sector. For *innovation* only*,* the presence of ICT professional makes a positive contribution to total factor productivity growth.

Table 3.7 The impact of skills on total factor productivity growth (ΔTFP) in the Energy sector (1979–2003).

Skills Indicator	Innovation	Diffusion
Education Attainment, +25	(+)	(+)
HRST-Core	(-)	(-)
HSRT-Occupation	(-)*	(+)
HRST-Education	(+)	(-)
Managers	(-)**	(-)
Technicians	(-)	(-)
Training	(-)	(-)
ICT	(+)***	(+)

Note: (+) positive effect, (-) negative effect. (***), (**) and (*) significant at 1%, 5% and 10% respectively.

Summary and policy reflections about innovation, productivity and competition

This section has revealed that labour productivity performance of the EU in the energy sector as a whole has improved compared to the USA, but the EU lags behind Japan. In terms of total factor productivity, EU performance has been impressive with a clear take-off during the 1990s. The EU is the world leader in terms of TFP in the energy sector. At the same time, the EU has performed relatively well in accumulating skills, especially those related to ICT. In general, of all the different types of skills discussed here, only of ICT professionals seems to make a favourable impact on pushing the world frontier. Deregulation of the energy production markets may result in positive externalities which by far exceed welfare gains due to intra-sectoral production efficiency. From this point of view, it is more interesting to study

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[7] The actual numbers can be reviewed in the background documents.

economy-wide spillover effects from production efficiency gains (i.e. lower energy prices per energy unit) than productivity trends *per se* in this particular sector.

3.4.2 Knowledge Production Function

It has now become a part of conventional wisdom that OECD economies are *knowledge-based economies*, characterised by the increased influence of knowledge creating activities on economic growth. New theories now include knowledge more directly as input for economic growth (Griliches, 1979), because investments in knowledge, embodied in people and technology, increase the productivity of labour and capital and result in new products and processes. In this section, we analyse the determinants of knowledge generation, by linking an observable innovative output – patents – to observable inputs for the energy sector. The underlying rationale is that knowledge created at any given point in time is a function of investments in knowledge creating activities, past knowledge stock and the efficiency of the knowledge creating process (e.g. Porter and Stern (2000); Furman, Porter and Stern (2002)).

In particular we compute both short and long term elasticities between the current flow of patents and research inputs, that is, R&D and knowledge stocks. We use the results of the Knowledge Production Function (KPF) to infer research efficiency of each country in each period in converting research inputs into outputs. In addition, we examine whether these differences in efficiency are a function of science and technology related institutions (i.e. the National Innovation System-NIS), or the effects of environmental conditions that affect the economy at large.

Data, Variables and Descriptive Analyses

Comparisons based on international patents are the main focus of analysis in this section. We measure the flow of patent applications at EPO and granted patents at USPTO.[8] The comparisons are based on the available information for 21 EU countries plus the US and Japan, for the period 1979–2000. The use of patenting data to measure the production of ideas at the national level requires some clarification. Of course, patent applications are not the only ideas produced in the sector. However, as many of the other sources are unobservable, patent statistics provide a unique and systematic approximation for the overall innovative activity in the sector.

There are two key independent variables needed to explain patenting in the energy sector: *Research and Development* expenditures and the past *stock of knowledge*. This stock is computed by accumulating the yearly flow of patents using the perpetual inventory method (assuming a depreciation rate of 15%). R&D expenditures are taken from the ANBERD data set. This data set covers the period 1987–2003 and the information is partially available for majority of the countries in the sample. The R&D series were deflated using the GDP

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[8] The main source is:http://epp.eurostat.cec.eu.int/portal/page?_pageid=1090,30070682,1090_30298591&_dad=portal&_schema=PORTAL. Data for USPTO patent applications are used for robustness checks on results obtained using EPO data.

deflators from EUROSTAT, and Purchasing Power Parity (PPP) currency exchange rates from the OECD, and hence can be expressed as real values in 1995 PPP dollars.[9]

The variables used to examine differences in research efficiency are based on two sets of country level measures: (a) those that capture various aspects of the National Innovation System, and (b) those that depict some characteristics of the general economic environment in each country. The former include: *R&D Subsidies (SUBS); R&D Performed by the Government (GOV)* and the *Intellectual Property Rights Protection (IPR) index (*Ginarte and Park, 1997). The latter are as follows: *Monetary Stability (MS); Freedom to Trade Internationally (TRADE); Regulation of Credit, Labour and Business (MARKET).* All of these are qualitative indices elaborated by the Fraser Institute. In addition we also include the *percentage of domestic credit* that goes to the private sector (*CREDIT*) and the flow of *Foreign Direct Investment* as proportion of GDP (*FDI*), both taken from the World Bank.

Table 3.8 shows basic descriptive statistics. We report the statistics for the five largest R&D spending countries; the remaining countries are aggregated in the category 'All others'. Column (1) refers to the average number of EPO patents applications per country over the 1987-2000 time period. Column (2) summarises the average number of USPTO granted patents. Column (3) is the average amount of R&D investment (in MUS$ and PPP adjusted). Column (4) summarises the average research efficiency by country in the energy sector where research efficiency is measured as EPO patents application per R&D. Column (5) shows the average research efficiency when using USPTO patents applications. Finally, Column (6) refers to the mean stock of knowledge by country (based on EPO applications).

Table 3.8 shows that over the period 1987 to 2000 the most prolific countries in terms of patenting at the EPO are the USA, Japan and Germany. The USA and Japan also have the highest R&D budgets. The German R&D budget seems to be low (for example, Germany has almost three times more EPO patents than France but only 30 per cent of the French R&D budget). The highest number of EPO patent applications per dollar spent in R&D is found in Germany (as a result of its very low R&D budget), followed by Japan. In terms of USPTO (granted) patents, the most prolific country (by far) is the USA, followed by Japan and Germany. Excluding Germany, the highest number of USPTO patent applications per dollar spent on R&D is found in Japan and the USA. The knowledge stock (in terms of EPO patents applications) is the largest for the USA and Germany.

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[9] PPP exchange rates are preferable to market exchange rates as they reflect actual cost differences rather than differences imposed by market valuations.

Table 3.8 Basic Statistics per Country (averages 1987–2000)

Country	(1)	(2)	(3)	(4) = (1)/(3)	(5) = (2)/(3)	(6)
DEU	301.8	194.0	88.2	3.42	2.20	1487.4
FRA	110.1	72.3	277.9	0.40	0.26	519.4
GBR	94.2	62.5	281.5	0.33	0.22	462.7
JPN	240.1	351.3	412.7	0.58	0.85	1027.5
USA	503.1	1117.8	2056.0	0.24	0.54	2244.3
All Others	28.8	16.5	39.4	0.73	0.42	119.2

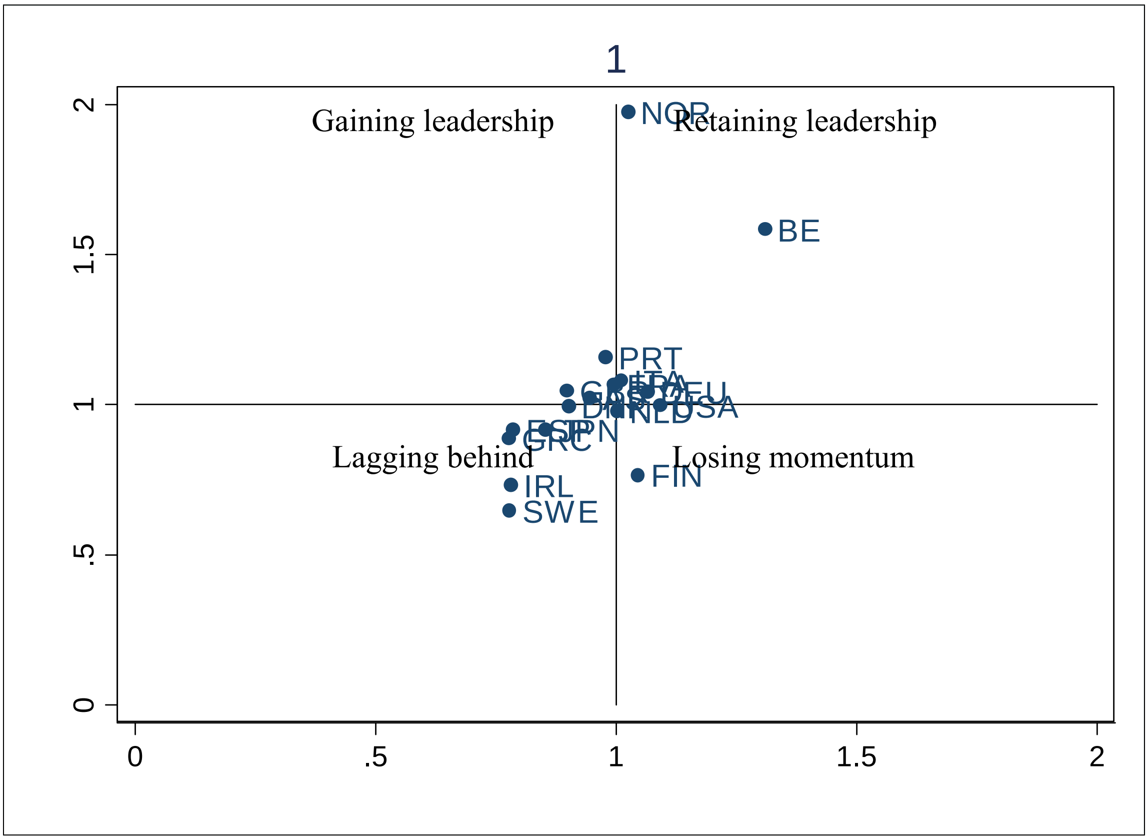
Note: Columns as follows: (1) Innovation Output: EPO Patents (ΔA); (2) Innovation Output: USPTO Patents (ΔA); (3) R&D (reported data only) MU$S 1995 (H); (4) EPO Patents per MM U$S; (5) USPTO Patents per MM U$S 1995; (6) Knowledge Capital (A).

National Patterns of Knowledge Accumulation

Patent data can be used to depict national patterns of technology accumulation. In this research, we use the *Revealed Technological Advantage (RTA)* Index, which compares the share of energy patents in total patents for a given country with the same share for all countries included in our sample. The issue addressed here is the dynamics of specialisation patterns on the basis of this index. One way of assessing this is by plotting each country on a 2-dimensional map with *RTA* in the late eighties (1987-–990) along the X-axis and *RTA* in the late nineties (1997–2000) along the Y-axis, as shown in Figure 3.8. Countries located in the north-east quadrant have a persistent technological advantage in the sector, putting them in a good position for future growth. Those in the south-east quadrant have lost their technological advantage over time – and may continue to loose momentum in the future – whereas countries appearing in the north-west quadrant have moved up the technological scale, gaining a positive technological advantage over the decade. Finally those located in the south-west quadrant have a low technological advantage in both periods: such countries are simply lagging behind.

Figure 3.8 shows that different countries tend to cluster around the middle of the Figure, which suggests that is difficult to discriminate among many of them. There, are some exceptions. Norway and Belgium have persistent technological leadership. On the other hand countries such as Ireland and Sweden are lagging behind, while Finland seems to be losing momentum. It is worth bearing in mind this analysis is based on EPO patenting and hence ‘over-represents’ the EU countries and ‘under-represents’ Japan and the USA. Moreover just because a country is the technological leader does not necessarily mean that it will be also the leader in terms of labour productivity or total factor productivity. This may be due to at least two factors, one being the high variance of economic value of inventions, the other pointing to the time lag necessary to transform good ideas into economic wealth. In other words, the transformation of EPO patent applications into productive efficiency – either in terms of new products (increasing the numerator of the TFP ratio) or new processes (reducing the denominator) – is neither guaranteed nor immediate.

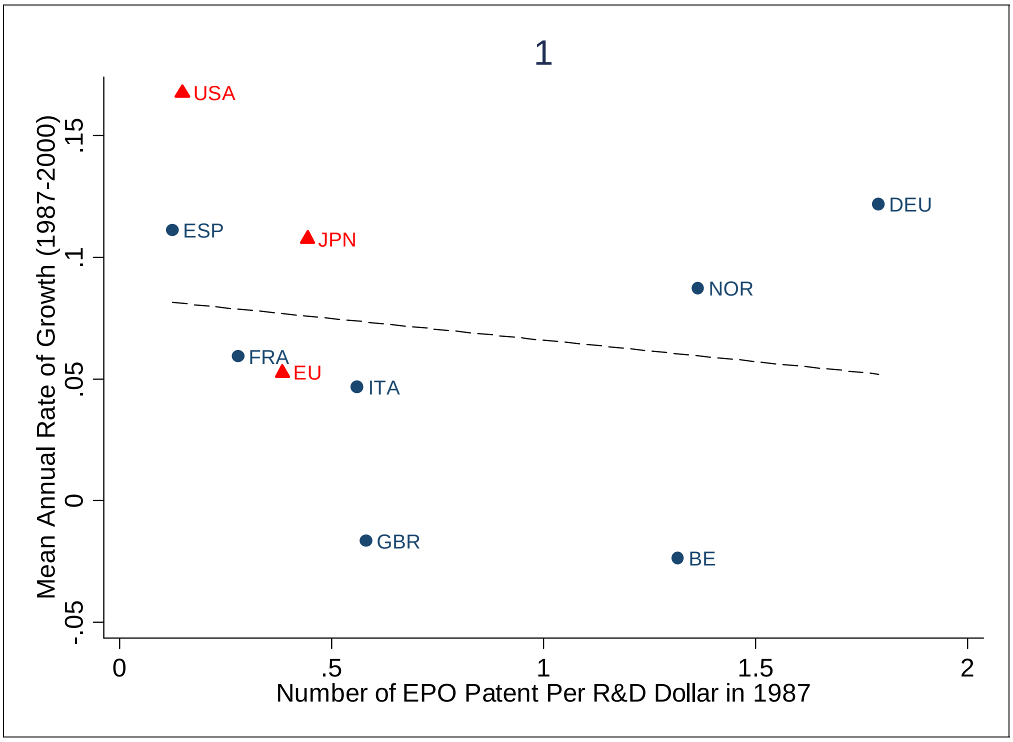
Figure 3.8 The Dynamics of Relative Technological Advantage



Convergence or Divergence in Research Efficiency

Here we examine the extent to which there is convergence in research efficiency, measured as patents per unit of R&D expenditure amongst the countries in the sample. In other words, the question being addressed is the extent to which laggard countries are moving closer to the levels of research efficiency exhibited by the leaders. One simple way of exploring this issue is by correlating the growth rate in research efficiency in the period 1987–2000 with the levels of research efficiency in 1987. The results of this experiment can be seen in Figure 3.9. There is no sign of convergence in patents per unit of R&D in the energy sector.

Figure 3.9 Convergence EPO Patents Applications per R&D $



Note: the X-axis is in logarithmic scale

A comparison of research efficiency between the EU-15 and Japan (identified by the red triangles in the plot) shows some interesting patterns. The EU-15 and Japan started from similar levels of initial values of efficiency and growth, but the growth rate of Japan has been higher than the EU-15. On the other hand, the comparison between the USA and the EU reveals that while the USA started with lower levels of efficiency compared to the EU, it grew at a much higher pace. One interesting question requiring further research is the extent to which these relatively better performances by both Japan and the USA might become a threat to the EU-15 leadership in this sector.

Determinants of Knowledge Production

Here, we present the results of our modelling exercise aimed at analysing the determinants of knowledge production in the energy sector. The model is based on the idea that the production of innovative ideas (patents) is dependent on both the level of resources invested in R&D and on the stock of past knowledge. The rationale is that new research projects do not start from zero, but build on previous inventions and discoveries. We also take into consideration both the long-term and short-term aspects of the relationship. The reasoning for this is that an increase in R&D expenditures in a given year will normally induce a steady flow of patents only after the research projects are finished and patenting procedures have been completed. Consequently, we report not only short-term impacts of R&D but also the predicted long term impact after all the potential lags have been taken into consideration.

Table 3.9 shows the results for the determinants of EPO patent applications for the energy sector. For comparison, we also add the results for all systematic sectors combined in the bottom row of the table. The table shows that in the short run, an increase of 1 per cent in R&D expenditure will increase the number of patent applications by 0.022 per cent, but the effect is not statistically significant. On the other hand, an increase of 1 per cent in the past stock of knowledge will lead to an increase of 0.21 per cent in the number of patent applications. These effects are much higher in the long run, when an increase of 1 per cent in R&D expenditure will induce an increase of 0.08 per cent in the number of patents, while the same increase in the stock of knowledge will lead to an increase of 0.78 per cent in patents. However, even the long-run elasticities for current R&D expenditures estimates may be imprecise.

Table 3.9 Short-run and Long-run Elasticities in EPO–KPF (1987–2000)

	Short-Run Elasticities		Long-Run Elasticities		Knowledge Capital / R&D Investment
	R&D	Knowledge Stock	R&D	Knowledge Stock	
Energy	*0.022*	0.215*	*0.080*	0.782*	∞
Pooled Sample	0.075**	0.283***	0.185***	0.706***	3.8

Authors' own calculation

* denotes significance at 10% level or less. Italics denote non-significance at 10% level.

Overall we see that past knowledge stock is more important than current R&D in explaining patenting behaviour in a given year in the energy sector. In other words, what one can invent today is strongly determined by how much he/she has invented in the past, suggesting strong knowledge cumulativeness in this sector. This conclusion is further corroborated if we compare the long run elasticities in the energy sector with all sectors combined. In the energy sector, the effect of R&D (current additions to knowledge) is always smaller than the effect of past knowledge stock (see Table 3.9).

An important question for discussion is the extent to which this high degree of cumulativeness might lead to strong persistency in leadership and great difficulties in catching-up by the followers. (Note that this is also consistent with the lack of convergence in research efficiency analysed above.) What can the followers do in order to increase their innovation rates in this sector?

Determinants of Research Efficiency and R&D

In this section we report the results of a modelling exercise aimed at considering two related research questions: What are the country characteristics that affect research efficiency and R&D investments in the energy sector? As explained above, two sets of country characteristics are considered as determinants: variables related to the NSI and those related to macroeconomic environment.

Table 3.10 shows the results of the exercise for the energy sector. The impact of each variable is assessed separately, and in the table we indicate whether the impact is positive or negative and the statistical significance of the impact. The results suggest the most of these country-specific variables are not correlated with research efficiency or but that several of them are indeed correlated to R&D. Regarding research efficiency, the only positive and significantly correlated variable is credit to the private sector. On the other hand, R&D investment in the energy sector is positively and significantly correlated with R&D subsidies, market competition and deregulation, and the degree of monetary stability (a proxy for low macroeconomic uncertainty). Surprisingly the exposure to international trade reduces the incentives to invest in R&D in this sector.

Table 3.10 National Systems of Innovations and the determinants of research efficiency and R&D investment

		Efficiency	R&D
SUBS	Proportion of BERD funded with public funds	+	+**
GOV	Proportion of total GERD performed by the Government	+	-
IPR	Index for IPR protection. (A higher score means more protection)	+	-
CREDIT	Percentage of domestic credit that goes to the private sector	+*	-
MARKET	Index of domestic regulation. A higher score means more *competition* in the domestic market.	-	+***
FDI	Flow of foreign direct investment as a percentage of the GDP	-	+
TRADE	Index of Free Trade. A higher means more freedom to trade.	+	-***
MS	Index of Monetary Stability. A higher score means more monetary stability.	-	+***

The efficiency regression controls for lag research efficiency while the R&D variable controls for lag value added. Both variables are statistically significant.

Summary and policy reflections about knowledge production

The analysis of the changes in patenting specialisation suggests that if Norway and Belgium are excluded, there are no clear technological leaders in this sector. There is no evidence of convergence in research efficiency across the different countries, although both the USA and Japan showed higher efficiency growth rates. Energy knowledge production shows a high degree of cumulativeness: changes in R&D do not significantly affect patent production in this sector. Those countries with better credit access by firms produced more patents than expected given their R&D and knowledge endowment. Those countries with more generous R&D subsidies, less financial uncertainty and more competition, spent more on R&D in this sector.

3.4.3 Innovation and Competition

Empirical analysis of the relationship between innovation and competition has a long history. According to Cohen and Levin (1988), a majority of the early studies that examined the relationship between concentration and market power and innovation (R&D) found a positive relationship in a cross-section of industries or firms. However, one consistent finding throughout all these early studies was that the explanatory power of market concentration contributed very little to the explanation of the variance in R&D intensity. The second half of the 1990s saw the emergence of a new wave of empirical studies using panel data frameworks and introducing the concept of ‘rent’ (or gross profits) as a proxy for competition. Using “rents” has the advantage that it does not require the observation of the firm’s complete market in order to measure concentration. The overall message of these recent studies is that innovation and competition are positively correlated, suggesting that the negative relationship found in many of the early studies was mainly due to data quality and problems associated with omitted variables.

In this report, we employ recent models and econometric techniques to analyse the actual pattern of the relationship between competition and innovation efforts for the energy sector. Additionally, we also assess if this relationship changes when we take into account whether countries are technological leaders or followers. The underlying rationale for including the notion of technology gap is that we expect the effect of competition on innovation to vary according to where countries are positioned in the world technological frontier.

Data, Indicators and Descriptive Statistics

We start this section by summarising the data sources and indicators, and presenting some descriptive statistics for the two key variables: innovation and competition. We measure innovation using sector level R&D intensity, obtained from the OECD ANBERD data set. This data set covers the period 1987–2003 and has information for majority of the countries in the sample (for transition economies the coverage starts around 1993). The data for value-added (to construct R&D intensity) are taken from the OECD STAN data set.

As mentioned above market competition can be measured in a number of different ways. Many early studies used measures of concentration, for example, proportion of sales accounted for by the top *N* firms. However, in common with most recent studies our working measure of competition is based on the idea of gross margins: the difference between value added and labour compensation as a proportion of value added. The idea is that low competition is associated with high profits, and as the gross margin is typically the largest component of profits, it can be used as an approximation for the intensity of competition in the domestic market. As gross margin varies in the range [0,1], we define our competition index as 1 minus the gross margin. Therefore, high competition will be associated with an index close to 1. In order to compute the competition index, we need information for value added and labour compensation, both of which are taken from the OECD STAN database.[10]

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[10] One potential concern with this definition of the competition index is that the use of gross margins might confuse monopolistic rent with normal returns to capital, as a sector may have high gross margins not because there is a monopoly rent but because it has large capital costs (which are not included above). This might be true, for example, if the sector in question has high capital intensity. The best way to correct for this would be by including information on the user cost of capital for the sector. However, such data are not available. We attempt to circumvent this problem by either including the capital to value added ratio in the analysis or by assuming that capital costs equal the depreciation rate in our empirical analysis. The results were robust in this problem.

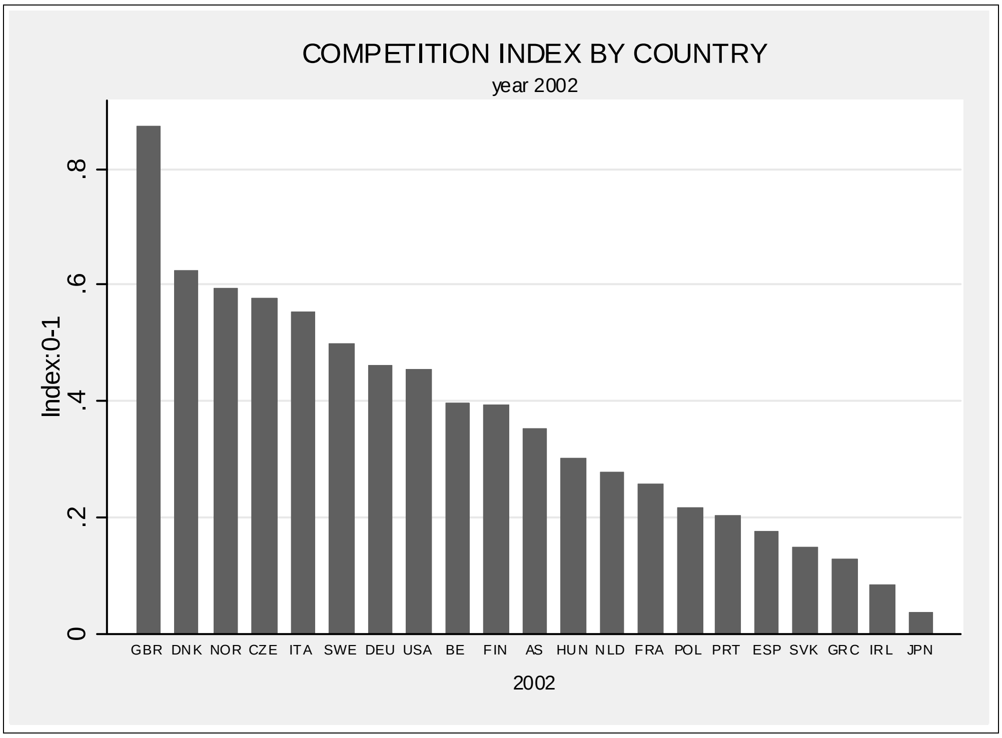
Table 3.11 shows the mean and median values for R&D intensity and competition for the energy sector. The last row in the table also shows the pooled results for the eight sectors covered in the Systematic project.[11] The mean R&D intensity in the sector is 4.6 per cent, which is well below the mean for all eight Systematic Sectors combined. Thus among the sample of sectors considered in this research, the energy sector can be considered as a low R&D intensive sector. The mean competition index for this sector is 0.36, which is well under the eight sector average, indicating that competition pressures in the energy sector are not as intense as in other sectors.

Table 3.11 R&D and Competition in the Energy Sector (1979-2003)

	MEAN		MEDIAN	
	R&D	C	R&D	C
Energy	0.046	0.361	0.026	0.391
Total across all sectors	0.095	0.660	0.043	0.633

Figure 3.10 shows the results of the competition index for all countries in our sample in the year 2002. The country with the highest competition intensity by far is the UK, followed by Denmark and Norway. On the other hand, the lowest competition levels are found in Japan, Ireland and Greece. The USA shows competition slightly above average. One interesting question to investigate further is the extremely high competition index in the UK. Can we attribute this to some particular characteristics of the UK regulatory frameworks?

Figure 3.10 Competition in the Energy Sector. Results by Country (2002)



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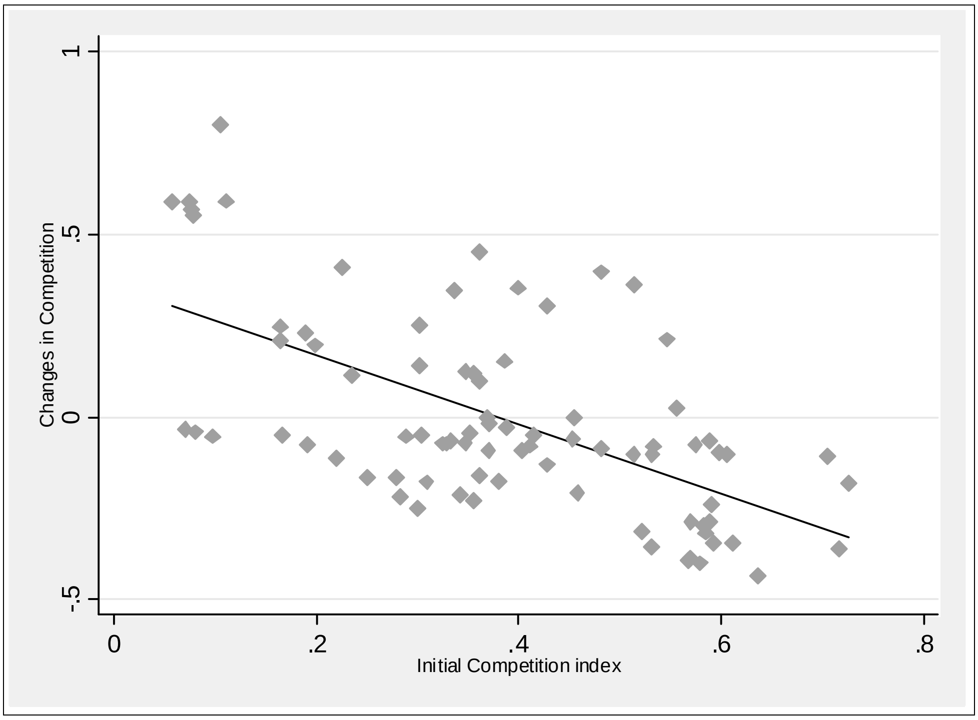
[11] These sectors are Energy, Food, Textiles, Chemicals, Machinery, ICT, Automotive and Aerospace.

In Figure 3.11 we assess whether there have been big changes in the level of competition amongst the sample countries. on the X-axis, we have the initial level of competition and on the Y-axis we plot the changes in the competition index. The results show that there is a negative correlation between initial competition and subsequent changes in competition. This can be interpreted as suggesting some degree of convergence in the intensity of competition across the countries in our sample. Thus, countries with low levels of competition at the beginning of the 1980s have seen increasing competition levels in the subsequent years. This may be due to increased globalisation, i.e. increasing international trade and foreign direct investment, or it may be due to specific policies related to the regulation of the domestic markets. This is an interesting issue for further research.

Figure 3.11 Competition Convergence in the Energy Sector, 1999/03-1979/83.



Relationship between R&D intensity and competition

In this section we present the results of the modelling exercise aimed at exploring the relationship between R&D intensity and competition in the energy sector. The main aim of this exercise is to determine the 'shape' of the relationship. As discussed above, previous literature has been divided on this issue, with some studies claiming a linear relationship and others (including the latest studies) claiming an inverted 'U' shape. We also allow for the fact that competition is not the only determinant of innovation by including a range of country characteristics that may also have an effect. Additionally, we control for the possibility of reverse causality, i.e. whereby competition may be affected by R&D investments.[12]

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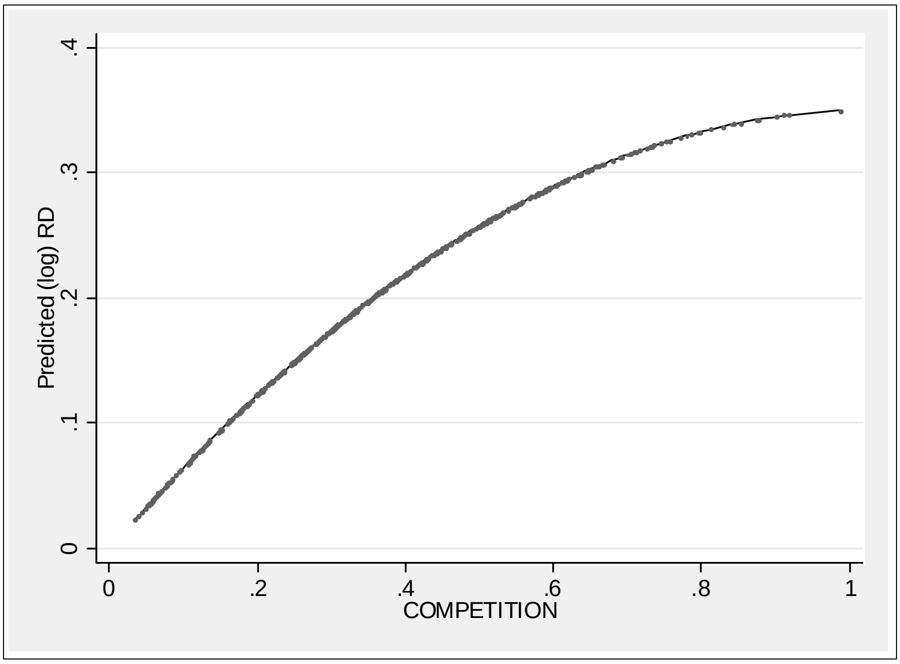
[12] See Background paper for full details.

The results of this exercise are reported in Figure 3.12 and suggest that there is a positive relationship between R&D intensity and the intensity of competition pressures in the energy sector. The shape of the relationship, however, is not linear: when competition increases, starting from low levels, R&D intensity tends to grow quite fast. However, if competition continues to increase, its effect on R&D intensity becomes progressively weaker over time. The estimated inflection point is above 1 (the maximum value for the competition variable) suggesting that increased competition is not likely to lead to reduced R&D intensity.

This result has a very important implication. O,n average increased competition seems to be a good incentive for investment in R&D and innovation. However, if the actual level of competition is very high in a particular country then any further introduction of measures to increase competition will lead to very small increases in R&D intensity.

Figure 3.12 The Relationship between Competition and R&D Intensity



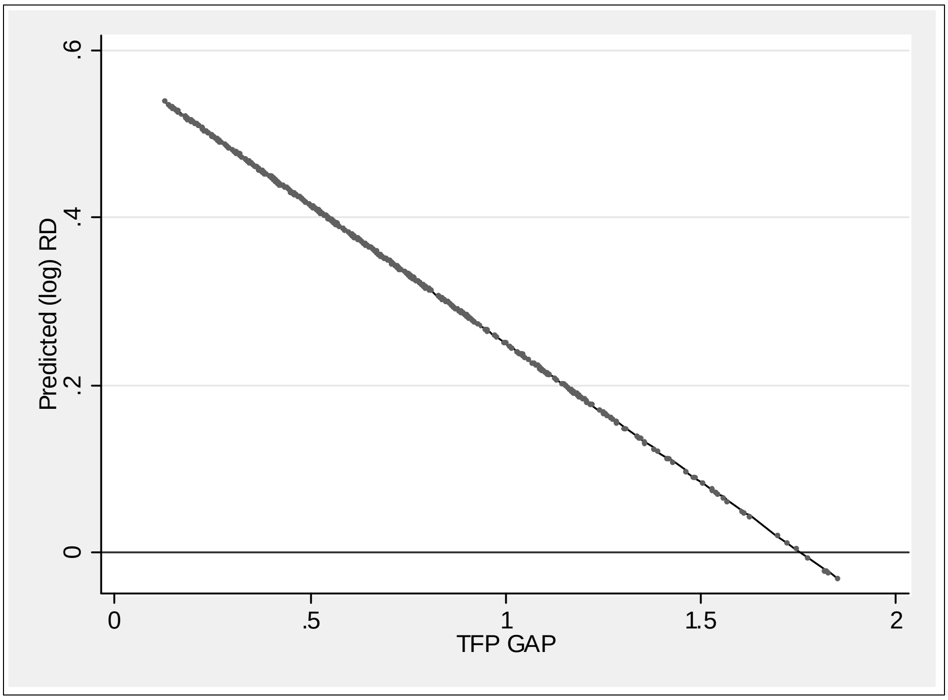
R&D intensity, competition and technological gap

The results in the previous section suggest that the impact of competition on R&D investment is heterogeneous in all countries. One source of heterogeneity that has been recently explored in some detail focuses on the differential effect of competition on countries that are at the forefront of innovation, and those that lag behind the frontier. The main motivation for this analysis rests on the idea of absorptive capacity: in an open economy one way of resisting competition is by innovating and moving towards the frontier as quickly as possible. However, how far each country can go in this race will depend on initial conditions. If initial levels of technology are too low, then the required jump to close the technological gap before competition arrives might be too high.

In order to study this issue, we focus on the correlation between competition and R&D intensity but we allow this correlation to change with each country's technological gap. We measure technological gap on the basis of total factor productivity indices. For each year we identify the best country in the sector and compute the total factor productivity difference between this frontier country and the rest, and use this as an additional variable in our model.

The results of this exercise are summarised in Figure 3.13. The Y-Axis shows the impact of competition on R&D intensity while the X-Axis orders countries according their technological gap. Of course, a technological gap close to zero means that the country is on or very near the best practice frontier in its sector. We have also plotted a line that corresponds to the situation of zero effect of competition on R&D intensity. As shown in the figure, the positive impact of competition on R&D intensity declines markedly when a country is away from the technological frontier. The gap must be higher than 150 per cent in order to have a negative effect on R&D intensity from increased competition, and in our current sample only Czech Republic, Slovak Republic and Poland are just around that figure.

Figure 3.13 The impact of competition on R&D intensity and the technological gap



Summary and policy reflections about innovation and competition

The analysis of the relationship between competition and R&D investments in the energy sector is based on the fact that the sector has a relatively low R&D intensity and also low levels of competition. The strongest competition pressures are in UK and the weakest in some transition economies including Greece, Ireland and Japan. Over time there is a certain degree of convergence in the level of competition between countries, that is, those with more protected or regulated domestic markets which have started to experience increasing competition. On average, the relationship between R&D investment and competition is positive. However, when competition is already fierce in a given country (or sector), further increases in competition are likely to have only a very marginal effect on R&D expenditure. The positive effects of competition on R&D investment decline when a given country is not near the world technological frontier. For countries very far from the frontier, competition might actually harm incentives for R&D investment. However, in our sample this threat only appears to be valid for some of the transition countries. Overall, the positive effects from competition will be weaker for lagged countries. This leads to the conclusion that policy recommendations which emphasise the benefits of increased competition cannot have the same effect on lagging countries as they have in frontier economies.

3.5 Sectoral innovation performance – Input-output linkages

One particular study in the Sectoral Innovation Watch Systematic project investigates product-embodied technology diffusion across industries and national borders in 25 European countries plus the United States and Japan.[13] The paper uses input-output tables from around the year 2000 to measure the embodied R&D flows in these industries, the relative importance of inter-sectoral linkages, and the three key industries that are linked to each of the eight industries. The study shows that business enterprise expenditure on R&D accounts for about one-half of the total R&D content in countries at the technological frontier, and between one-quarter and one-half of the total R&D content in countries below the frontier. While the variation was not large across countries at the level of total business R&D activity, there was considerable variation across industries and across countries within the nine industries covered in the paper.

The study in question is concerned with measuring the direct and indirect flows of technology into and out of eight sectors: energy extraction and production, food beverages and tobacco, textile and leather products, chemicals, machinery and equipment, automotive, ICT equipment, and computer related service activities. These industries not only differ in their research and development expenditure relative to domestic product of industry (R&D intensity), but also with respect to their use of technology contained in goods produced in other industries and other countries. Upstream suppliers and downstream customers are essential for understanding these flows and the relative importance of industries with relatively low R&D intensity. Further, they are important for formulating industrial and technology policy. The focus is on the measurement of product-embodied technology diffusion in these eight industries in 25 European countries as well as the United States and Japan.

The basic idea of measuring inter-industry relationships goes back to at least the time of Quesnay's *tableau economique*, and appears in a more modern form in what Leontief (1936, 1937) calls IO (input-output) analysis. In its most basic form, technology appears in this framework as the coefficients of production reflecting the quantity of the output of a sector i that is used by sector j per unit of total output of sector j. Technical change and technological

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[13] Knell M., Embodied Technological Diffusion and Intersectoral Linkages in Europe, paper to the Europe Innova Sectoral Innovation Watch Systematic Project, WIFO, LABEIN, LOGOTECH, MERIT, NIFU STEP, SPRU, TECHNOPOLIS, ZEW, January 2008

learning are essentially exogenous events that occur outside the economic system underlying the input-output table.[14] Nevertheless, this interdependence between industries may be an important source of technological learning. Schmookler (1966) observed that one of the best ways to innovate is 'to improve the inputs it buys from other industries'. Since learning takes place in production, user-producer interaction provides important learning economies, which suggests that most innovation emanates from within the production system in the narrow sense, or what is sometimes called the national innovation system in the broad sense (Lundvall, 1988). Input-output analysis provides a way to measure the interdependence of the national production system, as well as its interdependence in the global economy.

Results

The energy sector is well below the national average of R&D as a percentage share of value added. Technology multipliers tended to be above two in most instances, which indicated that embodied technology diffusion tends to play a more important role in industries that spend relatively less on R&D. The United States, for instance, relies much more heavily on product-embodied R&D in these industries. This suggests that the so-called 'low technology' industries are getting technology through the use of products from other more high tech industries. The analysis also indicates that there is considerable heterogeneity across countries in these industries. This reflects the considerable heterogeneity within the industry itself.

In the energy sector, as shown in Figure 3.14 below, own R&D activity appears to exceed 2 per cent of value added only in Japan and Finland, and makes up about one-third of the total R&D content on average. This shows that there is much more variation across countries when the analysis moves to the industry level. This variance might reflect structural differences across the economies, but may also be due to the relative size of the sector, the importance of imports, and the apparent R&D activity in this sector. Some countries such as Ireland, Germany and many of the new Member States, rely very heavily on product embodied R&D, and a relatively large percentage of this comes from imported inputs. By contrast, the food industries rely more heavily on R&D embodied in domestically produced products, but there are numerous counter examples among the new Member States.

The measurement of linkages in the European economy

The study provides calculations of the relative importance of backward and forward linkages. These are calculated in terms of domestic input-output tables. Differences arise because of global linkages, and which tend to have a larger impact on small open economies and countries with lower per capita incomes. Jones (1976) suggests that the domestic linkages capture differences in natural resource endowments. Nevertheless, there is a general pattern found in each of the industries at the domestic level that transcend the national innovation system.

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[14] Some more contemporary developments of input-output economics are contained in Leontief (1986). The dynamic inverse (Leontief, 1970), which introduced capacity expansion and investment, provides some dynamics into the system.

The various industries that make up the energy sector are shown in Figure 3.14. The backward linkages tend to be relatively more important for the mining (energy) industries than for the other industries in the energy sector, and it appears to have relatively more forward linkages. The petroleum industry tends to be less important in this context.

Table 3.12 provides a simple overview of the energy sectors for the Euro Zone average, the United Kingdom and the United States. Almost all of the key industries related to the mining of energy producing materials are services, except for forward linkages to the production of electricity, gas and water supply. The backward linkage from the production of electricity, gas and water supply to mining is also clear, just as the forward linkages in this industry are to the service industries. Mining is also a key backward linkage to the production of coke, and refined petroleum products, and certain services plus construction are key forward industries.

Services play a prominent role in these tables mainly because they make up a very large proportion of value added in Europe, the United States and Japan.

Figure 3.14: Percentage share of total R&D content in the energy sector

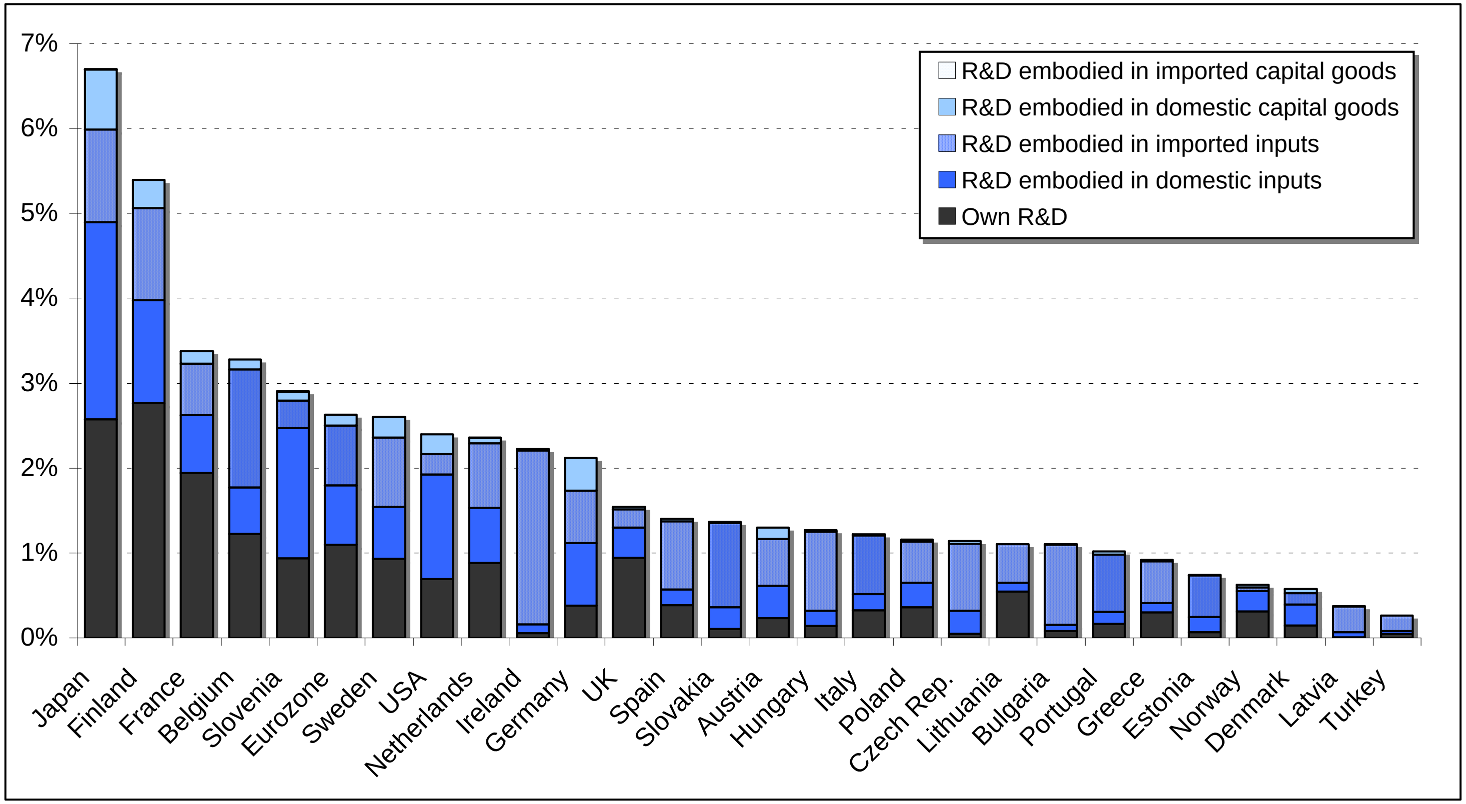


Figure 3.15: Relative importance of backward and forward linkages in the energy sector

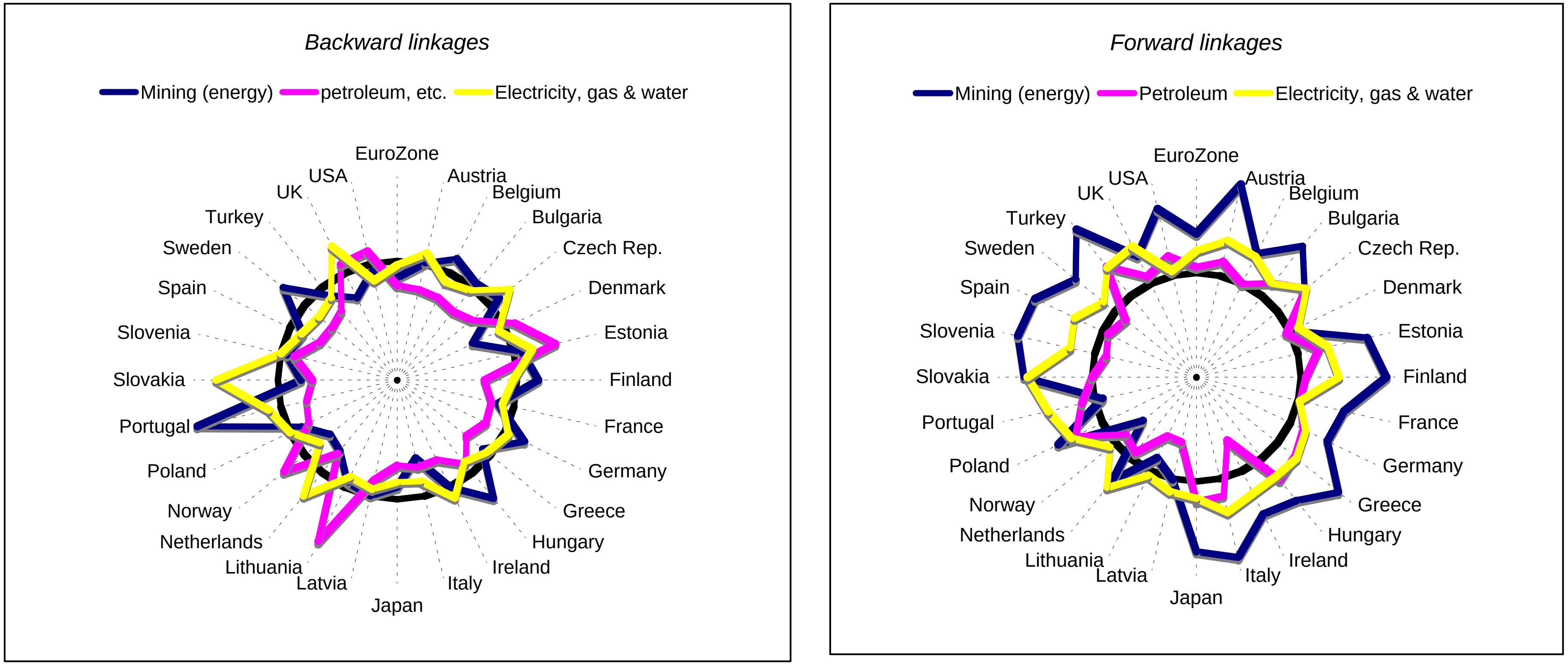


Table 3.12: Top three backward and forward linkages in the energy sectors of the EURO countries, UK and USA.

Backward linkages	Mining (energy)		Petroleum, etc.		Electricity, etc.	
EURO countries						
1	Other business activities	12.2	Mining (energy)	52.1	Mining (energy)	25.6
2	Finance & insurance	8.9	Other business activities	6.5	Other business activities	10.0
3	Machinery & equipment	8.3	Finance & insurance	4.3	Petroleum, etc.	7.1
UK						
1	Finance & insurance	17.2	Mining (energy)	64.2	Mining (energy)	41.8
2	Other business activities	13.3	Finance & insurance	5.3	Finance & insurance	7.9
3	Construction	7.6	Other business activities	4.7	Other business activities	7.0
USA						
1	Finance & insurance	28.0	Mining (energy)	48.6	Mining (energy)	32.3
2	Other business activities	15.6	Finance & insurance	10.0	Land transport	10.5
3	Wholesale & retail trade	6.4	Other business activities	8.1	Finance & insurance	10.1
Forward linkages						
EURO countries						
1	Wholesale & retail trade	24.9	Wholesale & retail trade	30.5	Wholesale & retail trade	27.1
2	Construction	9.5	Construction	11.1	Construction	9.5
3	Electricity, etc.	9.1	Other business activities	7.2	Public administration	7.7
UK						
1	Wholesale & retail trade	34.9	Wholesale & retail trade	44.9	Wholesale & retail trade	32.4
2	Electricity, etc.	11.4	Other business activities	7.2	Other business activities	8.7
3	Other business activities	7.1	Finance & insurance	6.3	Health & social work	7.2
USA						
1	Wholesale & retail trade	19.0	Wholesale & retail trade	21.4	Wholesale & retail trade	26.1
2	Real estate	10.6	Other social & personal services	11.7	Real estate	20.2
3	Electricity, etc.	10.4	Construction	10.6	Other social & personal services	10.0

Source: Own calculations based on OECD Input-Output database and ANBERD databases, 2006, supplemented with Eurostat data for non-OECD Member States and OFFBERD data.

Notes: Data for Norway and Bulgaria are for 2001; data for Greece and Portugal are for 1999; and data for Ireland, Latvia, and Turkey are for 1998.

4 Sectoral Innovation Barriers, Drivers and Challenges

This chapter addresses barriers to innovation, drivers of innovation and innovation challenges in the energy sector. Section 4.1 concerning innovation barriers and innovation drivers focuses on five aspects that have been possible to analyse by means of quantitative data. They include finance, taxation, regulation, competition and demand. Section 4.2 is about innovation challenges – a topic that has been studied by reviewing existing reports and documents addressing current and prospective trends and challenges in the sector.

4.1 Innovation barriers and drivers

It is Work-package 9 in the Innovation Watch Systematic project that has been responsible for analysing innovation barriers and drivers. The five themes in this section are organised into three sub-sections; 4.1.1 Finance, 4.1.2 Taxation and regulation, and 4.1.3 Competition and demand.

4.1.1 Finance

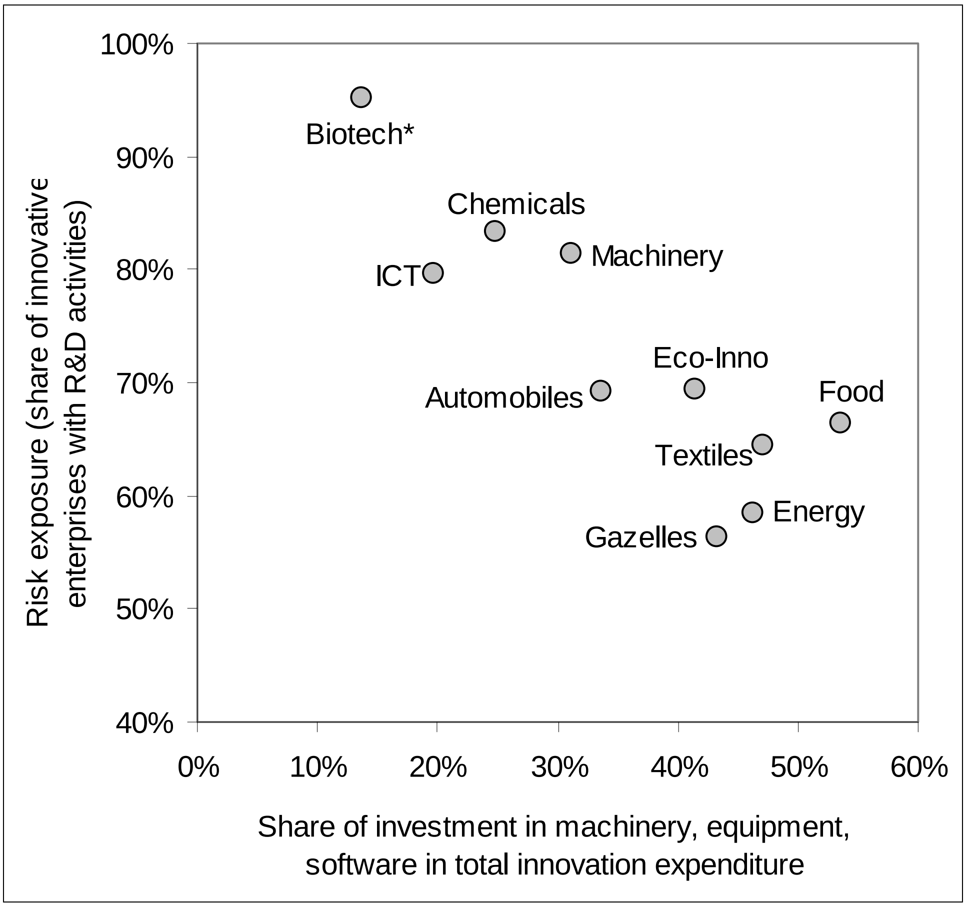
Getting access to sufficient financial sources is one of the main challenges in innovation. In general, firms have more ideas for technically feasible and customer demanded innovation than they can fund with the resources at hand (see Peeters and van Pottelsberghe 2003). Financing restrictions thus reduce the volume of innovation activities of firms.

In the following, we analyse the empirical significance of financing restrictions as a barrier to innovation, as well as the supply with financing sources for innovation (cash flow, venture capital) in the energy production sector. We draw on information from CIS (concerning the relevance of financing as a hampering factor for innovation) as well as from the OECD STAN database (cash flow) and the European Private Equity & Venture Capital Association (EVCA) (private equity supply).

Risk exposure and fixed investment share of innovation activities
The challenge of financing innovation is very much associated with the type of innovation being performed in a sector. Innovation financing will become the more difficult the larger a project, the higher the technological and market risk, the longer the project duration, and the lower the volume of available collaterals (Hall 2005). With respect to loan funding – which is in general the most important funding source for investment in enterprises – risk exposure and collaterals are the two most important factors.

Figure 4.1 shows the position of the **energy production** sector with respect to risk exposure of innovation activities (measured by the share of innovative enterprises that perform in-house R&D) and the fixed investment share in innovation expenditures (as a proxy for the share of innovation expenditure that can be used as a collateral for securing a loan). Sectors on the left upper corner of the matrix are likely to rely strongly on internal funding sources and external equity due to high risk exposure of innovation activities and few collaterals to secure debt financing. Sectors to the right lower corner of the matrix should be able to finance a significant part of their innovation activities through traditional instruments such as loans and will thus depend primarily on their creditworthiness to obtain sufficient funds for their innovation activities. As we see, **Food**, **Textiles** and **energy** invest comparatively large sums in fixed assets while R&D is a less important innovation activity. **Gazelles,** which also may include energy firms, are interestingly little R&D-oriented on average but invest a high share of innovation expenditure into new fixed assets. The latter can be associated with their rapid growth which demands relatively high fixed investment. The low R&D orientation may be due to the fact that there are many imitators among Gazelles (as defined here, i.e. small enterprises with less than 50 employees in 1998 which grew to more than 50 employees in 2000), i.e. growth does not rest so much on the introduction of market novelties but to adopt existing products and technologies to specific customer needs or market niches (follower strategy). Hence **Food**, **Textiles**, **Energy** and **Gazelles** are sectors which should be able to use to a significant extent loan financing for funding their innovation projects.

Figure 4.1: Risk exposure and fixed investment share of innovation by sectors



* NACE 73, including other R&D services than Biotechnology

Source: CIS-3, ZEW calculations.

Funds for innovation: internal financing, external equity, and public funding

Further, the availability of the most critical sources for financing innovation is empirically analysed, i.e. internal funds and external equity. In addition, the role of public funding for innovation financing is btiefly discussed.

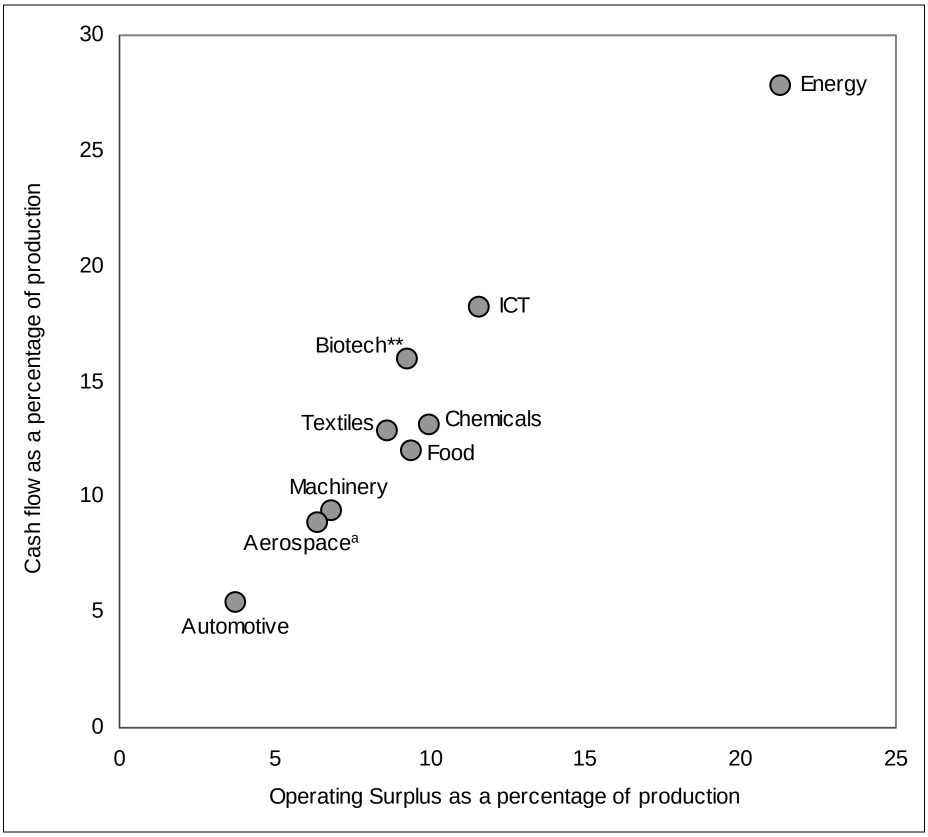
Internal Financing

The availability of internal funds in the **energy production** sector is assessed by employment of data from the OECD STAN database. This provides key economic variables for 2- and some 3-digit sectors for a large number of EU-25 countries (as well as other OECD countries) based on a harmonised method. STAN allows a calculation of two indicators of internal funding situation: **operating surplus** is basically defined as earnings before interest and taxes (EBIT). Adding depreciation to this figure gives a rough estimate of **cash flow**, though some components such as changes in long-term provisions typically added to cash flow are not considered while interest payments are included. Both variables are expressed as a percentage of total production.

Data are available for eight SYSTEMATIC sectors Aerospace, Automotive, Chemicals, Energy, Food, ICT, Machinery, and Textiles. There are no data available for Eco-Innovation and Gazelles. All data are calculated as the mean for the period 1995–2002. In the following we present the main results as a weighted average for all EU-25 countries for which data are available in STAN for the respective sectors. .

Figure 4.2 shows both indicators for the nine sectors covered, averaged over time and countries. The best position in terms of internal financing is occupied by **energy**.

Figure 4.2: Operating surplus and cash flow as a percentage of production by sectors (weighted averages, 1995-2002, EU-25)



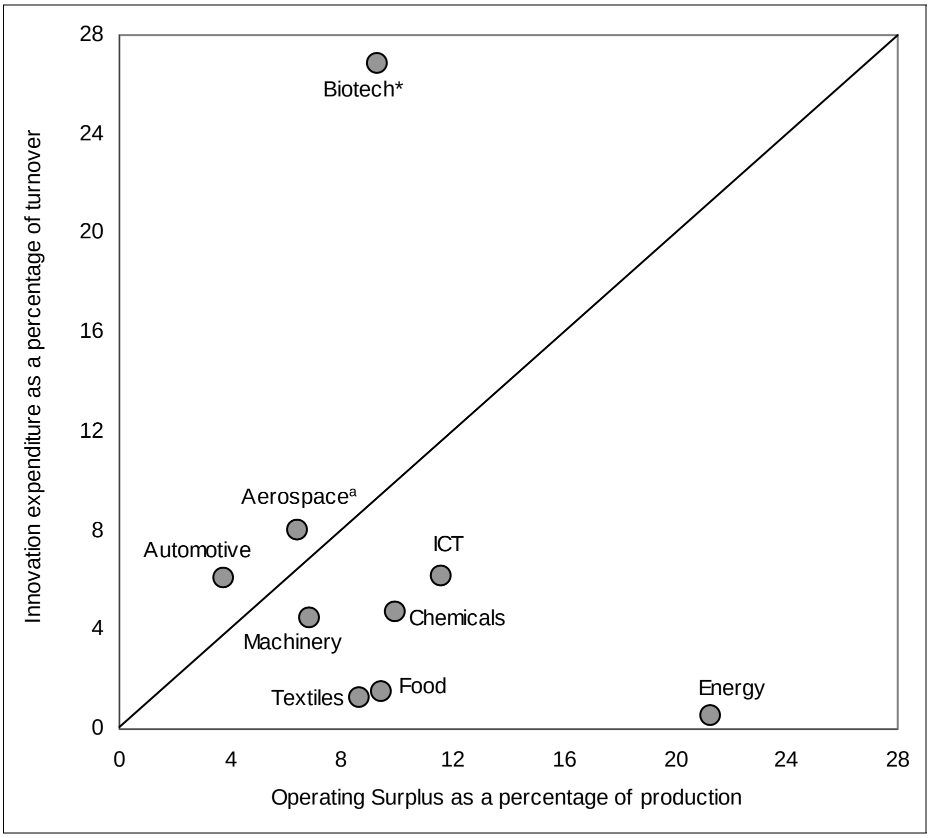
** NACE 24.4 (pharmaceuticals) plus NACE 73 (R&D services), i.e. it includes a number of non-biotechnology activities.
a) Cash flow for Aerospace not available in STAN, for presentation purposes it was estimated as 1.4 times operating surplus.

Source: OECD - STAN database, ZEW calculations.

In order to get a rough impression of the relation of available internal financing sources and the **demand for innovation financing** within a sector, we compare the operating surplus ratio with the share of total innovation expenditure in total sales, the latter taken from CIS-3 and CIS-4, using the average from both surveys in order to control for likely business cycle fluctuations in innovation intensity. Relating the both indicators is, of course, highly tentative, and interpretation has to be very cautious. First, operation surplus to production may vary considerably between innovative and non-innovative enterprises, tending to be higher for innovative ones. Innovation intensity of innovative enterprises is, on the other hand, clearly higher than the average figure, especially in sectors with a low share of innovative companies. The average innovation intensity is thus likely to underestimate the financing demand of innovating enterprises. Secondly, a large part of innovation expenditure refers to current expenditure and is thus already deducted from the operating surplus. Relating operating surplus to innovation expenditure thus refers primarily to the ability of a sector to pre-finance innovation activities. In case of short innovation cycles, i.e. a rapid backflow of returns from innovation processes, pre-financing demand is less critical.

Figure 4.3 shows the results of this exercise. The **energy** sector occupies an extreme position in this respect, since extremely high profits correspond with very low innovation expenditure of less than 1 per cent in turnover. Internal funding of innovation should not be a principal difficulty, though competition to investment in fixed assets is particularly fierce in the energy sector.

Figure 4.3: Operating surplus as a percentage of production and innovation expenditure as a percentage of turnover by sectors (weighted averages, 1995-2002, EU-25*)*



* NACE 24.4 (pharmaceuticals) plus NACE 73 (R&D services), i.e. it includes a number of non-biotechnology activities.
a) Innovation intensity for Aerospace refers to NACE 35 and thus includes manufacture of ships and boots, railways, motorcycles etc.

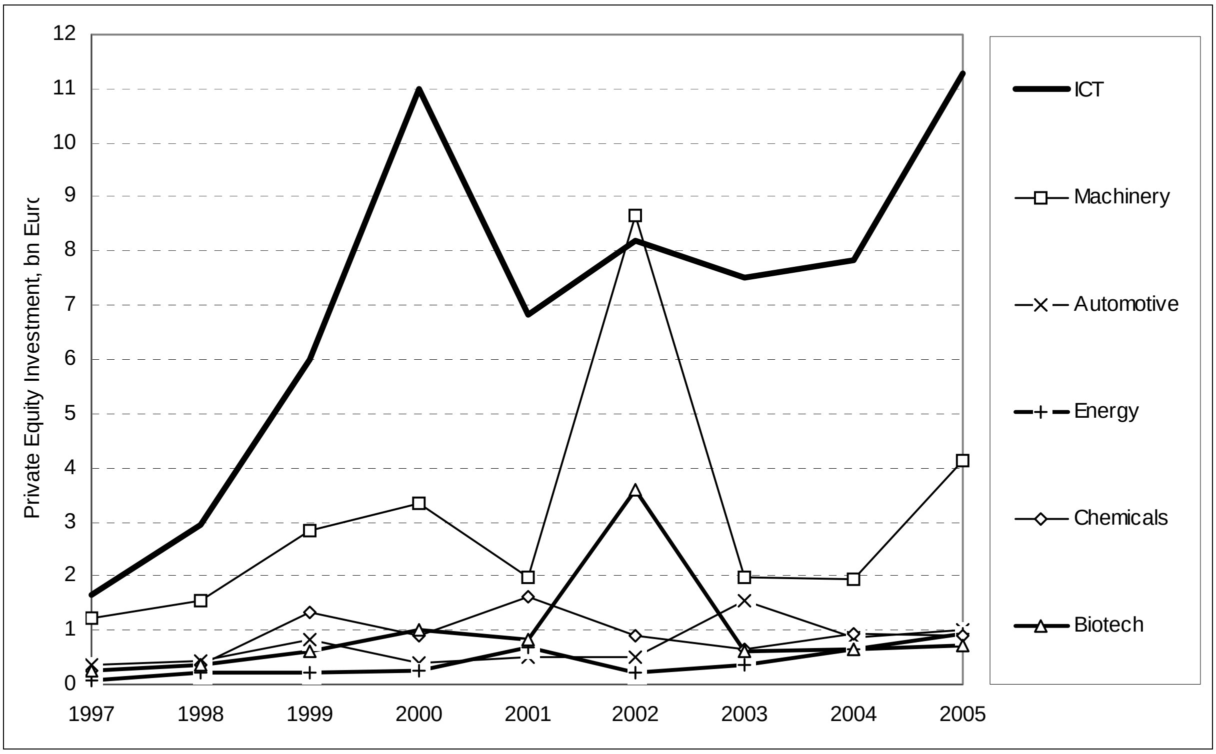
Source: OECD - STAN database, CIS-3, CIS-4 ZEW calculations.

Private Equity Financing

Another important source for financing innovation is external equity funding. Enterprises may access external equity through two main channels: placing company shares on stock markets, or acquiring investment from private equity companies. While the former is open to a small number of publicly listed firms only, the latter has become an increasingly important source for corporate financing within the last ten years in Europe, including SMEs and start-up companies. We focus here on private equity as an external funding source.

Private equity is traditionally separated into two types of investment: venture capital and later stage. Venture capital is used to finance the start-up of new, typically technology-based firms as well as the expansion of fast growing companies. Later stage investment represents financial investment into companies that promise growing profits and is often associated with restructuring. From an innovation financing perspective, venture capital is the most important component of private equity. On average, this represents about a quarter of total private equity investment in Europe.

Figure 4.4: Volume of private equity investment in Europe by sectors 1997-2005 (EU-25)*



* New member states CZ, ET, LV, LT, PL, HU, SK only from 2003 on, no data for SV, MT, CY, LU.

Source: EVCA[15], OECD - STAN database, ZEW calculations.

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[15] Data on private equity investment in Europe is provided by the European Venture Capital Association (EVCA). While EVCA publishes a wealth of data, sector specific information is only available for the total sum of all stages, and not separately for venture capital investment. Moreover, EVCA applies a sector classification different from NACE, restricting the number of sectors to be covered. Data for total private equity investment in Europe can be obtained for the **Energy production** sector as the EVCA sector ‘energy’.

One can see in Figure 4.4 that the ICT sector is attracting the largest proportion of private equity investment in the EU-25 over the past nine years. At the other end of the scale, private equity investment in Energy is among the lowest of the six sectors compared (€0.4bn per year).

Public Innovation Funding

Public funding for innovation activities is an important source for some companies and sectors. Public financial support for industrial innovation can occur in very different ways. The most direct way is public grants to enterprises for covering parts or all costs of innovation. Within the EU, such direct public support is typically restricted to pre-competitive research and in general may not exceed 50 per cent of total project costs. Another way of directly financing innovation by the government is to commission the development of innovative products and to purchase innovation.

Internationally comparable sector data on the extent of such government innovation funding activity is widely missing. For sector information, one is thus bound to CIS data, which provide at least an indication about the distribution of government funding for innovation among enterprises. Although there is no information available on the magnitude of this funding in total innovation expenditure.

The highest share of innovative enterprises that receives funding is to be found in the **Biotech** sector where three out of four enterprises make use of public money to fund their innovation activities (referring to 1998–2000, and including R&D service providers outside biotechnology). Sectors with a rather low innovation propensity also show quite high ratios of publicly funded innovators. This is especially true for **Textiles**, but also holds for **Food** and **energy**. One has to keep in mind here that only a small share of all enterprises in these sectors are conducting innovation activities. Out of this small group, a significant number receives public funding. Finally, only 1 out of 4 **Gazelles** received public funding (with respect to innovation activities in 1998–2000).

Role of financial barriers to innovation in the energy sector

Factors hampering innovation curtail the profitability of innovative projects, and are an indication that framework conditions are acting to reduce the extent of innovation activities in certain sectors of the economy. In the energy production sector, market-related economic risks, cost factors, problems on the technological side of the innovation process as well as internal factors constitute important obstacles to the expansion of innovative activity. Moreover, the following can be noted:

- Companies in the energy sector put the innovation costs at the top of the ranking of the hampering factors to innovation. About 17 per cent of companies reported having problems innovating due to high innovation costs.
- The lack of an appropriate source of finance is another obstacle of medium importance in this sector. Fifteen per cent of the energy companies are restricted due

to the lack of funds within their enterprise or group. The access to external sources of financing such as public money, venture capital or loans is a serious problem for less than 13 per cent of the enterprises.

- Compared to the hampering factors mentioned above, all the other selected obstacles such as uncertain demand, abuse of market power, the lack of qualified personnel, the lack of information on technology or the lack of information on markets as well as difficulties in finding cooperation partners are not, or are relatively small, impediments to innovation activities.

There is evidence in the CIS data that innovative and non-innovative companies in energy industries grade the factors that constitute barriers to innovation projects differently (Table 4.1). From a global point of view, the ranking of factors hampering innovation activities is similar for both groups of companies. However, those innovative companies with their own R&D suffer significantly more from financial problems and innovation costs in the innovation process than non-innovative firms or firms without continuous R&D. Innovation costs and excessive perceived economic risks are notable factors that affect innovation activities seriously and delay or prevent innovative projects.

Table 4.1: Financing related innovation barriers perceived as high in the energy sector

Innovation barrier (high)	**Innovative companies**		**Continuous R&D**		**Market innovations**	
	yes	**no**	**yes**	**no**	**yes**	**no**
Excessive perceived economic risks	**21.1**	**11.5**	**43.8**	**13.0**	**41.7**	**10.7**
Innovation costs too high	**27.1**	**14.5**	**47.1**	**17.1**	**33.3**	**12.9**
Lack of appropriate sources of finance	22.7	15.0	29.4	17.0	**16.7**	**5.0**

Source: CIS-3, ZEW calculations.

Energy industries have a wide range of technologies that span from ‘low- to high-technology industries’. Energy production comprises the energy life cycle, i.e. primary production of energy, and the transformation, conversion and processing of energy. Directly linked to the need for R&D and innovation are major infrastructure investments and re-regulation of market mechanisms.

The inter-sectoral comparison of hampering factors reveals that the number of companies in energy industries that reported innovation costs and excessive economic risks is remarkably high. Funding innovation activities is not a serious barrier to innovation. Contrary to other sectors, most of the common obstacles to innovation are of minor relevance in the energy sector.

4.1.2 Taxation and regulation

Taxation may affect innovation through various channels. On the one hand, a high tax burden may decrease the propensity to invest in general; on the other, specific tax incentives for R&D and innovation will presumably support decisions to carry out innovation activities.

Most countries employ indirect as well as direct instruments for promoting R&D investment. As both ways have specific advantages and disadvantages it depends on the detailed design of tax incentive schemes as well as grants and subsidies that often make the difference between efficient and wasteful fiscal support to R&D (OECD, 1998). *Table 4.*2 provides an overview from a survey of National Experts on the most commonly used fiscal incentives in the member states.

Table 4.2: Types of fiscal incentives

Sector	R&D allowance	Tax credit	Grants, subsidies
Biotechnology	8	9	13
Food/Drink	6	8	9
Machinery/Equipment	8	9	10
Textiles	7	10	7
Chemicals	7	8	9
Energy	**6**	**10**	**9**
ICT	8	11	14
Space & Aeronautics	6	7	10
Automotive	6	9	9
Eco-innovation	7	8	11
Gazelles	8	8	9

Source: Survey of National Experts, ZEW calculations.

The table shows that direct R&D promotion (grants, subsidies) seems to be slightly more popular in the member states than indirect instruments like R&D allowances or tax credits. Within the indirect instruments, the tax credits prove to be more frequently used than R&D allowances. Hence, it will be of interest to know how both forms of indirect R&D promotion interact to determine the tax burden of companies performing R&D activities.

The European Tax Analyser (ETA)[16] was developed in a joint research project by the Centre for European Economic Research (ZEW) and the University of Mannheim, Germany. It is a computer program for calculating and comparing effective average tax rates (EATRs) for companies located in different countries.[17]

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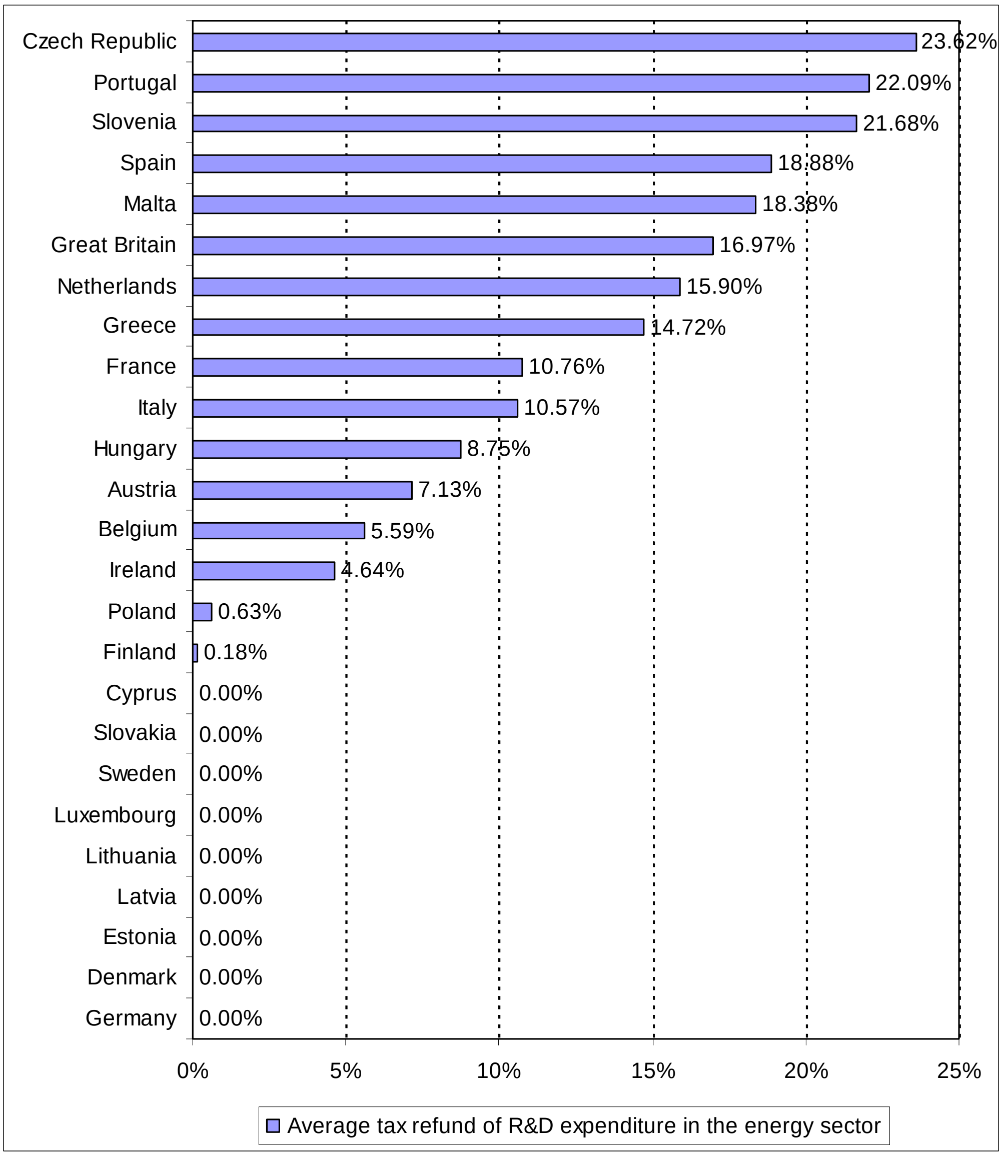
[16] For detailed descriptions of the model see Spengel (1995), Jacobs and Spengel (1996), Meyer (1996), Jacobs and Spengel (2002), Stetter (2005) as well as Gutekunst (2005).

[17] The software has been used for various international corporate tax comparisons so far, including work for the European Commission. The ETA calculates these effective average tax burdens based on the model-firm approach. Within this conceptual framework, the calculations take as a starting point an industry-

Figure 4.5 shows the average tax refunds of R&D expenditure due to fiscal incentives for the energy production sector. The Czech Republic, Portugal and Slovenia show particularly high refunds with over 20 per cent of R&D expenditure. This is followed by Spain, Malta and Great Britain. As we see, the European Tax Analyser indicates that many of the Member States have below 10 per cent average tax refund of R&D expenditure. A number of countries have no tax refund mechanisms at all.

Figure 4.5: Average tax refund of R&D expenditure in the energy sector



Source: European Tax Analyser, ZEW calculations.

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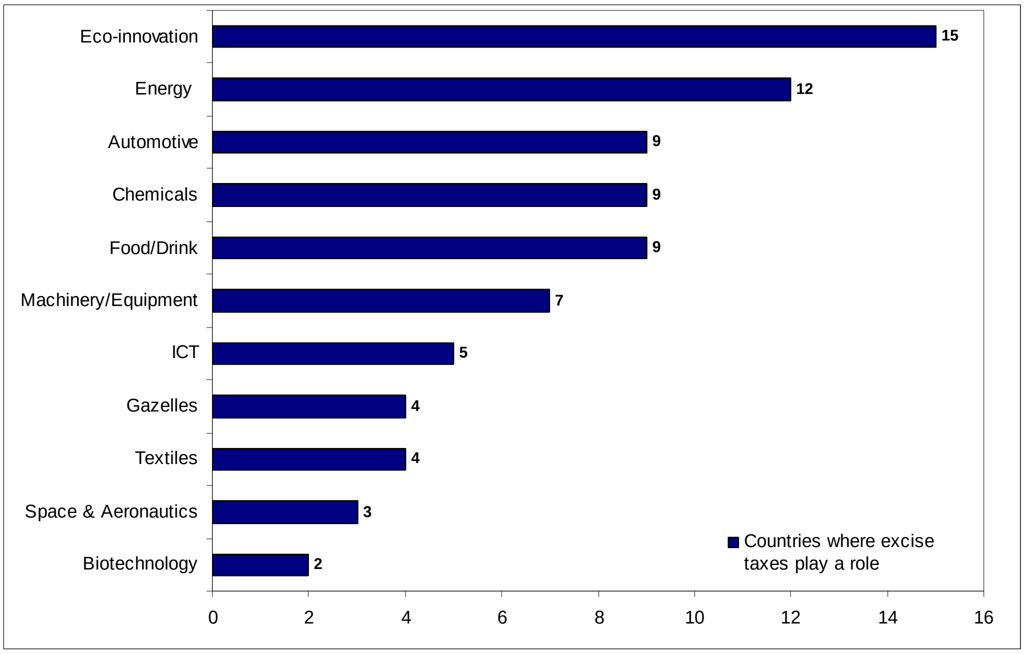
specific combination of assets and liabilities. This industry-specific data is taken from the official business statistics of the German Federal Reserve Bank. Based on the capital stock, the future pre-tax profits are derived on the basis of estimates for the future cash receipts and cash expenses associated with the initial capital stock. In order to determine the post-tax profits the tax liabilities are derived by taking into account the tax bases according to the national laws and then applying the national tax rates. As such, model-firms, if computer based, can easily be run under alternative sets of assumptions on key variables such as pre-tax receipts and expenses, types and age of assets, sources of finance, R&D expenditure etc., they may provide reliable results (i.e. EATR) for different circumstances and different industries.

There may also be implicit innovation preferences for a national taxation system. In the following, the role of excise taxes is evaluated, i.e. taxes that are imposed on the manufacture and distribution of certain consumer goods, for example, environmental taxes, communications taxes, and fuel taxes. Accordingly, this chapter evaluates the incentives to innovate that result from excise taxes. The analysis is based on the survey of National Experts who were asked to evaluate the role that excise taxes play in the respective national economy. *Figure* 4.6 gives an overview on the results. It turns out that most excise taxes exist in the eco-innovation sector, followed by energy production, automotive, chemicals, food and drink as well as machinery and equipment. In the remaining sectors, excise taxes seem to be of less importance.

Figure 4.6: Countries where excise taxes play a role



Source: Survey of National Experts, ZEW calculations.

In fact, most National Experts cite an ‘ecotax’ contribution as an important excise tax that is primarily directed to deal with the consequences of production, i.e. waste management. By increasing the prices for such goods, however, excise taxes may also provide incentives for producers to engage in innovation activities that explicitly have, for example, a positive effect on environmental issues and thereby circumvent the levying of excise taxes. Accordingly, the National Experts were asked to assess the impact of excise taxes on the ability of firms to innovate of the firms in a sector. Table 4.3 provides an overview on the estimated impacts per sector.[18]

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[18] The difference of the sum of responses to 25 indicates a non-response by the National Experts.

Table 4.3: Evaluation of the impact of excise taxes on innovativeness

Sector	**Positive**	**Negative**	**No impact**
Biotechnology	2	1	10
Food/Drink	4	3	9
Machinery/Equipment	4	2	9
Textiles	2	1	10
Chemicals	7	2	5
Energy	7	5	5
ICT	2	3	9
Space & Aeronautics	2	1	9
Automotive	4	2	8
Eco-innovation	9	2	7
Gazelles	4	1	9

Source: Survey of National Experts, ZEW calculations.

The table shows that excise taxes seem to play only a secondary role with regard to their impact on the ability to innovate. Exceptions to this are the chemicals, energy and eco-innovation sector where in most countries a positive impact on innovativeness is observed. The energy sector, however, also seems to be effected negatively in five countries. Apart from this, negative impacts of excise taxes seem to be negligible, and the overall tendency is towards a positive impact. To sum up, the impact of excise taxes with regard to the innovation behaviour of firms in the EU-25 member states seems to be rather positive or should at least be neutral.

Regulation

Apart from taxation, governmental activities and their potential impact on innovation may also centre around regulation issues. Regulatory activities include laws that influence the decision behaviour of firms. In the context of innovation, they may provide incentives to innovate on the one hand, or deter from particular innovation activities on the other. A prominent example of regulation that may spur innovation is the environmental legislation that leadd to a number of environmental innovations, i.e. innovations that prevent, limit, minimise or correct environmental damage to water, air and soil, as well as problems related to waste, noise and eco-systems. On the other hand, regulatory activities might also hamper innovation in that certain regulations critically limit innovation processes due to ethical, environmental or other reasons. *Table* 4.4 shows results from the survey of National Experts on the importance of regulation for innovation.[19]

Table 4.4: Importance of regulation per sector

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[19] The difference of the sum of responses to 25 indicates a non-response by the National Experts.

Sector	Importance of regulation high	medium	low	not relevant
Biotechnology	14	4	4	1
Food/Drink	13	5	3	2
Machinery/Equipment	2	8	8	7
Textiles	2	7	10	4
Chemicals	13	6	1	2
Energy	16	3	1	2
ICT	3	11	6	4
Space & Aeronautics	8	1	4	7
Automotive	8	5	4	6
Eco-innovation	13	5	3	2
Gazelles	7	0	5	9

Source: Survey of National Experts, ZEW calculations.

It turns out that there are a few sectors with a high importance of regulation in the member states. The top position occupies the energy production sector with the highest share of countries where regulation is of high importance. This finding reflects particularly the environmental regulation.

The investigation of regulation as a driver for innovation is based on CIS-3 and CIS-4 data. However, neither data set provides a direct evaluation of regulation as a driving force. Instead, there is only information on the effects of innovation activities that have to be assumed to lead towards a compliance with certain regulations or formalities. In such case, it can be argued that regulation has been a driving force of innovation activities.

Accordingly, meeting regulations as an effect of innovation activities of firms is shown in the bottom row of *Table* 4.5. Among the observed industries chemical firms account for the highest share of firms that report a meeting of regulations through their innovation activities. This sector is followed by the food, energy and the automotive sector. As outlined in the preceding text, these results can be explained by the exposure of these industries to regulations which are more pronounced in environmental and consumer sensitive sectors. Compared with other effects on innovation activities, however, the importance of a meeting of regulations is rather low. Apparently, innovation activities mainly focus on increasing the range of goods, market share or quality, but not on regulation.

Table 4.5: Effects of innovation activities

	Food	Textiles	Chemicals	Machinery	ICT	Automotive	Energy
Increased range of goods	36.8	32.9	42.6	37.8	48.8	40.8	15.0
Increased market share	32.2	23.1	36.2	32.4	40.7	35.3	17.2
Improved quality	40.9	33.4	39.3	36.4	45.4	42.6	30.2
Improved production flexibility	22.9	24.1	20.3	22.0	26.6	24.3	18.4
Increased production capacity	29.5	20.5	23.7	17.8	21.1	28.1	14.0
Reduced labour costs	21.9	16.2	18.2	13.1	15.1	23.3	10.4
Reduced materials	13.3	9.9	13.1	8.2	4.8	14.6	13.7
Improved environmental impact	20.0	12.0	25.8	14.0	4.9	20.4	31.3
Met regulations	*26.9*	*14.1*	*28.2*	*14.9*	*14.2*	*20.4*	*26.0*

Source: CIS-4, ZEW calculations.

Apart from the positive effects that regulation may have on innovation activities there is also a widely spread notion that the regulatory framework is not always suitable for conducting R&D activities and therefore being innovative. Several examples from regulation affected industries show the relevance of the legal framework as an obstacle to R&D. As previously indicated, a prominent example is the restriction in working with human stem cells in the biotechnology sector. Furthermore, the automotive industry faces regulation which aims at limiting the emissions of carbon dioxide of cars as well as a speed limit on highways which will naturally influence the development of motors and other car components.

In CIS-3 companies were asked to evaluate to what extent legislation, regulation and standards pose a barrier to their innovation activities. The results show that 8 per cent of the companies rank the factor *insufficient flexibility of regulation and standards* as a highly important innovation barrier. This is not the factor that is considered important by the highest share of companies.

Given the position of this particular hampering factor for innovation among the other hampering factors, regulation does not seem to be that important in influencing innovation activities. Table 4.6 provides an overview on the perception of the innovation barrier in the various industries, differentiated by innovative companies, companies that continuously perform R&D, and companies with market innovations.

Table 4.6: Shares of companies that ranked insufficient flexibility of regulations or standards as highly important innovation barrier

Sector	Innovative companies		Continuous R&D		Market innovations	
	yes	no	yes	no	yes	no
Food	**9.6**	**9.2**	10.1	9.3	10.1	8.8
Textiles	7.4	6.9	5.1	7.2	5.8	6.6
Chemicals	12.9	10.4	12.8	12.0	17.0	9.5
Machinery	7.1	8.2	5.4	8.5	**6.5**	**8.5**
Automotive	4.9	4.3	6.0	4.1	6.0	1.7
Aerospace	10.9	7.2	6.7	9.6	9.9	8.1
ICT	7.0	5.5	**5.4**	**7.3**	6.6	6.9
Energy	11.5	11.0	17.7	10.7	0.0	15.7
Biotech	13.5	8.6	14.4	8.3	10.6	17.5
Eco-innovators	12.0	--	13.3	10.1	11.4	11.5
Gazelles	7.3	7.9	6.4	7.5	10.5	8.3

Source: CIS-3, ZEW calculations.

The results show a mixed perception of the innovation barrier between innovative and non-innovative firms. The innovation barrier is more important when no continuous R&D is performed or when the firm does not have market innovations. Other differences are not significant and should hence interpreted with care. To sum up, the general perception of regulation as a barrier for innovation seems to be rather subordinate. Particularly those barriers that focus on financing the innovation process are given considerably higher importance. Compared with the positive effects of regulation on innovation activities it seems as though innovation activities may be stimulated by certain regulatory interventions. However, it is too simple to argue that every regulatory activity has an innovation stimulating effect. What is important is rather how exactly the regulatory activity is designed.

4.1.3 Competition and demand

This section analyses and discusses the role of product market structures both as a driving force and barrier for innovation activities of firms. We take into account three effects of a firm's product market features on innovation decision and success:

- the role of competition with other firms as an incentive or barrier to innovate,
- competitors as a source of innovation and a partner in innovation projects,
- customers (or more generally speaking: demand) as a driver or barrier for innovation.

The role of competition with other firms as an incentive or barrier to innovate
Empirical analysis of the effect of competition in a particular sector on the sector's R&D intensity (Crespi and Patel 2007) shows that market structure effects on innovation tends to be quite different among sectors: only two sectors show a uniform positive relationship between the degree of competition[20] and the level of R&D intensity (Aerospace and Energy), while five sectors (Food, Chemicals, Machinery, ICT and Automotive) show an inverse U-shaped relation, i.e. R&D intensity tends to increase up to a certain level of competition, and then decreases. One sector (Textiles) shows a U-shaped relation, i.e. high R&D intensities in case of very low and very high levels of competition.

The significance of market dominance as barrier to innovation holds true for all sectors. In all sectors examined in the SYSTEMATIC project except Textiles, market dominance is the second most important obstacle for innovative enterprises (in Textiles, it is ranked third, after financing and lack of qualified labour). For non-innovative enterprises, it is either the second (Textiles, Chemicals, ICT, Energy) or third most important factor (Food, Machinery, Automotive).

With respect to non-innovative enterprises, in **energy**, only a small fraction of enterprises cites market dominance as highly important as an obstacle for innovation. This may be associated to the fact that a large portion of enterprises in this sector see no need for innovation due to market conditions such as having a regional monopoly in supplying energy or water.

Competitors as a source of innovation and a partner in innovation projects
While competitors can hinder innovation activities in case they exert market dominance, competitors can also serve as a source for innovation. Using impulses from competitors (or more generally speaking, from other companies in the same product market) is typically associated with imitation strategies, i.e. enterprises copy innovations already introduced by their competitors, or learn from their innovation efforts (including failures) for their own activities.

The significance of competitors as a source of innovation is rather limited. Just 11 per cent of all enterprises that performed innovation activities in 2002–2004 cited competitors as a highly important information source. There are significant differences in the relevance of competitors as source for innovation among sectors. In the energy sector, competitors are – in relative terms – more important as a source for innovation than in any other sector. 20 per cent of all innovative enterprises in this sector cite competitors as highly important information source. This is about the same share as for clients (22 per cent) and suppliers (21 per cent) and underpins the high potential of imitation as an innovation strategy in this sector.

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[20] Degree of competition was measured as gross margin as a percentage of production, assuming that a high level of competition squeezes profits and result in low average margins. There are, of course, other factors than competition that may affect the level of gross margin in a sector in a particular country, such as innovation rent, differences in industrial relations and capital intensity.

Cooperation with competitors in innovation projects is not very common. About 10 per cent of all innovative enterprises in the *systematic* sectors cooperated with competitors in the period 1998–2000. Among all cooperation partners, this is the lowest share. One has to bear in mind that only 35 per cent of all innovative enterprises are engaged in any form of innovation cooperation.

Cooperation with competitors is also relatively common in the energy sector. Here, competitors are the second most important type of cooperation partner (17 per cent of all innovative enterprises cooperate with competitors). Cooperation may be stimulated in this sector by the fact that many enterprises act in the regional markets as monopolists. Cooperation with other regional monopolists can reduce innovation costs while having no immediate effects on the market position of each partner.

Customers/demand as a driver or barrier for innovation
A large number of empirical studies show that customer proximity is of great importance for the innovation process.[21] The results of the third Community Innovation Survey (CIS-3) once again confirm the prominent role of clients in providing momentum for the innovation process. A total of 26 per cent of innovators assess their customers' role as important for innovation.

Whether or not it is considered necessary to intensively involve customers in the innovation process varies from sector to sector (Figure 4.7). Such sectors as Biotechnology (46 per cent), Machinery/Equipment (42 per cent), the Automotive Industry (42 per cent), the ICT/Electrical/Optical sector (41 per cent), Eco-Innovators[22] (40 per cent) and the Chemical Industry (38 per cent) cite customers as a highly important source for innovation. On the other hand, the frequency with which sectors like Space & Aeronautics (30 per cent), Textiles (29 per cent), Gazelles[23] (23 per cent), Energy Production (22 per cent) and Food and Drink (21 per cent) refer to their customers' wishes is well below average.

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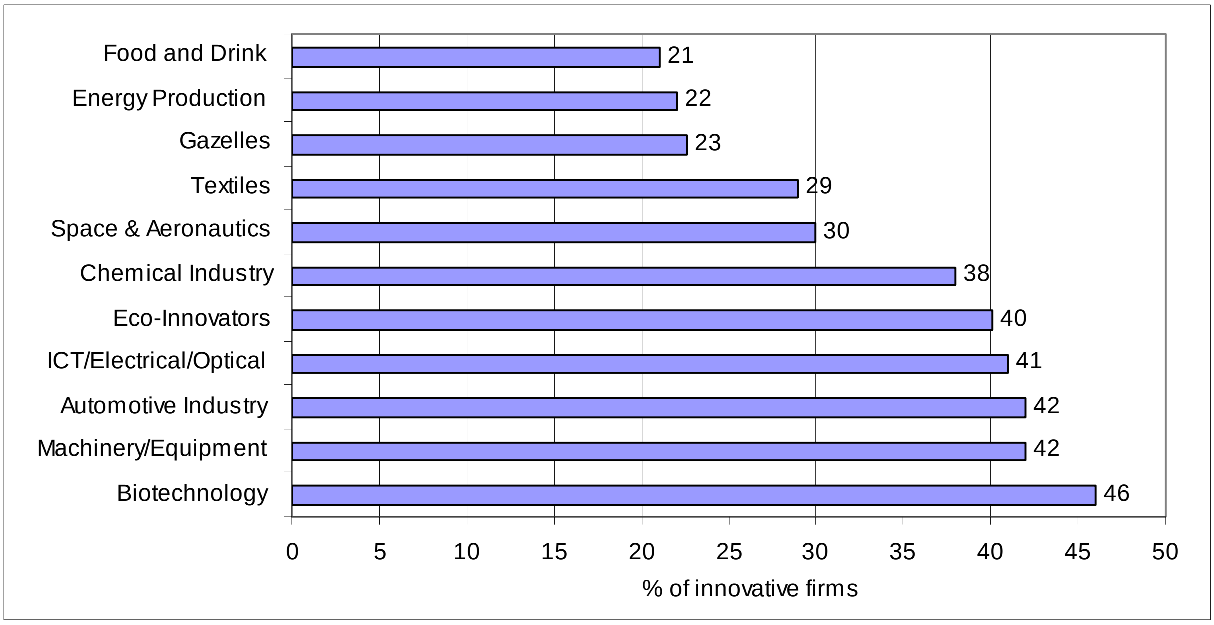
[21] See for excample Gemünden, H.G., Heydebreck, P. and Herder, R. (1992); Cooper, R.G., Kleinschmidt, E.J. (1987).

[22] Eco-Innovators are defined as innovative firms that assessed 'reduced materials and energy per produced unit' as a highly important effect of innovation.

[23] Gazelles are defined as fast growing innovative SMEs that moved up from smallest size category (10–49 employees) to larger size between 1998 and 2000.

Figure 4.7: The importance of a high customer acceptance for innovative firms



Source: CIS-3, unweighted, ZEW calculations.

4.2 Innovation Challenges

4.2.1 Structural features and sectoral innovation characteristics

Structural features

The generic function of energy makes the prospective challenges in the energy sector relevant to the development of society as a whole. The energy sector faces three basic challenges:

- industrial competitiveness
- security of supply
- sustainability.

It has been argued that these challenges or policy objectives are contradictory. In particular, the concern addresses how it is possible to meet targets of security of supply and sustainability, given the dominant role of fossil fuels in Europe. Cleaning fossil fuels is very costly and has not come far. It is difficult to see how policy targets of sustainability are to be reached without fundamental changes in energy consumption patterns in European countries in the foreseeable future. This depends largely on development and innovation in the energy sector, and represents a prospective innovation challenge with relevance to the demand side and the markets of the energy sector.

The overall structural feature of the energy sector in European countries, with basically large companies in existing, ‘traditional’ energy production, and SMEs in new renewable technologies, represents a fundamental innovation challenge if political objectives of more energy production based on renewable energy sources are to be given attention by means of policy instruments. This structure has implications for the incentives to work with innovation in renewable technologies and has implications for financial capacity of innovation in renewable technologies.

Characteristics of innovation

The different sub-sectors of the energy sector include a range of different production technologies with correspondingly different maturity. Many types of energy production and energy transformation facilities are large-scale complex plants in which innovation is incremental and supplied by intense user–supplier interaction in a complex collaboration between customer, research and development and engineering departments and machinery and equipment firms. This applies, for example, to certain mature parts of energy production. In fossil fuels energy, there is a specific challenge related to cleaning CO_2 emissions. In hydro-energy, production efficiency improvements can be gained through investment in updated production infrastructure (for example pipes) and turbine and generator technology. The challenge in this domain is above all the need for large-scale investment.

In more immature renewable energy production (wind, biomass, hydrogen technology, photovoltaic), innovation is taking place in small and medium sized companies. The technologies are under development; there are several alternative solutions, and the risk is correspondingly higher in terms of returns on investment in R&D and technology. Access to public financial suuport is an important challenge for these companies.

4.2.2 Technologies

Technological development will be critical in shaping the future energy system. An examination of the technical possibilities for the forthcoming years suggests that new portfolios of energy technologies will challenge conventional technologies based on fossil and renewable sources with electricity as a main carrier. It is indispensable to explore the role of CO_2 cleaning (carbon capture and storage) in future energy systems, options for producing and using hydrogen, diversified distributed electricity systems, and end-use technologies with very low energy and/or very low emissions. Table 4.7 gives an overview.

Table 4.7 Energy technologies, status and challenges

	Technologies	Status and challenge
Renewable sources of energy	**Photovoltaic**	**Technological development, innovation, deployment, market access**
	Wind and wave	
	Hydrogen	
	Hydro-electric power	**Investment possibilities, efficiency potentials**
Handling of carbon based energy use	**Biomass**	**Technological development, innovation, deployment, market access**
	CO_2 cleaning	
Fossil Fuels/Non-renewable sources of energy	**Petrol**	**Cleaning and efficiency potentials**
	Nuclear Fuel	**Basic security challenge**
	Gas	**Cleaning and efficiency potentials**
	Lignite/Coal	**Cleaning and efficiency potentials**

The innovation paths of the energy sector are extremely diverse, and so are the R&D priorities. The following R&D priorities illustrate the emphasis that is put on the energy domain as a complete system, and not as mere technological problem-solving. The list is taken from the OECD/IEA 2003 publication with the title *Energy to 2050, Scenarios for a sustainable future.*

- Network issues for distributed generation systems
- Development of more sustainable power generation technologies, whether conventional, renewable or nuclear
- Increased efficiency in both generating technologies (including CHP) and endues technologies
- Transportation technologies such as fuel cells and associated infrastructure biomass and waste utilisation
- Large scale energy storage
- Carbon dioxide sequestration
- Improved fossil fuel extraction (conventional or unconventional)
- Social science investigation of behavioural issues
- Regulatory mechanisms to facilitate emission trading, investment in energy efficiency
- Regulatory and market mechanisms that allow renewable energy entry into energy markets.

In this heterogeneous field it is, of course, very demanding to determine the most important prospective innovation challenges. One way of narrowing down the diversity is to see prospective challenges in terms of technologically generic applications, and another way is to see prospective challenges in terms of disruptive trends of technology (replacing existing technologies). The generic path is about challenges development or ‘greening’ of the existing energy technology regimes. This is above all a question of overcoming environmental difficulties. The disruptive path is the question of how, and how fast, renewable technologies are developed and able to be diffused and deployed in society.

Generic technological solutions – Cleaning Fossil Fuels
Continued economic growth is expected to result in increased use of fossil fuels with likely increases in the emissions of local and global pollutants. In the next twenty years, fossil fuels will continue to be dominant in electric power generating capacity. Cleaner fossil energy is vital but must overcome its environmental difficulties. 'Clean fossil fuel systems' have significantly reduced pollution. However, apart from improving energy efficiency, they have not addressed the problem of CO_2 emissions. To address this problem, a number of promising technologies have been developed but have not yet been deployed. Too high cost is the main problem. With these technologies, fossil fuel plants can achieve near zero or zero emissions of regulated pollutants and CO_2. They are all based on the strategy of separation, transportation and sequestration of CO_2.

Disruptive technological solutions – Renewable energy technologies
Most renewable energy technologies are disruptive in the sense that they are by and large environmentally friendly and represent something radically new to the existing technology regimes. The latter does not apply to hydroelectric power, wind power and geothermal power, which are integrated in a number of countries' energy infrastructure. Moreover, some countries have come far in the deployment of certain technological systems, such as biofuels in Brazil. Most renewable technologies depend on a new infrastructure. Alternatively, there is need for connection to the existing utility grid. As part of a new infrastructure, the deployment of new renewable technology depends on changed consumer behaviour. The following list shows the most important technologies to be developed in European energy production in the years to come.

- Hydrogen economy
- Wave power
- Wind power
- Solar power/photovoltaics
- Hydroelectricity
- Tidal power
- Ocean energy
- Ocean thermal energy conversion
- Geothermal power
- Biofuels
- Marine current power
- Biomass.

Perhaps the most promising, and certainly the cleanest technology, is solar power or photovoltaics. Of all the renewable energy sources available, solar cells have the smallest environmental impact. Electricity produced from photovoltaic cells does not result in air or water pollution, deplete natural resources, or endanger animal or human health. The only potential negative impacts are associated with certain toxic chemicals like cadmium and arsenic which are used in the production process. These environmental impacts are minor, and can be easily controlled through recycling and proper disposal.

4.2.3 Demand and market issues

Energy production feeds into energy consumption very differently. Nearly all types of human activity imply energy consumption. The demand side of energy by and large follows economic growth and increased welfare in the world's countries. Energy demand and consumption is therefore growing steadily. The European Commission estimates that the European Union's energy consumption is approximately 20 per cent higher than can be justified on economic grounds[24]. Energy saving is therefore high on the priority list. The European Commission launched directives on energy savings in 2003. In a follow-up from 2006 on 'The promotion of end-use efficiency and energy services', it was stated that Member States shall submit their first National Energy Efficiency Action Plan (NEEAP) to the Commission by June 30, 2007. In their NEEAPs, Member States should show how they intend to reach the 9 per cent indicative energy savings target by 2016. This is an overall policy target that puts an energy saving pressure on the Member States. The implications are, hopefully, that the growth in European energy consumption can be brought to what is considered acceptable levels. At the same time the supply side of the energy system, energy production, is struggling to increase its production and efficiency.

The generic application of energy in society as a product, and the relevance that energy consumption has to environmental issues, are factors that have fundamental influence on the discussion of energy demand and markets, and prospective innovation challenges. It is the political objective to decrease, or at least stabilise, demand (consumption of) for energy, and it is the political objective to contribute to a switch of energy supply from high emission fossil-based energy to low or non-emission renewable energy. One may argue that the challenges in relation to this switch illustrate how interwoven technological, infrastructural and regulatory factors and market access are in the energy sector. Increased production and problem-free market access for renewable energy is difficult to implement as long as it has to compete with cheaper energy from fossil fuels and nuclear energy.

There are at least two types of regulation regimes supporting market access to renewable energy under development and implementation regionally and nationally within the EU Member States. A system based on negotiation of tariffs (feed-in tariffs) between national authorities and producers of renewable energy has been tested for some time. The system has been shown to be efficient and has had positive impact on the market access to renewable

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[24] http://ec.europa.eu/energy/

energy, but the system is considered to be relatively costly for the authorities, and consequently costly for the tax payers. The other system for encouraging renewable energy production is to establish markets of certificates. This system implies that production of renewable energy on the one hand, feeds electricity into the utility grid; on the other hand green certificates are issued. The energy distributors have to buy a certain amount (quota) of certificates annually. The price of the certificate is determined in negotiation between producer and distributor. The result is a market of certificates. The extra expense is split between the end-users. This sounds expensive but it is a fact that this system gives incentives to increased energy production. An investigation of how this market has worked in Sweden, showed a positive effect.

4.2.4 Skills and human capital

Data on skills in the energy sector at the European level is limited to the mature parts of the energy sector, namely Mining and Quarrying of energy-producing materials, Manufacture of coke, refined petroleum products and nuclear fuel, and electricity, gas, steam and hot water supply. The data source is the Eurostat's *Panorama of the European Union, European Business, Facts and Figures* (European Communities, 2006). The workforce in these energy sub-sectors can be characterised as male and full-time with a relatively high importance of older workers. In 2005, 81.5 per cent of the workers were male, more than 4 per cent higher than the industrial economy average. Correspondingly, the proportion of young persons (aged less than 30) was just about 13 per cent. The average for the industrial economy as a whole was around 20%.

There is reason to believe that the proportion of younger workers is higher in renewable energy SMEs. Moreover, there is reason to believe that the proportion of workers with higher education and advanced skills is higher in the renewable energy SMEs than in the mature energy sectors where larger firms dominate. Although the mature technology energy firms have challenges in relation to new expertise in development of energy efficiency and emissions control, the need for new expertise is even more pronounced in renewable energy companies. A statement from Department of Trade and Industry in the UK indicates a coming shortfall[25]. Such is the scale of the expected boom in green energy technology that there could actually be a shortfall in suitably-trained staff.

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[25] http://www.energyprojects.co.uk/skills_re.htm

5 Innovation Environment

This chapter presents results from two work packages in the Innovation Watch Systematic project. Section 5.1, based on Work Package 8, looks at national sectoral profiles by attempts to identify leading and laggard countries in the energy sector. Moreover, the aim is to evaluate how these countries perform with respect to a group of national characteristics important for innovation in this industry (or benchmarks).

Section 5.2, based on Work Package 10, addresses sociocultural determinants of innovation in the energy sector. Sociocultural barriers or drivers to innovation are sociocultural factors that influence sectoral innovativeness in respectively a positive or a negative way.

5.1 National Sectoral Profiles

Two composite measures of innovation performance were developed based on a number of indicators often used individually in innovation studies. The main issue in relation to the energy sector is that these conventional innovation proxies: *patents, total factor productivity* and *exports* may be of limited value in explaining innovation performance of countries. However due to a lack of availability of alternative indicators this was the only course of action open within this project. In the future, the same methodology could be applied to a different, more appropriate, set of performance measures.

The main results to emerge from analysing the relationship between innovation performance and the national characteristics in the energy sector may be summarised as follows:

- In general, there is no relationship between the developments in the *knowledge base* and the *level* of innovation performance.
- Two dimensions of *agents and interactions* are positively associated with country level innovation performance, namely *international orientation* (selling in international markets and cooperating with firms outside the EU) and *cooperation with government* to innovate.
- *Demand stability*, *favourable demand* and *market liberalisation* are positively associated with innovation performance.
- The most controversial results are that the two indicators related to regulation, *innovation linked to meeting regulations,* and *innovation linked to reducing environmental impact,* are negatively related to innovation performance.

At best, the above results can only be seen as being indicative as there is a great deal of debate whether the measures used here to analyse innovation performance in the energy sector are the most relevant. However, the methodology developed here can be applied equally to new and better indicators as they become available.

Despite the mentioned fundamental problems related to relevance of the indicators for the energy sector, we shall present one of the three central issues addressed, namely the part that attempts to identify the leading countries in the energy sector with respect to innovation outcomes.

5.1.1 Identification of Leading Countries in the Energy Sector

First we describe the methodology used to construct each of the three main indicators and the composite index that are used to compare countries. The main aim in each case is to construct a *relative* index to eliminate the possibility of country bias in the data.

1) *Index of Patenting Advantage (PA)*. For each country this is the number of EPO patent applications per employee in the energy industry as a proportion of the total number of EPO patent application in this industry (across all countries) per employee.

2) *Total factor productivity* (TFP). For each country TFP has been calculated using index number approaches. It is based on data for value-added at constant prices, number of hours worked and value of capital stock at constant prices.[26] This indicator is available over time.

3) *Index of Market Advantage (MA).* For each country, this is simply total exports per employee in the energy industry divided by total exports in the industry per employee. This indicator is available over time.

These indicators are used to calculate two composite indexes of innovation performance: one capturing static performance and the other the dynamics. The first is based on the average levels of the three indicators between 2000 and 2003 and, the second is based on the changes in these variables between 1990 and 2003. More specifically, the calculation of the level of the *index of innovative performance* involves the following steps:

- First, we calculate the average for the period 2000/2003.
- Second, we normalise the values of the three indicators with respect to the maximum.
- Finally, we calculate a simple average of the normalised values of each indicator:

$$IIP_i = \frac{NorPA_i + NorMA_i + NorTFP_i}{3}$$

where *IIP* stands for Index of Innovative Performance, *Nor* for Normalised value, and *i* for country.

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[26] This was first calculated in Crespi and Patel (2006).

The same weight is allocated to each individual indicator in this calculation implying that each of the dimensions measured by an individual indicator is in principle equally important as a measure of the innovative performance in the energy industry.

The calculation of the *index of change* involves the following steps

- First, we calculate the average of the indicators MA, PA and TFP for two periods: 1990–93 and 2000–03.
- Second, we calculate the growth between these two periods (absolute growth).
- Third, we calculate the normalised values of the growth per each indicator,
- Finally the composite index of growth is calculated as the average of the three measures.

In the following we present the results obtained based on the composite index of innovative performance.

In Table 5.1, we identify the leading countries according to the level of innovative performance in the energy sector in the period 2000–2003 (column 1). Thus, the leading EU countries are Denmark, Netherlands, Norway, Belgium, and Sweden. At the other end of the spectrum are countries with a low level of innovative performance: Hungary, Czech Republic, Poland, Slovakia, Ireland and Greece. In-between, with levels of performance around the median are Germany, France, Italy, Finland, Portugal, UK, Spain and Austria. USA has a value for the innovation index well below the average for Europe, and Japan is at the level of the EU average.

Columns (2), (3), and (4) show the performance of the different countries with respect to the individual indicators of innovative performance included in the index. Thus, the overall leadership of Denmark is based on a strong performance with respect to all three indicators of innovative activities used to construct the composite index. It is among the top five countries with respect to *patent advantage*, *market advantage* and *total factor productivity*.

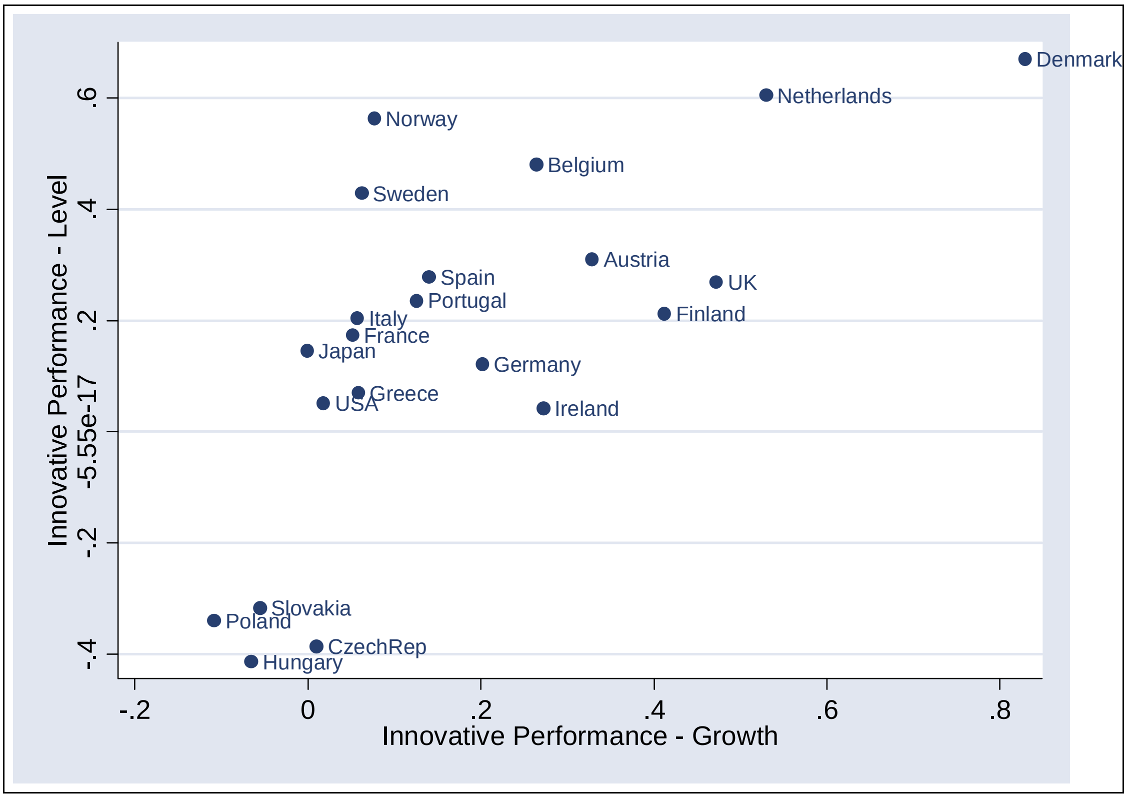
Table 5.1 Innovative performance in the energy industry (top five countries in bold)

Country	**Index Level (1)**	**PA (2)**	**MA (3)**	**TFP (4)**	**Index of Growth (5)**
Denmark	**0.67**	**1.87**	**4.73**	**2.14**	**0.83**
Netherlands	**0.60**	**2.40**	**10.17**	0.68	**0.53**
Norway	**0.56**	0.90	**20.68**	0.67	0.08
Belgium	**0.48**	**2.18**	**7.37**	0.38	0.26
Sweden	**0.43**	1.55	1.98	**1.16**	0.06
Austria	0.31	1.02	1.14	**0.96**	**0.33**
Spain	0.28	0.31	0.99	**1.40**	0.14
UK	0.27	1.23	**2.54**	0.37	**0.47**
Portugal	0.24	0.04	0.36	**1.44**	0.13
Finland	0.21	**1.71**	1.82	-0.35	**0.41**
Italy	0.20	0.85	0.71	0.48	0.06
France	0.17	1.26	0.98	-0.11	0.05
Germany	0.12	**2.05**	0.75	-1.13	0.20
Greece	0.07	0.05	0.55	0.35	0.06
Ireland	0.04	0.34	0.69	-0.11	0.27
Slovakia	-0.32	0.02	0.39	-2.09	-0.06
Poland	-0.34	0.01	0.12	-2.21	-0.11
Czech Rep	-0.39	0.04	0.22	-2.53	0.01
Hungary	-0.41	0.05	0.19	-2.72	-0.07
Luxemburg			2.54		
Japan	0.15	1.13	0.15	-0.09	0.00
USA	0.05	1.17	0.32	-0.75	0.02
Average	0.16	0.92	2.52	-0.11	0.18

Column (5) lists the countries according to the index of change discussed above. In particular, this shows that Denmark, Netherlands, UK, Finland, and Austria, are the fastest growing countries in terms of innovation in the energy sector. USA, Czech Republic and Japan are growing at rates below the median, and Poland, Hungary, and Slovakia are declining over time.

Figure 5.1 shows the position of countries with respect to the level and the growth of the index of innovative performance. A number of different clusters can be identified by their position on this diagram.

Figure 5.1: Position of countries according to the Index of Innovative Performance - Energy



A first cluster of countries with relatively high values with respect to both the level and the growth of the index of innovative performance can be identified in the top right of the graph. This includes Denmark and Netherlands, and can be considered as the group of *leading countries.*[27] Another cluster of good performers in the energy industry includes Norway, Sweden and Belgium. These countries have well above average level of innovation performance and but low rates of growth. The third cluster, comprising Austria, UK and Finland, demonstrates good performance with respect to growth but less so with respect to levels. At the other end of the spectrum are countries with low levels of innovation in the energy sector: Hungary, Poland, Slovakia and Czech Republic. The final group of countries, which are neither amongst the leaders nor amongst laggards, are Spain, Portugal, Italy, France, Japan, Greece, USA, Germany, and Ireland.

Interpretation

How are the results to be interpreted given our introductory objections to the relevance of the indicator for the energy sector? The innovative performance level is based on each country's patent activity, total factor productivity and export performance of the energy sector. The Danish situation is evidently linked to the long-standing performance in wind energy technology. Norway has a strong history in hydropower energy production, and oil and gas extraction, which have brought both patents, high productivity and exports. Generally the high

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[27] These results should be interpreted with caution since, as mentioned, other indicators of innovative performance should be included in the analysis for evaluating innovative performance in the energy sector.

score of the Nordic countries on the innovative performance composite index may be influenced by the open energy market between these countries. Additionally, as mentioned, Norway performs particularly well with respect to *market advantage* and Sweden with respect to *total factor productivity*.

Explaining why the largest countries have lower scores is more difficult. It is a fact that Germany, UK, Spain, France, Japan and Italy are the countries that have the largest and most successful energy sector firms.

5.2 Innovation Environment

Energy policy-makers face a range of interrelated trends and challenges such as energy demand, prices, markets, efficiency, security, etc., which render the energy production sector a complex and policy-sensitive sector. The considerations below represent some stylised features of sociocultural determinants of innovation in the energy production sector.

According to Foxton (2003), the most common strategy to develop innovation in the energy sector is the technology push approach, which might nevertheless lead to technologies that are unable to fulfil their promise because of a lack of attention paid to the implementation process and to their societal embedding. Indeed, as pointed out by Grubb (2004), innovation in energy production is not heavily based on product differentiation and therefore on market pull forces as in classic R&D intensive sectors. Rather, it relies on matters of efficiency and price in delivering the same product (electrons).

Taking the example of fuel cells, the OECD (2006) points out that successful innovation in this sector requires much more than R&D. Since fuel cells represent a new way of satisfying energy needs in areas where old technologies are well established, the market development factor is highly important. The switch to renewable energy bears high costs and risks, and users may delay this investment as long as they are not fully convinced of the reliability and capabilities of these sources (see also Unruh, 2002).

In order to change public opinion and individual behaviour, there is need for improved education and more information to be available to people. According to Geels (2004), user preferences are notably influenced by concerns about negative externalities (e.g. environmental impacts, health risks and concerns about safety), wide cultural patterns (e.g. history, education, country), financial considerations (e.g. costs/benefits analysis) as well resulting from the personal interactions with new technologies. To Foxton (2003), technology developers and policy makers often assume that focusing on the ‘techno-economic dimension’ of an innovation is enough to ensure its adoption and diffusion. In practice, many energy projects (including wind, bio fuel energy and hydrogen) face severe resistance (often labelled resistance to change) from various stakeholders, including actors that are not direct users of the technology and public bodies. Such new technologies often require for a transformation in societal thinking, which otherwise might hamper their development.

As underlined by the Europe Innova panel, informed consumers may probably accept reductions in their energy consumption for the sake of future generations as well as they demanding clean(er) energy production from their energy providers. The public is indeed generally favourable towards new energy sources as long as these new technologies do not affect their private space (as reflected, for example, in local debates on the building of new wind farms).

The Eurobarometer study (No. 262) provides evidence on the general attitude of European citizens towards different energy sources.[28] In general, they are highly positive about the use of renewable energy sources: 80 per cent support the use of solar energy (particularly in Denmark, Cyprus and Greece), 71 per cent wind energy (from 85% in Czech Republic to 26% in Malta), 65 per cent hydroelectric energy, 60 per cent ocean energy (but less than a quarter of Latvians and Estonians) and 55 per cent biomass energy (three-quarters of Germans in contrast to only 21% of Maltese). The greatest supporters of solar and wind energy (86% and 76% of people in favour) are found in the group of people who consider that reducing energy consumption is a very important issue in their country.

Regarding fossil fuels, 42 per cent of EU citizens are in favour of the use of gas (56% in EU10 only) and about a quarter accept the use of oil and coal (approximately 40% in EU10 only). Respondents in the new Member States are consistently more positive about the use of fossil fuels in their country: 56 per cent are in favour of gas, 41 per cent of oil and 38 per cent of coal. Females, the elderly and those with a low level of education appear to be more in favour of using these energy sources. Nuclear power divides public opinion as 37 per cent of European citizen express outright opposition towards this form of energy. An absolute majority of citizens in seven countries is opposed to the use of nuclear power in their country: 80 per cent of Austrians, 73 per cent of Greeks and 70 per cent of Cypriots express their opposition to nuclear energy. Interestingly, these countries do not have operational nuclear power plants. Swedish, Slovakian and Lithuanian respondents are most in favour of the use of nuclear power in their country. This is perhaps understandable since a great part of energy in these countries is produced by nuclear power (Eurobarometer 262).

Several studies have attempted to assess the importance of the ‘not-in-my backyard’ phenomenon for attitudes to renewable energy, for example, by comparing the attitudes of people living close to energy plants to those living further away (e.g. Devine-Wright, 2004a). As reported by Heiskanen et al. (2007), the distribution of costs and benefits of an innovative project in the energy sector may indeed be a critical issue. Nonetheless, the concept of ‘shared responsibility’ requires the active involvement of all economic and social players. Environmental benefits are expected to help the overall community to meet their greenhouse gas reduction targets, but the environmental impacts on the local community may be expected to be negative in the form of increased traffic and emissions, loss of landscape value and

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[28] See annexes 2 to 11 for poll results across EU-countries on the general attitude of citizen towards different energy related issues

biodiversity. The study by Brohmann et al. (2007) indicates that successful demonstration and early deployment projects are therefore not only important for technical development, but also for user learning, credibility and for the evolution of supportive institutions and cultural practices.

The results of a Eurobarometer study (No. 247) underline that more than half of European citizens are willing to reduce their energy consumption. Notwithstanding, 12 per cent stated that they would not decrease their energy consumption even if prices increase. Citizens of Luxembourg, the Maltese and Dutch seem to be keener to change their practice in terms of energy use. The Danes appear to be most prepared to accept a price increase in order to maintain their habits while the Greeks and Hungarians are the most unwilling to make any change, either in terms of use or cost. The higher the level of education achieved the more citizens seem to be willing to assume commitments in terms of changing their energy consumption habits.

A significant percentage (40%) would be prepared to pay a premium for energy from renewable sources; 27 per cent would even accept an increase of 5 per cent and 13 per cent an even higher price rise. A first cleavage is to be found amongst the old EU15 Member States (especially Luxembourg, Denmark, Finland and the Netherlands with more than half of the population prepared to pay more), and the ten new Member States, with the latter group being clearly more reluctant to pay higher prices for ‘green energy’, opposition to such a measure reaching 76 per cent in Slovakia. It is interesting to note that 56 per cent of Germans are not prepared to pay more, although the country is the foremost European producer of wind energy. Education seems to be an essential determinant of the willingness to pay for renewable energy: more than 25 points separate those with long education from those who ended it by the age of 15 (55% compared to 28%).

Notwithstanding the widespread support for new technology and energy efficiency and the readiness to take actions in this regard, new energy projects often fail because of a lack of stakeholder acceptance (Heiskanen et al., 2007). Public perception as reported in surveys is obviously not the same as consumer acceptance or acceptance at the local level. There have been great advances in mainstreaming new energy technologies, visible in the growth rates of renewables in the European energy mix, but top–down policies may sometimes be insensitive to the local context.

The study carried out for the Create Acceptance European project on 25 different projects[29] (see Heiskanen et al., 2007) leads to the conclusion that some countries and localities have very successful experiences with the development and diffusion of renewable energy technologies, whereas similar projects have become highly controversial in others. These

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[29] The data consist of a meta-analysis of 25 case studies in new energy technologies in different geographic regions - West Europe, North Europe, Central and Eastern Europe, South Europe and South Africa, as well as in different local settings within these regions. The analysis focuses on cases exhibiting various degrees of successfulness in terms of societal acceptance and techno-economic outcomes.

differences are not, however, due to inherent characteristics of different nationalities, or even fully explicable in terms of individual policy instruments. The authors do not explain these differences in terms of natural endowments, even though solar energy has been well received in Austria, Germany and Greece, but not in other Mediterranean countries (Tsoutsos 2002). Another example is the stronger local opposition to wind energy projects in the UK, France, the Netherlands and Greece than, for example, in Denmark or Germany (Predace 2003; Szarka 2006).

According to the authors, *'Societal acceptance is not necessarily an issue of accepting or rejecting a specific technology, but rather pertains to the way in which the technology is introduced in a new context*' (see also Green 1999). Users and supplier networks are often more critical stakeholders in energy efficiency and solar energy projects, whereas local residents would appear more often critical concerning bio-energy and wind power facilities (Brohmann et al., 2007). Some of the cases indicate that the regional familiarity with aspects of the different technologies support acceptability (e.g. the use of biomass in a rural context in Germany or the use of photovoltaics panels in Italy). Here, innovation could be linked to the traditional use of renewable energies or to culturally already accepted practices such as agriculture or forestry.

Brohmann et al. (2007) identified four broad categories of contextual factors that influenced the societal acceptance of new energy projects at the national and local level. Some factors are particularly interesting.

– In terms of *political and policy issues*, the stability of policy instruments is considered to have an influence on public confidence in the new technology projects, as well as government policies are influenced by the societal acceptance of policies and technologies. Moreover, national and local policy cultures and administrative procedures provide variable conditions for projects to seek alignment among different interests. The importance attributed to energy independence and security of supply at national and regional levels could significantly boost the societal acceptance of some projects, whereas low energy prices, high production factor costs and competing technologies and industries were problems that many projects have to grapple with.

– *Socio-economic issues* are found to be important in promoting several projects, but the case studies also indicated that issues of development were often subjects of controversy in which projects could become embroiled.

– *Cultural factors* relate to historically shaped traditions and beliefs. These include the level of trust in different institutions involved in the project. Different local traditions influence the ability of projects to mobilise bottom-up initiatives or to introduce top-down plans without resistance. Levels of environmental awareness influenced the relevance of environmental arguments (such as combating climate change) in justifying the projects. Furthermore, different technologies have variable track-records in terms of positive or negative historical experiences among the local population. Some citizens are more supportive because they have more knowledge and experience with specific technologies. Further, overall attitudes to new technologies can also influence the acceptability of a project: novelty can be a bonus in some regions, but a cause for concern in others.[30] Furthermore, social references seem to influence both acceptance and resistance to renewable energy technologies. For example, friends and neighbours seem to be important references for investing in solar panels (Fischer and Sauter, 2004). Similarly, friends and relatives' opinions were found to be important determinants of people's views on local renewable energy projects (Devine-Wright, 2005).

– Concerning *geographic factors*, while the availability of natural resources may be regarded as an objective input, the authors found that perceptions of the abundance of different energy sources could differ, and influence public confidence in the projects.

The analysis of controversial and successful projects shows that new technologies cannot be merely brought into a new context without preparation or adaptation. In ideal situations, new technologies would be 'reinvented' in the local context. The analysis highlights the importance of achieving local embeddeness as an important success factor. According to the authors, the concept of 'local reinvention' points to the notion that such problems engenders new, innovative solutions that enhance the technology but suggesting new configurations of local fuel production, energy generation, energy supply and use, and the supporting institutions. (Brohmann et al., 2007). Innovation may therefore arise from the necessity to translate foreign ideas into local contexts (e.g., Powell et al., 2005).

The study by Heiskanen et al. (2007) indicates that trust or distrust in the initiators of the project (press, government, large companies, religious institutions, voluntary organisations, and in other people…) can influence the possibilities of the project to gain societal acceptance. For example, the successful Polish projects under focus in this study indicate the importance of the involvement of local government, as trust in the national government is relatively low.

Concerning information about energy issues, Europeans tend to trust mostly scientists (71%) and to a great extent environmental protection organisations/consumer associations (64%). On the other hand, political parties enjoy the confidence of only 13 per cent of respondents. Presumably, EU citizens tend to trust those information sources, such as scientists and NGOs, that do not apparently have a direct interest in the energy field in commercial or political terms (Eurobarometer 262). Considering public authorities, 69 per cent of Swedish respondents indicate that they trust local/regional authorities and 66 per cent have faith in the national government while only 9 per cent of French citizen believe in information given by the national government, and 29 per cent of British respondents trust their local authorities.

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[30] For example, the Icelandic ECTOS case (Heiskanen et al., 2007) shows that the entrepreneurial national spirit and interest in new things facilitated the introduction of a hydrogen project, which was novel and risky at the time it was launched. The novelty of the technology actually served as an attractor for the project, whereas it might be a cause for suspicion in another context.

The main factor that seems to emerge as an explanation for variations in local support or resistance is the level of participation of local residents in the planning process (see also McLaren Loring, 2006). Social factors that have been shown to contribute to local conflicts include (Predac, 2003; Khan, 2004; Rohracher et al., 2005, as reported by Heiskanen et al., 2007):

- The development is involuntarily imposed on the locality from someone from 'outside'
- The technology is not familiar
- Local people's concerns are overlooked and they are not involved in the decision making
- The development is for corporate profit rather than local benefit
- The developer uses 'decide-announce-defend' – strategy.

5.2.1 Policy recommendations

The following policy recommendations emerged from one of the energy panel meetings that was organised under the Innovation Watch Systematic project. The energy panel has energy sector experts as participants. In general, the panel acknowledged the crucial importance of sociocultural factors for innovation, in particular the role of public awareness as a shaping factor of the sector's economic performance. The panel expressed interest to communicate this issue to the president of the European Commission presenting it as a major theme for future actions in the energy sector. The panel considered a number of issues to address in this context including education plans, life long learning, public understanding and literacy issues.

The panel has put forward several policy recommendations related to the sociocultural issues identified in this study:

– Consumer willingness to pay for eco-innovative products and services was mentioned as a key factor. Nevertheless, it was argued that high prices of energy stimulate research and innovation on renewable energy sources.

– It was also suggested that EU should support research on technologies with an indirect but considerable environmental impact, most notably ICT. Technologies for monitoring energy management in households could be another area for further inquiry with a potential for innovative solutions for reducing energy waste.

– More research on incentives for attitude change, behavioural change is an area for innovation policies. Energy consumption is intrinsically related to lifestyle. Consequently, policy planing must take into account changes in consumer behaviour and public awareness related to energy consumption.

– The shortage of engineers and technicians with relevant skills and competences is a clear problem to innovation and growth for all kinds of energy production. Since, there are considerable differences throughout the world in terms of the quality of education at lower skill-levels, one should not only focus on skills in tertiary education, but also at lower levels;

it is the complementary and balanced mix of skilled labour that would be important, not just the quality of the high end of the formal skills.

– The experts also agreed on the point that mobility of researchers is currently below the optimal level. EU research and innovation policies should therefore stimulate public–private mobility flows of human resources in science and technology.

– The panel was very supportive for further research on sociocultural factors shaping innovation in the sector and advised the EC to focus more research funding on these issues. Furthermore, concrete action involving sending a letter with recommendations to the EC on this point will be taken before the end of the Sectoral Innovation Watch project.

6 Innovation Policy

6.1 Overview of sectoral innovation policy programmes

In order to establish an overview of the existence of policy measures and policy programmes in the European context, a dedicated survey was constructed. It aimed at the identification of specific sectoral measures in all EU countries and for all sectors. Measures were defined rather broadly:

> (Dedicated) initiatives which influence the given sector such as financial incentives, a specific regulation, quality requirements or research and innovation programmes.

A total of 790 measures were identified.[31] While this sounds impressive, a closer analysis of the measures indicates that only a small share is devoted to the specific sectors under analysis *as such*. Fiscal incentives, quality regulations and even research programmes are rarely made on an exclusive basis but every so often they apply to 'SMEs', 'the manufacturing sector', 'strategic sectors' etc.

Table 6.1 Number of measures per sector and share of targets and types in per cent (Number of cases: 1157)

Sector	**ICT**	**Aeronautics**	**biotech**	**chemicals**	**automotive**	**food**	**gazelles**	**machinery**	**eco-inno**	**energy**	**textile**	**Total**
What are the targets of the measures?												
All industry sectors	36	24	30	37	40	28	41	41	49	36	47	433
particular industries	25	44	38	49	38	44	19	38	32	38	34	416
large companies	36	59	45	43	45	34	17	46	38	45	42	466
SMEs	57	67	59	59	61	61	85	59	61	45	65	710
Research organisations	39	56	64	49	46	39	26	39	49	42	30	502
Individuals	21	13	22	20	18	27	20	20	30	35	15	258
Other	25	21	18	14	10	11	8	23	18	16	12	181
What are the types of measures?												
Cluster initiative	23	24	32	21	24	22	16	13	29	7	14	241
Technology platform	26	24	16	24	18	14	14	17	31	25	14	235
Innovation program	45	35	45	43	56	43	45	48	49	35	47	520
Regulation	9	11	6	9	3	10	6	3	9	13	3	85
Competition regulation	1	3	2	0	1	6	0	0	1	5	2	22
Quality regulation	2	8	3	6	4	13	1	4	5	7	9	64
Fiscal initiative	16	24	26	21	30	23	38	24	31	35	20	302
Other	24	25	18	23	21	17	25	28	15	15	20	237
Number of measures	121	63	125	111	120	109	105	71	115	110	107	1157

The respondents were asked to provide specific information on the targets (such as large companies, SMEs) and the type of measure (e.g., cluster initiative, quality regulation). Multiple responses were possible. Comparative aggregate data for all the sectors are provided in Table 6.1.

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[31] Finland is not covered in this analysis.

Comparing the number of measures (790) and the number of cases (1157), one notices that a number of measures are not specific to a single sector but are valid for more than one sector.

In absolute numbers, the smallest number of measures was reported in the space and aeronautics sector (63) followed by machinery (71) while the largest number – almost twice the size of aeronautics – was reported in biotechnology (125).

In terms of **targets**, there are similarly wider differences between the sectors. SMEs are the favourite target of most measures. 61 per cent of all cases embrace SMEs in one way or another. While they are the prime focus of gazelles measures (85%), for the more classical industry sectors, the energy sector scores the lowest (45%) and the aeronautics sector with 67 per cent the highest. However, shares around 60 per cent are found in all other sectors as well. When it comes to **type of measure**, again, interesting differences were reported. For example, we asked for 'cluster initiatives' and 'technology platforms', two types of measure which have influence at EU level. Both types were found in 21 per cent or 20 per cent of all cases but there is a greater variance between the sectors for both types. The lowest share for clusters was found in the energy sector (7%) while the highest was reported for biotechnology (32%).

Another way to characterise a measure is by asking the policy intention: fiscal incentives, quality regulation, technical norms etc. are types of political choice.

Compared to the descriptors above, the policy intentions were reported to be of less importance. It seems that at least a larger share of the measures provide fiscal incentives (26%), which is rather high compared to 7 per cent for general regulations, 6 per cent as a quality regulation and only 2 per cent as competition regulation. The 'other' regulation type received a high share of 20 per cent. Among this group are several explanations which can be re-grouped under the previous headings such as 'legal norms' which fits under 'regulation' or 'Grants to increase competitiveness/innovativeness of economy' which is a 'financial regulation'.

Among the politically motivated regulation types, differences between sectors are for example the highly regulated energy sector (13 per cent), regulated with competition and quality laws is the food sector (6%). Gazelles are the (non-traditional) sector benefiting most from fiscal incentives (38%), followed closely by the energy sector (35%) and eco-innovation (31%). Fiscal initiatives are not too common in the ICT sector (16%).

Compared to the other sectors under scrutiny, the energy sector is characterised in terms of policy measures by an average number of measures (110 in total). Measures can be found in almost all EU countries: 36 per cent of the measures are addressed at all industry sectors and 38 per cent at particular industries. Above average are those measures addressed to large companies (45%) while SMEs are addressed below average (45%). Research organisations receive a share of 42 per cent and individuals 35 per cent – the latter is the highest share among all sectors covered. In terms of frequency, the sector has the highest share of innovation programs among its measures (35%). In terms of cluster initiatives the sector has the lowest share among all sectors with 7 per cent, and an above-average share of 25 per cent in technology platforms

In terms of political intentions, the energy sector has above-average shares in all regulative items: it has the highest share among all sectors in the category of (general) regulation (13%), competition regulation (5%) and quality regulation (7%). Similarly, fiscal initiatives receive an above average share (35%).

6.2 Policy challenges

European energy policy-makers face a range of interrelated trends and challenges such as energy demand/consumption, energy prices, energy markets and integration/(de)regulation, energy efficiency, energy security, sustainability and climate change. The relation between these factors and their projected long-term trends renders the energy production sector a complex and policy-sensitive sector. The EU Green Book on *European Energy Strategy* (2006) outlines energy policy trends. Europe as a whole is facing a number of serious challenges and trends discussed in The Green Book. These include the following:

- Investment. There is an urgent need for investment. In Europe alone about 1000 billion euro are needed to cover expected energy demand and to replace worn-out infrastructure.
- Imports. The dependence on imports is increasing. Some imports will originate in politically unstable regions.
- Reserves. Reserves are concentrated in relatively few countries. About 50 per cent of EU gas demand is currently covered by three countries: Russia, Norway and Algeria. The dependence on imported gas will increase to about 80 per cent of EU gas demand over the next 25 years.
- Global demand. Global demand for energy is increasing. Total energy demand – and corresponding CO_2 emissions – is expected to increase by about 60 per cent over the next 25 years. Demand for oil is increasing by about 1.6 per cent per year.
- Prices. Prices of oil and gas are increasing strongly, as is the price of electricity. It is tough for the consumers, but may represent an incentive for innovation and increased energy efficiency.
- Market. The EU has not yet fully developed competitive internal energy markets. The EC advocates that the consolidation of the energy sector should be market-driven if Europe is to be able to handle these challenges and make the necessary investments in the future.
- Climate change. Climate change indicates that global temperatures are increasing. The UN panel on climate (IPCC) has warned that if we do not act now in order to decrease emissions of greenhouse gas, all parts of the world will be affected. About 25 per cent of global sulphur dioxide and nitrogen oxides originate in Europe. Europe alone

accounts for 25 and 16 per cent of global carbon dioxide and methane emissions respectively arising from all human activity.

- Pollution. The main impacts arising from energy use are local air pollution, acidification, and climate change (just a minor impact can be mentioned with respect to tropospheric ozone). There are also more local impacts on water, soil and land.
- Emissions. Energy consumption accounts for around 95 per cent of human-induced sulphur dioxide emissions, and 97 per cent of nitrogen oxides in 20 European countries (1990).

7 Conclusions and policy recommendations

7.1 The innovation policy argument

Europe faces a considerable number of challenges in the energy production sector, challenges which may be difficult to reconcile. Europe is committed to reduce its CO_2 emissions, to reduce its dependence on energy imports and it must meet the rapidly increasing consumer energy demand. At the Spring 2007 EU Summit, Member States committed themselves to take the lead against the threat of global warming, a bold policy decision which unites all Europe behind a common and ambitious policy project where the EU provides a moral example.

Europe’s greatest policy challenge in the next few decades is hence to find a good balance between these three policy objectives, that is, to secure CO_2 emissions, to secure its energy supplies, reduce energy imports and to satisfy the increasing energy consumption. In this policy context, European innovation policies can play a key role for achieving these broader energy policy objectives.

Admittedly, innovation policies have as their ultimate objective and justification the increase of productivity, competitiveness and economic growth in the entire economy. This is probably a most justified goal for many other industrial sectors in the economy, but in the case of energy production we may need to promote innovations and innovation policies which could lead to temporary losses of economic efficiency in exchange to larger gains in environmental efficiency and reductions in energy supply risks in the future.

In other words, the trade-offs between socio-economic and societal goals seem to be more articulated in innovation policies for the energy production sector compared to other sectors of economic activity such as, ICT, textiles and so forth. For example, considerable sums are invested in research activities aiming at cost reductions in oil production processes. These investments result in improved economic performance in the sector, but it do not necessarily lead to more sustainable energy production in the future. There are countries, such as Norway, where the public supports directly and indirectly such research activities because these have an obvious positive impact on the national economy and on the national innovation system.

The European challenges in this sector are, however, not of the economic productivity and novelty type. One of the most profitable industries in the European economy is the oil and gas industry and the electricity production industry. As clearly indicated in Chapter 2, the European energy production sector has increased labour productivity, and value added per employee in the period 1996–2004 compared to manufacturing.

However, if efficiency and effectivity gains in the sector take place at the expense of a rapid uptake of renewable-based energy supply, this is clearly a suboptimal result seen from a dynamic efficiency perspective. As mentioned, there is a commitment in Europe dictating that in the long run, all energy production must be sustainable as well as cost-efficient. Given that, all scenarios reducing the pace of the substitution from non-renewable to renewable energy sources should be considered as dynamically inefficient.

On the other hand, all modern economies, depending on the intrinsic specificities of their national energy systems, have to find a time-frame, an optimal combination of energy sources and energy policies which lead to the fastest transition paths to sustainable energy production by keeping the costs of this transition within socially acceptable levels.

Hence, there is an obvious trade-off between long-run environmental benefits versus short run economic costs, including costs of developing new sustainable technologies. In our view, innovation policies can contribute to alter the terms in this trade-off, with the ultimate goal of contributing to finding the optimal path for the fastest and least costly transition to fully sustainable energy production systems.

Keeping this in mind, one could agree on some basic simple principles for what qualifies as a good (dynamic efficient) innovation policy for the energy production sector. First, a reasonable policy direction would be to stimulate – and probably support financially– the further development and adoption of advanced cleaning technologies (CO_2, coal, peat, etc.) in order to limit the detrimental environmental effects from fossil-based energy sources as far as possible. As mentioned, Europe and the entire world are dependent on oil, gas, coal, peat and lignite energy consumption, probably for many years to come. The fact that in China one new coal-based energy production plant is built every week underscores the importance – and the market potential – of this policy task.

Second, innovation policies should aim at a balanced support for the creation, the improvement and commercialisation efforts of all types renewable technologies. Not all of these technologies are relevant to all Member States. Therefore, it would be helpful to assess costs against potential benefits from the many existing and competing with each other renewable energy sources for an estimation of an optimal[32] energy source mix at a regional, national and European levels.

Third, innovation policies should support R&D and innovation efforts on more flexible and ‘smarter’ infrastructure set-ups allowing a more efficient, cheaper and faster uptake of energy supply from renewable energy plants. As documented in the report, there are indications that infrastructure investments in electricity (and gas) supply have been falling in recent decades, a fact that many experts consider as a very worrying indication, not only because this slows down the uptake of (more unstable) renewable energy supplies, but because it increases incidents of blackouts and unstable energy supplies in the (traditional) energy supply system. There is an ongoing debate whether infrastructure investments suffer from the increased

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[32] Optimal in a dynamic sense, since both costs and benefits may alter considerably as the technology front in all these technologies constantly shifts due to R&D and innovation.

market competition on the national markets of energy supply, reducing profit margins and hence rendering marginal grid investments more expensive than prior to the new market liberalization regimes. We are not entering into this discussion, but it suffice here to note that infrastructure technologies and new infrastructure equipment play a decisive role in the future development of the European energy system. Without 'smarter' and more flexible energy supply infrastructures it is also more difficult to achieve a real common European energy market.

Fourth, traditionally with innovation policies, we understand public support to R&D and innovation activities. This is what OECD 2004 referred to as narrow-innovation policies. There are a number of other more horizontal (holistic) policy initiatives which are also needed if Europe is to achieve its ambitious energy policy objectives. Primarily, there is a need for improved interaction and integration of innovation, energy and competition policy governance settings, both at the national and European levels. Subsequently, boosting efforts for a common European energy market is a fundamental prerequisite, not only for the more efficient use of energy supplies in the Union, but also for the uptake of renewable energy supply. For example, Europe could profit from common regulation and incentive measures, such as an *European market for green certificates*, an European plan for advanced electricity grid infrastructures, common pricing systems, etc. For this, there is a need for coordinated action throughout Member States and across policy sectors in EU.

7.2 Implementation of energy production innovation strategies

An effective implementation of innovation policies goals has to take into consideration the structure, modes of innovation activities and human resources available in the fragmented European energy innovation system, as well as the actors, networks, technological frontiers and knowledge bases available.

Innovation modes and industrial structure
Chapters 3 and 4 in this report establish beyond any reasonable doubt the fact that the dominant innovation mode in the energy production sector is that of a non-R&D based incremental and process-oriented type. This is true for all the three sub-sectors, oil, gas, peat, coal and other mining (NACE10-12), manufacturing of petroleum end related products (NACE 23) and electricity and heat production (NACE 40-41). There are few large R&D-intensive actors and these usually large oil companies. This, despite the fact that sector consists of a relatively high number of large and profitable companies; it is a well-established fact that large firms as a group invest much more in R&D compared to the group of SMEs.

From CIS-data we know that the large players in the energy sector mainly pursue non-R&D-based innovation strategies seeking efficiency gains within the existent technological paradigm of fossil-fuels (or nuclear) energy production. These companies have also an unusual high profitability and profit rates (see Figure 4.2 in Chapter 4).

Having said that, almost all large companies within the oil and gas mining sector – Shell, BP, Esso, StatoilHydro and so forth conduct research of considerable size and scope either on cleaning technologies or on renewable technologies or (which is most often the case) on both. Some critics claim that this is mainly a decoy device for maintaining their good branding among their consumers while keeping 'business as usual'. However, this claim seems unfair as it contradicts with the fact that oil companies' involvement in the renewable sector is normally organised as separate business units dedicated to promote and generate income. It is in fact a rational choice for these companies to differentiate their product and energy source portfolios in order to position themselves in the upcoming new generation of technologies in the sector. Incidents of predatory behaviour against promising small young companies have been reported, but this seems to be more the exception than the rule.

Unlike the large firms in the mining sub-sectors, the large firms in the electricity production sub-sector are far less R&D-intensive. By contrast, there is a considerable share of younger SMEs in this sector which are R&D-performers on renewable technologies but they experience much lower profit margins compared with the larger companies in this sector.[33]

Very schematically, we could claim that the sector is polarised between large, non-R&D process innovating incumbents on the one hand, and on the other hand small new entries, often R&D-based and specialised on one type of renewable energy technology. The latter seem to experience liquidity challenges and growth barriers while the former are the incumbents who seem to reap the benefits of increasingly more efficient (but conventional-sourced) technologies.

Furthermore, there are indications, that all firms in the sector, large, medium and small, seem to overly depend on and benefit from innovation taken place within and in collaboration with knowledge-intensive suppliers (which are excluded form our statistical definition of the energy production sector).

Given these stylised facts – and keeping in mind that there is a structural heterogeneity between Member States which render policy generalisations a slippery domain – the innovation policies should focus on the following.

- Environmental taxes should be invested in R&D on renewable and cleaning technologies as there is a clear need and expectation to increase the overall government R&D-budgets within this socio-economic objective. A (partial) redistribution of taxes for R&D activities will also provide conditions for increased

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[33] Please note that in the SYSTEMATIC-project it was not possible to identify the number, the size, R&D-investment shares etc. of firms based on energy production from renewables. Our argument is therefore, based on the opinion of sector experts and only indirectly from the actual quantitative evidence produced for the SYSTEMATIC-project. The main reason for that is that the existent industrial sector statistical nomenclature (NACE 2.1) does not separate renewable from conventional energy production. In the new version of industrial sector classification this problem is solved.

funding of large scale research programs addressing systemic problems (as some technology platform initiatives do).

- Stimulate cross-border research collaboration in the field of renewable energy.
- Increase substantially public R&D funding to small firms (within the renewable paradigm) in the sector. This could be done in the form of more favourable tax credits to these firms compared to others.
- Engage larger companies, in particular within the electricity production sub-sector in R&D-activities within new and/or improved cleaning technologies or at developing renewable technologies. In doing this it is important to involve suppliers and, if appropriate, other smaller energy producers.
- Stimulate, promote and support collaboration between small and large companies and universities, government pubic research organisations (GPOs) within renewable technologies.

Technologies and human resources
There is a large number of renewable technologies and the scientific frontier within each one of these technologies is changing fast as a result of new knowledge from R&D as well as learning-by-doing externalities. All seem to have strengths and weaknesses but all share in common that energy from renewable sources is still costlier than energy from fossil-fuels, though surging oil prices changes this fast and opens an opportunity window for many if not all alternative types of renewable energy sources.

Several countries have already developed a specialisation profile for energy production. Denmark excels in wind technologies, Norway on CO^2 storage, Germany, Spain and others on photovoltaics etc.

This natural evolution represents a strength for the European energy production system, but it is also important to avoid duplication of efforts and suboptimal research activities if and when they occur.

We also know little about the more detailed skill and competencies needs of the energy production sector. We document in this report that ICT-personnel are considered as a scarce factor, less so the managerial personnel. We need to further investigate both demand and supply shortages of skills and competences in the sector with the Member States. More attention could be paid to curricula providing special studies within the energy production among engineering students and in other areas of technical education.

Consumer demand – European sociocultural characteristics
Energy consumption is intrinsically related to lifestyles and broader patterns of consumption. Policy planning must therefore take seriously into account changes in consumer behaviour and public awareness. Educational programs, marketing information campaigns shape the

consumer's mindset and willingness to pay for costlier but also more environmentally friendly energy production devices and infrastructures. From the innovation literature we know that learning by doing externalities are of crucial importance for the inception and further development of a technology. This is also true for the new renewable technologies. Favourable conditions in consumer demand and grass root pressure on governments for more environmentally friendly energy production policies are key factors for a rapid change from fossil to renewable energy production in Europe.

Hence, promoting public understanding of energy technologies, education programmes on energy sources (at all levels) and more determined public procurement policies are some of the broader issues that should be addressed in relation to the more specific innovation policies for this sector.

7.3 Conclusions

As a conclusion, a realistic European innovation policy strategy could be consisting of a balanced combination of:

7) providing incentives for development and the adoption of advanced cleaning technologies, an area where Europe could develop a know-how and a technological advantage;

8) increasing public and private R&D in renewable energy sources at national and EU-levels , since public R&D-support is below the level one would expect based on the centrality of the issue in later policy rhetoric (see Pedersen, Kaloudis 2006);

9) supporting and stimulating energy efficiency and saving technologies as well as consciously develop competitive advantages for Europe in eco-innovation and green product industries. Energy saving technologies will contribute to lower levels of consumption of fossil-based energy sources, to the slowing-down energy demand increases and, hence, to the containing of energy supply risks for EU (this argument is more developed in the eco-innovation final sectoral report);

10) introducing incentives and standards which encourage the take-up of efficient renewable technologies;

11) keeping the focus on developing a European energy market with a pricing system which ensure that the beneficiaries pay full costs, including environmental costs.

12) investigating and experimenting how innovation activities in the energy sector may directly and be shaped by sociocultural parameters, mark-up margins the public is willing to pay for cleaner energy sources, public awareness, public acceptance of new energy sources, etc. This is a clearly unexplored policy area of a great potential impact.

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Annex

Table A1 Characteristics of Energy innovators by innovation mode (average for all sectors highlighted)

	All firms		**Non-innovators**		**Innovators**		**Strategic innovators**		**Intermittent innovators**		**Diffusion innovators**	
FIRM CHARACTERISTICS												
Share of all firms			63.8	62.9	36.2	37.1	2.7	5.9	11.6	15.5	21.9	15.7
Share of innovative firms							7.4	15.9	32.0	41.7	60.6	42.4
Product only innovator (% share)	11.8	11.9			32.5	32.1	45.9	32.1	14.4	36.4	40.4	27.9
Product and process innovator (% share)	13.0	16.0			35.9	43.1	51.4	67.7	61.6	49.2	20.4	27.8
Process only innovator (% share)	11.4	9.1			31.6	24.7	2.7	0.0	24.0	14.1	39.2	44.3
Average firm size (employee)	421	140	193	49	824	294	6426	948	526	227	297	114
Labour productivity (1000's euros per employee)	383	239	226	178	448	256	527	261	427	242	258	265
Turnover growth (%-point)	7.55	6.53	4.99	5.19	8.12	6.80	9.29	7.19	6.51	5.97	4.72	7.10
Employment growth (%-point)	-3.80	1.86	-3.36	0.76	-3.98	2.18	-4.94	2.45	-2.01	1.77	-3.15	2.13
Export growth (%-point)	24.14	11.77	22.69	5.81	24.33	12.46	24.08	13.71	27.73	10.97	16.58	10.39
Share of employees with higher education	15.0	14.2	15.2	10.9	14.9	15.1	15.4	16.4	15.4	13.8	12.8	13.6
SALES												
Sales share due to new-to-firm products	9.4	18.2			11.4	21.8	9.5	20.2	15.1	22.9	15.8	24.6
Sales share due to new-to-market products	7.3	7.1			8.9	8.5	12.3	10.4	1.9	7.4	1.2	5.0
(Inter)national market most significant market	28.4	58.6	20.4	53.2	42.4	67.9	100.0	100.0	60.2	76.2	26.0	47.7
National market most significant market	*21.7*	*39.9*	*14.3*	*37.8*	*34.7*	*43.4*	*75.8*	*52.3*	*47.9*	*49.7*	*22.7*	*33.9*
International market most significant market	*6.7*	*18.8*	*6.1*	*15.4*	*7.7*	*24.5*	*24.2*	*47.7*	*12.3*	*26.5*	*3.3*	*13.8*
INNOVATION ACTIVITIES												
Share of firms that perform intramural R&D	17.6	20.5			45.6	51.0	100.0	100.0	90.6	76.7	15.3	7.4
Share of firms that acquire extramural R&D	11.0	7.2			25.8	18.5	36.6	36.3	56.4	22.6	8.3	7.8
Share of firms that buy advanced machinery and equipment	28.1	26.3			70.6	66.7	58.0	71.6	66.1	63.7	74.4	68.0
Share of firms that buy other external knowledge	7.3	8.5			19.5	21.5	23.9	30.4	29.0	21.3	14.0	18.3
Share of firms that train personnel	16.2	16.9			36.6	42.7	40.2	62.2	39.0	46.4	34.9	31.7
Share of firms that spend money on market introductions	11.5	13.6			29.7	34.6	39.8	58.1	26.2	39.8	30.3	20.7
Share of firms that spend money on design or other preparations for production/deliveries	14.2	13.4			33.1	33.5	44.1	56.0	22.8	37.0	37.1	21.6
INNOVATION ACTIVITIES - SPENDING												
Intramural R&D expenditures	32.0	55.9			34.0	56.1	46.6	67.3	47.0	45.8	7.6	37.9
Extramural R&D expenditures	12.9	5.2			13.1	5.2	13.8	6.8	16.5	5.2	8.9	0.6
Acquisition of advanced machinery and equipment	38.5	32.0			36.4	31.8	32.3	23.9	30.2	40.8	47.1	42.8
Acquisition of other external knowledge	15.8	6.8			15.5	6.8	6.6	2.0	4.8	7.8	35.8	18.5
Other innovation expenditures	0.8	0.2			0.9	0.2	0.7	0.1	1.5	0.4	0.5	0.1
PUBLIC FUNDING												
Receive funds from local or regional authorities	3.3	5.7			8.3	15.0	17.4	22.5	9.0	13.3	6.7	13.9
Receive funds from central government	4.7	5.1			12.3	13.1	23.8	26.1	14.4	12.6	9.8	8.6
Receive funds from EU	1.9	2.3			5.2	5.9	22.5	11.1	7.9	6.0	1.7	3.9
INTELLECTUAL PROPERTY PROTECTION												
FORMAL METHODS												
Applied for patent	7.8	6.2	0.7	1.7	20.2	14.0	69.1	38.6	41.6	14.9	2.9	4.0
Used registration of design patterns	3.3	5.6	0.5	1.8	8.1	12.2	51.7	28.8	11.7	13.5	0.9	4.6
Used trademarks	7.1	9.9	2.4	5.2	15.3	18.0	57.7	34.4	20.1	20.4	7.5	9.4
Used copyright	1.8	2.7	0.4	1.1	4.2	5.4	37.0	11.0	2.4	5.9	1.2	2.7
STRATEGIC METHODS												
Used secrecy	12.9	12.8	4.3	4.8	28.0	26.3	81.1	54.4	52.1	29.7	8.9	12.3
Used complexity of design	3.9	7.7	0.8	2.4	9.2	16.7	51.7	32.1	10.6	19.6	3.2	8.0
Used lead-time advantage on competitors	9.5	15.7	4.1	5.9	19.2	32.4	83.3	61.2	28.1	37.0	6.7	17.0
STRATEGIC OR ORGANISATIONAL CHANGE	64.8	56.5	56.8	43.0	79.0	79.6	96.7	90.2	84.6	82.9	73.8	72.3
Implemented new or significantly changed corporate strategies	35.2	26.5	32.4	16.4	40.2	43.7	45.2	58.8	43.2	46.6	38.1	35.3

	All firms		**Non-innovators**		**Innovators**		**Strategic innovators**		**Intermittent innovators**		**Diffusion innovators**	
Implemented advanced management techniques	38.1	24.3	29.7	15.7	52.8	38.9	49.2	52.2	59.9	40.8	49.5	31.9
Implemented new or significantly changes organisational structures	40.2	35.1	36.7	23.8	46.4	54.2	91.5	68.9	38.8	55.9	44.9	47.1
Changed marketing concepts/strategies	29.3	25.8	25.0	17.3	36.8	40.3	39.7	54.9	36.8	43.0	36.5	32.0
Changed aesthetic appearance or design of products	17.1	29.6	11.1	19.3	27.5	47.1	70.6	60.3	23.2	49.8	24.5	39.5
EFFECTS OF INNOVATION												
PRODUCT ORIENTED EFFECTS												
Increased range of goods or services	21.9	28.2			60.3	75.7	89.6	91.9	52.9	82.3	60.7	63.1
High degree of impact	*3.2*	*4.9*			*8.8*	*13.0*	*8.2*	*8.0*	*8.9*	*15.0*	*8.7*	*12.9*
Increased market or market share	20.6	28.5			56.8	76.5	92.6	93.7	50.3	82.6	55.8	64.1
High degree of impact	*9.9*	*6.1*			*27.4*	*16.4*	*16.2*	*11.3*	*11.6*	*17.6*	*37.1*	*17.1*
Improved quality in goods or services	28.9	31.1			79.5	83.7	96.1	94.8	89.4	88.2	72.3	75.2
High degree of impact	*3.9*	*2.9*			*10.7*	*7.9*	*15.0*	*7.4*	*11.1*	*8.8*	*9.9*	*7.2*
PROCESS ORIENTED EFFECTS												
Improved production flexibility	16.8	24.3			46.4	65.3	84.8	78.6	45.0	67.7	42.4	57.8
High degree of impact	*6.1*	*5.2*			*16.8*	*13.8*	*18.5*	*13.1*	*14.9*	*14.5*	*17.6*	*13.4*
Increased production capacity	18.1	25.4			49.9	68.2	81.2	75.4	72.0	69.8	34.5	63.9
High degree of impact	*4.4*	*5.0*			*12.0*	*13.5*	*16.5*	*17.7*	*16.2*	*13.7*	*9.3*	*11.7*
Reduced labour costs per produced unit	19.1	23.8			52.9	63.9	83.1	72.9	67.7	65.3	41.3	59.1
High degree of impact	*6.4*	*6.7*			*17.7*	*18.1*	*27.1*	*21.1*	*18.2*	*19.5*	*16.3*	*15.6*
Reduced materials and energy per produced unit	17.9	19.5			49.3	52.3	82.2	62.2	68.3	55.8	35.3	45.1
High degree of impact	*4.6*	*8.1*			*12.8*	*21.6*	*15.1*	*23.6*	*9.6*	*24.2*	*14.3*	*18.4*
OTHER EFFECTS												
Improved environmental impact or health and safety aspects	20.8	18.2			57.0	48.9	94.3	57.8	80.4	51.7	40.1	42.9
High degree of impact	*4.0*	*5.0*			*11.0*	*13.4*	*4.1*	*17.2*	*10.3*	*13.5*	*12.2*	*11.9*
Met regulations or standards	21.2	20.4			58.3	54.7	92.0	66.7	48.7	57.3	59.3	47.6
High degree of impact	*7.9*	*4.4*			*21.9*	*11.8*	*24.2*	*16.1*	*8.1*	*12.5*	*28.8*	*9.5*
INFORMATION SOURCES USED												
INTERNAL SOURCES												
Within the enterprise	36.3	33.8			88.5	85.1	97.6	94.9	90.0	89.5	86.6	77.1
High degree of importance	*7.4*	*5.0*			*18.2*	*11.8*	*19.7*	*6.3*	*11.7*	*12.1*	*21.4*	*13.5*
Other enterprises within the enterprise group	16.2	8.1			37.2	20.4	41.1	29.5	55.5	22.8	27.1	14.7
High degree of importance	*3.7*	*1.8*			*9.2*	*4.4*	*11.6*	*7.1*	*14.7*	*5.0*	*6.0*	*2.8*
MARKET SOURCES												
Suppliers of equipment, materials or software	30.1	30.0			73.6	76.2	97.4	78.0	78.0	77.3	68.4	74.3
High degree of importance	*8.5*	*7.9*			*20.1*	*19.6*	*4.4*	*26.8*	*36.2*	*20.5*	*13.5*	*15.9*
Clients or customers	26.8	29.8			64.9	74.9	87.4	87.0	73.4	78.9	57.7	66.4
High degree of importance	*9.1*	*8.4*			*21.1*	*21.2*	*15.7*	*14.8*	*33.4*	*21.0*	*15.3*	*23.7*
Competitors and other enterprises from the same industry	30.5	26.4			74.8	66.4	86.2	72.7	74.0	69.4	73.8	61.2
High degree of importance	*10.3*	*11.1*			*27.0*	*28.0*	*49.1*	*30.3*	*34.8*	*28.8*	*20.1*	*26.4*
INSTITUTIONAL SOURCES												
Universities or other higher education institutes	19.0	11.3			45.6	27.8	53.8	50.3	43.0	30.5	45.9	16.6
High degree of importance	*9.2*	*5.6*			*23.5*	*13.7*	*16.4*	*19.6*	*15.5*	*15.6*	*28.5*	*9.5*
Government or private non-profit research institutes	11.2	8.3			23.4	20.7	42.0	36.7	29.6	22.4	17.9	13.0
High degree of importance	*4.0*	*4.6*			*9.4*	*11.6*	*17.9*	*19.8*	*10.1*	*12.7*	*8.0*	*7.5*
OTHER SOURCES												
Professional conferences, meetings, journals	30.1	25.8			72.9	64.4	93.8	78.2	83.6	67.0	64.7	56.8
High degree of importance	*7.7*	*10.3*			*19.6*	*26.1*	*5.4*	*26.3*	*36.7*	*27.0*	*12.4*	*25.2*
Fairs, exhibitions	24.5	29.5			57.1	74.0	92.2	83.3	56.3	77.3	53.3	67.4
High degree of importance	*10.1*	*9.8*			*26.1*	*24.7*	*23.3*	*25.8*	*24.4*	*26.2*	*27.4*	*22.9*
HAMPERED INNOVATION ACTIVITIES												
Innovation activities: seriously delayed	11.0	13.6			27.5	33.4	81.4	53.8	27.1	35.3	21.1	23.8
Innovation activities: prevented to be started	3.7	8.4			7.1	20.4	20.8	23.5	10.7	22.4	3.5	17.2
Innovation activities: burdened/cumbered with other serious problems	5.4	9.0			14.4	22.2	15.3	29.6	18.1	25.8	12.3	15.9
FACTORS HAMPERING INNOVATION												
ECONOMIC FACTORS												

	All firms		**Non-innovators**		**Innovators**		**Strategic innovators**		**Intermittent innovators**		**Diffusion innovators**	
Excessive perceived economic risks	42.9	48.4	33.0	40.7	60.3	61.4	46.4	66.9	44.1	62.7	70.6	58.1
High degree of importance	*13.0*	*13.1*	*10.1*	*10.3*	*18.1*	*17.7*	*7.3*	*20.5*	*10.2*	*19.1*	*23.6*	*15.3*
Innovation costs too high	47.1	53.1	38.0	44.9	63.0	67.1	86.8	71.7	46.1	68.9	69.0	63.5
High degree of importance	*19.0*	*10.7*	*13.1*	*8.8*	*29.5*	*14.0*	*42.1*	*17.2*	*14.2*	*15.8*	*36.0*	*11.1*
Lack of appropriate sources of finance	35.2	46.0	29.4	39.4	45.4	57.2	73.0	65.8	35.4	58.9	47.3	52.4
High degree of importance	*15.6*	*14.5*	*11.2*	*12.1*	*23.4*	*18.5*	*11.5*	*23.0*	*17.7*	*18.5*	*27.9*	*16.8*
INTERNAL FACTORS												
Organisational rigidities within the enterprise	37.4	37.0	27.4	30.2	55.2	48.6	32.0	52.4	40.5	50.6	65.7	45.2
High degree of importance	*17.2*	*17.6*	*12.3*	*13.5*	*25.8*	*24.6*	*16.9*	*30.3*	*17.1*	*26.3*	*31.5*	*20.9*
Lack of qualified personnel	40.1	45.2	32.2	37.1	54.1	59.1	64.7	64.4	38.8	61.6	60.8	54.7
High degree of importance	*16.4*	*15.2*	*14.1*	*12.4*	*20.5*	*20.0*	*16.4*	*23.6*	*12.9*	*21.5*	*25.0*	*17.1*
Lack of information on technology	30.7	37.7	23.7	31.4	43.1	48.5	63.3	52.6	32.8	50.7	46.1	44.8
High degree of importance	*17.5*	*19.7*	*13.7*	*15.1*	*24.3*	*27.5*	*27.4*	*34.1*	*18.6*	*29.9*	*26.9*	*22.7*
Lack of information on markets	32.4	37.3	24.6	30.8	46.1	48.4	32.0	54.6	32.6	50.3	54.9	44.1
High degree of importance	*22.0*	*19.7*	*18.8*	*15.6*	*27.7*	*26.6*	*10.4*	*30.0*	*20.4*	*29.3*	*33.6*	*22.7*
OTHER FACTORS												
Insufficient flexibility of regulations or standards	39.4	36.0	31.8	30.7	52.9	45.0	81.5	51.7	37.6	45.9	57.4	41.5
High degree of importance	*12.4*	*14.6*	*10.2*	*12.0*	*16.3*	*19.0*	*18.8*	*24.9*	*15.7*	*20.2*	*16.2*	*15.5*
Lack of customer responsiveness to new goods or services	41.8	39.8	36.9	35.9	50.5	46.5	76.2	54.1	32.4	48.2	56.9	41.9
High degree of importance	*17.5*	*17.9*	*16.1*	*14.6*	*20.1*	*23.4*	*6.9*	*29.4*	*16.0*	*25.5*	*23.8*	*19.2*

Table A2 Characteristics of energy industries by innovation mode

	All firms			**Innovators**			**Strategic innovators**			**Intermittent innovators**		
	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40
FIRM CHARACTERISTICS												
Share of all firms				30.0	58.0	33.9	2.2	11.9	1.1	7.4	19.5	11.3
Share of innovative firms							7.5	20.5	3.3	24.8	33.6	33.2
Product only innovator (% share)	13.0	16.0	10.6	43.4	27.5	31.4	4.7	78.2	6.7	22.3	27.2	9.0
Product and process innovator (% share)	9.4	24.5	11.9	31.3	42.2	35.0	78.2	21.8	93.3	45.2	57.4	65.9
Process only innovator (% share)	7.6	17.6	11.4	25.3	30.3	33.6	17.2	0.0	0.0	32.6	15.4	25.1
Average firm size (employee)	536	371	399	1301	584	781	11414	1844	12471	533	310	592
Labour productivity (1000's euros per employee)	108	1301	329	124	1280	386	122	1691	400	163	561	448
Turnover growth (%-point)	-7.38	24.76	2.04	-8.78	24.77	2.26	-12.76	27.19	0.41	0.18	17.91	5.05
Employment growth (%-point)	-8.22	3.90	-3.11	-10.25	4.51	-2.69	-12.96	7.40	-2.76	-4.37	-2.36	-1.55
Export growth (%-point)	12.70	36.49	32.59	11.58	36.44	45.65	8.13	41.22	471.36	18.53	25.61	50.03
Share of employees with higher education	8.1	20.8	16.5	8.0	21.2	16.2	7.8	26.2	16.2	12.5	11.8	16.5
SALES												
Sales share due to new-to-firm products	3.5	10.8	9.2	4.2	12.1	11.8	5.4	12.6	6.5	1.9	12.0	16.5
Sales share due to new-to-market products	1.6	5.6	9.2	1.8	6.3	11.8	2.5	7.2	19.8	1.1	1.0	2.1
(Inter)national market most significant market	44.2	56.5	18.9	66.5	76.5	25.9	100.0	100.0	100.0	85.2	58.7	56.1
National market most significant market	*24.6*	*46.3*	*16.4*	*40.0*	*63.1*	*24.5*	*63.2*	*85.0*	*65.2*	*35.0*	*31.4*	*55.4*
International market most significant market	*19.6*	*10.2*	*2.5*	*26.5*	*13.4*	*1.4*	*36.8*	*15.0*	*34.8*	*50.2*	*27.2*	*0.7*
INNOVATION ACTIVITIES												
Share of firms that perform intramural R&D	10.6	37.1	16.0	32.7	61.6	43.8	100.0	100.0	100.0	90.3	83.2	92.9
Share of firms that acquire extramural R&D	8.2	9.9	12.0	15.3	15.6	31.5	53.8	22.3	54.5	35.0	28.6	69.1
Share of firms that buy advanced machinery and equipment	29.1	38.4	26.0	70.0	63.7	72.9	76.7	35.8	90.5	54.1	46.9	74.4
Share of firms that buy other external knowledge	3.2	8.0	8.4	9.9	13.3	23.8	32.0	5.5	54.9	27.4	19.2	32.4
Share of firms that train personnel	12.1	11.5	18.2	13.7	18.4	47.9	53.8	12.2	86.3	28.8	37.1	41.4
Share of firms that spend money on market introductions	4.1	8.9	14.0	13.8	15.0	38.2	66.5	16.6	69.6	29.4	31.1	24.1
Share of firms that spend money on design or other preparations for production/deliveries	11.7	9.5	15.7	13.0	16.4	43.2	75.9	21.7	69.6	21.7	24.7	22.5
INNOVATION ACTIVITIES - SPENDING												
Intramural R&D expenditures	25.8	39.4	31.8	32.3	39.6	32.3	44.8	49.5	43.6	19.2	22.9	56.4
Extramural R&D expenditures	30.9	4.8	8.0	38.0	3.6	7.6	41.0	1.5	7.3	53.8	2.9	13.2
Acquisition of advanced machinery and equipment	41.6	48.9	32.9	27.7	49.8	34.2	10.7	47.4	29.0	25.0	65.6	23.8
Acquisition of other external knowledge	0.9	5.3	26.8	1.2	5.4	25.3	1.8	1.1	20.1	1.5	3.0	5.8
Other innovation expenditures	0.7	1.5	0.6	0.9	1.6	0.6	1.7	0.5	0.0	0.5	5.7	0.7
PUBLIC FUNDING												
Receive funds from local or regional authorities	1.6	4.9	3.5	4.9	6.4	9.7	21.8	5.6	37.8	6.8	9.8	9.2
Receive funds from central government	5.3	4.4	4.5	17.8	7.1	12.5	48.3	8.0	40.4	11.3	8.8	16.7
Receive funds from EU	2.0	2.1	1.9	6.8	3.2	5.4	31.1	6.7	48.2	9.9	0.8	9.7
INTELLECTUAL PROPERTY PROTECTION												
FORMAL METHODS												
Applied for patent	5.5	20.8	6.0	15.9	31.8	17.6	81.3	80.5	40.4	31.1	40.7	43.8
Used registration of design patterns	2.7	14.6	1.4	8.1	22.4	3.6	17.2	88.6	0.0	16.3	12.7	10.5
Used trademarks	7.0	17.9	5.1	21.2	28.0	9.8	66.5	67.1	34.8	16.0	37.7	15.4
Used copyright	2.2	4.2	1.2	7.1	5.8	3.0	21.8	23.1	72.2	10.8	3.1	0.7
STRATEGIC METHODS												
Used secrecy	12.9	31.6	9.5	15.7	48.4	24.7	41.3	91.5	82.9	44.9	46.8	55.1
Used complexity of design	3.5	13.5	2.2	11.0	21.6	4.9	43.7	72.5	16.3	23.0	20.2	5.3
Used lead-time advantage on competitors	14.1	24.5	5.6	19.7	38.8	13.0	53.0	92.9	81.9	52.6	43.2	18.9
STRATEGIC OR ORGANISATIONAL CHANGE	43.1	68.0	70.3	53.4	74.6	86.6	100.0	95.8	96.8	68.3	78.9	89.4
Implemented new or significantly changed corporate strategies	*24.6*	*38.1*	*37.6*	*28.4*	*44.8*	*41.7*	*32.1*	*32.8*	*76.0*	*48.0*	*54.8*	*38.7*
Implemented advanced management techniques	*28.2*	*30.1*	*42.2*	*34.0*	*41.7*	*60.8*	*58.5*	*32.8*	*75.6*	*50.1*	*44.8*	*66.4*
Implemented new or significantly changes organisational structures	*32.9*	*46.0*	*41.1*	*35.7*	*54.8*	*46.4*	*71.6*	*94.4*	*96.8*	*52.2*	*38.3*	*36.5*
Changed marketing concepts/strategies	*14.7*	*27.2*	*33.7*	*23.6*	*26.9*	*43.2*	*14.8*	*27.6*	*76.9*	*34.0*	*38.0*	*37.0*
Changed aesthetic appearance or design of products	*6.3*	*23.2*	*18.9*	*10.0*	*33.2*	*30.0*	*22.8*	*84.8*	*69.6*	*24.0*	*28.4*	*21.4*

	All firms			**Innovators**			**Strategic innovators**			**Intermittent innovators**		
	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40
EFFECTS OF INNOVATION												
PRODUCT ORIENTED EFFECTS												
Increased range of goods or services	21.8	35.1	19.5	72.2	60.5	57.3	59.5	98.5	89.1	62.4	74.4	44.4
High degree of impact	*4.3*	*2.2*	*3.0*	*14.2*	*3.8*	*9.0*	*0.0*	*9.7*	*9.9*	*8.5*	*3.4*	*10.7*
Increased market or market share	21.6	28.7	18.9	71.5	49.5	55.5	78.2	98.5	89.1	56.2	73.8	41.9
High degree of impact	*4.6*	*1.9*	*12.9*	*15.3*	*3.3*	*37.9*	*0.0*	*5.6*	*45.5*	*7.1*	*3.2*	*15.1*
Improved quality in goods or services	24.0	45.7	27.2	79.4	78.7	79.8	100.0	98.5	89.1	76.0	94.2	90.3
High degree of impact	*5.7*	*2.5*	*3.6*	*18.9*	*4.2*	*10.6*	*17.2*	*4.1*	*34.8*	*11.4*	*2.8*	*13.6*
PROCESS ORIENTED EFFECTS												
Improved production flexibility	25.0	34.7	11.3	83.0	59.7	33.2	95.3	75.1	97.4	79.3	62.5	33.3
High degree of impact	*17.0*	*9.7*	*2.4*	*56.2*	*16.7*	*7.1*	*17.2*	*6.9*	*41.5*	*15.6*	*36.3*	*8.0*
Increased production capacity	26.3	32.4	13.2	87.2	55.9	39.0	78.2	72.3	100.0	76.0	84.1	67.4
High degree of impact	*7.7*	*9.8*	*2.4*	*25.6*	*16.9*	*7.2*	*23.3*	*1.5*	*41.5*	*9.5*	*38.9*	*10.3*
Reduced labour costs per produced unit	16.4	43.4	15.5	54.7	74.8	45.6	95.3	70.8	100.0	74.5	67.2	66.7
High degree of impact	*9.7*	*15.7*	*3.8*	*32.3*	*27.0*	*11.3*	*58.7*	*6.7*	*48.8*	*20.0*	*35.0*	*12.5*
Reduced materials and energy per produced unit	16.0	33.6	15.6	52.9	57.8	45.8	95.3	73.9	90.8	62.1	68.3	69.4
High degree of impact	*7.8*	*10.2*	*2.8*	*25.9*	*17.6*	*8.1*	*58.7*	*1.5*	*17.1*	*20.6*	*13.4*	*6.3*
OTHER EFFECTS												
Improved environmental impact or health and safety aspects	21.7	40.5	16.9	71.6	69.8	49.4	95.3	92.7	96.6	75.5	84.9	80.0
High degree of impact	*4.6*	*9.0*	*2.9*	*15.3*	*15.5*	*8.6*	*0.0*	*5.7*	*3.2*	*14.2*	*6.2*	*10.9*
Met regulations or standards	12.6	46.3	19.0	41.1	79.8	55.8	76.7	94.1	96.6	64.6	76.5	37.0
High degree of impact	*5.0*	*1.9*	*9.8*	*16.8*	*3.2*	*28.9*	*0.0*	*4.3*	*75.9*	*13.2*	*7.0*	*7.6*
INFORMATION SOURCES USED												
INTERNAL SOURCES												
Within the enterprise	36.7	53.0	33.2	83.7	88.9	89.6	95.3	97.1	100.0	83.9	83.2	93.2
High degree of importance	*6.5*	*6.7*	*7.8*	*21.4*	*11.6*	*19.4*	*0.0*	*17.5*	*34.8*	*4.4*	*5.5*	*15.0*
Other enterprises within the enterprise group	27.7	22.2	11.9	54.9	37.8	32.7	35.8	13.6	96.8	53.5	42.1	60.1
High degree of importance	*1.0*	*4.9*	*4.3*	*3.0*	*8.1*	*11.0*	*4.7*	*1.5*	*34.8*	*6.4*	*21.9*	*13.9*
MARKET SOURCES												
Suppliers of equipment, materials or software	25.3	41.0	29.5	56.4	69.3	79.1	100.0	97.2	96.6	84.1	74.4	78.0
High degree of importance	*2.3*	*5.1*	*10.8*	*7.8*	*8.8*	*26.6*	*9.3*	*5.4*	*0.0*	*18.5*	*20.3*	*44.5*
Clients or customers	23.8	37.3	25.8	50.5	63.9	68.7	60.0	90.5	96.6	79.5	67.8	74.0
High degree of importance	*7.7*	*10.6*	*9.3*	*24.9*	*17.9*	*21.2*	*4.7*	*16.2*	*20.7*	*19.1*	*15.0*	*41.8*
Competitors and other enterprises from the same industry	23.3	41.7	30.5	49.5	71.9	81.9	72.5	90.3	85.7	74.8	62.1	77.6
High degree of importance	*8.8*	*17.3*	*9.4*	*29.2*	*29.8*	*25.5*	*17.2*	*80.7*	*6.2*	*30.0*	*18.6*	*40.8*
INSTITUTIONAL SOURCES												
Universities or other higher education institutes	15.5	19.2	20.0	24.0	32.6	54.9	53.8	31.5	96.6	56.8	36.5	42.6
High degree of importance	*2.5*	*6.4*	*11.5*	*7.8*	*11.1*	*31.2*	*0.0*	*24.5*	*9.9*	*24.0*	*15.4*	*14.0*
Government or private non-profit research institutes	15.1	8.5	10.6	22.4	13.2	26.9	48.3	30.0	61.8	44.7	18.2	30.4
High degree of importance	*2.8*	*4.3*	*4.3*	*9.1*	*7.5*	*10.1*	*17.2*	*21.9*	*10.5*	*16.3*	*8.0*	*9.7*
OTHER SOURCES												
Professional conferences, meetings, journals	18.0	40.8	31.5	32.2	67.9	84.5	77.2	97.1	96.6	73.5	71.4	89.2
High degree of importance	*1.9*	*11.4*	*8.6*	*6.1*	*19.7*	*22.9*	*4.7*	*6.7*	*3.2*	*16.6*	*30.0*	*42.5*
Fairs, exhibitions	34.0	38.2	19.3	76.5	64.5	50.1	72.5	95.6	96.6	78.3	63.4	50.0
High degree of importance	*10.3*	*22.8*	*7.7*	*33.2*	*37.9*	*20.7*	*17.2*	*9.7*	*52.9*	*39.2*	*40.8*	*16.5*
HAMPERED INNOVATION ACTIVITIES												
Innovation activities: seriously delayed	9.9	29.8	7.9	32.7	51.4	18.7	71.1	81.6	86.7	27.0	25.5	27.6
Innovation activities: prevented to be started	2.3	4.6	3.9	7.2	7.0	7.1	39.0	8.4	34.8	11.3	12.4	10.1
Innovation activities: burdened/cumbered with other serious problems	9.3	8.5	3.8	30.2	13.4	10.8	36.8	8.0	17.5	30.6	27.1	13.0
FACTORS HAMPERING INNOVATION												
ECONOMIC FACTORS												
Excessive perceived economic risks	49.5	33.6	42.8	78.6	47.6	59.8	71.1	20.5	82.5	46.0	69.8	35.6
High degree of importance	*18.1*	*13.8*	*11.5*	*41.5*	*21.6*	*11.3*	*27.5*	*1.5*	*7.3*	*8.9*	*11.0*	*10.2*
Innovation costs too high	52.9	46.9	45.5	80.2	62.1	59.0	71.1	86.3	96.6	52.7	72.6	36.5
High degree of importance	*23.5*	*21.7*	*17.3*	*40.1*	*28.7*	*27.1*	*4.7*	*65.8*	*17.3*	*10.0*	*29.7*	*10.1*
Lack of appropriate sources of finance	42.6	31.9	33.8	79.4	38.6	39.2	71.1	84.9	50.9	52.5	40.0	30.8

	All firms			**Innovators**			**Strategic innovators**			**Intermittent innovators**		
	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40	NACE 10-12	NACE 23	NACE 40
High degree of importance	*17.7*	*11.1*	*15.8*	*39.1*	*14.9*	*22.2*	*21.8*	*11.2*	*6.5*	*17.7*	*20.8*	*16.7*
INTERNAL FACTORS												
Organisational rigidities within the enterprise	41.2	31.6	37.5	64.5	39.0	57.9	31.1	4.2	85.7	50.7	56.8	33.5
High degree of importance	*30.3*	*10.6*	*14.8*	*58.4*	*9.9*	*22.8*	*26.5*	*1.5*	*41.1*	*34.4*	*27.0*	*10.8*
Lack of qualified personnel	42.2	41.4	39.3	68.6	45.2	53.2	48.3	70.9	61.8	56.6	38.7	35.7
High degree of importance	*27.3*	*10.1*	*14.6*	*52.5*	*9.0*	*16.3*	*39.0*	*8.0*	*19.9*	*35.1*	*9.0*	*10.1*
Lack of information on technology	34.1	25.8	30.7	66.6	28.2	41.9	48.3	74.0	50.9	55.7	22.9	31.6
High degree of importance	*23.5*	*14.2*	*16.5*	*50.0*	*12.7*	*21.6*	*43.7*	*12.7*	*46.9*	*28.6*	*16.8*	*17.3*
Lack of information on markets	32.4	18.3	34.9	65.6	17.1	50.3	48.3	13.9	57.7	46.7	25.3	32.3
High degree of importance	*23.5*	*12.3*	*23.4*	*47.9*	*10.4*	*28.1*	*9.3*	*4.2*	*22.9*	*32.8*	*15.1*	*19.8*
OTHER FACTORS												
Insufficient flexibility of regulations or standards	39.8	41.2	39.0	55.7	53.5	52.0	48.3	83.3	96.6	44.7	45.2	34.0
High degree of importance	*16.2*	*9.6*	*11.8*	*45.4*	*10.1*	*11.0*	*14.0*	*17.7*	*23.7*	*25.8*	*11.2*	*15.3*
Lack of customer responsiveness to new goods or services	45.5	40.8	41.0	64.7	39.5	50.5	43.7	80.7	85.7	42.3	45.6	26.5
High degree of importance	*24.2*	*10.0*	*17.0*	*35.2*	*9.8*	*19.5*	*21.8*	*0.0*	*12.1*	*21.5*	*21.2*	*13.4*