KNOWLEDGE
ECONOMY
INDICATORS

Workpackage 1

Policy Scenarios:
1. Supply of scientists and engineers
2. Environmental innovation
3. Demand for innovation

Deliverable 1.4

2008

List of contributors:
Anthony Arundel, Adriana van Cruysen, Wendy Hansen, Minna Kanerva, René Kemp, MERIT

Main responsibility:
Anthony Arundel, Adriana van Cruysen, Minna Kanerva, MERIT

C1S8-CT-2004-502529 KEI

The project is supported by European Commission by funding from the Sixth Framework Programme for Research.

http://europa.eu.int/comm/research/index_en.cfm
http://europa.eu.int/comm/resarch/fp6/ssp/kei_en.htm
http://www.corids.lu/citizens/kick_off3.htm
http://kei.puplicstatistics.net/

Table of Contents

1. Introduction

The purpose of this work package is to develop scenarios for a number of key policy issues in order to identify the types of indicators that would be necessary to track progress. The three key issues in the scenarios' development are: supply of human resources (scientists/engineers), demand for innovation and environmental innovation.

Box 1. What is a scenario?

A scenario is usually a 'thought experiment' conducted to investigate how the future might look if certain events did or did not take place. Such a scenario does not necessarily include any forecasted or estimated data.

However, in addition to involving 'what if' ideas, a scenario can include projections or simple simulations based on numerical data. Although these simulations must usually be based on a number of broad assumptions and simplifications and cannot account for unforeseen events, they do provide an idea of trends and possible outcomes. For example, how well would the European Union do in the future in terms of its stock of researchers, if it *didn't* succeed in attracting more foreign researchers, or, if it *did* manage to get more women into science? Such scenarios enable us to look at the effect of changes in one or more variables, and also importantly, to find out which variables, or factors, have the most effect on the outcome, and which are less relevant.

The goal of this trio of scenarios is assessing the existing indicators to see how they can be used to feed into policy scenarios, and to suggest new indicators where necessary. Part of this exercise includes simple simulations to develop ways and means for policy to monitor and consider current trends. The results of the scenarios will provide guidance for policy and also feed into the European statistical system (e.g. evaluation of existing indicators).

2. Summary of key findings

On supply of scientists and engineers

In general, important policy considerations include both policies to increase supply and to increase demand. The former includes total funding for higher education, immigration policies, coordination of EU higher education and provision of sufficient and easily accessible information on it outside the EU, funding for teaching positions in the public sector, retirement policies, and retraining policies. Policies to increase supply by creating demand include funding for research positions in the public sector, increasing the number of post-doc places, subsidies to firms to hire new S&E graduates, and subsidies to firms for R&D in general.

Key policies are related to retirement, education and immigration. The role of women in increasing the supply of scientists and engineers in the EU should also be considered a policy priority.[1]

There are a number of ways in which the relevant indicators and data collection could be improved on. One important point is that most data should be broken down by gender. A major challenge for measuring international mobility of students and scientists and engineers is that relevant data are often either unavailable or not comparable. The issues involved are numerous, but include different migration or citizenship policies among different countries, varying definitions for immigrants and international students, varying education systems, lack of systematic data collection on migration flows or on qualifications of the foreign-born.[2]

On environmental innovation

Environmental innovation is an essential part of a knowledge based economy (KBE) because environmental innovation makes economies more efficient by encouraging and facilitating the use of fewer material or energy inputs per unit of output. In this respect, environmental innovation replaces material inputs with knowledge. Environmental innovation and eco-technologies can thus be considered the link between the EU's sustainable development strategy and the Lisbon agenda to make the Union "the most competitive and dynamic knowledge-driven economy by 2010".

Environmental innovation should also result in fewer externalities, or negative environmental impacts, which ultimately affect our health and well-being, not to mention the potentially huge impact of global climate change. Our society will be more prepared for significant global changes, environmental or otherwise, if we employ environmental technologies as far as possible. Furthermore, technology shifts caused by technological breakthroughs, rapid changes in demand for resources, or environmental imperatives could impel societies to invest more heavily in research on how to use energy and other resources more efficiently.

Based on both literature and our data analysis, the key indicators include measuring:

[1] Moreover, increasing the participation of women in the S&E work force has implications for social policy (e.g. child care, work arrangements, making it easier for workers to leave and re-enter the workforce).
[2] There have been recent efforts to rectify some of these problems, but the fact remains that many valuable indicators are simply not available or are only available for a few countries.

- Environmental regulations and venture capital for the eco-industry
- Environmental publications, patents and business R&D
- Eco-industry exports and FDI
- Sales from environmental innovation across sectors
- Energy intensity and resource productivity of economies.

Finding key eco-innovation indicators is therefore important to a KBE, as such indicators measure factors that either help or hinder meeting societal, (sustainable) economic growth and environmental goals.

On innovation demand

Firms invest in product innovation based on current or expected demand. Without a current or potential market, innovation activity may be compromised.

The development of demand related policies to encourage innovation requires an understanding of demand and relevant indicators to measure its different aspects. The demand scenario briefly evaluates the main factors that influence demand, dividing them into three main groups: domestic demand, foreign demand and the role of government. Domestic demand is further divided into quality and quantity aspects, demand and sector structure, while role of government is divided into regulations and standards and procurement.

This background is used to identify key demand indicators currently available, plus new indicators that should be developed to better assess demand conditions in a given country. These indicators would be useful to evaluate national differences in demand factors and how policy could influence demand in a way that would stimulate innovative activity.

Our findings indicate that demand conditions are influenced not only by domestic demand quality aspects, such as the existence of lead users made up of sophisticated buyers, but also by quantitative aspects including the actual numbers of consumers in such markets. The sophisticated buyer is constituted by highly skilled and educated people, whose higher incomes are a reflection of their level of education.

Demand can be created if firms can make use of sophisticated marketing tools to capture customers' needs and desires. Unfortunately, we are not able to measure the effect of advertising in creating demand due to a lack of data. It would be relevant to quantify the impact of advertisement in demand creation while breaking down innovation into disruptive and incremental innovation. As most innovations consist of minor improvements, advertisement might play an important role in demand creation.

Not only domestic demand is relevant for local firms, but also foreign demand. It is through proximity, both geographical and cultural and through the creation of international standards, that firms can reach markets beyond local ones. Reaching new markets can be decisive for firms that lack large domestic markets. If domestic markets are not large enough, firms are not able to recoup their investments in innovation.

Government also plays an important role, by not only consuming innovative products through procurement, but also by creating regulations and standards that can free up demand, both by reducing uncertainty and improving quality. Furthermore, governments must intervene in markets to avoid market dominance by few firms, creating incentives for firms to compete and to innovative.

We found large gaps in indicator availability. These include indicators of the different effects of demand by sector, demand structure (monopsony, polypsony and oligopsony), the role of niche markets, the ability of firms to use foreign markets to replace limited domestic markets and the impact of advertisement in creating demand. All of these indicators should be developed to support policy.

3. Policy scenario: Supply of scientists and engineers[3]

Prepared by Adriana van Cruysen, Minna Kanerva and Anthony Arundel

3.1 Summary of findings

This scenario has examined how a large increase in the supply of researchers – or scientists and engineers - could be attained in the next ten years or so, and investigated the factors that influence the supply of researchers. Where relevant, simulations have been used to manipulate variables that might have an effect on the stocks of scientists and engineers and to identify key factors. The report has used a number of indicators and identified the key indicators among these that can be particularly helpful to the policy community for tracking progress towards the goal of increased supply of researchers and S&Es. The analyses carried out under this scenario presents issues related to a number of additional potentially relevant indicators. Finally, forecasted possible outcomes that might occur if certain actions, trends or other developments would take place, or alternatively, if current trends would continue unchanged are included.

The estimates of required numbers of scientists and engineers discussed in this report vary from around 3.5 million[4] to as much as 10 million[5] depending on what the point of departure is (in terms of R&D intensities - R&D against GDP - and a realistic researchers to S&Es ratio). The overall conclusion is that, if we look at the highest target estimate, the EU is not likely to meet it domestically, and therefore must look outside its borders to both international S&E students and scientists and engineers who are already working in their fields. On the other hand, the lowest target estimate would be fairly easy to reach.

One of the main goals of this scenario has been to identify key indicators for tracking the success of the EU in reaching its R&D intensity goals in terms of the pool of scientists and engineers. Table 1 lists the most relevant indicators and the impacts of reasonable change in these indicators within the simulations performed.

Nearly 90% of the total impact in this exercise comes from the reasonable manipulation of only five indicators:

- Increasing average retirement age in the EU
- Increasing proportion of students choosing S&E studies
- Increasing proportion of S&E graduates getting S&E employment
- Bringing in more scientists and engineers from countries like China and India (or even the United States)
- Increasing proportion of women studying S&E fields.

[3] This is a condensed version of the full report available separately: KEI WP1.4a (Policy scenarios – Supply of scientists and engineers).
[4] This lowest estimate is based on the estimate from the European Commission that around 700,000 (see EC, 2003a) additional researchers would be required, and the 19% current reseachers to S&Es ratio in the EU. Applying a 25% ratio of researchers to S&Es, observed in those countries that have their R&D intensity currently between 2 and 4%, would give an even lower estimate of 2.8 million additional S&Es.
[5] This highest estimate is based on the individual EU member state R&D intensity targets agreed in 2006 and the calculations made for this report.

In addition to the indicators used in this scenario, there are other useful and desirable indicators that could be collected. However, in the case of many of these indicators, greater detail is required than what has been available until recently. A significant issue is related to having enough consistency between countries, both in terms of what data are collected and how indicators are defined, these points being particularly important for international mobility data (see Table 5 later for missing or inadequate indicators).

Table 1. Summary of key indicators and the impacts of reasonable change.

Category	Indicator	Change	Extra S&E stocks by 2015 after changes implemented from 2007	Percentage contribution to total number of additional scientists/ engineers
Loss of scientists/engineers	Average age of retirement	Increase average age of retirement in the EU to 65 years	2,000,000	36.0%
Domestic and Foreign Students	Students in S&E fields	Increase proportion of students choosing S&E fields instead of other fields by 2% per year	1,165,000	21.0%
Supply of scientists/engineers	Employed S&E graduates	Increase proportion of graduates that opt to work in S&E fields from 65% to 75%	850,000	15.3%
Supply of scientists/engineers	Engineers produced in the US, China and India	Bring 10% of this pool of engineers to work within EU borders	540,000	9.7%
Domestic and Foreign Students	Female enrolments in S&E studies	Increase participation of women studying S&E fields by 10% per year, by shifting from other fields	385,000	6.9%
Supply of scientists/engineers	Foreign S&E graduates	Retain 50% of foreign EU S&E graduates (coming from outside the EU) and keep them working within EU borders	226,000	4.1%
Loss of scientists/engineers	Unemployment of scientists/engineers	Reduce unemployment rate in S&E fields by 10% per year as from 2007	185,000	3.3%
Loss of scientists/engineers	Number of specialized temporary workers in the US	Retain scientists/engineers who would otherwise migrate to work in the US	141,000	2.5%
Domestic and Foreign Students	Chinese and Indian tertiary students studying in the US	Increase participation of Chinese and Indian students at EU universities, by shifting 25% of the pool of potential S&E students from the United States into the EU.	63,000	1.1%
Total Impact			**5,555,000**	**100%**

3.2 Introduction

This is an exercise to identify the relevant and most important indicators in terms of increasing the supply of scientists/engineers. Where relevant, simulations are used to estimate trends in supply and to help identify the key factors that need to be tracked over time. 'Decision points' where policy intervention could promote a substantial increase in the supply of scientists and engineers, and 'bottlenecks' that could interfere with a process to reach the targets are also explored. Finally, there is a forecast of possible outcomes, if certain actions, trends or other developments take place, or alternatively, if trends continue unchanged.

This supply scenario has some important limitations to keep in mind when considering the results:

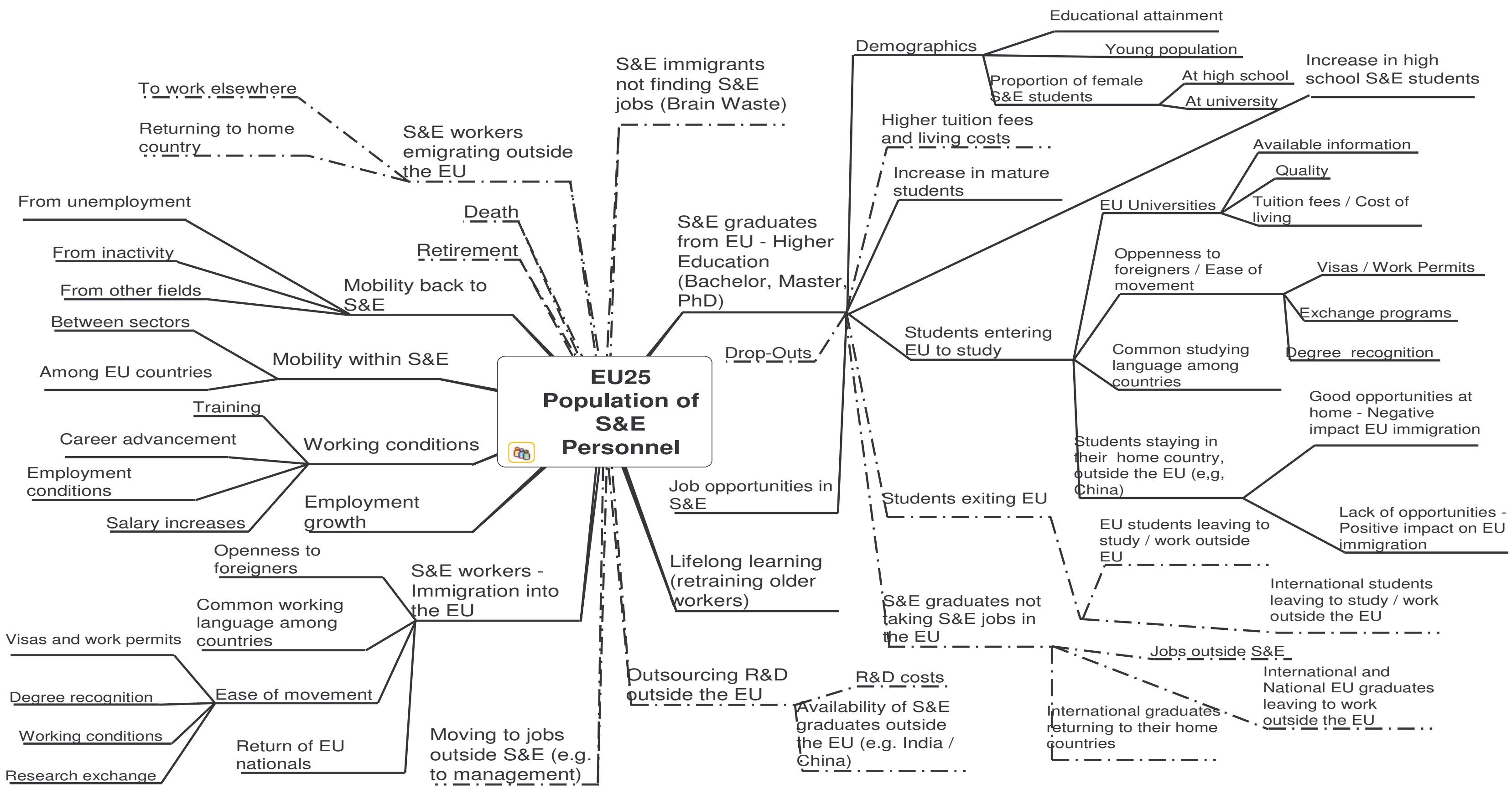
- The study assumes that there is enough demand for researchers and therefore does not, for example, evaluate the likelihood of the business and public sectors increasing their R&D expenditures sufficiently to reach the 3% R&D intensity target.
- The study does not address the quality of scientists and engineers. It may be, for example, that European researchers working in the US are on the average 'better' researchers than their EU counterparts,[6] or that unemployed S&Es attracted back to work are less qualified compared with recent S&E graduates. However, for the purposes of this scenario, all researchers and all S&Es are considered equal in terms of quality.

Possible influences on the flows and stocks of scientists and engineers include not only each EU member state's domestic policies, population trends, industry structure, employment rates etc., but also domestic conditions in countries outside of the EU including countries like the US, India and China. In order to avoid too much complexity, many of these influences are not included in the current scenario. However, the international mobility of S&E students and S&E personnel is included. The inflow of students into fields in S&E an essential part of the picture as is the international flow of scientists/engineers. They need to be taken into account in a scenario to enable the EU to better reach its R&D targets in the near future.

Figure 1 shows the complexity of the situation by identifying factors influencing the supply of S&E personnel. Four separate 'modules' are considered within this larger picture: the domestic higher education system in the EU, international student mobility, the main supply channels to the stock of European scientists and engineers and the main loss channels that decrease the number of scientists and engineers in the EU.

[6] See Saint-Paul (2004) for his concerns about 'European stars' – top 5% of PhDs - working in the US.

Figure 1. Influences on the supply of scientists and engineers.



Note: Dashed lines indicate a negative effect.

One of the main goals of this scenario has been to identify key indicators for tracking the success of the EU in reaching its R&D intensity goals in terms of the pool of scientists and engineers. As Table 1 in Section 3.1 shows, nearly 90% of the total impact in this exercise comes from the manipulation of just five indicators:

- Increasing average retirement age in the EU
- Increasing proportion of students choosing S&E studies
- Increasing proportion of S&E graduates obtaining S&E employment
- Bringing in more scientists and engineers from countries like the US, India and China
- Increasing proportion of women studying S&E fields.

More than half of the impact comes from the top two indicators listed above. On the other hand, individual impacts from factors, including trying to retain non-EU students working in the EU after graduation, reducing unemployment in S&E fields, trying to retain EU scientists and engineers in the EU (as opposed to letting them migrate, for example, to the US) and getting more Chinese and Indian students to choose the EU for their studies, all remain small at somewhere between 1 and 4%.

The key indicators presented in Table 1 can also be considered in terms of two types of factors: bottlenecks – critical areas, which Europe or at least certain countries with the EU, have problems with - and policy decision points – currently debated or otherwise significant policy questions. These factors are closely related, as some of the bottlenecks (e.g. early retirement of scientists/engineers, science subjects not being popular enough at school, Chinese and Indian S&E students going to the US instead of the EU, or lack of women in S&E) are opportunities for policy intervention.

In addition to the identified key indicators, there are other useful indicators but these cannot often be used because of lack of detail, time series and country coverage for comparability purposes. Definitions and interpretation of definitions present additional constraints on country comparability. Altogether, thirty-five indicators were used in this scenario, sixteen of which have been included in the simulations.

Research of the European Commission (2003b) identifies factors that influence the development of careers in R&D, namely training, recruitment methods, employment conditions, evaluation mechanisms and career advancement. The EU has also made recommendations to improve the number of researchers in the European Union[7] as part of strategy to meet the objective of increasing European research spending to 3% of GDP in the EU. According to estimates from the European Commission (see EC, 2003a), this would require a net increase of approximately 700,000 additional researchers to the current stock, and another 500,000 to replace those researchers that have been lost to retirement or from job changes. The highest estimate made in this report suggests that an additional 1,400,000 researchers might be required.[8]

Estimating labour requirements for R&D is difficult given the lack of data on educational qualifications of researchers in many EU countries and on the share of science and engineering (S&E) graduates that go into S&E occupations (see Box 2 for definitions). According to Eurostat, there were 1.8 million researchers in the EU-25 in 2004 and 9.5 million employees in science and engineering occupations. If we make the assumption that all researchers have science and

[7] Council of the EU (2003): Resolution on the profession and the careers of researchers in the EU.
[8] This estimate is based on calculations made in this report.

engineering occupations, then about 19% of these occupations were in research in the EU in 2004 (1.8/9.5*100). Based on the estimate that only 19% of S&E occupations are currently in research, production of 700,000 more researchers would require about 3.5 million more S&E employees. Using a rough estimate that about 65% of S&E graduates end up in S&E employment,[9] this would mean that about 5.5 million additional S&E graduates would be required to fill 700,000 research positions if the additional supply were to be met only by increased higher education output. An estimate of 1.4 additional researchers would require about 9 million additional S&E graduates.[10]

These numbers of additional working scientists/engineers or S&E graduates are not likely to be obtainable under current trends. Consequently, in this scenario with respect to the supply of scientists and engineers, we investigate the various pathways and linkages that influence the stock of scientists and engineers in the European Union, whether the requirements could be met from within the EU alone or, whether the EU needs to look outside its borders. Rather than assess the likelihood of reaching the goal by 2010 or even by 2015, we try to identify a limited set of key indicators for tracking progress towards the goal, whenever it might be reached.

[9] There is very little detailed data available on the careers of graduates. However, based on the fairly large European CHEERS graduate survey, Teichler (2002) notes that 'more than two-thirds of graduates from most fields of study are concentrated on one or two economic sectors which can be viewed as most closely linked to the respective fields' four years after graduation.

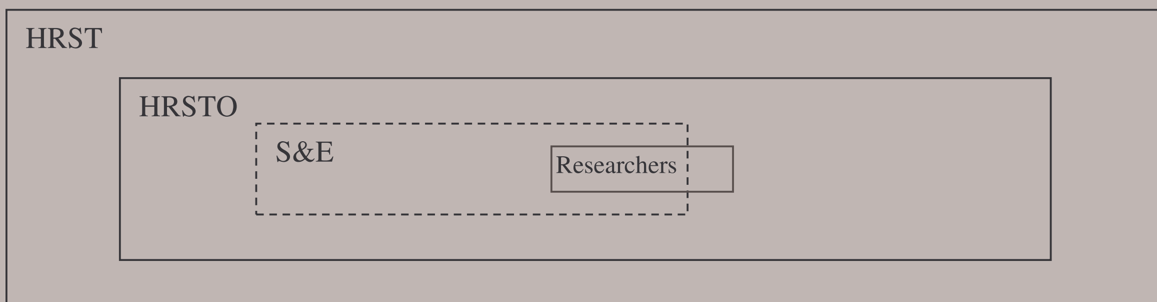
[10] Although the EU-25 average for the researcher/S&E ratio is around 19%, there is a lot of variation between countries, from around 7% to as much as 43%. These 'targets' will be further discussed in this scenario, together with a target of 25% 'research intensity' among S&Es. Currently, the countries with an R&D intensity between 2 and 4 % have about 25% of researchers in their stocks of S&Es, on average.

Box 2. Scientists and engineers (S&E) compared with human resources in science and technology (HRST)

The concepts of S&E and HRST can be somewhat confusing, as the 'science' in 'HRST' includes social sciences and humanities, in addition to natural sciences. In other words, people with degrees in, say, economics are counted as HRST. It is easy to assume that the two groups of S&Es and HRST contain more or less the same number of people, whereas in reality, in 2004 only 17% of those with an HRST occupation were scientists/engineers (Eurostat).

In this study, the fields are limited to science and engineering, as most researchers can be found in this pool. In comparison, only 3% of people with an HRST occupation were researchers in 2004 (Eurostat).

This illustration hopefully further helps to put the various categories into perspective:



The following definitions for human resources in science and technology (HRST, HRSTE and HRSTO), science and technology (S&T) and scientists and engineers (S&E) are used by Eurostat, and are mostly based on the Canberra Manual:

HRST – people who have completed tertiary level education (ISCED 1997 levels 5a, 5b and 6) in a S&T field of study (HRSTE) or, people who are not formally qualified in this way, but are employed in a S&T occupation where tertiary qualifications are normally required (HRSTO).

S&T field of study – natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences, humanities and other fields.

S&Es – people who work in physical, mathematical and engineering occupations or in life science and health occupations.

Additionally, the Eurostat data for tertiary level science and engineering education is grouped as EF4 (science, mathematics and computing) and EF5 (engineering, manufacturing and construction).

3.3 Methodology in brief

This scenario focuses on both the theoretical framework of how the supply side of the stock of scientists/engineers can be expected to function, as well as simple simulation exercises with data from the EU-25[11] and from outside the EU where relevant. Following is an overview of the methods used.

Step 1. Initially, the functioning of each module is explained in some detail. Subsequently, certain linkages between subcomponents in the module are explored and the relevant literature is discussed.

Step 2. The 'theory' described above is used to identify the most relevant indicators for each module. This is done by scaling down the number of potential indicators.

[11] Bulgaria and Romania, members from January 2007 were not included in this report.

Step 3. Clustering is used to identify peer countries in the EU. This is useful to see how the relevant indicators differ between clusters.

Step 4. Baseline simulations are run to determine the basic trends in the data for individual EU-25 countries and for the five clusters. These baseline simulations are meant to explore whether the EU and – specifically, which member states – would or would not meet the targets without any changes in policy, instead just based on past demographic, educational output, retirement and S&E stock data.

Step 5. Modifications of some of the variables that might have a significant impact on the supply of scientists/engineers are made to see what changes would help the EU to meet its targets.

Finally, recommendations are given for the key indicators that can be used to both follow the developments in the supply of scientists/engineers, and to try to influence the trends in the most efficient manner.

3.3.1 Indicators

In total, thirty-five indicators were used for this scenario, each of which was assigned to one of the four modules (see the full report KEI WP1.4a for list and details of indicators used). Of these indicators, sixteen were used in the simulations (see the full report).

Although many of the key indicators are available, in some cases greater detail would be required than what has been available, at least until recently. Data on the educational fields of human resources in science and technology (HRST) to allow us to extract scientists/engineers from overall HRST have only been collected by Eurostat since 2003.[12] This means that the time series for other variables such as gender and age are also only available from 2003. These variables are important. For example, an estimate for the probability of augmenting the supply of S&E personnel by drawing from the older age cohorts (e.g. left research positions and/or retirees) requires age data. Currently, Eurostat provides data for S&E personnel in most of the EU-25 in a rather approximate manner with older age data added together under a 45-64 years of age cohort.

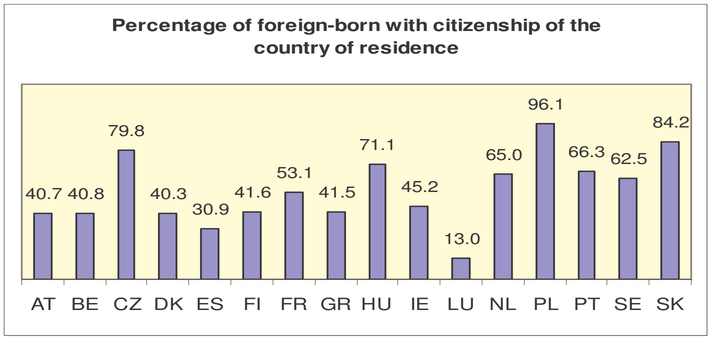
A major challenge for measuring the international mobility of S&E students and employed personnel is that relevant data are either unavailable or not comparable. The issues involved are numerous and include:[13]

- Migration/citizenship (including work foreign student and work visas) policies vary among countries. Figure 2 shows some of the variation among EU member states in the foreign-born acquiring the citizenship of the country of residence;
- Definitions vary among countries — in some countries ‘temporary immigrants’ are not counted as immigrants; national statistical offices may or may not discriminate between long-term and short-term migrants;
- Foreign-born (non-citizens) in higher education are often counted as international students despite years of residence in the foreign country prior to enrolling in their studies;[14]
- Detailed data on qualifications of foreign-born (e.g. level of degree, field of specialisation) is rarely collected, and even when collected it is not necessarily available due to issues of confidentiality and political sensitivities (and again, this varies across the EU-25);

[12] The average share of HRST educated in S&E fields was 27% in 2005 (Eurostat, 2006).
[13] This paragraph is mostly from Auriol (2006).
[14] It has been estimated that non-mobile students with a foreign citizenship make up between 18% and 50% of all students with foreign citizenship (Lanzendorf and Teichler, 2003).

- Education systems and qualifications vary among countries and this impacts on data comparability;
- Data collection on departures or emigration is not systematic in many countries;
- Flows of migrants are often measured based on data from non-targeted survey sources (e.g. population census, labour force survey).

Figure 2. Acquisition of citizenship in selected receiving EU countries.



Source: OECD (2005).

The Eurodata study by Kelo, Teichler and Wächter (2006) found that up to half of all temporarily mobile (e.g. Erasmus) students are not included in the official student mobility statistics, and that in fact, most EU countries do not collect data on genuine student mobility.[15] [16]

There have been recent efforts to rectify some of these problems. For example, the OECD, together with Eurostat and UNESCO launched a project in 2004 to measure careers and international mobility of earned doctorates (PhDs). The OECD has also worked on improving the databases on education and migration (Auriol, 2006). IPTS, with the support of DG Research, is funding a number of studies on mobility and careers of European scientists/engineers (refer to IPTS web site). However, the fact remains — many valuable indicators are simply not available or are only available for a few countries.

3.3.2 Country clusters

The EU-25 is composed of countries with dramatic differences that are even more accentuated when we consider the new member countries. Such differences are based on many aspects, ranging from their economies, environment, population and social conditions, reflecting distinctive stages of development when it comes to the KBE. Clustering countries into distinctive groups helps to understand their strengths and weaknesses and will serve as a starting point for our analysis in this scenario.

We can expect that the EU-25 countries differ from each other in terms of their stocks of scientists/engineers and their ability to supply their needs either by producing' enough scientists/engineers (e.g. education system) or attracting them from other sources (e.g. foreign workers).

The EU-25 countries are clustered into five groups that take into consideration characteristics in a wide range of areas that include the economy, digital / ICT infrastructure, society, government and

[15] In other words, students moving across country borders for the purpose of study.
[16] The study by Kelo, Teichler and Wächter (2006) found that three European countries (Finland, Germany and the UK) as destination countries provide fairly complete data on student mobility, e.g. making a distinction between mobile and foreign students.

environment. The areas are interlinked and together form a broad background that allow us to group the EU-25 countries that are similar to each other into clusters of high internal homogeneity and high external heterogeneity, facilitating the understanding of specific clusters' weaknesses and strengths in terms of the KBE. The stage of a country development in the KBE considers several factors such as economy (relative importance of the tertiary sector); ICT infrastructure that creates the conditions for knowledge to be created and diffused; society, in terms of tertiary education, workforce, retirement age, GDP per capita, opportunities for research; government and its institutions, rule of law (protection of inventions) level of corruption that reflects a country's propensity to either attract or repel foreign capital; and finally, environment.

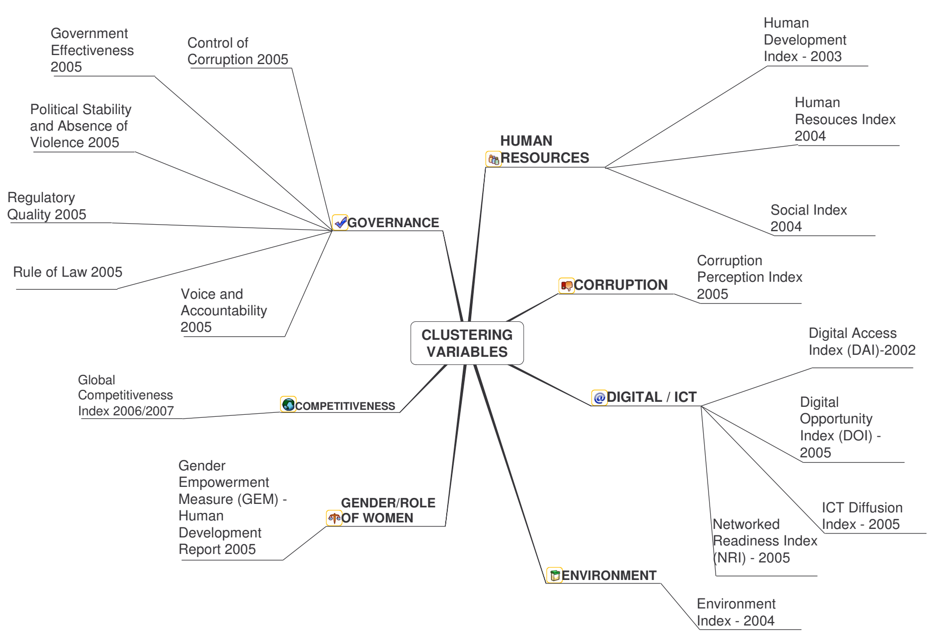
Clusters differ in the factors described above, and consequently countries belonging to different clusters ask for different measures, policies and priorities in terms of forming a pool of S&E personnel necessary to achieve the Lisbon goals in terms of Research and Development, which is analyzed in this scenario. Clustering the EU-25 is the first stage to understand the EU-25 countries, their current position and their needs to achieve the 3% goal of R&D in relation to GDP by 2015.

3.3.3 Clustering method

In order to group the EU-25 countries into five clusters, we used a group of indexes developed by well-known institutes (see the full report KEI WP1.4a for a list of these indexes).[17] These indexes covered the following areas: competitiveness, corruption, ICT, environment, role of women, governance and human resources.

Within each of the above seven areas covered, the selection of specific indexes was based first, on the index being representative of the aspect it was expected to represent and second, on the availability of the index for the EU-25. Figure 3 illustrates the seven factors used to group the EU-25 into clusters, as well as indexes and sub-indexes that were included under each factor.

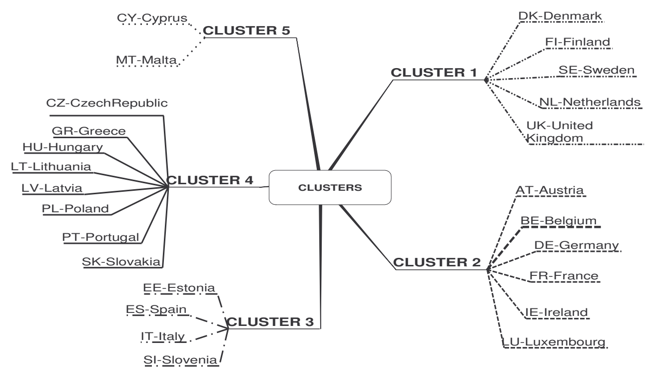
Figure 3. Factors used for clustering.



[17] For clustering, we used SPSS software, hierarchical - agglomerative procedure with average linkage. We opted for Euclidean distance – squared to measure the similarity of magnitudes in the values.

The clustering exercise resulted in five clusters that ranged from only two countries up to eight countries (see Figure 4).

Figure 4. Country clusters.



3.4 Scientists, engineers and researchers – Relationships and projections

There is little detailed data describing the stock of researchers in the EU. We do know that only a small proportion of scientists and engineers are researchers and that most researchers are found in the S&E stock. Our starting point considers the S&Es stock. By establishing links between the two stocks, S&Es and researchers, we can bridge the gap for current information needs and develop projections. We first establish the relationships between S&Es and researchers. We then explore where countries stand in terms of the number of S&Es and researchers they will need to achieve the 3% Lisbon goal. Finally, we calculate potential shortages or excesses in the supply by projecting both stocks into 2010 and 2015.

The EU-25 are in different stages of development in the KBE and proportions of S&Es to researchers may differ depending on the level of R&D intensity in countries across the EU.

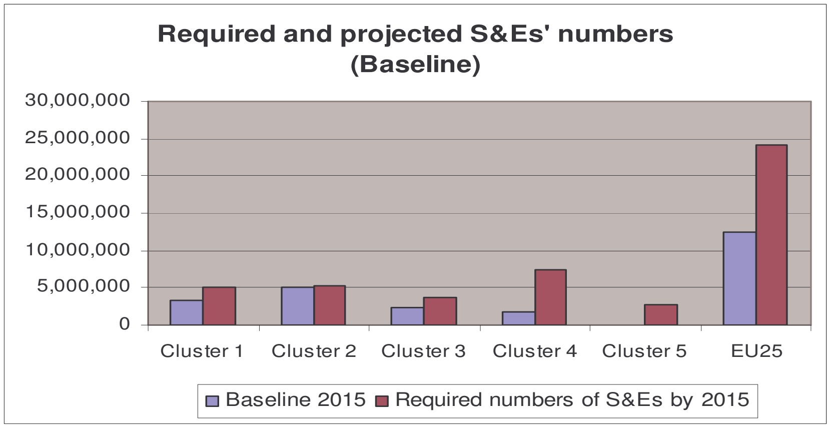
The results of this exercise lead to some interesting points: when considering the sum of the EU-25, and current trends in terms of annual number of S&E graduates and average retirement age, there could be a shortage of some 7.5 million S&Es[18] by 2015. This means that the EU-25 countries might be able to 'produce' only about 62% of their needs of S&Es to meet the 3% R&D/GDP goal. The balance would have to come either from outside the EU-25 or from changes within the EU-25 borders.

However, this shortage is not equally distributed among the five previously defined clusters. According to our estimates, Cluster 2 (Austria, Belgium, France, Germany, Ireland and Luxembourg) would be able to cover 95% of its requirements, followed by Cluster 1 (Denmark, Finland, Netherlands, Sweden and the UK) with approximately 86%. Cluster 3 (Estonia, Italy, Slovenia and Spain) would be able to account for around 47% of its needs, while Cluster 4 (Czech Republic, Greece, Hungary, Lithuania, Poland, Portugal, Slovakia, and Latvia) would cover around

[18] This estimate assumes that the ratio of researchers to S&Es is 25%, currently true of countries with R&D intensity between 2 and 4 %.

31% of its requirements. Cluster 5 (Cyprus and Malta) would only be able to produce around 15% of its required numbers. Figure 5 illustrates projected and required numbers of scientists and engineers based on Baseline calculations for 2015.[19]

Figure 5. Baseline - Required and projected numbers of S&Es.



Within clusters, a few countries would not have to be concerned about meeting their requirements of S&Es by 2015 in order to achieve the goal of 3% of R&D/GDP — France, Finland and Sweden will be producing in excess of their needs. Table 2 shows a more detailed projection of required numbers of researchers, calculated as approximately 25% of stocks of S&Es[20] in 2010 and 2015 as well as projected numbers according to the baseline forecast that is limited to current domestic trends in supply and losses.

According to these projections, by 2010 all EU-25 countries, with the exception of Sweden, would have a shortage of S&Es based on current trends in supply and losses for retirement. By 2015, Sweden would continue to generate enough S&Es for its own requirements, as well as Finland and France. All other countries, for both years 2010 and 2015 would have a shortage, when considering current trends. On the other hand, considering the EU-25 countries as a whole, there should be an improvement in numbers of S&Es from 2010 to 2015, as countries approach their 3% R&D/GDP targets.

Considering that countries that have an intensity level of R&D between 2% and 4% of GDP have approximately 25% of their S&Es going to research, we extrapolated numbers obtained through the baseline for S&Es into numbers of researchers. By doing this simple exercise, the shortage of researchers throughout the EU25 can be assessed at that level of R&D intensity. By 2010, Belgium, France, Germany, Ireland, the Netherlands and the UK would generate enough researchers if present trends continue, and if in fact 25% of S&Es end up in research. By 2015, the same countries plus Sweden would have sufficient numbers of researches for their needs. All other countries would be behind in their required quotas.[21]

[19] Baseline was calculated assuming current trends for the domestic supply of new S&E personnel and losses of S&E personnel to retirement.
[20] Calculated using relationships among S&Es and researchers between 2 and 4% R&D intensity.
[21] This picture is only valid if in fact 25% on average of all S&Es end up in research. If this proportion is not maintained, then these prognostics may change dramatically.

Table 2. Baseline projections — Number of researchers in years 2010 and 2015.

	N. Researchers required 2010	N. Researchers projected - Baseline* 2010	Shortage/ Excess 2010	N. Researchers required 2015	N. Researchers projected - Baseline* 2015	Shortage/ Excess 2015
Austria	58,700	33,655	25,045	58,700	37,147	21,553
Belgium	71,217	87,556	(6,339)	71,217	90,724	(19,507)
Cyprus	3,268	3,811	(543)	9,803	3,843	5,960
Czech Rep.	55,836	44,432	11,404	81,314	47,234	34,080
Denmark	47,822	39,959	7,863	81,314	41,995	39,319
Estonia	11,836	5,897	5,939	18,689	6,933	11,756
Finland	59,213	48,961	10,253	59,213	53,336	5,878
France	327,498	434,099	(106,601)	327,498	535,066	(207,568)
Germany	490,697	525,775	(35,078)	490,697	533,083	(42,386)
Greece	74,507	51,602	22,906	149,014	54,348	94,666
Hungary	62,223	42,743	19,480	103,705	42,370	61,335
Ireland	33,721	47,190	(13,469)	40,465	58,278	(17,813)
Italy	246,725	230,620	16,106	296,070	251,549	44,521
Latvia	20,089	10,980	9,109	40,179	12,397	27,782
Lithuania	26,792	24,197	2,595	40,188	29,983	10,206
Luxembourg	3,846	2,129	1,717	3,846	1,821	2,025
Malta	1,063	1,037	26	4,252	1,044	3,208
Netherlands	95,054	122,642	(27,588)	95,055	122,070	(27,015)
Poland	284,422	154,047	130,375	517,130	182,991	334,139
Portugal	88,483	51,014	37,469	147,471	58,581	88,890
Slovakia	61,249	20,856	40,393	102,082	24,961	77,121
Slovenia	12,087	11,240	847	12,087	11,574	513
Spain	320,700	274,519	46,181	481,050	302,210	178,840
Sweden	77,052	74,855	2,197	77,052	82,353	(5,301)
UK	364,066	436,925	(72,859)	436,880	519,693	(82,813)
Total EU25 (SUM)	2,898,166	2,780,739	117,427	3,744,971	3,105,582	639,389
EU25**	**2,898,166**	**2,783,551**	**114,615**	**3,744,971**	**3,100,603**	**644,368**

* Calculated as 25% of numbers of S&Es
**Calculated for EU25 as a whole

In summary, given the numbers of S&Es projected for 2010 and 2015 and taking into account the relationship between numbers of researchers and numbers of scientists and engineers at R&D intensity between 2 and 4%, there could be a gap of 7.5 million S&Es by 2015. Consequently, the EU-25 would need to assess this difference and the possible alternatives at hand to close this gap.

Important indicators for controlling stocks of S&Es:
In this section, when calculating the baseline projection for numbers of S&Es and researchers, three main indicators were considered:

- Science and engineering graduates
- Demographic age cohorts
- Retirement age.

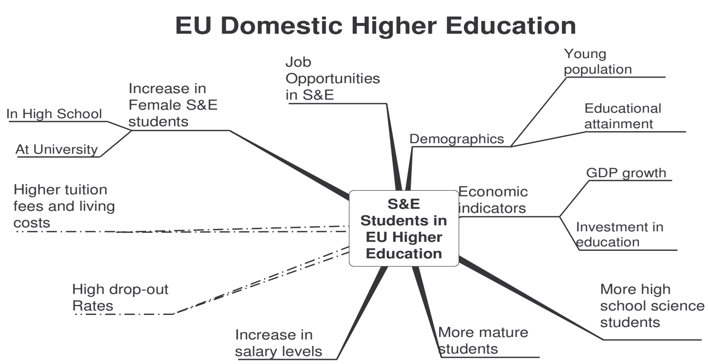
3.5 The modules[22]

3.5.1 Domestic supply – Higher education

One of the principal ways to increase the pool of S&E workers is to increase the supply of national graduates in S&E disciplines.[23] In order to increase the supply, more students should be attracted to the S&E programmes at the tertiary level, including attracting them from other programmes.[24] Enrolment into S&E programmes might be increased by making S&E careers more attractive by increasing salaries and/or by increasing awareness of the benefits of S&E for society as a whole and for an individual's pursuit of an interesting and successful career.

This module examines the factors that influence the supply of national citizens who graduate with a tertiary degree in an S&E field. Within each EU country (Figure 6), the domestic higher education system is fed by domestic secondary school graduating classes. There are also an increasing number of mature students entering tertiary education. Increases or decreases in the number of S&E students are influenced not only by demographics (i.e., the number of young people within specific age cohorts), but also by the popularity of science as a subject at secondary schools and tertiary institutes which is influenced by general social attitudes towards science.

Figure 6. Module – Domestic higher education.



Note: Dashed line indicates a negative effect.

The share of tertiary students enrolling in S&E over the last decade has remained relatively constant. Figure 7 depicts the situation for 2004, where on average, a quarter (25.8%) of all EU

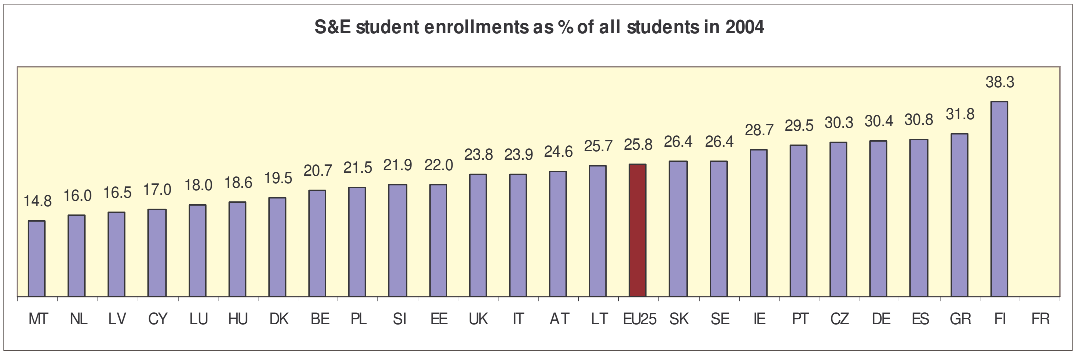
[22] A fuller discussion and analysis of these modules and related data, indicators and simulations are given in the full report KEI WP1.4a, available separately.

[23] Paradoxically, the European Union produces more science and engineering graduates than the United States, but has fewer researchers in the labour market (EC, 2005b). For example, according to the National Science Foundation (NSF), in 1998 the share of 24-year-olds with S&E degrees was about 40% higher in the UK than in the US (NSF, 2000).

[24] However, this is a challenge, as a recent study (Sjoberg, 2002) examining how 13-year-old pupils perceive science and scientists indicated: children in developed countries are very choosy about their interests, and boys and girls likes and dislikes differ considerably. Another recent study (as part of ROSE, an international project supported by the Norwegian government and the University of Oslo, see http://www.ils.uio.no/english/rose/) covering a range of European and non-European countries found that most 15-year-olds think science is important, but many children from developed countries have negative experiences with science at school, and they do not want to become scientists. Conversely, in many developing countries science is popular at school and as a future career option, also among girls.

students studied science or engineering. The range was quite wide from some 15% in Malta to more than 35% in Finland. In 2003, S&E graduates earned 24.2% of all degrees awarded (EC, 2005a).[25]

Figure 7. Science and engineering student enrolments in higher education in the EU in 2004.

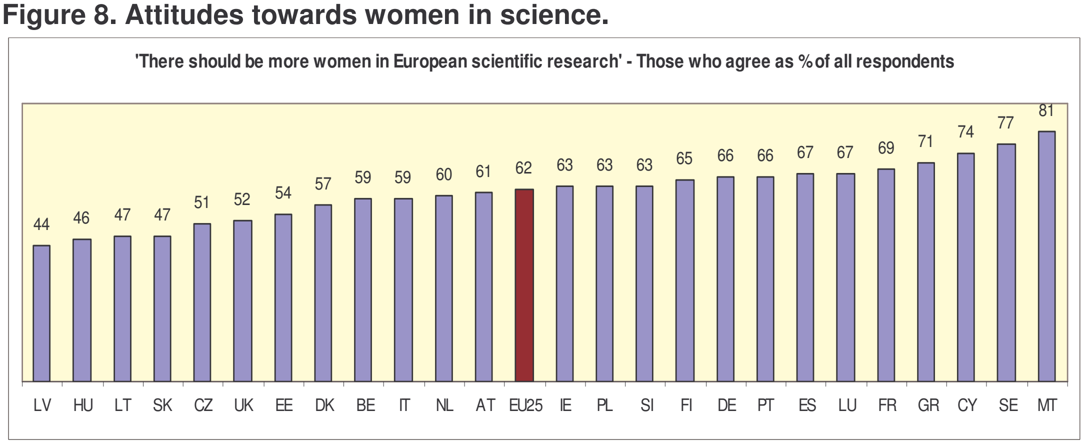


Note: Data for France is missing; data for Luxembourg are for 2002.
Source: Eurostat

Increasing the participation of girls and women in science subjects is an important issue for domestic supply of S&E personnel. Although women outnumber men in tertiary education, the proportion of female graduates in S&E fields remains fairly low. Portugal had the highest proportion of female S&E graduates in 2004 at 41% and the Netherlands had the lowest at 20% (Eurostat). The proportion of women studying S&E subjects varies greatly between the EU countries. For example, in 2004, it varied from approximately 5% in the Netherlands to approximately 20% in Greece (Eurostat). However, if one looks into the near future, it can be estimated that by 2015 the number of young people of secondary school age (aged 10-14) will decrease in most EU countries (decreasing by 12% in the EU-25), especially within the new member states (Eurydice, 2005). This suggests that it is even more important that as many young women as possible choose S&E programmes of study, both for their education and as a career.

Figure 8 shows Europeans' attitudes towards increasing the number of women in scientific research. Clearly, there is potential to do so given that the majority of the EU-25 would like to see more women in science. However, it is interesting to note that there is a wide range of support from an approximate rate as low as 44% in Latvia and as high as 81% in Malta.

Figure 8. Attitudes towards women in science.



Source: Special Eurobarometer 224 (Europeans, Science and Technology), June 2005.

[25] However, the corresponding figure for the US is only 18.5%, and 23.1% for Japan (EC, 2005a).

Other factors that can influence the supply of S&E graduates include domestic policies on tuition fees, general living costs, spending on higher education, and the image (true or false) associated with scientists and engineers (i.e., earnings, rate of success in their career). Potential increases to the number of S&E graduates might be realized by decreasing the relatively high drop out rate in European higher education. Drop out rates at EU universities and within degree programs vary from just under 20% to more than 60% (Teichler, 2000).[26] Finally, the unified BA/MA/PhD model under the Bologna process might also be a method to increase both enrolment and graduation rates, as more students view Bachelor programs as a viable option (EC, 2005b).

Mature students[27] are an increasing source of graduates in many countries. For example, there has been a rapid increase in the number of mature students in the last 20 years in the UK, due partly to policies intended to expand the higher education system to a larger population. However, Purcell et al. (2003) and others have found that mature students often have difficulties in securing their initial graduate jobs and when they do, they receive a smaller financial benefit for their degrees.[28] On the other hand, it seems that over time the differences between 'traditional' student graduates and mature student graduates converge at least to some extent. Additionally, mature students tend to be more loyal to their employees than the 'traditional' graduates (Purcell et al., 2003). In any case, the greater the number of mature student graduates, the larger the pool of potential scientists and engineers.

The introduction of tuition fees is one of the more controversial issues in Europe. Increasing fees could potentially reduce enrolment. In the UK, the increase in tuition fees from £1,200 to £3,000 led to a decrease in enrolments by 3.7% between 2005 and 2006.[29] [30] On the other hand, there is recent evidence from the US that a gradual increase in tuition fees does not affect enrolments over the long term and might in fact increase the prestige of the universities in question. Furthermore, and in line with what has been happening in the United States, while higher fees may have deterred students from attending university in the UK last year, they may not have a long lasting impact, given that the latest figures show a 6.4% rise in applications for the next academic year. The increase in applications was particularly important for the science and math subjects which were previously struggling. The latest increase in applications might be related to the fact that the wealthy, middle-class students continue to dominate admissions, particularly at elite institutions.[31] The increase in fees in the UK has been justified as necessary to meet the challenges of university expansion and to maintain its position and the quality of its education. The UK experience, as the US experience, seems to indicate that increasing tuition fees might not affect numbers of enrolments over the long term.

---

[26] Related indicator, survival rate is calculated as the number of graduates/number of new entrants at the typical age of entrance. In 2000, the rate was 66% for 13 EU countries for which data existed, compared to an OECD average of 70% and a rate of 94% for Japan (EC, 2005b). The proportions varied greatly among EU countries.

[27] There is no universal definition for the term 'mature student', but generally, the term refers to someone commencing his/her university studies several years after completing secondary school. In the study by Purcell et al (2003), 'young mature graduates' referred to those graduating between ages 24 and 30, and 'older mature graduates' referred to those getting their first degrees after the age of 30.

[28] Although they are also apparently less likely to highlight the importance of an attractive salary (Purcell et al, 2003).

[29] The Guardian, 19 October 2006.

[30] Increasing tuition fees, would of course also increase the 'private investment' in EU higher education, which is so far from the levels in the US, where tuition fees are much higher (in fact, they were around 3,800 euros in public universities in 2004 according to EC, 2005b (quoting the Guardian newspaper on p. 22).

[31] Guardian Unlimited, February 14th 2007 'Top-up fees - the year after'

Indicators

Indicators on the potential supply of S&E personnel from the domestic educational system include both demographic and educational indicators. This following set of indicators can be used to measure the potential effect of policy intervention:

- *Secondary school science students*: The higher the numbers of students studying science in secondary school, the higher the potential input for tertiary science and engineering studies. Furthermore, changing attitudes towards a girl who chooses science at this level can provide some indication of the number of women who chose to study science at the tertiary level. Currently, these data are only available at an overall ISCED97 level 3 (upper secondary). A breakdown of the data to levels 3a (high school), 3b and 3c[32] is required to assess the impact of changing attitudes on tertiary science and engineering students. Therefore, these data were not used for our current simulations.
- *Participation rates in tertiary S&E programmes*: Participation rates can be used to develop more dynamic indicators such as the participation of men compared to women and the way in which these indicators have changed over time. These data are available from Eurostat.
- *Math, science and technology related fields of study as a proportion of tertiary education*: the share of maths, sciences and technology related programmes in relation to total fields at tertiary level. These data are available from Eurostat.
- *Number of mature tertiary students:* This data is currently available from Eurostat defined either by age groups or by field of study, but not combined as both age and field of study.
- *Survival rates:* Share of students entering tertiary S&E fields that complete an S&E degree. This indicator is available from the OECD, but is not currently available by field of study.
- *Youth and mature education attainment:* Percentage of a population cohort that have at a minimum, completed upper secondary education. These data are available from Eurostat.

The actual supply of S&E graduates will also depend on a set of indicators based on the attractiveness of science (including image and potential salary rates), and the influence of tuition fees, salary increases for graduates and other factors based on the decision to pursue a tertiary education.

3.5.2 International student mobility

The United States has benefited from the number of international S&E students studying in the United States, as they become a source of employees for the S&E sector upon their successful graduation. The EU could take a similar approach and increase its supply of S&E personnel by encouraging more non-EU students to study within the EU[33] and by making it easier for them to work in the EU after graduation.[34]

International student mobility from within or outside the EU-25 (see Figure 9), is partly influenced by similar factors experienced by domestic students, such as tuition fees and general living costs, but is mostly influenced by a variety of different factors. A study by the OECD (2001) indicates

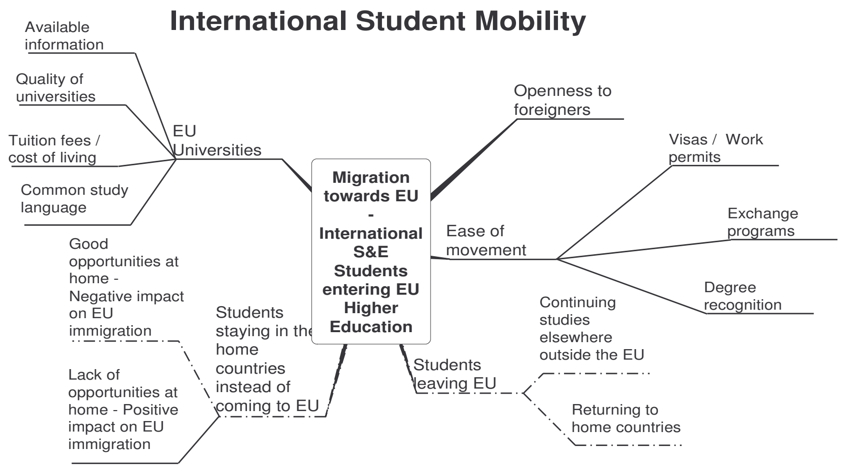
[32] ISCED97 level 3a generally leads to level 5a, 3b to 5b and 3c to ISCED level 4 or other level 3 programs.

[33] Around 50% of international students in Europe are mobile EU students, i.e. originate from another EU country (Vlk, 2006). Such mobility is also beneficial, and the EU has a target according to which 10% of the student population should be mobile one way or another (EC, 2006c). Although 'internal' EU student mobility may increase the total number of S&E graduates in the block, as discussed in the text, we concentrate more on foreign students coming from outside the EU.

[34] Additionally, some of these students (PhD students) also contribute to R&D activities in their host countries.

that the driving forces of outward student mobility in Europe and elsewhere are related to the size of the country (i.e., the smaller the country size the greater the influence) and the institutional and geographical proximity.

Figure 9. Module – International student mobility.



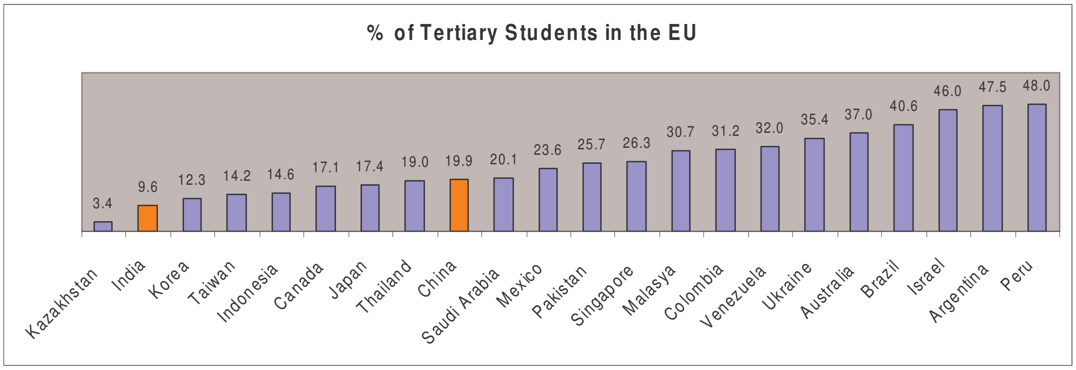
Note: Dashed line indicates a negative effect.

International students choose their host universities or host countries by their reputation, the image they have of the openness of the country in question, the language of instruction, the ease of movement (i.e., problems/excessive paperwork with visas, recognition of final degrees, existence of exchange programs), and finally, the amount of information they can find about certain universities or countries.

Several factors in the home country will influence the decision to study abroad and to remain in the foreign country after graduation. These include a lack of opportunities to study at home (i.e., in terms of programs or places offered) and post-study options for employment. Internal EU student mobility is relevant here, given that the future possibility for an S&E career within certain countries may be bleaker than in others. Sufficient mobility helps to ensure that students look for the best study opportunities for themselves, and should therefore increase the total number of graduates in the EU. Finally, there is also outward international student mobility (exiting the EU) caused by non-EU students returning to their home countries before or after graduation, and by EU citizens leaving the EU to pursue studies or work abroad.

Figure 10 shows the proportions of non-EU tertiary students choosing to study in the EU instead of other destination alternatives. Some countries tend to 'send' a substantial part of their tertiary to the EU. For example, of all tertiary students that Peru sent abroad in 2003, 48% of them chose to go to the EU, while just 19.9% of all Chinese students sent abroad to attend tertiary education in 2003 opted to go to the EU.

Figure 10. Non-EU tertiary students going abroad – EU as a destination (% of all students going abroad from the source countries).



Source: Atlas of Student Mobility - 2003

Although countries such as Argentina and Peru have high percentages of their tertiary students sent abroad to study in the EU, when the absolute numbers are considered, they are only minor suppliers of tertiary students in the EU25 countries. Table 3 shows in absolute numbers the main suppliers of tertiary students from outside the EU25. China comes out at the top.

Table 3. Main sources of tertiary students in the EU from outside the EU25 – 2004.

Country of origin	**Absolute numbers in the EU**
China	96,000
United States	26,000
India	22,000
Japan	13,000
Korea	12,000
Hong Kong	11,000
Norway	10,000
Brazil	9,000

Source: Eurostat.

When considering a study abroad, students seem to have a clear preference for studying in English-speaking countries. Furthermore, the same countries that offer education in English are those that have the largest numbers of universities that rank among the Top 500 (i.e., ranking of the 500 best universities around the world).[35] The United States takes the first place with its 167 universities, followed by the UK with its 43 universities and Canada with its 22 universities. According to data from the Atlas of Student Mobility for 2002/2003, 68% of mobile students (students outside their countries of citizenship) chose an English-speaking country as their destination.[36]

International student mobility has doubled in the last 20 years within the OECD countries (Vlk, 2006). The global demand for international higher education is projected to continue rising at a rapid pace, with a four-fold increase in the estimated number of international students (from 1.8

[35] 'Top 500 World Universities' – 2005 – Institute of Higher Education, Shangai Jiao Tong University.
[36] Böhm et al., 2002 estimate the share of the major English-speaking destination countries (the US, the UK, Australia, Canada and New Zealand) to be considerably lower, at 46.8% in 2003.

million to 7.2 million)[37] between 2000 and 2025, 70% of which are estimated to come from Asia (Böhm et al., 2002).

Discussions in a recent study conducted for the European Commission coupled with the perceptions of EU higher education in Asia, Latin America and Russia (Muche et al., 2006)[38] suggest that there is unrealised potential in getting students to come to the European Union. Although a net recipient of tertiary students similar to the US, the EU still lags behind the US in attracting foreign students, especially students from Asia.[39] Eighty-two percent of the total number of Indians going abroad for their tertiary education opted to study in the US in 2000. For Chinese students, this proportion was 50%.[40]

Foreign students in Europe are concentrated in just a few countries, mainly the UK, Germany and France.[41] The study by Muche et al. (2006) found overall, that information on Europe and its higher education system is missing or hard to access. The above three countries were practically the only EU-25 countries for which students in the potential supply countries were able to access good information on higher education. There was not enough information about studying in the new EU member states, nor was there adequate information about English-taught programs in non-English speaking EU countries.[42]

According to the above study, when Russian and Latin American students considered alternative destinations for their studies, they generally placed Europe at the top of their study destinations, whereas Asian students preferred the US, considering European cultural and language diversity a 'problem'. Other general factors that hampered study in Europe were related to finances and immigration policies. The most important overall criteria for choosing study destinations was the quality of education, reputation of degrees, and the prestige of the university, whereas the world region played an insignificant role.[43]

The obvious source countries for potential new international students in the EU are China and India. These two countries, together with South Korea, have been the largest suppliers of international students for the OECD countries (OECD, 2004).[44] However, as estimated by Khadria (2004), in 2001, almost 80% of the Indian students enrolling in tertiary education in the OECD countries went to the US. Additionally, the rapid growth of universities in Asian countries is challenging Europe and the US in terms of attracting doctoral candidates in S&E.[45] This may be partly due to the fact that the numbers of Chinese students in the UK have levelled out after a strong increase in recent years. On the other hand, Yao (2004) argues that as the competition for study places in Chinese universities gets tighter, some of the left-over students may be heading overseas, therefore lowering

---

[37] The estimated number of international students in 2015 is over 4 million.
[38] The target group for the study included students wanting to or already studying abroad, university staff and school teachers.
[39] Other data show that the EU is also behind the US as a destination for studies in S&E. For example, 55.8% of doctoral engineering degrees in the US were earned by foreign students in 2001, as compared to 10.7% in Germany or 22.0% in France (in 1999). The UK had a similar proportion (51.2%) to the US (Moguerou, 2006).
[40] Atlas of Student Mobility.
[41] Europe is still seen more as a range of different countries (in terms of quality or education, costs and student support) than as a block with similar attributes when it comes to deciding where to go to study.
[42] Cai (2005) also argues that lack of information in China about European study programs significantly affects the flows of Chinese students to Europe.
[43] The study participants recommended three essential measures to increase Europe's attractiveness as a study destination: an information portal about EU study programs, EU-wide rankings of universities, and financial support for non-EU students. The study itself recommended further that a European higher education 'brand' should be created, immigration and visa policies made more flexible and number of English-taught programs increased.
[44] South Korea, although not the largest supply country in absolute terms, sent out the highest number of its national students – 18 - for each foreign student received (OECD, 2004).
[45] International graduate admissions survey, US Council of Graduate Schools, Dec 2005.

the overall quality of Chinese students studying outside of China. On a similar note, Cai (2005) predicts that China's growing middle class might shift the source of Chinese overseas students from those that are more academically inclined to those from wealthy families.

The participants in the EC commissioned study (Muche et al., 2006) recommended three essential measures to increase Europe's attractiveness as a study destination: an information portal about EU study programs, EU-wide rankings of universities, and financial support for non-EU students. The study further recommended that a European higher education 'brand' be created, immigration and visa policies made more flexible, and the number of English-taught programs increased. Finally, the EU should look to its strengths in terms of academic study areas and invest in those. For the purposes of increasing the supply of scientists and engineers, it would therefore be important to look to European universities that are strong in the S&E fields.

Finally, as mentioned earlier, openness of a society to ideas or people from other countries can be a significant pull factor for both international students and highly skilled workers. Brandi (2002) concludes from her study of foreign researchers in Italy that skilled migration is considerably influenced not only by the attitudes of the immediate surroundings, but of the whole host society. Oftentimes, feeling welcome within a society can make up for other problems encountered, e.g. bureaucracy. Hooper (2001)[46] argues further that Germany's initial failure to attract Indian IT specialists was largely caused by and/or due to the image that Indians had of Germany as being an unwelcoming society.

Indicators

Ideally, the share of foreign students earning EU degrees and remaining in the EU (e.g. number of foreign EU degree recipients that remain in the EU versus the number that leaves the EU upon graduation), should be estimated. Such data are not available EU-wide, but if available, are important for measuring the impact of foreign students on supply. As mentioned, there are data for the US that show that, in the long term, approximately 50% of doctoral degree recipients stay in the US (see Finn, 1997).

- *Proportion of students from outside the EU in European S&E programmes:* data on non-EU students are important for developing dynamic indicators on the popularity of the EU-25 as a destination for S&E studies. These data are available from Eurostat, but are not available by field.
- *Student mobility data*: this data is important for assessing the inward (brain gain) and outward (brain drain) flows between the EU and other countries. However, such data have not been particularly reliable.
- *Data on factors influencing flows of international students*: these data sets are potentially important predictors for incoming student flows and include data on the quality of universities within the EU-25, data on lack of opportunities to study in the students' home countries outside the EU, data on openness of countries towards foreigners in general within the EU, and finally, data on availability of information on European universities. Some of these data can be found.

Other potential influences on inward student flows include common languages between home and host countries. However, students may not actually follow the assumption that common language draws more interest, i.e. they may choose their study country based on a *different* language, which they want to learn. On the other hand, the OECD (2001) notes that science and engineering

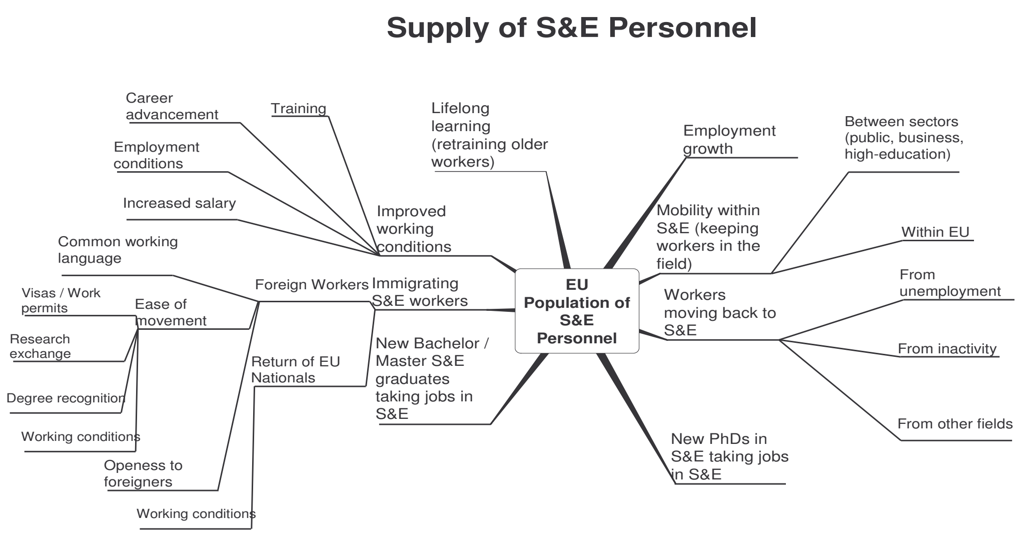
[46] An article titled 'Germany to offer permanent future to skilled migrants' in the Guardian newspaper on 5 July 2001.

students may not follow this behaviour, as languages are not an essential part of S&E studies, and these students may in fact prefer common languages.

3.5.3 Supply of personnel

As shown in Figure 11, the most obvious input to the pool of S&E personnel are new 'domestic' S&E graduates (at all three levels: Bachelor's, Master's and PhD). However, many S&E graduates choose or, are forced to choose, occupations outside S&E. On the other hand, there are other supply channels, such as people moving from jobs outside S&E back to S&E positions, graduates from outside S&E fields, inactive or unemployed people going into S&E, retraining of older workers (often referred to as lifelong learning), and immigration of S&E workers (including workers returning from a temporary stay abroad).

Figure 11. Module – Supply of science and engineering personnel.



Many of the factors influencing the international mobility of S&E personnel are the same as for international S&E students. Generally, mobility between sectors or countries is considered to have positive economic effects in addition to keeping workers happier provided their experiences are positive. Factors affecting the within country flows include general economic outlook (employment growth), working conditions (salary levels, career advancement and training opportunities), policies on public R&D expenditures, and the retirement age (e.g. increasing retirement age or attempting to keep people working longer).

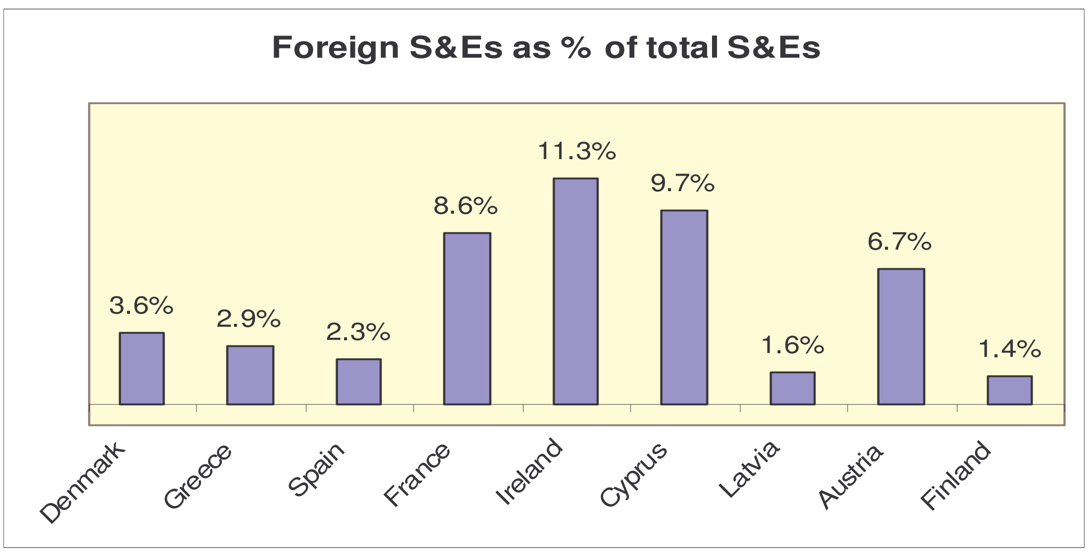
As mentioned earlier, one important way to increase the number of working scientists and engineers is to attract more women into S&E fields. There is a slight positive trend in the EU-25 in the ratio of female S&E graduates to all S&E graduates.[47] However, the decreasing young population in the EU means that there will be fewer graduates overall to supply the pool of S&Es in the future.

[47] However, the trend is negative when looking at what women choose, in other words, the ratio of women choosing S&E fields of study to women choosing other fields of study has decreased (Eurostat).

Currently, the growth rate of women working in S&E is lower than that for men. If such a trend continued, the proportion of women in S&E (29% in 2004) would decline even further.[48]

Another way to increase the supply of people working as scientists and engineers in the EU is through the 'import' of trained scientists and engineers as both temporary workers and immigrants. With respect to this, an example of a pull effect is suggested by Solimano and Pollack (2004) who note that the ratio between R&D expenditure in the EU and in Latin America is more than 8 to 1. Such a difference creates strong incentives for flows of S&Es from Latin America to the EU (or possibly other OECD countries). As can be seen from Table 4, which shows the origins of foreign S&Es in a number of EU countries, the flows from Latin America are still rather small, except for when the destination country is Spain. Although one must bear in mind the problems related to obtaining accurate data on international mobility, both Figure 12 and Table 4 do indicate that there is quite some variability in how well countries attract foreign S&Es and where they come from. Using Latvia as a proxy for the new EU member states (NMS), it would appear that before the 2004 EU enlargement, most S&Es did not come from other NMS, but from the 'rest of Europe', i.e. from other Eastern European countries, including Russia and Turkey.[49] The EU Labour Force Survey has collected data on tertiary educated foreign-born populations on a yearly basis and this data indicates that many EU countries have increasing amounts of recently (1-5 years) arrived tertiary educated foreign-born immigrants (Eurostat, 2005).[50]

Figure 12. Proportions of foreign scientists and engineers in certain EU countries.



Note: The original data are obtained from the 2001 round of Population and Housing Censuses, and are for latest available year. Source: Eurostat.

[48] A recent EC publication (EC, 2006d) has looked at R&D expenditures *per capita* researcher and across Europe. Interestingly, the countries with the lowest levels of expenditure per researcher (mainly Eastern European countries) have the highest proportion of women in research. Conversely, countries with high levels of expenditure per researcher (the Netherlands, Switzerland) have low levels of women in research. This could simply reflect the gap in salaries for women and men.

[49] For Latvia, the proportion of Russian S&Es may be particularly high because of the sizeable Russian minority there. Although the exact proportion is not known, it can be seen from the original data that other countries have sizeable contributions to the Latvian foreign S&Es as well.

[50] An obstacle to the free movement of highly educated workers – or brain circulation – has been the complicated legal and administrative procedures required for the entry of both non-EU students and workers. In addition to certain individual EU member states taking actions to increase the numbers of highly-skilled immigrants, the European Union has recently taken steps to ease these procedures by introducing a 'researchers visa' which must be transposed into national law during 2007 (EC, 2006a).

Table 4. Foreign S&Es by origin as a % of all foreign S&Es in certain EU countries.

Denmark	37.3%	2.7%	14.4%	4.2%	3.9%	1.7%	0.8%	0.9%	100.0%
Greece	36.9%	15.8%	10.3%	8.7%	4.3%	2.0%	2.3%	1.8%	100.0%
Spain	29.9%	0.9%	4.4%	2.8%	2.0%	28.4%	3.6%	0.1%	100.0%
France	29.9%	2.4%	3.7%	13.6%	1.1%	2.4%	20.6%	0.2%	100.0%
Ireland	33.9%	1.3%	2.4%	18.3%	1.9%	1.1%	6.2%	2.8%	100.0%
Cyprus	31.9%	1.6%	12.8%	22.2%	1.0%	1.0%	1.0%	0.7%	100.0%
Latvia	4.2%	4.2%	89.8%	1.9%	0.0%	0.0%	0.0%	0.0%	100.0%
Austria	44.5%	8.9%	5.5%	2.7%	1.6%	0.9%	1.0%	0.3%	100.0%
Finland	42.4%	20.4%	3.6%	6.8%	2.3%	1.6%	1.6%	0.7%	100.0%

Note: The original data are obtained from the 2001 round of Population and Housing Censuses, and are for latest available year. NMS = new member states.
Source: Eurostat and own calculations.

As discussed in the previous section on international student mobility, an important component for international mobility of scientists and engineers is also intra-EU mobility. Figure 13 depicts the attitudes of managers from EU-15 regarding the impact of intra-EU mobility on innovation. The numbers indicate that, at least at the time of the Innobarometer in 2001, there was no great overall enthusiasm for such mobility, although some countries (Portugal, Greece, Spain and Italy) were quite positive. However, the Innobarometer also shows that among large companies and exporting companies, the majority of managers considered intra-EU mobility to be at least somewhat important for innovation. The EU LFS data for 2000 and 2004 shows that intra-EU migration of the tertiary educated is increasing in most EU countries (Eurostat, 2005).[51]

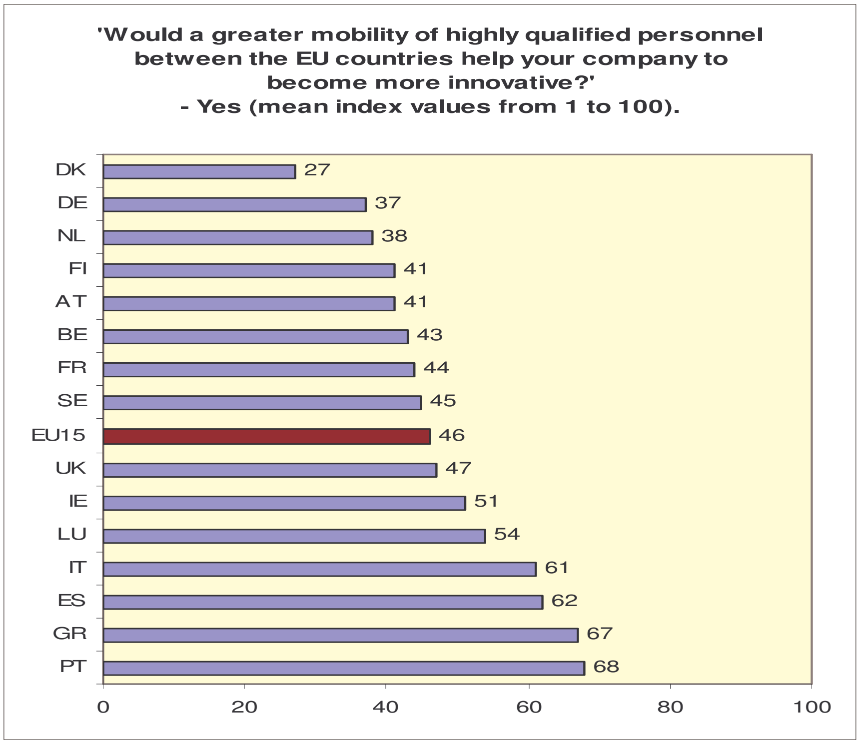
Available US data can be used as a rough model for Europe in terms of brain gain from the developing countries. The data from Finn (1997) indicate that roughly half of all foreign doctoral recipients return to their home countries immediately after their graduation. However, almost half continue working in the US for long periods of time (measured in years and decades), thus representing considerable brain gain. This has been, at least until recently, especially true for China and India.[52]

Human resources in science and engineering include both persons educated in S&E and persons who are working in S&E (most individuals fall into both categories). Thus, for example, inactive and unemployed people who are nonetheless educated in an S&E field are included in the larger pool of potential scientists and engineers and as such, attracting people from this group back to the working world is an important option to consider for the future.

[51] The study by Graversen et al. (2001) of migration of the highly skilled between the Nordic countries concluded that migration in this region seemed to lead to overall brain circulation rather than brain gain or brain drain. However, the picture may be different elsewhere in Europe. For example, an underemployed scientist in one of the new EU member states may well find an appropriate S&E job in another EU country, thus increasing the total number of fully employed scientists and engineers in the EU. The Graversen et al. (2001) report does not cover the two newest EU member countries Bulgaria and Romania. These two countries may be contributing significantly to such intra-EU mobility in the near future.

[52] On the other hand, even those who stay, have been shown to contribute to their home countries scientific and technological development by networking with researchers in their home countries (see e.g. Choi, 1995), as well as by contributing financially (via remittances) to the development of their home countries. In two thirds of the mostly developing countries studied by Adams (2003), less than 10% of the tertiary educated population migrates. However, for a small number of developing countries, e.g. those close to the US or many countries in Africa, the picture is much bleaker with a large share of the best educated emigrating (Adams, 2003 and Docquier and Marfouk, 2004). OECD (2005) also points out that, small countries, with high rates of emigration of the highly skilled, may not be able to reach a critical mass of human resources necessary for fostering long-term economic development.

Figure 13. Potential impact of greater mobility of highly qualified personnel.



Source: Innobarometer 2001 (Flash Eurobarometer 100), Innovation Papers no. 22.

The stock of S&E personnel could also be increased by extending the working lifetime of scientists and engineers before mandatory retirement (see next section for more on issues related to retirement). Furthermore, the numbers could be increased by opening up new opportunities and responsibilities in S&E occupations so that scientists and engineers could collect benefits and rewards of their S&E knowledge and skills without leaving research. Scientists and engineers in other occupations could be re-attracted back into S&E occupations, and older workers retrained for new and more challenging positions.

Finally, lifelong learning (LLL) is a way to increase the numbers of S&Es. Eurostat data indicates that women tend to participate at somewhat higher rates than men do in formal education (mostly, but not exclusively tertiary education) after 25 years of age (at the EU-25 level the proportion of women was 55.2% in 2003). Looking at the S&E fields of study at the EU-25 level in 2003, 39.7% of LLL science students were women and 19.2% of LLL engineering students were women[53] (Eurostat).

Indicators

The main data in this module include:

- *Immigration data on highly skilled S&E workers from outside the EU:* these data are at least as important as student mobility data and as difficult to obtain. However,

[53] The corresponding ratios (females/total) for all tertiary level S&E graduates in 2003 were: 41.8% and 22.7%, i.e. fairly similar (Eurostat).

there are some recent efforts to develop better data, including data on the inflow of EU S&Es returning to Europe, and non-EU S&E immigrants.[54]

- *Data on unemployment:* in this case we can include data on unemployment among the highly skilled, which can be used as an indicator for the potential employable workforce, given there is enough demand. These data are available from Eurostat.

Further indicators could be developed to investigate the potential number of S&E personnel that return to S&E occupations from inactivity or from other jobs. This topic is discussed further in the following section.

Ideally the data should be available by gender for each of the indicators suggested above. The potential contribution of women is particularly important given the ageing of Europe's scientists and engineers and increasing global pressures on the worldwide supply of scientists and engineers. It is also important to consider all levels of university education. Although the literature focuses on indicators for PhD graduates, the majority of research positions are filled by individuals who have Bachelors and Masters' degrees.

3.5.4 Loss of scientists and engineers

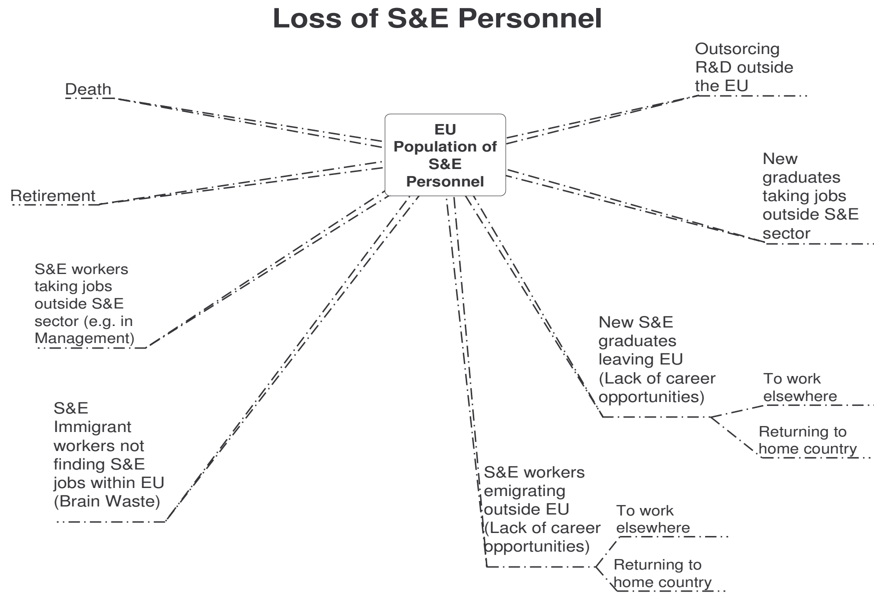
This section identifies factors that contribute the most to the loss of working scientists and engineers, and experiments with possible policy changes regarding these factors. However, estimating the feasibility or costs associated with the attempt to reduce losses within any specific factor, is difficult. For example, is it easier or less expensive to reduce losses by increasing the retirement age by a few years, by improving the ability of S&E graduates or S&E immigrants to get an appropriate job in S&E or by trying to retain more European S&Es in Europe? Given the size of contributions from these factors, it would seem that a postponement or extension to retirement age would be most effective.

The main outflow from the stock of scientists and engineers is retirement. Other important loss channels (as seen in Figure 14) are leaving S&E occupations for jobs outside S&E (mainly for management jobs), emigration to other countries (or outside the EU-25), or industry outsourcing of R&D to other countries (or outside the EU-25). Lack of career opportunities in the EU is an obvious reason for emigration or for missing the potential pool of international S&E workers coming to the EU. Similarly, there are other groups of potential S&E workers who for one reason or another do not end up in the S&E pool, for example, S&E graduates who choose other jobs or as important, immigrants with S&E backgrounds who are not able to find appropriate employment within S&E.[55] The latter phenomenon is often referred to as brain waste. Policies involved here include those mentioned in the previous paragraph as well as immigration policies.

[54] Change in the supply of highly skilled S&E immigrants could also be estimated from, 1) economic growth rates in supply countries (the lower the rate, the more likely it is that highly skilled workers will emigrate), and 2) increases in R&D expenditures or employment opportunities in supply countries, which in turn, could reduce the potential supply of skilled immigrants to the EU.

[55] Regarding this 'brain waste', a European Commission study (Employment in Europe) shows that the employment rates of the highly educated non-EU immigrants in 2002 were on the average considerably lower than the rates for highly educated internal EUimmigrants. This was particularly true for highly educated immigrant women (58% vs. 80%).

Figure 14. Module - Loss of science and engineering personnel.



Note: Dashed line indicates a negative effect.

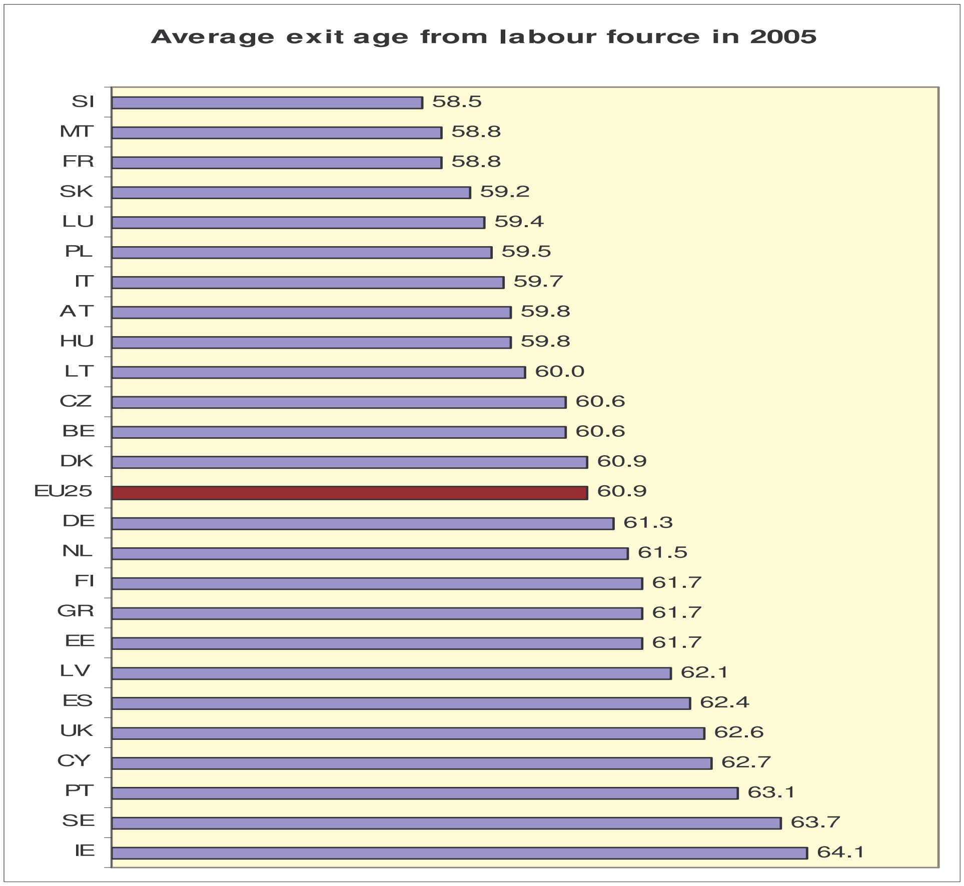
The reserve labour pool in the EU includes those scientists and engineers, including new graduates, who lack suitable career opportunities. If EU member states manage to keep such potential EU researchers from seeking career opportunities in competing countries such as the US (with better funded R&D opportunities), then this newly established pool would represent an opportunity to increase the number of working S&Es in Europe.

Some EU member states may have relatively large pools of unemployed or under-employed S&E researchers or graduates who have sought employment outside the science and engineering field. For example, there is an apparent lack of job opportunities in Spain and Italy (e.g. in public research), and unemployment and under-employment of scientists and engineers is apparent in some of the new EU member states. According to earlier research by Teichler (1989), in the 1970s and 1980s the proportion of under-employment, mismatch or 'inappropriate' employment among university graduates in general, varied between 3% and 40% in surveys undertaken in various European countries.

This reserve labour pool could also help fill an increase in demand. However, successfully attracting such people back to research activities is not the same as securing an increase of new graduates to join the S&E workforce, as the years out of research are likely to have an effect on the quality of work at least over the short term. On the other hand, these people could replace those already working in S&Es who are planning to move away from S&E to management or other jobs.

Some EU countries are facing a more serious problem from an aging workforce than others. In particular, Latvia, Hungary, the Czech Republic, Greece, Italy and Lithuania had a high proportion at 40% or more of their scientists and engineers in the 45-64 age group in 2005, which is significantly above the approximate 35% rate of EU-25 average (Eurostat). These countries may have problems replacing their retiring scientists and engineers. Figure 15 shows the current average retirement ages in the EU-25. As can be seen, the range is sizeable.

Figure 15. Current retirement age in the EU-25.



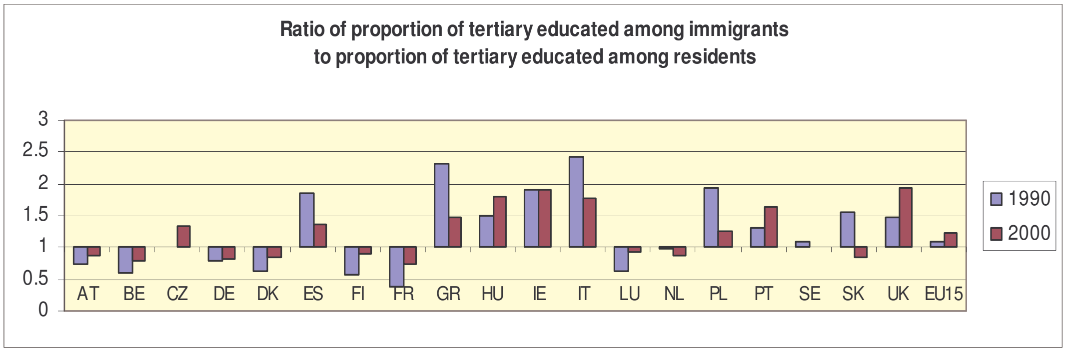
Note: For Germany and Cyprus, the data is from 2004.
Source: Eurostat.

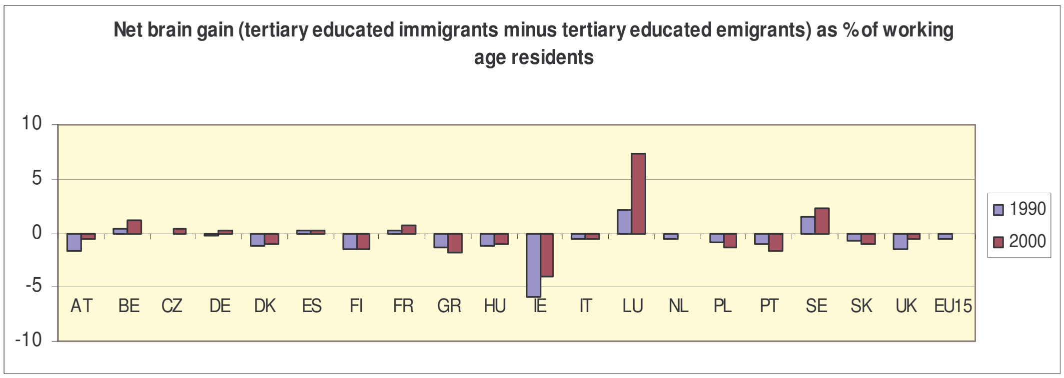
Europeans gain from attracting highly educated foreign workers. However, the other side of the coin is the possible brain drain experienced by countries – including European countries - supplying the global movement of highly educated workers. Recently, Docquier and Marfouk (2004a and 2004b) have made a significant contribution to this topic by building a database describing brain drain from all of the developing and developed countries to the OECD countries.[56] Figure 16 shows some of the results for Europe. Firstly, the numbers indicate that immigrants coming to Europe have been, at least recently and on average, better educated than residents.[57] Secondly, the 'net brain gain' as measured in Docquier and Marfouk (2004a and 2004b) was only slightly negative for the EU-15 in 2000 and has improved from 1990.[58] Based on these data, the country experiencing the largest brain drain has been Ireland, and conversely, the biggest proportional gains have been experienced in Luxembourg. Data from the OECD in Auriol (2006) indicate that most EU countries are either net beneficiaries of highly skilled migration or that the inflows and outflows balance out. Another report, also using OECD data (OECD, 2005), found that a few EU countries,

[56] Docquier and Marfouk collected data on the immigration structure by educational attainment and country of birth from all OECD receiving countries. Census and register data were available for almost all OECD countries in 2000, and for more than half of them in 1990, the rest of the data are from surveys. The data are estimated to cover 92.7% of OECD stock of adult immigrants in 2000 (and 88.8% in 1990).
[57] Conversely, the Docquier and Marfouk data indicate that Americans are currently, on average, better educated than immigrants.
[58] However, for the US, the 'net brain gain' had risen from 3.6% in 1990 to 5.4% in 2000.

notably Poland and to a lesser extent, Ireland and Finland, suffer from brain drain, but for most EU countries international mobility of the highly skilled seems beneficial.

Figure 16. Net brain gain in Europe in 1990 and 2000.





Notes: In the first graph, a value of 1 equals no gain, no loss. For example, the value of nearly 2 for the UK in 2000, means that the proportion of UK immigrants with tertiary education was almost twice as high as the proportion of UK residents with tertiary education.
For the Czech Republic, the data for 1990 is together with the data for Slovakia.
For the Netherlands, the data in the second graph for 2000 is truly 0.0%.
Source: Docquier and Marfouk, 2004.

Docquier and Marfouk (2004a and 2004b) have also calculated emigration rates by educational attainment for the countries in their database. For most countries the rates slightly decreased between 1990 and 2000, but Malta (55.2%), Ireland (34.4%), the UK (16.7%), Slovakia (15.3%), Estonia (13.9%) and Portugal (13.8%) still had high or fairly high proportions of their tertiary educated population emigrating in 2000.

There have been abundant data and studies on the United States regarding brain drain (see e.g. OECD, 2001; Gupta, Nerad and Cerny, 2003; Saint-Paul, 2004 or Finn, 1997), and this data can be used to further assess the brain drain from Europe to the US given that most emigrating S&Es from Europe head for the US. Based on data from the US Dept of Homeland Security and Eurostat, the UK, France and Denmark 'lost' some 60,000 highly skilled workers to the US in 2005, but as a proportion of each country's HRSTO (HRST by occupation), this amounts to less than 0.5%. Ireland had the highest proportion of its HRSTO obtaining H-1B visas for the US (0.84%).

With respect to longer term stay in the US, the study by Gupta, Nerad and Cerny (2003), indicates that only around a third of European PhDs trained in the US return home for their first jobs after graduation, with those trained in S&E fields even more likely to stay in the US after graduation. Those that stay are important to their host country. After all, approximately 25% of US PhDs are foreign born (OECD, 2005). Saint-Paul (2004) looked specifically at European expatriates in the US, and argues somewhat worryingly that even though the absolute numbers of expats may be low, a large proportion of 'European stars'[59] are in the US, possibly slowing down growth and innovation in Europe.[60] Data in Potočnik (2005) indicate that European S&Es have been on average, slightly keener to stay in the US than other foreign recipients of US S&E doctorates.

Regarding reasons to leave the EU, a study of internationally mobile scientists and engineers (Hansen, 2003)[61] indicated that economic factors such as higher salary are usually not as important as other factors. For EU-born scientists and engineers, the most important reasons to go abroad to work are related to a broader scope of activities and better access to leading technologies.

Outsourcing of R&D to outside the EU-25 is considered a problem for increasing R&D investment within the EU. However, from the point of view of S&E personnel in Europe, there is literature suggesting (see ISA, 1999 or Gaillard, 2001) that expanding businesses outside the EU does not necessarily increase EU brain drain, as domestic employees seem to rarely move permanently to foreign business locations.[62] Companies themselves continue to prefer to locate R&D in their home country, according to the 2005 EU survey on R&D investment trends (EC, 2006b).[63] The most attractive R&D destinations outside the EU are the US, China and India. Importantly, the report also indicates that high labour costs of researchers – although not insignificant - may not be among the most important factors for deciding where to locate R&D. A more important reason seems to be on the supply side, i.e. the availability of researchers, which can be affected by policy.[64] There can be problems on the other side of the equation as well. The McKinsey Global Institute has studied the offshore markets, and argues that, although the pool is increasing, currently only about 13% of professionals in the developing world (or, as an example, 10% of Chinese engineering graduates) are capable of working for a Western multinational in a high-grade job.[65] The problems are related to cultural and language skills, quality of education, and geography among others.

Indicators

The main data sets in this module include the following:

- *Outward mobility of S&E graduates and employees:* such a measure is not straightforward due to issues mentioned earlier, but is nonetheless important to consider. The loss of highly skilled S&E employees has important implications for supply scenarios in the EU. The US government agencies collect and provide access to detailed data of highly skilled persons in the US such as highly skilled Europeans working in the US on a temporary basis. Changes in the US, in terms of how many foreigners are hired and where they come from, also have an impact on Europe.

[59] Saint-Paul uses this term for the top 5% of PhDs.
[60] However, even if highly skilled workers stay on after graduation, they may still have plans to return to their home countries after a number of years of foreign experience. For example, Swedish data points to a high return rate for expatriate engineers, with more than 65% returning within eight years stay abroad (Gaillard, 2001), suggesting that expats return according to their original schedule, rather than change their minds and remain abroad. Gaillard (2001) sees this as a home country pull effect for returning expats, rather than a foreign location pull effect for potential emigrates.
[61] The study looked at internationally mobile scientists and engineers originating mostly from the EU or the US.
[62] It does, of course, most likely lead to loss of jobs in the domestic market.
[63] Nearly 60% of respondents to another survey said that do not currently offshore R&D and do not plan to do in the near future either (The Economist Intelligence Unit, 2006).
[64] Other important reasons for locating R&D were found to be market access, access to R&D knowledge and results, economic and political stability and R&D cooperation opportunities (EC, 2006b). However, these results varied by sector, with pharmaceuticals & biotechnology considering such factors more important.
[65] The study was quoted in an article titled 'Nightmare scenarios – Western worries about losing jobs and talent are only partly justified' in the Economist of 5 October 2006.

- *S&E graduates choosing jobs outside S&E fields:* there are some data sets containing information on this topic, but mostly for a small number of countries.
- *Immigrant workers not finding S&E work:* this measures what is known as brain waste, which is unfortunately relatively common in the EU. Some data are available.
- *Unemployment in S&E field:* includes the numbers of S&Es that are unemployed and consequently could be either immediately re-integrated into the workforce or re-integrated after some (re-)training. There are data available on unemployment within S&Es from Eurostat.
- *Retirement age:* the baseline scenario estimates the losses from retirement in the next 10 years or so. In this case, we try to determine what effect changing the retirement age would have on those losses.

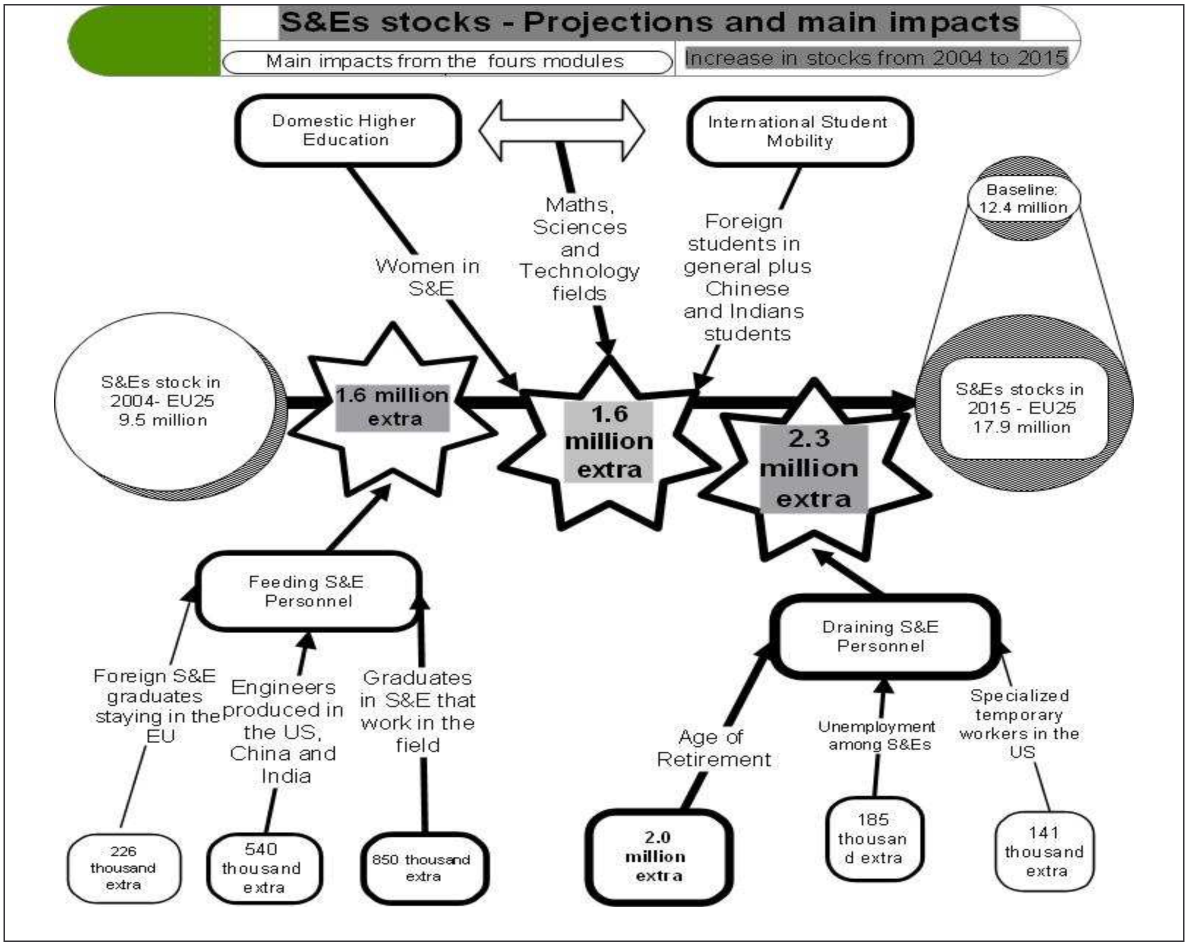
Additionally, data on issues such as outsourcing of R&D to locations outside the EU-25 could help develop a better picture of the overall situation, even if outsourcing doesn't necessarily take EU employees out of the EU, it still (potentially) reduces R&D performed in the EU-25.

3.5.5 Putting the modules together

Considering all the four modules and the related indicators, our simulation model was built by first looking at science and engineering students in tertiary education, and then graduate numbers of S&Es. Then we looked into stocks of S&E and the variables that were influential not just in increasing projected stocks, but also those that would have a negative impact on S&E stocks and consequently, if manipulated, would have a less significant influence in final numbers of S&Es. Before introducing these changes, final stocks of S&Es could reach 12.4 million by 2015. After the changes, such stocks could be forecasted to reach 17.9 million by 2015. All of the changes combined could therefore create a net impact of around 5.5 million extra S&Es by 2015.

Figure 17 suggests the 'big picture' by quantifying some of these influences and showing some potential pathways of reaching the goals of additional scientists and engineers.

Figure 17. S&E stocks – Projections for 2015 and main impacts.



Data, indicators and full explanations of the analyses and simulations carried out under the scenario is given in the full report KEI WP1.4a.

3.6 Conclusions

This scenario has examined how an increase in the supply of researchers – or scientists and engineers - could be attained in the next ten years or so, and investigated the main factors that impact this supply. Some of these factors, measured through a set of available indicators, were manipulated through simulations, resulting in a set of relevant factors and indicators that have an important effect on the stocks of scientists and engineers. These key indicators can be particularly helpful for the policy community in tracking progress towards the goal of increased supply of researchers and S&Es to reach the Lisbon goal of 3% R&D against GDP. Furthermore, this report has discussed issues related to additional potentially relevant indicators.

By manipulating a set of factors that have an impact on S&E numbers, this report has forecasted possible outcomes, considering that certain actions, trends or other developments would take place, or alternatively, if current trends would continue unchanged.

The estimates of required numbers of scientists and engineers discussed in this report vary from around 3.5 million[66] to as much as 10 million,[67] depending on what the point of departure is (in terms of R&D intensities - R&D against GDP - and the ratio of researchers to S&Es).[68]

Clearly, by just following present trends, the EU countries, as a group, will not be able to supply the upper target estimates of S&Es necessary to reach the 3%goal, although individual countries, such as Finland, Sweden, and France might be able to do so by 2015 (considering present trends in terms of retirement age, number of S&Es graduates and demographics). Other EU countries will need to monitor other factors (and indicators), developing relevant policies to be able to reach this goal.

Moreover, this report has identified groups of member states, with different degrees of likelihood of meeting this goal. These groups varied from countries that should not have too much trouble in meeting their goals (including Scandinavian and other Northern European countries, as well as France, Germany and Austria), to countries, such as the new member states and Southern Europe, that would seem to have considerably greater difficulties in reaching the desired numbers of scientists and engineers.

All the four modules identified as being influential in the numbers of S&Es, (domestic higher education system, international student mobility, supply channels to the stock of European S&Es and loss channels that decrease the number of S&Es) have been demonstrated to be relevant for policy. By manipulating indicators in the four modules, we were able to evaluate individual contributions that would help closing the gap in the numbers of S&Es required to reach the Lisbon goal. The module with the highest impact on S&E numbers was the module focussing on losses of S&E personnel, where the retirement age indicator had the most significant impact of all proposed indicators.

Other modules and indicators were also relevant for the analysis, contributing with significant amounts to the stocks of S&Es, if certain changes take place. Most relevant ones were the modules on domestic higher education and international student mobility and the indicators on students in S&E fields and female enrolments in S&E studies. As for the module on the supply of S&E personnel, the most relevant indicators were the proportion of graduates opting to work in S&E fields and bringing foreign graduates in this area to work in the EU.

By manipulating indicators within the four modules, the stock of scientists and engineers in the EU could be expected to reach about 18 million by 2015. All the changes combined could therefore create an impact of around 6 million extra S&Es by 2015 (on top of the expected around 12 million from the current trends in the stock of S&Es). Such an increase would cover most of the estimated goals for S&Es in this report – except for the highest estimate of 20 million. Consequently, also the overall goal of 3% R&D intensity could (nearly) be reached in this manner, if the identified changes could actually take place.

In summary, nearly 90% of the total impact of manipulations in key indicators within the four modules, comes from only five indicators:

- Increasing average retirement age in the EU

[66] This lowest estimate is based on the estimate from the European Commission that around 700,000 (see EC, 2003a) additional researchers would be required, and the 19% current researchers to S&Es ratio in the EU. Applying a 25% ratio of researchers to S&Es, observed in those countries that have their R&D intensity currently between 2 and 4%, would give an even lower estimate of 2.8 million additional S&Es.
[67] This highest estimate is based on the individual EU member state R&D intensity targets agreed in 2006 and the calculations made in Section 3 of this report.
[68] In this scenario, we used the proportion of 25% as the share of S&E personnel in research based on R&D intensity ranging from 2 to 4%.

- Increasing proportion of students choosing S&E studies
- Increasing proportion of S&E graduates getting S&E employment
- Bringing in more scientists and engineers from countries like China and India (or even the United States)
- Increasing proportion of women studying S&E fields.

More than 50% of the impact comes from the top two indicators listed above. On the other hand, individual impacts from factors, including trying to keep non-EU students working in the EU after graduation, reducing unemployment in S&E fields, trying to retain EU scientists and engineers in the EU (as opposed to letting them migrate, for example, to the US), and getting more Chinese and Indian students to choose the EU for their studies, all remain small, at somewhere between 1 and 4%.

In addition to all the indicators used in this scenario other useful and desirable indicators exist, or data for them could be collected. In the case of many of such indicators, greater detail is required than what has, at least until recently, been available. Another important issue is having enough consistency between countries, both in terms of what data are collected and how indicators are defined.

Missing or underdeveloped indicators (see Table 5) require prompt attention, specifically the ones that are policy relevant. Those include for example data on further careers of graduates (1, 5 and 10 years after graduation), and numbers of immigrants by educational background and gender, but are not restrict to them.

Table 5. Potentially relevant, but currently inadequate or missing indicators.

Indicator	Details	Relevance
Stock of HRST		
Educational background of researchers	Currently Eurostat collects data on the educational background of S&Es, but does not collect such data on researchers.	Assessing the origin of researchers would be important.
Age distribution of HRST, S&Es and researchers	Currently data on the age distribution of HRST and S&Es are collected, but the age brackets are too wide, especially at the higher end.	Accurately assessing historic and future trends in the stocks, including losses to retirement would be important.
Further careers of EU graduates – e.g. in 1, 5 and 10 years after graduation	There are a number of country studies focusing on graduate careers, and at least one study covering several countries (CHEERS), but no EU level data collection has taken place so far, although there are some current plans for this.	It would be important to estimate the contribution of S&E graduates to the S&E fields of work and R&D in the EU, and the contribution of graduates in other fields to the S&E stock, and the careers of the large proportion (possibly a third) of S&E graduates, who do not end up working in S&E.
Further careers and locations of non-EU graduates	There is currently no EU wide collection of such data.	Estimating the contribution of international S&E graduates to the stock of S&Es and researchers in Europe (vs. outside Europe) would be relevant.
Domestic and foreign students and graduates		
High school pupils studying S&E subjects by gender	Currently, there are data for the overall ISCED97 level 3, but a further breakdown would be required.	Accurately assessing the potential contribution of such pupils to university enrolments in S&E fields would be relevant.
S&E students in higher education	These data are collected, but there are inconsistencies between countries in counting university students, especially at the PhD level.	Accurately estimating the potential contribution of S&E graduates to S&E fields and research performed in the EU would be important.
Survival rates in education by field of study and gender	Survival rates are currently collected by the OECD, but not by field of study.	Obtaining such data on the difficulties in S&E fields vs. other fields in getting students to graduate, and the differences in the rates of female/male students finishing their studies would be relevant.

Indicator	Details	Relevance
Mature students by educational field, age and gender	Eurostat currently collects data on mature students by age *or* by field of study, but not combined by age *and* field of study.	Assessing the potential contribution of mature S&E graduates to the S&E fields of work in the EU would be relevant.
Foreign students and graduates by nationality, gender and field of study	Foreign student data is not currently available by field of study form Eurostat. There are also still inconsistencies in how international students are defined and counted, or not counted as is often the case. Graduate numbers are not currently collected by foreign/non-EU vs. domestic/EU basis.	Accurately estimating the contribution of non-EU students to the stock of S&Es and researchers in Europe would be important.
Quality indicator for EU universities/S&E programs	Currently, there are two main worldwide indices (the 'Shanghai Index' and the Times Higher Education Supplement rankings), which are, however, based on different criteria and give different results.	Assessing the relevance of university/program quality on e.g. enrolment rates of EU or non-EU students would be important.
Inward EU mobility		
Immigrants by educational background and gender	There are great inconsistencies in how immigrants are defined and counted. Some countries collect data on the educational background of immigrants, but most do not. There are some recent developments to improve data availability.	Obtaining accurate data on the flows of immigrants and their potential contribution to the stock of S&Es and researchers would be relevant.
Employment rates of immigrants by gender	There are some data on this, but not adequate enough across countries.	Obtaining such data would help in assessing the contribution of immigration to the stock of S&Es and researchers. Currently, highly educated female immigrants have greater difficulties in getting appropriate employment than their male counterparts.
Relevance of educational background of immigrants to current employment	Such data are mostly not collected.	Getting such estimates would be relevant for assessing the potential contribution of immigration to the stock of S&Es and researchers.
Outward EU mobility		
Data on outward mobility of S&E graduates and personnel	Adequate exit data are not currently widely collected in EU member states.	Assessing the true 'brain drain' from Europe would be important.

4. Policy Scenario: Environmental Innovation[69]

Prepared by
Minna Kanerva, René Kemp and Anthony Arundel

4.1 Summary of findings

A major goal of European governments is to encourage the transition of the European Union to a knowledge-based economy and more specifically to meet the Lisbon and Barcelona agendas. Environmental innovation, both intentional and unintentional, makes economies more efficient by encouraging and facilitating the use of fewer material or energy inputs per unit of output. In effect, environmental innovation involves using inputs more 'intelligently', so that the level of inputs used is reduced through the application of knowledge. Environmental innovation can thus be considered the link between the EU's sustainable development strategy and the Lisbon agenda to make the Union "the most competitive and dynamic knowledge-driven economy by 2010".

This report explores and identifies relevant indicators for environmental innovation, so that these indicators could be used for developing innovation policy for all economic sectors, as well as for the field of environmental technologies. Where adequate indicators are missing, usually due to problems of definition or measurement, better indicators are recommended.

With the help of discussion and correlation data analysis we investigate a large number of potential indicators. In addition, we discuss the definition and location of environmental innovation, and conclude that it takes place in the whole economy, although it is more concentrated in the environmental goods and services sector (EGSS), which can, however, be hard to define. We also sketch a scenario which illustrates the process of eco-innovation.

Following this scenario, we divide the forty-five[70] included indicators into the five different types mentioned above: pressures, facilitators, inputs, outputs and effects, and discuss each indicator in some detail. The correlation analysis performed for this scenario includes all those thirty-nine indicators for which we have been able to obtain national level data for the EU member states. Sectoral level data were in many cases unfortunately not available. The correlations we focus on are between different types of eco-innovation indicators, e.g. between innovation pressures and inputs, or between outputs and environmental effects, following our eco-innovation scenario. Strong and rational relationships between indicators from these groups help us identify a number of key eco-innovation indicators.

The correlation results are mixed. Much of them follow the lines of the discussion and literature, often showing interesting evidence for links between the indicators. A few of the established relationships are not found in these data. However, there are a couple of issues that most likely contribute to this: firstly, in some cases, the data coverage of the EU countries is poor, and secondly, it is not always possible to obtain data following the flow of time in the innovation chain.[71]

Table 6 below includes those fifteen indicators that we consider - based on both literature and our data analysis - to be the key indicators for measuring innovation with environmental benefits. In choosing the key indicators, we have tried to take into account several aspects particular to eco-innovation to have maximum possible coverage. These characteristics include:

- Different types of indicators: pressures, inputs, etc.
- Intentional and unintentional eco-innovation

[69] This is a condensed version of the full report available separately: KEI WP1.4b (Policy scenarios – Environmental innovation).
[70] See Annex II in the full report KEI WP1.4b for a complete list of indicators considered.
[71] For example, some data on environmental effects were too old, and some data on innovation pressures were too new to fit well in the scenario.

- Intentional eco-innovation within the EGSS, but also elsewhere in the economy
- Different types of innovation: product, process etc.[72]

Our main recommendations, concentrate on improving data collection and data availability. Some of the recommended key indicators still need further exploration and development, and refining the questions on eco-innovation in the Community Innovation Survey should also be considered. Last but not least: an overall recommendation for developing data collection for eco-innovation related indicators would be that much more sectoral level data should be made available.

Table 6. Summary table of key environmental innovation indicators.

Indicator	Details	Relevance
Part I. Available indicators		
Pressures		
Environmental regulatory regime index (ERRI) or something similar on the stringency, clarity and stability of environmental regulations	Index data obtained from surveys on: Environmental regulatory regimes; stringency of environmental regulations; or clarity and stability of regulations. Not yet consistently available on an annual basis.	Important pressure factor, although captures only regulation related eco-innovation (but across sectors).
Inputs		
Eco-innovation related publications in specialized journals	Publications in 'environment/ecology' in the EU-25 per 100,000 capita.	Potentially good indicator, but mostly only captures (intentional) product innovation, and may not do so evenly.
Eco-innovation related patent counts in the EGSS, or outside it	Patent counts in the EGSS based on priority dates of patent applications (included here: environmental technology, wind energy, fuel cell technology) – national indices relative to population size used. Existing patent databases should be further developed to allow for easier access to eco-innovation related patents.	Fairly established eco-innovation indicator, which also captured diffusion, but up-to-now mostly confined to the EGSS. Also, focus only on product innovation.
Outputs		
Intermediate material inputs (IIM) or intermediate energy inputs (IIE)	IIM – material inputs at current purchasers' prices per GDP (NACE A to O); IIE – energy inputs at current purchasers' prices per GDP (NACE A to O). Data collection is not yet annual or EU-wide.	Also intermediate input. Measures an important factor in the eco-innovation process between inputs, outputs and effects. Captures also unintentional eco-innovation.
Exports in EU eco-industry products to large developing economies, such as China and India	EGSS exports in EU as share of total EU exports to China and India. Further refinement of EGSS product code lists or product classification systems would be important (efforts underway at the World Bank).	Potentially a good indicator, also measuring diffusion. Confined to the EGSS and product innovation.
Relative world shares (RWS), or revealed comparative advantage (RCA)	RWS – relative position of a nation in international trade in EGS (export orientation); RCA – EGS export-import ratio compared to the pattern of all traded goods.	Not as sensitive to the EGSS product code list issue discussed above. Include some measure of diffusion. Confined to the EGSS and product innovation.
Effects		
Energy intensity of the economy	Gross inland consumption of energy divided by GDP, kgoe (kilogram of oil equivalent) per 1000 euro.	Important effect indicator on energy use. Measures also effects from unintentional eco-innovation. To be used as one of the key indicators.
Resource productivity of the economy	GDP per direct material consumption (DMC), euro/kg. Currently, no annual data is available.	Important effect indicator. Measures also effects from unintentional eco-innovation, as well as decoupling of economic growth from resource use.

[72] More and more of eco-innovation is taking place, for example, within improved processes.

Indicator	Details	Relevance
Effects from product or process innovation in terms of reduced materials and energy per produced unit, or highly improved environmental impact	Survey data, weighted by share of innovative firms. The data are collected at a detailed sectoral level. Environmental effects are currently combined with health and safety effects in the questionnaire.	Potentially valuable indicators. These indicators should also capture unintentional eco-innovation across sectors, as well as process innovation. Further development of the CIS survey, and an improvement in response rates desirable.
Weighted emissions of greenhouse gases	Million tonnes of CO2 equivalent per capita for the EU-25.	Important effect indicator for the future. Measures also effects from unintentional eco-innovation. To be used as one of the key indicators, although a longer time lag may still be needed to see the effects from intentional eco-innovation to reduce greenhouse gases.
Weighted emissions of acidifying pollutants	1 000 tonnes of acid equivalent per GDP for the EU-25.	Important effect indicator. Measures also effects from unintentional eco-innovation, although to a lesser extent, as most pollution reductions are made to meet regulations. To be used as one of the key indicators.
Part II. Potentially relevant, but currently inadequate or missing indicators		
Pressures		
Venture capital for firms in the EGSS	No data currently available at the European level. There may, however, be some EU data available from European Venture Capital Association (EVCA) in the near future.	Important pressure factor, although confined to the EGSS.
Inputs		
Business environmental R&D, as a share of total business expenditure on R&D (BERD)	No data are available at the European level (for a large enough number of countries).	Although R&D data are generally considered far from innovation outputs, this could be a useful eco-innovation indicator, with a link to regulation. Data collection should be further developed.
Outputs		
Sales or profits from environmentally beneficial innovation across sectors	No data are available at an international level.	Potentially very valuable indicator, as would measure eco-innovation across sectors (including unintentional eco-innovation). Data collection should be developed. The topic could be included in the CIS.
Foreign direct investment in EGSS (outside the EU)	FDI data are only available by very aggregate sectors, and therefore identification of EGSS not possible at the moment.	Potentially a good indicator, and would also measure diffusion. However, this indicator is confined to the EGSS.

4.2 Introduction

The main goal is to explore and identify relevant indicators for environmental innovation that could be used to develop innovation policy for all economic sectors, as well as for the field of environmental technologies. Where adequate indicators are missing, due to problems of definition or measurement, better indicators are recommended.

What makes a group of indicators generally relevant depends on how well the available *input* indicators correlate with, and are causally related to, the desired *output* indicators. Innovation input indicators usually include activities that support innovation, such as R&D, patents, or investment, and outputs include indicators on results of innovation expenditures, such as sales or profits from, or trade in innovative products.

In the case of environmental innovation, we can consider additional *pressures*, for example, environmental regulation or public opinion, which may affect the level of inputs. Moreover, certain organizational or management changes can influence the level of eco-innovation inputs. We call such indicators *facilitators*. Finally, the eco-innovation output indicators relate to desired environmental *effects*, such as fewer material resources consumed, or less pollution or greenhouse gases generated. We may be able to link, with the help of correlations, some of the pressure or input indicators to desired outputs or positive environmental effects. Such links could then help us pinpoint the key indicators.

Environmental innovation is an essential part of a knowledge based economy (KBE) because environmental innovation makes economies more efficient by encouraging and facilitating the use of fewer material or energy inputs per unit of output. In this respect, environmental innovation replaces material inputs with knowledge. Environmental innovation and eco-technologies can thus be considered the link between the EU's sustainable development strategy and the Lisbon agenda to make the Union "the most competitive and dynamic knowledge-driven economy by 2010".

Environmental innovation should also result in fewer externalities, or negative environmental impacts, which ultimately affect our health and well-being, not to mention the potentially huge impact of global climate change. Our society will be more prepared for significant global changes, environmental or otherwise, if we employ environmental technologies as far as possible. Furthermore, technology shifts caused by technological breakthroughs, rapid changes in demand for resources, or environmental imperatives could impel societies to invest more heavily in research on how to use energy and other resources more efficiently.

Finding key eco-innovation indicators is therefore important to a KBE, as such indicators measure factors that either help or hinder meeting societal, (sustainable) economic growth and environmental goals.

This section on environment innovation is structured in the following way. In Section 4.3 we discuss some definitional issues, such as what is currently considered environmental innovation on the one hand, and where it takes place, on the other. We will also present a scenario on eco-innovation, i.e. how various factors are linked to each other in theory. Sections 4.4 and 4.5 will move on to discuss the issues with availability of indicators for environmental innovation and describe the methodology used in the analyses in this report. Potential indicators will then be discussed in detail in Section 4.6. Section 4.7 touches on the problem of causality and continues by presenting and discussing our correlation results. Finally, Section 4.8 gives some recommendations for relevant key indicators.

The full report (separate document KEI WP1.4b) presents a table of all the indicators considered and the relevant correlation tables.

4.3 Theory of environmental innovation

4.3.1 Non-intentional eco-innovation and economy-wide environmentally motivated innovation

Environmental innovations are also made outside of the environmental goods and services sector (EGSS). They do not need to even be environmentally motivated innovations. In fact, more than half of all technological innovations have been estimated to have beneficial effects on the environment (see e.g. Kemp, 2007).[73] Two recent studies, for the European Commission and the OECD, have also indicated that the share of firms that do not 'eco-innovate' in any form (intentionally or unintentionally) is only between 20-30% (Kemp, 2007).

[73] Additionally, some intentional eco-innovation can also have negative environmental consequences. For example, growing grain to make bio-fuels can create additional pressures on agriculture to produce enough food for human consumption, as well as require intensive agriculture (with high greenhouse gas emissions) to produce the fuel (Doornbosch and Steenblik, 2007).

Environmental innovation, in its broadest form, includes any innovation that reduces environmental harm. More specifically, environmental innovation can be defined as 'the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the firm and which results, throughout its life cycle, in a reduction of environmental risk pollution and other negative impacts of resource use compared to relevant alternatives' (Kemp, 2007). Every investment that an organization makes includes a choice (intentional or not) between more or less environmentally beneficial technologies. Total investment in all technology forms about 20% of GDP (EC, 2001).

Measuring the non-intentional environmental innovation activity is therefore crucially important, but there are some challenges to this. Throughout the innovation chain (from R&D and other innovation expenses to sales of innovative products or use of innovative processes, or organizational methods), it may be difficult for either interested researchers looking from the outside, or managers looking from the inside of an organization to identify something that is not intentional in the first place. Secondly, giving a monetary value for such environmentally beneficial innovation can also be difficult, since it has not originally been identified as 'eco-innovation'.

There have been attempts to measure the effect of product and process innovations on reducing inputs per output or on other environmental impacts, for example by the CIS (Community Innovation Survey). We are also using some of these data in this report.

In addition to such indicators, we can also measure certain environmentally-related innovation pressures, facilitators or inputs (such as environmental regulation or environmental R&D) against certain environmentally-related innovation outputs and effects in the environment (such as more efficient processes or less pollution), and draw conclusions about links with (mostly) intentional eco-innovation in the economy as a whole.

4.3.2 The environmental goods and services sector (EGSS)

Although environmental innovation can occur anywhere in the economy, it is also important to look at the environmental sector. Innovation can be expected to be more concentrated here and some of the environmental innovation indicators are very specific to the EGSS.

The OECD and Eurostat defined the EGSS in 1999 as: 'activities to measure, prevent, limit, minimize or correct environmental damage to water, air and soil, as well as problems related to waste, noise and eco-systems. This includes cleaner technologies, products and services that reduce environmental risk and minimize pollution and resource use'. This is still the most used overall definition of the sector, and it is relatively wide in its scope. Eurostat is in the process of updating the definition slightly to include resource management activities, such as renewable energy and water management and conservation (ICEDD et al., 2006).

In order to measure the EGSS, we need not only the basic definition, but preferably also detailed information on which firms can be classified as belonging to the EGSS, otherwise we have to rely on small-scale surveys and estimates, which has, indeed, been the case (see e.g. Ernst & Young, 2006, Peter, 2006 or ECOTEC, 2002).[74]

The first issue in terms of the general sectoral or product classification systems is that when they were first constructed there was no obvious need to classify activities or products in terms of their environmental impact. Secondly, the environmental industry is rather pervasive, covering areas that fall within many different areas of the economy. This is similar to, biotechnology, which can be

[74] For example, Ernst & Young (2006) estimated that 2.2% of European GDP is due to the core EGSS. In fact, the core EGSS could amount to an even larger share of the economy. Currently, the total turnover of the EGSS in the EU is estimated to be over 200 billion euro, nearly all of it currently within the EU-15.

used in many different technological areas. As a result, there are few ‘dedicated’ sectoral classes belonging to just the EGSS (an example is NACE37 – recycling), and a large number of classes, where often only a minor part belongs to the EGSS (e.g. a fairly detailed, 4-digit NACE class 29.12 – Manufacture of pumps and compressors, which includes wind turbines). So, even the 4-digit level of NACE codes - the most detailed level used internationally - does not, in most cases, allow one to separate eco-industry sectors from other sectors. The update to the NACE codes (rev. 2) published in 2007 is only marginally better.[75]

The EGSS can be looked at either in terms of producers of environmental technology and services (the traditional way), or in terms of the main sectors of application, e.g. those sectors which would most benefit from environmental technology by being very polluting. Often, the same actors can both produce and use their own environmental technology, especially within process innovation.[76]

Annex I of the full report (KEI WP1.4b) discusses these and other approaches (looking at products or patents, or searching through a list of NACE codes) to define the ‘environmental sector’, but in relation to the main producers of environmental technology, Eurostat is currently drafting a compilation guide for collecting statistics on the EGSS, so they are also in the process of trying to define the sector from the activities point of view (NACE codes). In their draft compilation guide, Eurostat (2007) defines the ‘core’ EGS sector as:

- DH25.12 Retreading (recycling tires)
- DN37 Recycling
- E41 Collection, purification and distribution of water,
- G51.57 Wholesale of waste and scrap
- O90 Sewage and refuse disposal, sanitation and similar activities.

Of these five core sectors, mostly in services, only three are defined at the 2-digit level, which means that currently, there are mostly no data for the other two sectors available from general databases, such as the Eurostat NewCronos. These three 2-digit sectors for which data are generally more easily available are DN37, E41 and O90.

The ‘non-core’ EGS sector has not yet been formally defined by Eurostat, but it covers firms that are at least partly active in the environmental or resource domain, but do not belong to the ‘core’ industry, and includes firms from a large variety of NACE groups.[77]

In our report, some of the indicators are specific to the EGSS, but this term is often not used entirely consistently for lack of better data. Therefore, sometimes we have data for a specific part of the EGSS, such as renewable energy, or pollution control technology, and at other times we include data that is more general to the EGSS, such as exports in EGSS-related products.

[75] The CEPA 2000 (Classification of Environmental Protection Activities and Expenditure, UN, 2001) developed by the UN and Eurostat is a very detailed classification system for the environmental sector, and it can also be used to classify products. It uses 2 and 3-digit classes and covers also cleaner technologies and cleaner products. However, there is no correspondence table between the CEPA and other, more general classifications systems, such as NACE, used by e.g. Eurostat to classify activities, or HS (Harmonized System) used to classify products.

[76] For example, a large petroleum refining firm can probably develop environmentally beneficial improvements in-house, without needing to go to the EGSS.

[77] Including Agriculture; Fishing; Mining and quarrying; Manufacturing; Electricity, gas and water supply; Construction; Wholesale and retail trade; Repair of motor vehicles and motorcycles; Hotels and restaurants; Transport, storage and communication; Financial intermediation; Real estate, renting and business activities etc..

4.3.3 Inputs, outputs and impacts – The eco-innovation scenario

Figure 18 explains how the different processes of environmental innovation can be linked, as well as showing some of the available indicators. We use an environmental innovation, namely supporting the farming and production of bio-fuels for beneficial environmental effects. Section 4.6 discusses the indicators in more detail.

Biofuels, such as ethanol, are not a new invention.[78] However, current concerns related to the *state of the environment* such as the problem of climate change, have bought biofuels back in fashion. Through *science* on climate change and *media* reporting on the science, *public opinion* as well as decision-makers have all put additional pressure on reducing CO_2 emissions from general fuel use. *Regulation,* in terms of required minimum amounts of biofuel content in fuels and subsidies for producing biofuels, has created advantageous *market conditions* for producing biofuels (i.e. their price has gone up), and together these factors have resulted in more biofuel related innovation inputs, such as *R&D* to improve the efficiency of amylase conversion of starch to fermentable sugars. As a further consequence, the innovation outputs, i.e. biofuel production has started to rise markedly in various countries and the *growth of this sector* and *profits* from selling biofuel have increased.

Presumably, the beneficial environmental impact of this change is then the *reduced amount of* CO_2 *pollution* from transport and other fuel use, which then again affects the *state of the environment* in a positive way. What firms do with their increased *income* from making biofuels can then be positive for the environment, e.g. they can invest in more efficient production processes, or negative, e.g. with increased shareholder income resulting in more consumption, which is generally bad for the environment. Last but not least, there are *wider economic changes* that can either be linked to the biofuel innovation process, or be totally exogenous to it, e.g. the price of food production going up (or more space required for food production) as a consequence of producing large amounts of biofuels, or some new invention to produce liquid fuel in a more efficient way, or sharp economic growth from e.g. China that results in even more demand for biofuels. Such changes would then again have an impact on the environment.[79]

Not included in the above description are innovation facilitators, or changes in environmental management or organisational systems. These cannot be said to be a necessary part of the innovation process, or to automatically lead to actual eco-innovation, but they have been shown in several recent studies to encourage such innovation.[80]

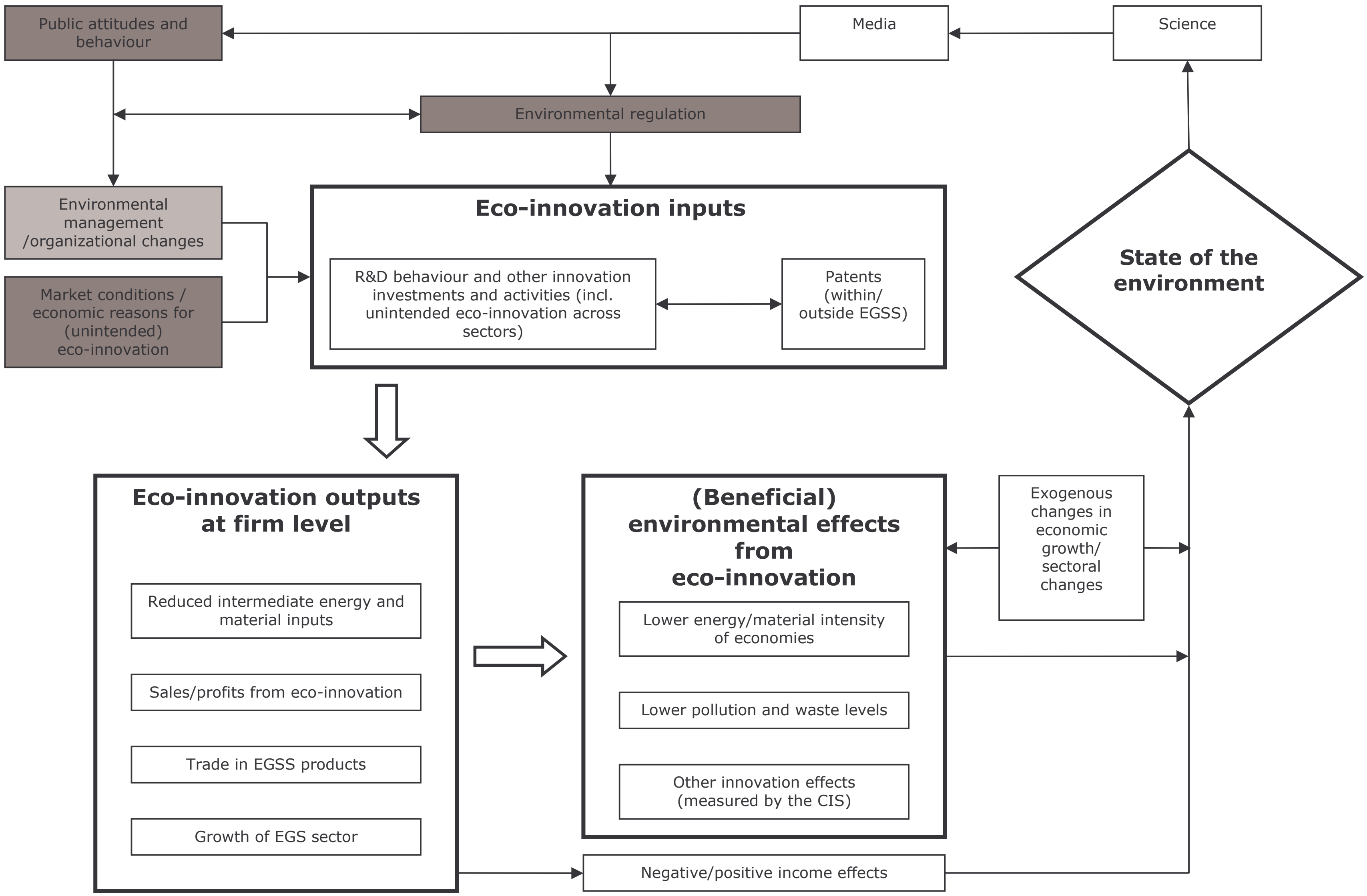
This eco-innovation scheme includes some time dimensional aspects as well, as going though the whole circle from pressures to impacts etc. takes a number of years. In the data that we include in our analysis, we try to take this into account to the extent possible. Data availability poses some problem here though.

[78] The first car of Henry Ford was fuelled by ethanol (Sasson, 2005).

[79] Additionally, biofuel production can have direct negative environmental impacts, as it is often likely to require intense (mono-) agriculture with pesticides and fertilizers (Sasson, 2005).

[80] Horbach and Rennings (2007) contains an overview of studies related to this and other eco-innovation determinants.

Figure 18. Scenario for environmental innovation. Key: dark shading = pressures, light shading = facilitators. Source: in consultation with Rene Kemp, September 2007.



4.4 Methodology

The indicators for environmental innovation cover five main categories. The first consists of *pressures*, for example, environmental regulation or public opinion, which can affect the level of innovation *inputs,* which include environmental R&D and patents, among others. Moreover, certain organizational or management changes (such as EMAS or ISO14001 certifications) can influence the level of eco-innovation inputs. We call such indicators *facilitators*. Finally, the eco-innovation *output* indicators, such as investment in the eco-sector or trade in eco-goods and services, relate to desired environmental *effects*, such as fewer material resources consumed, or less pollution or greenhouse gases generated. We may be able to link, with the help of correlations, some of the pressure or input indicators to desired outputs or positive environmental effects. Such links, if found, could then point to the key indicators.

In our report, we have concentrated the indicator analysis on looking at the correlations between various indicators (see Annex II of the full report KEI WP1.4b for the indicators themselves) following these general guidelines:

- Check for clear outliers in the data
- Run correlations with all indicators for which we have data
- Include indicators for final analysis with the following criteria:
    - Moderate to strong correlation with correlation coefficient greater or equal to 0.5 at 1% level, and greater or equal to 0.65 at 5% level.
    - Number of data points greater or equal to half of the maximum possible number.
    - In the case of similar indicators (same or similar indicator for different years, preferably with strong correlation between them) – leave only one or two with the strongest correlations with other indicators to exclude those that are possibly redundant.
    - Exclude indicators that do not follow the above criteria for any correlations.

As discussed earlier, the time dimension poses an additional problem, as time lags should be included to capture the effects of change between the different types of indicators (pressures, inputs, outputs etc.). For example, a pressure indicator for 2006 correlating with an effect indicator for 2000 does not really tell us much. Therefore, in our final analysis of the correlations, such positive or negative correlations must sometimes be ignored.

Regarding the final correlation results, relevant correlations between the following indicator categories are used to identify key indicator for environmental innovation:

- Pressures and inputs, outputs & effects
- Facilitators and inputs & outputs
- Inputs and outputs & effects
- Outputs and effects

Finally, a rational basis for the indicators and their relationships also needs to be established. The fact that two indicators correlate (even when the time flow is taken into account) does not prove a causal relationship.

4.5 Data availability

4.5.1 Non-intentional eco-innovation and eco-innovation outside the EGSS

There are a couple of issues on data availability to consider. First, there is the question of what exactly are we measuring, i.e. defining eco-innovation, as discussed earlier. Second, general economic data sets are usually not designed to include environmental issues, so some data are difficult or impossible to find. Third, the available data are often only available at an aggregate level, such as by country.

In some cases aggregate data are a problem, but in others, not necessarily so. For example, if we look at patent counts, exports, foreign direct investment (FDI) or EMAS certifications, it would be very useful to have detailed sector level data, which currently do not exist.[81] On the other hand, if we look at the energy intensity of whole economies, sector level data are not necessarily required (although they could, of course, be used for sector level analysis). Data such as trade, and especially patent data, can be relatively precise, but they do not necessarily translate well into NACE sectors.

Looking at the country level and more general eco-innovation indicators, there are a variety of indicators to choose from. Figure 18 shows the main factors and indicator types (pressures, facilitators, inputs, outputs and effects) under which eco-innovation indicators fall, and we currently have some available indicators for most of these factors, as discussed further in Section 4.6.

4.5.2 Environmental goods and services sector

The EGSS is yet to be defined in a precise way from the sectoral activities point of view. An additional problem is that generally available databases (such as the Eurostat NewCronos or the EUKLEMS databases) do not offer NACE 4-digit level data (or other similarly precise data), and mostly not 3-digit level data either. This means, for example, that we cannot get data for sectors such as NACE 51.57 (wholesale of waste and scrap), which is entirely in the EGSS, or 29.12 (manufacture of pumps and compressors, including wind turbines), which is only partly in the EGSS.

The only NACE 2-digit sectors for which data are available and which are almost totally within the EGSS are: DN37 (recycling), E41 (collection, purification and distribution of water) and O90 (sewage and refuse disposal, sanitation and similar activities).[82] This group could then form the 'core of the core' of the eco-industry. However, as these are mostly in the area of services, we do not get information on innovations with environmental benefits related to processes or manufactured goods from data on these sectors. So, until there is a much more detailed sectoral level classification scheme available (with at least four, but preferably more digits), with identified EGS sectors, we can only get a glimpse of the true EGSS by using NACE codes.[83]

4.5.3 Impacts and the time dimension

It would be most useful if indicators for both eco-innovation inputs and outputs were available for the same industry and over several years. This would enable us to track the effect, over time, of eco-innovation on outcomes. In most cases, however, time series data are unavailable. We can assume that any eco-innovation is a good thing, but we may not be able to establish a cause and effect relationship with outputs.

---

[81] In some cases, such as with FDI related to environmental technologies, there is no point in looking at data that are not disaggregated enough to include separate data for EGS sectors.

[82] In fact, for a lot of indicators available from NewCronos, O90 is not included, as it is considered to be mostly in the area of public services, and a lot of the available data covers only private services.

[83] For example, there are data on national investment in the two core EGS sectors of DN37 and E41.

The need for a time dimension poses some additional problems, as sometimes there are only very recent data available for a pressure indicator, and only somewhat dated data for an effect indicator. Looking at the relationship between such indicators is often irrelevant, as the pressure factor should precede the impact factor and not the other way around.

All the indicators considered in this report can be found in Annex II of the full report KEI WP1.4b that also includes availability issues with the indicators.

4.6 Examining the indicators

We evaluated forty-five indicators in total and have data for thirty-nine of them (12 pressure indicators, 3 facilitator indicators, 5 input indicators, 11 output indicators and 8 effect indicators). The full report KEI WP1.4b gives all the indicators considered in this report. The correlation tables presented in the full report KEI WP1.4b include correlation results with twenty-six distinct indicators.

4.6.1 Pressure indicators

Public attitudes and behaviour

The Eurobarometer surveys measure public opinion in the EU on a wide variety of issues. Some of the surveys include questions of relevance to research on environmental innovation. We have extracted the results of Eurobarometer questions on the following: preparedness to pay for renewable energy, acceptance of renewable energy sources, importance of reducing national energy consumption, importance of energy related research in the EU (2 surveys); and the importance of factors in choosing one car model over another (factors such as whether the cars are environmentally clean and how much fuel they consume).

Public opinion, of course can be far from concrete actions taken by the same public. For example, are public attitudes to renewable energy resources positively correlated with people's choices of energy for their homes? Are average car fuel consumptions related to the public attitude question on choice of car models, or do people still prefer to buy SUVs, even if they say they do not?

Figure 19 on how concerned Europeans are about climate change shows also that a number of factors can influence public attitudes. The higher the latitude of each nation's capital, the lower the concern, when all EU citizens should probably be concerned more or less equally about such a global problem.

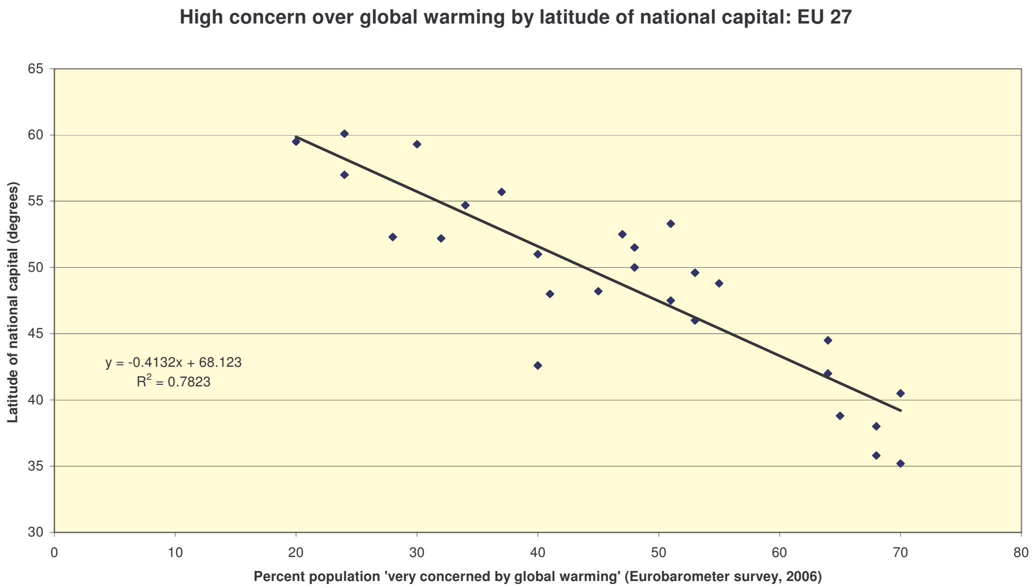
Ideally then, data on public attitudes should always be compared to hard data on actions, in order to see whether attitudes are followed up by decisions.

Incentives offered by governments to change behaviour would probably bring the public more in line with what they say they would *ideally* do. In any case, public attitudes (and behaviour) are likely to have some effect on government regulations, as well as public and private investment in eco-innovation.

For this report, we obtained data from six surveys (as specified above), but unfortunately we have not been able to find adequate data on relevant behavioral aspects. Nonetheless, the available data can be examined against other available indicators.[84]

[84] A problem with the current data is that two thirds of them are from 2006, which does not fit the pressure => input-output-effect time lag.

Figure 19. Warming by concern.



Environmental regulations

Government actions in their various forms (from ‘command-and-control’ regulations to incentive schemes and subsidies) have a significant influence on environmental innovation. There is still an ongoing debate about whether strict regulation based on limits such as pollution caps works better than economic incentives to improve the state of the environment, without discouraging innovation. However, there is a substantial body of literature (see Taylor et al., 2005 for an overview) that considers regulatory stringency and anticipation of regulation to be important drivers of innovation, and there are even those who think that some degree of uncertainty about future regulation is good for innovation (see Taylor et al., 2005). On the other hand, not all eco-innovation takes placed to comply with regulation. According to the results of the IMPRESS survey (ZEW, 2001), about a third of the most environmentally beneficial innovations were not introduced for regulatory reasons (Arundel, 2005).

We have included six different indicators to represent the regulatory push factor of environmental innovation: indicator on energy tax rates, three separate indexes from the Global Competitiveness Report on regulatory stringency and clarity,[85] and two indicators on perceived competitive disadvantage from the need to meet environmental regulations.[86]

Market conditions

Market conditions regarding, for example, the competitiveness of environmental technologies, whether it is economical for large firms to develop new (environmentally beneficial) process technologies, or whether venture capital firms will invest in certain new technologies, are an important pressure factor in the process of environmental innovation, either intentional or unintentional.

[85] Only one of these indicators is old enough to fit the time flow aspect of pressure => input-output-effect scheme.
[86] The last two indicators are from the 2004 Innobarometer survey of the Eurostat/European Commission, and therefore also somewhat ‘too late’.

We are not including any actual data of this kind in our report, due to the fact that such data are rather difficult to come by. However, to give an example of data that could be available on an EU-wide scale soon, data on venture capital could be used to track environmentally innovative start-ups. No data are currently publicly available at the required level, but according to Hernesniemi and Sundquist (2007), the European Venture Capital Association (EVCA) is in the process of adjusting its data collection to include information on investments in the environmental sector.[87]

4.6.2 Facilitators

Environmental management and organisational changes

There is a relatively established source of data for records of voluntary environmental management systems for firms. There are two increasingly popular standards, namely the EMAS (Eco-Management and Audit Scheme), which only applies in Europe, and the ISO14001, which is a worldwide scheme.[88] Marinova & McAleer (2006) use these data to look at country performances, and we have included them in our report to see how they fair against other eco-innovation indicators.

We have also included some data on the Community eco-label scheme awarded to products and services with reduced environmental impacts. This scheme has been operational in Europe since 1993, with the first EU eco-label awarded in 1996.[89]

Such voluntary schemes cannot be said to be a necessary part of the innovation process, but they have been shown in several recent studies to encourage such innovation (see Rennings et al., 2003, Rehfeld et al., 2004, Frondel et al. and Horbach, 2006).[90] They should also help us get a picture of how firms in general are willing to change to a more environmentally friendly direction, and how well they respond to public demand for such a change.[91]

4.6.3 Inputs

Environmental R&D and other innovation investments and activities

Although there is considerable controversy regarding the usefulness of R&D data to study innovation, since R&D is far from general innovation outputs,[92] R&D data are widely used to measure innovation. However, business environmental R&D has been found to be induced by government regulations and such data, if widely collected, could provide another link between environmental regulation and innovation inputs (see e.g. Arimura et al. 2007). Unfortunately, data

---

[87] Nonetheless, some general data are available from the venture capital companies and analysts. Cleantech, for example, says that European clean energy venture capital investment fell by 20% in 2006 to around US$500 million, when in North America it almost trebled to US$2.1 billion. Similar figures are available also from New Energy Finance, UK VC analysts (Europe lags, China catches up in clean energy race, story by G. Wynn for the Reuters Environmental News Service on 16/05/07). Ernst & Young (2006) argue that the development of environmental technologies has historically suffered from uncertainties regarding potential markets, and that this has hampered financing research activities for such technologies.

[88] The downside to these data is that their popularity from one country to another seems to vary widely, and that sectoral level data are not publicly available. Some sectoral level data for the ISO14001 can be obtained from the ISO Central Secretariat in Geneva, but this is not free. Furthermore, EMAS data are, in practice, currently only available for the EU-15, as the new member states were able to receive certifications only from the start of their EU memberships.

[89] Again, the same issue as in footnote 17 with the 12 new member states arises here, as they have only been able to receive awards from the start of their EU membership.

[90] See Horbach and Rennings (2007) for a literature overview.

[91] However, as the IMPRESS survey for the European Commission (see ZEW, 2001) found, firms are only likely to develop environmental innovations voluntarily if there are no substantial negative impacts on costs or quality.

[92] Moreover, the standard R&D surveys are criticized for underestimating R&D performed in smaller firms and overestimating R&D elsewhere due to definitional issues (Kleinknecht et al., 2002). In fact, Kleinknecht et al. (2002) argue that innovation surveys, which could also easily include questions on environmental innovation, may provide more accurate data on R&D.

on R&D expenditures for environmental innovation are rarely collected from businesses (see Fukasaku, 2005 for a discussion with some data),[93] and the collected data can also be unreliable.

Some public environmental R&D data do exist, mainly in the form of government budget appropriations and outlays (GBAORD). Public environmental R&D is usually firmly linked to environmental regulations. The only data provided by Eurostat are on regulation-related environmental R&D. We have included such data from Eurostat in this report to look at how it correlates with other eco-innovation indicators.[94]

Another reflection of the science base for environmental innovation are publication data, also called LBIO (literature-based innovation output) or, specific to the eco-industry, EPD (environmental product declarations). Such data offer the benefit of identifying specific technologies, and being an indicator for the market in environmental technologies. The downsides to LBIO data are that not all firms publish or market their eco-innovation products equally, and moreover, that process innovation – particularly important for environmental innovation - tends to be omitted from such data.[95] In this report we have used publication data from Peter (2006) for the EU-25 to see how it compares with other eco-innovation indicators.

Finally, not all innovation requires R&D, or results in publications. For example, production engineering, or relatively costless changes to production processes or organizational methods, could have large environmental benefits and not require any R&D. Additionally, firms can buy new technologies developed by suppliers, most of which will be better for the environment than older technology. To include some data on these forms of innovation investments, we use two indicators from the Community Innovation Survey (CIS) on firms' engagement in acquisition of machinery.

Patents – within or outside EGSS

Patent databases are a well-known source of innovation indicators, including data for environmental innovation.[96] However, it is difficult to obtain patent data for environmental innovation other than for EGSS.

One of the benefits of using patent data to study environmental innovation is that the detailed classification systems make it comparatively easy to identify intentional eco-innovation. Moreover, patent data can help track global diffusion of technologies, which is particularly important in eco-innovation. Lastly, patent data - although still considered to represent an input indicator here - are closer to markets and the outcomes of eco-innovation than many other input indicators, such as R&D data.

One of the main limitations of patent data is that patents vary greatly in their importance and probability of commercialisation. This can partly be corrected by using patent citation data or triadic patent families,[97] which generally include only the more economically important patents.[98]

[93] The few exceptions of countries which collect data on business environmental R&D include Canada (Arundel et al., 2006).

[94] The Stern Review (Stern, 2007) includes a discussion on the trends and quality of data in both business and public R&D on energy. The author also reviews the reasons why firms might not be willing to invest in energy R&D. Fukasaku (2005) includes data which indicates that private environmental R&D expenditures are in some countries larger than public government budget appropriations.

[95] On the other hand, Peter (2006) notes that environmental service innovation, which would mostly not show up in patent data, can potentially be captured by using publication data.

[96] Oltra et al. (2007) offer a thorough overview of using patents as an indicator for eco-innovation.

[97] However, when using triadic patent family data, one must bear in mind that the patent counts are likely to be considerably lower than those from single national patent offices (Popp, 2005).

[98] Kleinknecht et al. (2002) discuss other problems with patent data, such as under or over estimation due to higher or lower patenting thresholds for certain kinds of companies or certain kinds of technologies.

Particular to environmental technologies is the issue that patenting seems to focus on products, rather than processes, whereas environmental innovation is currently particularly important for process innovation based on clean production rather than end-of-pipe solutions (Popp, 2005).[99]

Both the OECD and Eurostat have recently set up large patent databases with data download possibilities.[100] However, it is still difficult to identify patents for environmental inventions. Researchers must either perform labour intensive patent searches or rely on others who have done so before. Unfortunately, this group of researchers is still relatively small. One pioneering work is by Lanjouw and Mody (1996), where a list of some 40 IPC patent codes for various environmental technologies is provided.

This report uses data from the OECD (2006) to calculate country specific indexes for specific environmental technologies. The results show that Germany was the top patentee in environmental technologies between 2001 and 2003. Weighted by population size, the top patentees were Finland, Germany and Austria. The OECD (2006) report also found that patent counts for environmental technologies have gone up globally in the past 10 years or so and can be expected to climb further. This is due to an increase in clean production processes and clean products, as patents for end-of-pipe technologies have been declining.

4.6.4 Outputs

Intermediate energy and material inputs

We have included data in our analysis from the EUKLEMS database on intermediate energy (IIE) and material (IIM) inputs into the economy. These data are available at both the national and broad sectoral levels.

We have also included data from Eurostat NewCronos on renewable energy shares in total electricity consumption. These data are available by very broad industry categories, but for our purposes, we have downloaded them at the national level. Similar to the intermediate energy and material input data (IIE and IIM), this indicator can be used either as an eco-innovation input indicator (as energy in general is an input factor), but it can also be seen as an intermediate output indicator for environmental innovation – the higher the share of renewable energy inputs, the lower the environmental impacts from production, households etc. This share is expected to increase in the future, partly due to EU targets.

Sales and profits from environmentally beneficial innovation

There are some estimates at a country level for sales of EGSS products, but no estimates (or actual hard data) exist for profits from environmentally beneficial innovation across all sectors of the economy. This type of data would be very valuable, and the topic could perhaps be included in one of the EU-wide surveys on innovation.

Growth of EGSS

Data on the narrowly-defined eco-industry do not capture larger environmentally beneficial (unintended) innovation. However, they do provide some insight into the growth of eco-innovation.

---

[99] Furthermore, as environmental innovation is often influenced by regulation, there may be problems using international patent offices or triadic patent family data for eco-innovation research. Environmental patents are likely to appear there only once it pays to patent in more than just one country, e.g. once specific related regulations apply elsewhere as well. Such patent data may therefore not be ideal for identifying first-movers in environmental technology (Popp, 2005).

[100] Within the Eurostat PATSTAT database, data can be identified based on nationality, 2 or 3-digit NACE manufacturing class, 2 or 3-digit IPC class, or certain high-tech fields.

There are several kinds of investment that are relevant to the EGSS, although data availability poses serious limitations.

Data on foreign direct investment (FDI) in environmental technologies would be very interesting to have, as it would also capture diffusion. However, the sectoral disaggregation available from international sources, such as Eurostat or UNCTAD, is not detailed enough to look at even the 'core' EGS sectors (with NACE codes DN37, E41 and O90).[101]

There are some data available on national investment in the EGSS. Eurostat provides data for two of the 'core' EGS sectors (DN37 and E41). These data are included below.

Another way to look at investment in the EGSS is to look at environmental protection expenditures at a sectoral or national level. This also covers PACE (pollution abatement costs and expenditures), and is a rather common measure of environmental innovation used to indirectly estimate the effect of government regulation on innovation (see e.g. Arundel et al., 2006, Brunnermeier & Cohen, 2003 and Lanjouw and Mody, 1996).[102]

Eurostat provides data for three indicators under this category collected mainly by surveys: investment in equipment and plants for pollution control, investment linked to cleaner technology, and total current expenditure on environmental protection. All data are provided for total industry (NACE C, D and E) and at the national level (or both), and are used in this report to evaluate the usefulness of such indicators for tracking environmental innovation.

Generally, a link between increased environmental innovation (measured by patents) and pollution abatement expenditures has been established in the literature (see e.g. Brunnermeier & Cohen, 2003).

Yet another way to look at investments in the EGSS that could be more useful in the future, is to look at projects under international schemes such as the Kyoto Protocol. The international clean development mechanism (CDM) projects that fall under this Protocol are registered by the UN and represent environmental investments from developed economies to developing economies. They would therefore be particularly interesting for studying innovation. Currently, however, there are only a few hundred projects registered, and although national level data are available in terms of numbers of projects, the sizes of the projects vary greatly, and cannot be accurately allocated to any one country.[103] If more detailed data become available, and if the numbers build up over the next few years,[104] this could be a valuable data source for measuring the diffusion of environmental innovation.

Finally, there are some ways to measure the pervasiveness of the EGSS, in other words, how large the core EGSS itself is, how widely certain methods to measure all firms' environmental performance have spread, or how many industrial firms take producing environmentally friendly products seriously.

One way suggested by Marinova & McAleer (2006) to explore the first point above is to look at long-established internet sites providing information about the eco-industry. The Green Pages

[101] Some data for NACE O90 (sewage and refuse disposal) are available.
[102] Lanjouw and Mody (1996) note that these data are particularly useful, as they capture 'not just regulation but monitoring, enforcement, and the strength of marketplace signals' (p. 554). However, Arundel et al. (2006) make the point that such expenditure costs do not reflect savings made by eco-innovation.
[103] However, if country level data were available, it would be possible to calculate the size of projects by CERs (certified emission reductions), each of which equals to one tonne of CO_2 reduced. This could then be divided, for example, by each country's CO_2 emissions.
[104] Currently, only 8 EU countries appear to be represented in the data.

(www.eco-web.com) (based in Switzerland) has provided a high quality database for environmental technologies since 1994, with listings of thousands of eco-industry companies from all over the world, with 2,600 (38%) based in Europe.[105] Marinova used data from this website to analyse eco-innovation at a country level, and similarly we have extracted data for this report for all 27 EU countries.[106]

Trade in EGSS products

International trade in environmental technologies provides a measurement of diffusion. Exports from the EU-27 to the large and rapidly growing economies of China and India seems particularly useful, especially since the EU eco-industry is export-oriented and China has long been an important trading partner.[107] The current WTO trade negotiations are meant to make international trading in environmental goods and services easier, although the recent stalling of these negotiations probably has hurt the exports industry due to high tariffs for environmental goods in most developing countries (Kennett and Steenblik 2005).[108]

Several large databases contain fairly detailed data on such exports (most importantly, the UN COMTRADE database and the OECD international trade statistics database). The main limitation is that trade data are based on product classifications and there is no agreed and high quality list of product codes for the EGSS. The OECD and APEC, among others, have each produced a separate list of products that have environmental uses. The two lists are together called the OECD/APEC list, with nearly 200 unique HS 6-digit codes (see e.g. Steenblik, 2005, for the lists). However, the main drawback of such lists is that many of the products have multiple uses, only one of which may be environmental.[109]

If we assume that the product code list provides a relatively good representation of the EGSS, we can calculate export statistics for the EGSS from each EU country to China and India. Such data from the COMTRADE database are used in this report.[110]

Other ways to get around the product orientation of trade statistics include constructing indicators such as 'revealed comparative advantage' (RCA) and 'relative world shares' (RWS) (see Legler et al, 2003). Peter (2006) notes that such indicators can be considered more meaningful, being that the EGSS product groupings are not accurate. We also use RCA and RWS data in this report.[111]

4.6.5 Effects

Energy and material intensity

Several indicators have been developed to measure the energy or material intensity of our economies, both in terms of what goes into the economy and what comes out of the economy. The

[105] The database is vigorously updated, with an average age of listings of only 253 days.
[106] However, these data are for 2007, which does not leave any room for the time lag between outputs and effects.
[107] Europe lags, China catches up in clean energy race, story by G. Wynn for the Reuters Environmental News Service on 16/05/07.
[108] There are, however, arguments that in the future, China may be concentrating on creating its own technology more than importing it (see source in previous footnote), and furthermore, that selling high tech products, including environmental technology, to China is becoming increasingly risky, due to violations of intellectual property rights inside China (Copyright fear hampers West's climate work in China, story by G. Wynn for the Reuters Environmental News Service on 17/05/07).
[109] Trade and Development Board (2003) discusses the limitations of the list in more detail. The WTO is currently attempting to update or improve this list.
[110] Since a product code list is far from accurate, taking a sample of a few core eco-industry products might provide more accurate, although giving more limited results. A report by Ernst & Young (2006) has compiled a list of 20 or so EGSS product codes and uses this list to estimate trade statistics for the EGSS.
[111] However, the problem is that these data are for 2000, and this does not fit the time dimension of our study.

‘input’ indicators can be used as intermediate eco-innovation output indicators, and the ‘output’ indicators can be used as effect indicators to evaluate the likely environmental impacts of economies in general, and environmental innovation, in particular.

These data are extracted from the following sources:

- NewCronos: energy intensity of economy (national level);
- Data in van der Voet (2005) on resource productivity of the economy (GDP per DMC – direct material consumption, data available for EU-27 at national level);[112] also measures decoupling between economic growth and environmental impact;
- NewCronos: CIS-3 and CIS-4 data on environmentally beneficial effects from product and process innovation (reduced materials/energy per unit output).[113]

The benefit of the CIS data is that they are also provided at fairly detailed sectoral level, as well as national level. However, as most other included indicators are only provided at national (or very broad sectoral) level, this is less useful.

Pollution and waste levels

Another output measure for environmental innovation is the level of pollution or waste and changes in such levels.

In this report, we have included weighted data for the EU-27 on air emissions, namely greenhouse gas emissions (including all six gases in the Kyoto ‘basket’) and emissions of acidifying pollutants (ammonia, sulphur oxides and nitrogen oxides), as well as data on amounts of waste generated.[114]

Other innovation effects

The Community Innovation Surveys (CIS-3 and CIS-4) include questions on effects from product and process innovation, namely, on reduced environmental, health or safety impacts and on meeting regulatory requirements. We have included these data in our report to see how they correlate with the other indicators.[115] The data on environmental impacts could also be used to identify unintentional eco-innovators in all sectors of the economy. The disadvantages of these data are that the impact question also refers to health and safety impacts, and the regulation question refers to all regulation, not just environmental regulation.

4.7 Identifying key eco-innovation indicators

4.7.1 Issues with causal linkages and correlations

A positive or a negative correlation does not prove a causal relationship between two indicators. To give some examples related to the topic at hand:

- Increases in income usually result in greater ecological damage, even as per unit damage may decline. Income increases would therefore be positively correlated with ecological damage, although they do not directly *cause* it. Rather they cause more consumption, which then tends to increase pollution;

[112] These data are for 2000, again, a problem, as this is an effect indicator.
[113] These data can also be used to identify unintentional eco-innovation.
[114] A common problem with these data is that they do not extend beyond 2004 (waste until 2003). This does not, in some cases, allow for a time lag between pressures, inputs and outputs on the one hand, and effects on the other.
[115] In particular, the CIS-3 data do not allow for a time lag, as they are for 2000. CIS-4 data are for 2004.

- An indicator on trade might correlate positively with an indicator on greenhouse gases, although increased trade as such would not *cause* the GHG increases (compare trade across a border with trade across continents), but the general increase in transport from trade does;
- Data on patent counts might correlate positively with GDP data, but this does not mean that more patents *cause* GDP to rise (or the other way around), they can just be linked with another indicator, such as increases in innovation expenditures.

Moreover, two indicators often share a common denominator, which causes the correlation. Some examples include:

- An indicator on investments in pollution control equipment might correlate positively with amounts of acidifying pollutants, which seems rather odd. However, looking further into the indicators, this correlation could be caused by the fact that both indicators include elements of, say, GDP in them;
- Many index indicators have been built in quite a complex way, and it can be difficult to exclude correlations between such indexes and other indicators that might be caused by some common data used in both.

Other factors that make it hard to see whether a correlation (or the absence of one) is true or not include:

- Too few cases;
- Outliers in the data.

Finally, we are examining a rather complex chain of factors potentially influencing each other (from *pressure* to *input* (with *facilitators* in between) to *output* to *effect*), and the further from each other any two indicators are in that chain, the less clear it is that correlations are in fact proof of *any* kind of a relationship between the two indicators.

4.7.2 Correlations from current data

Given the above constraints for the analysis, The full report KEI WP1.4b (a separate document) shows a reduced version of the original correlation table for the data used in this report. The original correlations included all the indicators for which we had data, and all the years (from 2000 onwards) for which we had data. The reduced version has been produced based on the principles stated in Section 4.4, so, only higher correlation coefficients are considered.[116]

In general, if the pressure, facilitator and input indicators are adequately measuring the output and effect indicators, we should detect some positive or negative correlations between indicators belonging to these groups.[117] Negative correlations are appropriate in cases where an input indicator is measuring some aspect of innovation, and an effect indicator is measuring pollution.[118]

Following is a discussion of the correlation results. A list of all considered indicators can be found in the separate report KEI WP1.4b.

[116] A number of outliers were removed from the data, in total eight data points. These mostly include data on the smaller (Malta, Cyprus) or newer (Bulgaria, Romania) EU member states.
[117] Time lags between the groups of indicators also have to be taken into account, as a pressure indicator should not follow an output indicator, rather, the order should be the other way around. In many cases we cannot assume that an indicator value for year X (which we do have) is close to a value for year X+4 (which we do not have), and therefore we have to ignore some of the positive or negative correlations as possibly not descriptive of the true situation.
[118] Those indicators which we would expect to correlate negatively with innovation-related indicators have been marked accordingly in Table 2 of KEI WP1.4b.

Pressures

Two attitude indicators (on research on clean transport and acceptance of domestic wind energy) were included and they show a few strong correlations. When taking the time dimension into account, the best correlation is between the clean transport research indicator and the indicator measuring acidifying pollutants (negative correlation). Even if we do not look at the time flow, the correlations make sense, although they are not numerous. A relationship between attitudes and investment in the eco-industry is not really visible in these data.

The three indicators measuring aspects of regulation (implicit energy tax, the ERRI index and an indicator measuring perceived negative impact on competitiveness from having to meet environmental regulations for products or services) have many strong correlations, especially with the innovation output and environmental effect indicators, as might be expected. There are also a couple of interesting correlations within the facilitator indicators. Firstly, there is some evidence of a positive relationship between the ERRI index and the ISO14001, although the correlation does not fit the time dimension. Secondly, notable is also the correlation between the competitiveness indicator and the indicator on eco-labels. There also appears to be a positive relationship (visible partly also across years) between environmental regulation and publications. Moving on to the output indicators, the first two regulation indicators (on energy taxes and ERRI) correlate fairly strongly with the indicator on EGSS-related exports to China. This could be interesting, as it gives support to the argument that stronger environmental legislation in EU countries results in more technology transfer into developing countries. Two unexpected negative correlation coefficients between the regulation indicators and national investment in EGSS (investment in recycling and water management) could simply be explained by earlier stronger regulations already taking care of most of the need for national investment.

Regarding the environmental effect indicators, the first two regulation indicators (mentioned above) correlate, as could be expected, with the indicators on energy intensity and acidifying pollutants. The third of the regulation indicators (on competitiveness) shows some unexpected correlation results with the effect indicators. However, this is at least partly explained by there simply not being enough time to allow for effects of a pressure indicator for 2004 on an effect indicator for 2005. Overall, there is some evidence in these results of regulation driving innovation.

Facilitators

Apart from what has already been discussed, the three indicators included (on EMAS, ISO14001 and eco-labels) show strong correlations mostly only with some input indicators. This seems reasonable, as these indicators would not be expected to have very strong influences on environmental innovation, and their potential impact would therefore be felt much closer in the eco-innovation chain. There are no strong relationships with effect indicators. Two strong coefficients are included here for the output indicators. The positive relationship between the EMAS indicator and the indicator on the share of renewable energy in energy use holds across the years, whereas the link between ISO14001 and investments in clean technology is not visible across the years. Looking at the input indicators, the number of ISO14001 certifications seems to have a positive relationship with the number of environmental publications, and the ISO14001 indicator also correlates positively with public environmental R&D. Based on these results, such innovation facilitators could be considered beneficial for innovation (inputs).

Inputs

Somewhat unexpectedly, our eco-innovation input indicators do not correlate as well as expected with our eco-innovation output and effect indicators. This may be partly due to the fact that although the type of the input indicators is traditional (publications, R&D, machinery, patents) the quality of the data is not always good, in particular regarding environmental R&D and for patents (discussed separately below). Unfortunately therefore, we cannot draw many conclusions from these relationships, except to say that better data are needed to measure (public and private) environmental R&D and environmentally beneficial patents.

There are strong correlations between the environmental publications indicator and other indicators. We have already discussed some above, but in addition to those, the results indicate that there is a moderate to strong positive relationship (visible across years) between this indicator and EGSS exports to China, a mild positive relationship (visible across years) between this indicator and the energy intensity of economies, and a fairly strong negative relationship (again, visible across years) between this indicator and acidifying pollutants. Additionally, there is a strong positive correlation between the publication indicator and the resource productivity measure. All in all, it seems that such publication data could be of some value in reflecting or predicting changes in the environmental innovation chain (from environmental regulation to innovation impacts in the environment), and such data could also be an indicator for the market in environmental technologies.

As discussed earlier, patent data are valuable in measuring eco-innovation, especially innovation specific to the EGSS, but collecting the data is still very time-consuming. Therefore, we have included some patent data in our analysis, but the data are incomplete, with results available for only a few EU countries. Although there are two strong positive relationships between the patent indicator and one regulation indicator (ERRI) and one facilitator indicator (EMAS), we cannot really say that the relationships are reliable.

Outputs

The indicators on the share of renewable energy in energy inputs to the economy, IIM for intermediate material inputs to the economy, and IIE for intermediate energy inputs show a number of strong relationships, mostly in expected ways. In addition to what has been discussed above, the IIM indicator correlates negatively with the indicator on EGSS-related exports to India, and some significant negative correlation can be seen with exports to China. This could reflect the structure of economies: the more material intensive economies do not (yet) export as much environmental technology to developing countries such as India and China. The IIM indicator shows a strong positive relationship with the effect indicator on total energy intensity of the economy, as could be expected, and a somewhat less strong negative relationship with the resource productivity indicator, again, this result could be expected. The better an economy is in turning resources into income, the less material intensive it needs to be. Finally, we can see a relatively strong positive correlation between the IIM indicator and the indicator on acidifying pollutants. In other words, the more material(/energy) intensive the economy, the bigger the externalities, such as pollution. The results here support this statement.

We also included as inputs indicators on national investments in some EGS sectors, investment in clean technology, investment in pollution control equipment and an indicator on the growth of the number of EGSS firms. In addition to a small number of correlations with pressure indicators or facilitators discussed above, the indicator on national investment in 2004 correlates rather unexpectedly (e.g. positively with pollutants and negatively with the CIS-3 indicator on high environmental impacts from innovation), although there is also a time flow problem with this indicator and some of the effect indicators. These unexpected results could be explained by the duality of this indicator: on the one hand, it reflects the growth of the EGS sector, and on the other hand, it may show some previous laxness in environmental protection. It is therefore not clearly a 'positive' eco-innovation indicator (i.e. one that correlates positively with other innovation indicators and negatively with pollution indicators). Otherwise, the investment indicators show only one other significant correlation, that between the indicator on clean technology investment and the indicator on meeting (environmental) regulations. This is a reasonable relationship, possibly reflecting investments made to meet environmental regulations.

Finally, the indicator on EGSS company listings (www.eco-web.com) has only two moderately strong correlations in these data, both of which seem somewhat strange. However, the first one with exports to China (and also India, from the larger correlation table), could be explained by the orientation of the exporting firms. The listings on www.eco-web.com possibly have a bias towards more developed economies, and therefore a firm concentrating on exports to China or India might not find it useful to list themselves. The negative correlation with the resource productivity indicator does not fit the time dimension of the innovation process at all, as these data are for 2000. The more general problem with the EGSS company listings data is that they are too recent (from 2007) to reflect any impact on other output or effect indicators.

The EGSS trade indicators (EGSS exports to China and India, and RWS, relative world shares, for general EGSS export orientation) do show several strong correlations with the other eco-innovation indicators, many of which have already been discussed. Regarding their impact on the effect indicators, we can see that there is a moderately strong negative relationship (holding across years) between exports to China and the indicator on acidifying pollutions. This is again interesting and indicates that countries strong in technology transfer to the developing economies are themselves already rather advanced in terms of reducing pollution levels. As could be expected, the export indicators on China and India correlate positively with the indicator on general export orientation in EGSS products (RWS). Exports to China are also positively correlated with the resource productivity indicator. However, it is doubtful whether any conclusions should be drawn from this, as the data for the productivity indicator precede the export data (even though the relationship does hold across years).[119] Finally, the RWS indicator on export orientation in the EGSS products correlates significantly (but negatively) only with the two CIS-3 indicators on positive (environmental) impacts from innovation and meeting (environmental) regulations. This seemingly unexpected result could be explained by the focus of the firms in question: the less export oriented firms probably focus more on meeting domestic regulation and similarly perhaps also see more immediate environmental impacts from their innovation.

Effects

Apart from what has already been discussed above, the three effect indicators on energy intensity, resource productivity and innovation effects in terms of reduced materials and energy per produced unit (from the CIS) correlate strongly, and as expected, with several of the other effect indicators. The strongest links can be found between the indicators on energy intensity and resource productivity on the one hand, and the indicator on acidifying pollutants on the other. This is not surprising, as the most energy intensive and least resource productive economies (Bulgaria, Romania and many other newer EU member states) often also have the most pollution. The other correlations are between two CIS indicators (reduced materials and energy per produced unit and positive (environmental) impacts from innovation), and between the energy intensity indicator and the CIS indicator for meeting regulation requirements. The former indicates consistency in the CIS data (the firms reporting less material and energy inputs also report general positive environmental effects), and the latter shows an expected negative relationship between meeting (environmental) regulations and higher energy intensities.

The indicators on greenhouse gases and acidifying pollutants are important effect indicators together with the 'intensity indicators'. The indicator on acidifying pollutants has already been discussed in connection with many correlations with other indicators. However, the greenhouse gas indicator shows only one correlation with the other indicators. It correlates moderately strongly and negatively with the national EGSS investment indicator. This relationship seems reasonable, but considering several problematic correlations between the national investment indicator and other indicators, perhaps not too much attention should be paid to the relationship. It may simply be that as the true efforts to reduce greenhouse gases are only really beginning, there cannot be any real relationship between this indicator and other eco-innovation indicators as of yet. It will therefore be interesting to examine such correlation results in a few years.

[119] If the relationship were real, an explanation could be that the more 'efficient' economies are more focused on technology transfer to e.g. China than less 'efficient' economies.

We also include CIS indicators on positive environmental (and health and safety) impacts from innovation and on meeting regulation requirements. These are quite interesting indicators, as they measure more general environmentally beneficial innovation.[120] Looking at the correlation results, the data for 2000 and 2004 for the same type of indicator do not, however, correlate well with each other. The actual correlations have mostly already been covered in the above discussion.

4.8 Conclusions

This section has explored - with the help of discussion and correlation data analysis - a large number of potential indicators that could be used to measure various aspects of innovation with beneficial impacts on the environment. In addition, we have discussed the definition and location of such innovation, and concluded that it takes place in the whole economy, although it is more concentrated in the environmental goods and services sector, which can, however, be hard to define. Finally, we have also sketched a scenario which illustrates the process of eco-innovation.[121]

Following this scenario, we classified the forty-five indicators into five different types: pressures, facilitators, inputs, outputs and effects, according to where they best fit in the eco-innovation chain. The correlation analysis has included all those indicators (thirty-nine in total) for which we were able to obtain national level data for a minimum of eleven EU member states.[122] [123]

Our correlation results have been mixed. Much of the results have followed the lines of the discussion and literature, often showing interesting evidence for links between, for example, innovation pressures and inputs, or innovation outputs and environmental effects. A few of the established relationships have not been found in these data. However, there are a couple of issues that have most likely contributed to this. First, in some cases (especially with patent data), the data coverage of the EU countries has been poor, and second, we have not always been able to obtain data that follow the time flow in the innovation chain.[124]

Based on both literature and our data analysis, the indicators that we consider to be the key indicators for measuring innovation with environmental benefits include:

- Environmental regulations and venture capital for the eco-industry
- Environmental publications, patents and business R&D
- Eco-industry exports and FDI
- Sales from environmental innovation across sectors
- Energy intensity and resource productivity of economies.[125]

We have tried to balance different types of indicators (pressures, inputs etc.), recognizing also that both intentional and unintentional eco-innovation should be covered. Similarly, the key indicators should not only measure innovation within the EGSS, but across all sectors of the economy.[126] Finally, the key indicators should also cover innovation types other than product innovation.

The indicators that were not included in the key indicators were mostly those with either a weak grounding in the literature and/or no strong correlation results from our analysis. For example, we

[120] However, they also include data on other impacts (health and safety) and other than environmental regulation.
[121] See Section 4.3.3 for the scenario.
[122] Only two indicators (4.3 and 5.1) had as few as 11 countries included. Otherwise, 15 was the minimum.
[123] Sectoral level data were in many cases not available. Therefore, we concentrated on the national level.
[124] For example, some data on environmental effects were too old, and some data on innovation pressures were too new to fit well in the scenario.
[125] Table 4 in Section 4.1 includes the specific 15 indicators.
[126] Most effect indicators measure innovation effects from all parts of economies. Taking an effect indicator on energy intensities as an example, the effects from increased use of traditional environmental technologies cannot easily be separated from the effects from energy savings from more efficient processes across the economy.

did not include an indicator on public attitudes among the key indicators, as it is somewhat questionable how strong an influence public attitudes can really have on eco-innovation, especially when they may not be followed by public action. We also left out an indicator on environmental management systems and organizational changes, although they have been found to facilitate eco-innovation. They are, however, not a very strong influence, or a necessary part, in the eco-innovation process.

Our main recommendations (included in Table 6 in Section 4.1) mainly concentrate on improving data collection and data availability. Some of the key indicators still need further exploration and development, and refining the questions on eco-innovation in the Community Innovation Survey should also be considered. Last but not least: an overall recommendation for developing data collection for eco-innovation related indicators would be that much more sectoral level data should be made available.

5. Policy Scenario: Demand for Innovation[127]

Prepared by

Adriana van Cruysen and Anthony Arundel

5.1 Summary of findings

In the KBE, productivity and economic growth are largely related to innovation. Firms invest in product innovation based on current or expected demand for innovative goods and services. Without a current or potential market, innovation activity may be compromised. The market can be other firms (business to business), individual consumers, governments, or export markets.

Demand as a driver for innovation activity has attracted increasing policy interest. The report "*Creating an Innovative Europe*" by the European Commission, for example, proposes several policy actions to improve demand as a driver of innovation investments, including the creation of a single market. But other demand related policies could influence innovation.

The development of demand related policies to encourage innovation requires an understanding of demand and relevant indicators to measure its different aspects. This report briefly evaluates the main factors that influence demand for innovations, dividing them into three main groups: domestic demand, foreign demand and the role of government. Moreover, these groups are further divided into sub-groupings for a better understanding of the factors at play. Domestic demand is further divided into quality and quantity aspects, demand and sector structure, while role of government is divided into regulations and standards and procurement

The groups and sub-groups of factors that may impact demand form an overall picture of demand conditions that helps understanding how demand may influence innovation. This background is then used to identify key demand indicators currently available, plus to identify new indicators that should be developed to better assess demand conditions in a given country. These indicators could be used to evaluate national differences in demand factors and how policy could influence demand in a way that would stimulate innovative activity.

Although not all factors impacting demand could be associated with specific indicators, a first sign that more indicators are required to measure demand conditions, other existing indicators were used as proxies to measure the different factors affecting demand. In order to select indicators that have an impact on demand, we first tested if they correlated to innovation activity output indicators. To be relevant, demand indicators should first be linked to innovation activity. We then correlated proposed demand indicators with each other, reducing them to a set of relevant demand indicators that capturing different factors influencing demand.

We found that demand conditions are influenced not only by domestic demand quality aspects, such as the existence of lead users made up of sophisticated buyers, but also by quantitative aspects including the actual numbers of consumers in such markets. Highly skilled and educated people, whose higher incomes are a reflection of their level of education, constitute the sophisticated buyer. Furthermore, this share of the population consists of prime age adults with the disposable income and interest to purchase sophisticated products.

[127] This is a condensed version of the full report available separately: KEI WP1.4c (Policy scenarios – Demand for innovation).

Moreover, demand can be created if firms can make use of sophisticated marketing tools to capture customers' needs and desires. Unfortunately, we are not able to measure the effect of advertising in creating demand due to a lack of data. It would be relevant to quantify the impact of advertisement in demand creation while breaking down innovation into disruptive and incremental innovation. As most innovations consist of minor improvements, advertisement might play an important role in demand creation.

Not only is domestic demand relevant for local firms, but also foreign demand. It is through proximity, both geographical and cultural and through the creation of international standards, that firms can reach markets beyond local ones. Reaching new markets can be decisive for firms that lack large domestic markets. Domestic markets may not be large enough to permit firms to recoup their investments in innovation.

Government also plays an important role, by not only consuming innovative products through procurement, but also by creating regulations and standards that can free up demand, both by reducing uncertainty and improving quality. Furthermore, governments must intervene in markets to avoid market dominance by few firms, creating incentives for firms to compete and keep fuelling markets with new and innovative offerings. Table 7 summarizes indicators that were found relevant for assessing demand conditions in any given country.

Table 7. Relevant innovation demand indicators

Indicator	Details	Relevance
Part I. Available indicators		
Quality of domestic demand		
Intensity of local competition	Index values (1 to 7) measuring whether competition in the local market is limited or intense (survey data).	Intense competition by producers both drives down prices and provides product differentiation, enabling consumers to select on optimum products/services.
Extent of market dominance	Index values (1 to 7) measuring whether corporate activity at national level is dominated by few firms or spread across many firms (survey data).	Another measure of the development of lead markets (see above).
Buyer sophistication	Index values (1 to 7) measuring whether buyers focus more on price or quality of products and services (survey data).	Preferences of individual consumers for innovative products are a key demand factor. Sophisticated buyers are the first to adopt new products.
Population (aged 24 to 65 years) with tertiary education	Number of persons (by age class) with some form of post-secondary education per 100 population.	Educated consumers are more likely to be comfortable with new ideas, demand sophisticated and novel products and services, and evaluate different options.
Quality of educational system	Index values (1 to 7) measuring whether national education systems meet the needs of competitive economies (survey data).	Another measure of education levels and quality (see above).
Brain drain	Index values (1 to 7) measuring whether talented people tend to leave to pursue opportunities in other countries or remain in their home country (survey data).	Lack of domestic opportunities for talented graduates can seriously affect national innovation systems and reduce the influence of lead buyers in creating sophisticated demand.
Euro creativity index	Measure of national competitiveness – composite indicator based on several indices measuring talent, technology and tolerance.	Innovative firm clusters tend to form in an environment with values and attitudes that facilitate the attraction of talent, also through immigration.
Gender empowerment measure	Gender inequality measure for political and economic participation and decision-making power, and power over economic resources.	Used as a proxy for income equality between men and women. More demand tends to be created when buying power is distributed among more heterogeneous population.
Quantity of domestic demand		
Youth share of the population	Ratio of the share of population under 30 to the share of the population 65 and over.	Large numbers of young people tend to either create more innovation demand, or conversely correlate with lower incomes and lower levels of demand.
Degree of customer orientation	Index values (1 to 7) measuring whether firms are responsive to customers and customer retention (survey data).	High customer orientation can turn firms towards user based or assisted innovation, which can be expected to increase overall innovation.

Indicator	Details	Relevance
Foreign demand		
Breadth of international markets	Index values (1 to 7) measuring whether exporting firms sell in a small or large number of foreign markets (survey data).	A large number of foreign markets potentially increase demand for innovation by domestic firms.
Public sector demand		
Demanding regulatory standards	Index values (1 to 7) measuring stringency of national standards on product/service quality and of energy and other regulations (survey data) .	Stringency of regulations and standards can have a positive effect on demand by reducing uncertainty.
Government procurement for advanced technology products	Index values (1 to 7) measuring whether government purchase decisions for advanced technology are based solely on price or also on technological performance and innovativeness (survey data).	Focus on performance and innovativeness is likely to further increase demand for innovation.
Part II. Potentially relevant, but missing indicators		
Quality of domestic demand		
Demand differences at sectoral level	No data currently available.	Innovation activity is sector oriented; therefore, measurement of sector specific demand conditions would be important.
Effect of demand structure (polypsony, oligopsony)	No data currently available.	Demand structure (many buyers vs. only a few buyers) is considered relevant for innovative activity.
Role of niche markets	No data currently available.	Existence of niche markets considered important for many new and sophisticated products (but can also be a sign of income inequalities).
Quantity of domestic demand		
Impact of marketing of innovative products on demand	No data currently available.	Marketing is a demand driver, but it is not known how effectively it can be used to create demand for innovation products. Adding new questions on marketing to the CIS could help to overcome this limitation.
Foreign demand		
Role of replacing inadequate domestic markets with foreign markets	The only currently available foreign demand indicator on the breadth of international markets does not fully capture this aspect.	Firms can use foreign markets as lead markets or as a source of sophisticated consumers.

There are large gaps in indicator availability. These include indicators of the different effects of demand by sector, demand structure (monopsony, polypsony and oligopsony), the role of niche markets, the ability of firms to use foreign markets to replace limited domestic markets and the impact of advertisement in creating demand. All of these should be developed to support policy makers assessing demand conditions in any given country.

5.2 Introduction

In the KBE, productivity and economic growth are largely determined by the application of knowledge to develop, and adopt, new technology and more efficient organizational structures (Chartrand, 2002). Competition compels firms to innovate to reduce production costs, but the factors driving product innovation are more complex and include both technology push factors and market demand factors.

Firms invest in product innovation based on current or expected demand for innovative goods and services. Without a current or potential market, innovation activity may be compromised. The market can be other firms (business to business), individual consumers, governments, or export markets.

A highly skilled and educated population is an essential prerequisite to the ability of firms to develop and implement productivity enhancing innovations. Furthermore, a skilled and educated population can also drive demand as consumers for more sophisticated products. These pools of sophisticated consumers can form national lead markets, defined as the first to adopt a dominant innovation design that is subsequently adopted by other countries.

Demand as a driver for innovation activity has attracted increasing policy interest. The report "*Creating an Innovative Europe*" by the European Commission proposes several policy actions to improve demand as a driver of innovation investments, including the creation of a single market. According to Georghiou (2006), "demand needs to be coordinated or aggregated to create large orders to make innovation worthwhile." Other policies that can influence innovation through demand include support for cluster formation, standard setting, regulations, and public procurement.

Demand is not necessarily a given. For example, consumer attitudes towards innovative products vary by country across Europe. Innobarometer 2005 surveyed Europeans in all 27 Member States about their attitudes to innovative products and services[128] and grouped the respondents into 4 distinctive categories: 11% were enthusiasts towards innovation, 39% were attracted by innovation, 33% were reluctant to purchase innovations, and 16% were anti-innovation. By country, the percentage of 'pro-innovation' consumers (the first two groups combined) varies from a low of 35% in Poland to a high of 64% in Malta These results suggest that there could be large differences across Europe in the role of consumer demand as a driver for innovation.

The development of policies that can use demand to encourage innovation requires an understanding of demand and relevant indicators to measure different aspects of demand. The purpose of this section is to briefly evaluate the main factors that influence demand for innovations. This information is then used to identify key indicators of demand that are currently available, plus identify new indicators that should be developed to better assess demand conditions in a given country. These indicators could be used to evaluate national differences in demand factors and how policy could influence demand in a way that would stimulate innovative activity.

5.3 Demand and innovation theory

The two main drivers of innovation are technology push and demand. Even though the influence of each driver differs by sector and circumstance, an interactive model that incorporates both drivers has gained relevance in explaining the innovation process.

In an interactive model, advances in basic technology make it possible to exploit new opportunities while market opportunities stimulate research. Technology-push relates more to the long-term, while demand-pull relates more to the short term. The generation of new ideas is dependent on inputs from the three basic components: organizational capabilities, the needs of the marketplace, and the science and technology base (Trott, 1998). There is no starting point: the innovation process is viewed as a complex set of communication paths (Rogers, 1995; Brown and Eisenhardt, 1995), with both internal and external knowledge flows. Innovation is consequently the result of both demand and the development of new applicable knowledge. In the extreme case, consumers not only create a demand for innovations, but can play an active role in their development (von Hippel, 1976; 2005).

Market demand is driven both by individual consumers and by firms and governments. Although distinct, both individual and business markets are also linked. A country with a sophisticated business market will be able to supply its individual consumer markets with more novel and complex offerings.

[128] Innovative products were defined as new or improved ones.

5.3.1 The role of demand in economic growth

Demand has a fundamental role in economic development. Economic development depends on the ability of an economic system to create new goods and services (growth in variety), which in turn creates new sectors (Saviotti, 1994, 1996). Demand is vital, as business, government, or individual consumers must purchase these new offerings.

In the beginning of the life cycle, new goods and services depend on niche markets, with a small number of sophisticated consumers that are willing to purchase novel products. These consumers are fundamentally important to the adoption and further diffusion of innovative products or services. Demand increases when the properties of these products improve and prices fall, with the niche becoming a market (Saviotti, 1994, 1996). The market size depends on the performance of the new product or service, its rate of improvement, and the rate of decline in costs and prices.

Even sophisticated consumers must understand how to benefit from new products and services. Consequently, the producer must effectively communicate information on the new product to the first adopters. Furthermore, consumers must be able to understand the information, which could require continual education and skill development of the consumer base. The greater the novelty, the more uncertainty consumers will face. Observing other consumers and imitating can reduce such uncertainty. This process will lead to both a reduction in uncertainty and to a convergence of choice on a single standard. Other factors driving convergence (for instance on a single technological trajectory) are cultural similarities among consumers (Georgescu-Roegen, 1954), status imitation Cowan et al (1997), and economies of scale that drive down prices (Lancaster, 1975).[129]

The initiation of a radical innovation comes from producers, as consumers do not have knowledge of the new offering (Saviotti, 1996). Producers must "educate" or create sophisticated consumers, giving them the necessary tools to evaluate the novelty. Learning by both producers and consumers can lead to product modifications and to the creation of further demand (Earl, 1986). As a product moves along its life-cycle, the importance of technology push gives way to demand pull.

5.3.2 Theories of demand and innovation

Porter (1990) identified four contributing factors to the competitive advantage of nations: natural, human, and infrastructural factors; the existence of related and supporting businesses; firm strategies and competition; and the *quality* of domestic demand. The latter influences whether firms can and will move from imitative, low-quality products and services to competing through differentiation. Porter recognized the need for sophisticated demand that could create lead markets, giving the country a competitive edge in global markets.

Beise and Rennings (2001) extended Porter's ideas on a lead market to include countries that adopt successful innovation quickly, even if they have not invented the technology. Even if users in other countries have adopted other competing designs, under some conditions the innovation design adopted in the lead market will end up dominating and displacing competing designs. The lead market is therefore the country that first adopts a globally dominant innovation design.

The empirical research by Beise and Rennings (2001) on lead markets identified five types of advantages for lead countries: price, demand, transfer, exports and market structure.

---

[129] Product differentiation also occurs later during the product life cycle, driven by status seeking behaviour and demand saturation.

Countries gain price advantage when the relative price of the nationally preferred innovation decreases compared to other solutions. Price reductions are a consequence of economies of scales, such as market size and market growth. Demand advantages develop when countries ahead of a new trend have their innovations adopted by other countries. Transfer advantages develop from the adoption of the national design by users in other nations. This requires strong links with other markets to transfer information on the usability of the innovative design (Takada and Jain, 1991). Export advantage refers to inclusion of foreign demand preferences in domestic designs. This advantage can be due to export experience by local firms or similar local demand conditions compared to foreign markets in terms of culture and social and economic factors. Finally, lead markets tend to be highly competitive, creating market advantages. Buyers tend to be more demanding and consequently local firms are under pressure to adopt new technologies that are 'tested' by domestic consumers.

Even though firms face different demand preferences and market conditions among countries, there are strong economic pressures, such as economies of scale, for firms to develop standardized products (such as the iPod) or semi-standardized products (such as mobile phones) that can be sold globally. Multinationals can use lead markets to generate products with global appeal, either by locating in lead markets or assigning R&D tasks to affiliates located in those markets. This could be one reason why R&D expenditures are concentrated in a few countries, with the ten largest R&D spending countries accounting for 86% of global business R&D in 2002 (UN World Investment Report, 2005).

Lead users

Lead users are defined as "being at the leading edge of markets, and having a high incentive to innovate" (Morrison et al, 2002). Lead users adopt a new invention earlier than others. Once the novelty has spread among several users with sufficient purchasing power, a lead market is formed.

Although lead users have requirements that will become general needs in future markets, they have those needs **before** most of the other users in the marketplace (von Hippel, 1986). In fact, research has found that users and not producers are often the ones to initiate the development of future commercially significant new products (Enos, 1962; Knight, 1963; Freeman, 1968; von Hippel 1988; Shah, 1999).

User needs for products and services are highly heterogeneous. They have more accurate and detailed information on their needs and how they intend to use a product, which can lead them to develop new product capabilities. Demanding users are then confronted with the option to innovate themselves or to convince manufacturers to adjust their product to meet their needs.

Manufacturers can respond to the needs of lead users by using their technical competences to develop customized solutions. Manufacturers that can successfully meet these needs can sometimes develop products that can be sold to other markets.

The recent work of von Hippel (2005) examines cases in which communities of lead users develop necessary innovations themselves – a process of 'democratizing' innovation. Users develop new products according to their wants instead of relying on manufacturers to translate their needs into products.

Research has shown that the higher the intensity of lead user characteristics present in an innovator, the greater the commercial attractiveness[130] of the innovation (Franke and von Hippel, 2003).

[130] Attractiveness is defined as the novelty of the innovation and the expected future generality of market demand.

Furthermore, empirical research shows that lead users tend to be among the first to adopt new products, fulfilling the function of opinion leaders and facilitating the diffusion of the novelty (Urban and von Hippel, 1988). According to Foxall (1989), lead users are fundamental for discontinuous innovations; they experiment with the new technology before later adopters and play an important role in the "contagion process" that encourages the adoption of novel products by other consumers (Morrison et al, 2002).

There are limits to the potential role of lead users in innovation. In highly technical areas, such as pharmaceuticals, lead users are unlikely to be able to actively participate in developing innovations, although they can be major sources of information on the types of innovations that are required. We can expect more direct customer involvement in product development in industries that are less science based.

Some authors have found that 'listening to customers' can hamper technological advance and that it can be detrimental for a business in the long run. Christensen and Bower (1996) note that firms in industries with constant technological change and opportunities for disruptive (radical) innovation should pursue innovations that are not demanded by their current customers. Disruptive innovation tends to create new markets that can eventually replace present ones. Schmitz (1995) found that inadequate focus on technical activities and too much focus on marketing activities (listening to customer needs) could be myopic, hindering the development of new innovations.

Sector structure
"Sciences based industries" such as electronics and chemicals, generate more fundamental innovations based on new technology inputs than other sectors. Other sectors tend to innovate through incremental improvements driven in part by customer demand.

Demand structure
There is a long standing debate over the effect of market structure on the rate innovation. Most of the debate concerns market concentration (the relative advantages of monopolies, oligopolies, and dispersed markets), but the structure of demand could also influence the incentives for firms to innovate. Rothwell and Zegveld (1985) point to three types of demand structures with potentially different effects on innovation.

In a **monopsony,** there is only a single buyer that accounts for 100% of demand. Pure monopsony rarely occurs in the real world, but near monopsonic conditions can occur when there is only one telecommunications provider. Under these conditions, the lack of a diversity of demand could hamper further innovation if the buyer fails to require innovative products and services.

In a **polypsony**, there are many different buyers, none of whom account for more than an insignificant share of total sales (Bannock et al., 1986). Under these conditions, competition between producers will tend to drive innovation, with a focus on market research or demand pull to develop products that interest consumers, rather than on technology push (Rothwell, 1992). The development of radical innovations could be constrained by a lack of consumer competence in assessing the value of innovations.

In an **oligopsony** purchasing power is concentrated but there are several large buyers, none of which controls demand, although each has a level of buying power. This demand structure could provide good conditions for private or government procurement demands to encourage innovation. The buyer can benefit from efficiencies created through competitive sourcing, but also avoid technological "lock in". In this type of market, suppliers, producers and users can all influence innovation, creating a "distributed innovation process" (Von Hippel, 1988). It is also possible for one oligopsonist to function as a quality leader, setting standards that will influence other players in the market (Foray, 1989). This structure can also facilitate cooperation among firms, helping to establish standards that support product innovation (Granstrand, 1984).

Proximity

Both cultural (Anderson et al, 1981) and geographical proximity explains some of the advantages of home markets, although globalization and improved communications are probably reducing the advantages of geographical proximity (Fagerberg, 1992).

von Hippel (2005) argues that the "natural advantage" of local firms to meet the needs of local consumers is being eroded by the internet. However, where the technical solutions for how to produce a product are not clear, proximity would still play a role. According to von Hippel (2005), in such cases, nations would be able to profit from user innovation to create competitive advantages for their domestic firms.

Market size

There has been an ongoing discussion about the relationship between innovation and the *size of the market*: does innovation take place irrespectively of market size or does market size have an influence on the creative process, as argued by Schmookler (1966)? If size of the market is an important factor, then certain industries will be more prone to innovation than others and certain countries will tend to be more innovative than others.

Domestic demand first expands and then tends to saturate, leading firms to both reduce prices and to seek new markets in other countries. The saturation effect will only create national competitive advantage if the composition of home demand either drives foreign tastes or is similar to products and characteristics demanded abroad.

According to Porter, domestic market size is most important in industries with large R&D requirements (aerospace), substantial economies of scale (automobiles), large generation leaps in technology (computing) and high levels of uncertainty (biotechnology). However in each of these examples, investments can be recouped by using foreign markets.

Income and income distribution

The expenditure power of a country's population has an impact on innovation: previous research has indicated that wealth influences the speed of adoption of new products in different countries (Helsen and Schmittlein, 1993; Rogers, 1995). Because wealthier people attach lower utility to money, they can afford the risks of adopting a new product earlier (Dickerson and Gentry, 1983). Moreover, prices of new products tend to start higher and then decline (Golder and Tellis, 1998) and consequently wealthier people can afford new products when prices are still high. Furthermore, we can expect that a more mature population will have more expenditure power than a young one due to number of years / experience in the work market and consequently higher incomes, which would have a positive impact on consumption.

5.3.3 Demand policy

Traditionally, governmental policies to influence demand have focused on the quantity of domestic demand through expenditures or the cost of credit. Porter (1998) argues that the main aim of demand-side policies should be to improve the *quality* of domestic demand to force firms to continually improve their products (export-driven models tend to ignore home demand, limiting advancement). Relevant demand side policies include regulations and standards and procurement.

Regulations and standards

Regulations and standards can affect demand conditions. Standards are often fundamental for reducing risks for both innovators and buyers. Standards and regulations for product performance, safety and environmental characteristics can pressure firms to improve quality. Regulations can also anticipate standards that will be adopted internationally and encourage the creation of specialized manufacturing and services firms that can compete on international markets.

Procurement
Demand-pull from businesses and governments often takes the form of technology procurement (Nelson, 1994), defined as "the procurement by a buyer of products, services or systems, which at the time being are not available on the market and for which some element of technical development is needed" (Granstrand, 1984). Procurement can reduce commercial uncertainty by setting standards or technical specifications. Technology procurement is often based on a cooperative relationship between the buyer and the producer (Lundvall, 1988: Edquist, 1997).

Both public and private procurement are used to create new markets and to diffuse innovation. Public procurement represents around 16% of European GDP and is concentrated in construction, health care and transport sectors.

Other influences
Government policies can improve demand quality by providing *information to buyers* or requiring firms to do so. Information is fundamental for better and more sophisticated demand choices.

5.3.4 Impact of demand on innovation

Firms respond to demand for innovative products by increasing investments in innovation activity. This could results in new patents,[131] increased sales of new to market products, increased employment in medium and high tech sectors, and increased exports to meet external demand. Relevant indicators for the effect of demand on innovation include the number of EPO patents per million population, employment in R&D intensive sectors as a percentage of the total workforce, exports of high technology products as a share of total exports, the share of total sales from new to market and new to firm products.

Furthermore, firms' innovative capabilities differ according to the role that innovation has in their strategies: while for certain firms, innovation is at the very core of their competitive strategy, for others innovation might be limited to the adoption of new technology. Other firms simply do not innovate. Data on percentage of firms that use different methods of innovating, or innovation mode, are available from the third Community Innovation Survey (CIS-3). A shift in the distribution of the innovation mode towards strategic innovators (firms that perform R&D in a continuous basis) or to intermittent innovators (firms that perform R&D in house, although not continuously) could be signs of favourable demand conditions.

5.4 Indicators for demand

Based on the review of theories of demand, the range of factors that may influence demand for innovative products and processes are illustrated in Figure 20. Demand is split into domestic and foreign markets, as different factors may influence one or another, or a single factor could affect both types of demand, but with different intensity levels. Furthermore, demand is influenced by government policy.

We classify the factors that influence domestic demand into four major groups: ***sector structure, demand structure, quality*** *and* ***quantity*** (market size) of demand. The response of firms to consumer demand is partly mediated by the firm's sector of activity. The demand structure refers to the existence of olipsonic or monopsonic buyers. The quality of demand is further broken down into market segmentation, lead users and lead markets, and sophisticated buyers. The quantity of

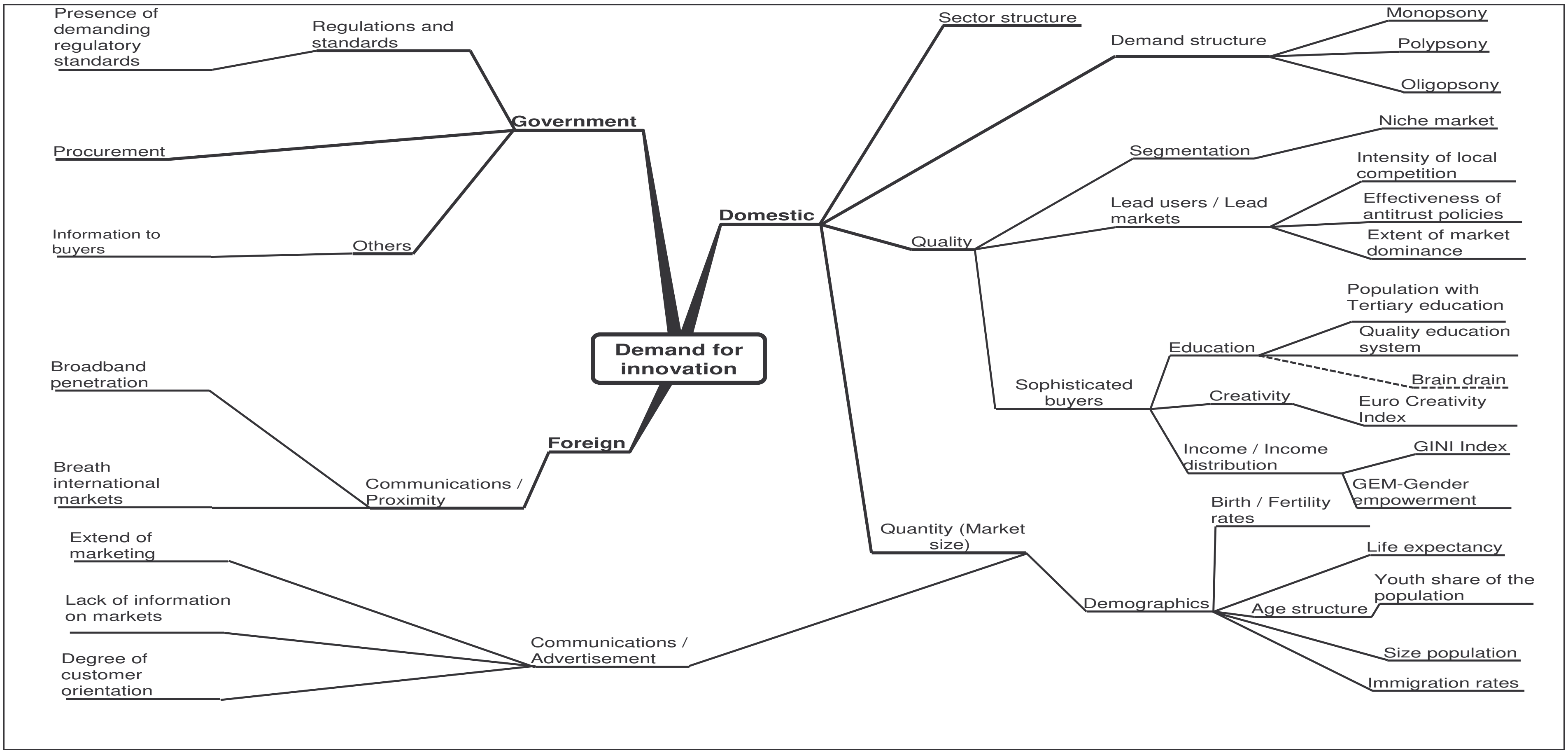
[131] Although patents are sector related.

demand relates to market size, and is affected by both demographics and by communications in terms of advertising.

Foreign demand is influenced by communications and proximity. Furthermore, we consider both individual consumer demand and demand from large buyers such as businesses or governments. Some indicators are specific to one or the other.

Relevant indicators are not available for all of the factors that could influence demand. This section identifies available indicators.

Figure 20. Factors influencing demand.



5.4.1 Domestic demand

The largest number of identified factors is for domestic demand and particularly for the quality of domestic demand. Some of these factors are closely linked. For example, the presence of sophisticated buyers will sometimes be crucial to the development of lead markets.

Two general indicators for the effect of demand on innovation are from CIS-3. Both a lack of demand for innovative products, or highly uncertain demand, can act as serious barriers for firms' investment in innovation. CIS-3 asks firms about the importance of uncertain demand and a lack of demand as reasons not to innovate. The reverse of each of these two indicators gives a general measure of the effect of good demand conditions on innovative activities.

Qualitative demand

Lead users and lead markets

It is difficult to develop indicators for lead markets because they are often only visible late in the product life cycle. A possible leading indicator is business R&D expenditures. However, this indicator would need to be available at a highly disaggregated sector level that matches specific types of products. This is impractical, given the low level of disaggregation available for R&D statistics. Furthermore, it will be impossible to determine if high R&D intensities are due to the existence of a lead market (innovation partly driven by demand) or to a technology push strategy.

The development of lead markets partly depends on intense competition by producers that will both drive down prices and provide product differentiation, enabling consumer choice to select on optimum designs. Three indicators are available from the World Economic Forum (WEF) for competition: intensity of local competition, extension of market dominance and effectiveness of antitrust policy.

Sophisticated buyers

The preference of individual consumer for innovative products is a key demand factor. Certain consumer characteristics are essential for the formation of sophisticated buyers that are the first to adopt new products. Many of the characteristics of individuals will also influence the demand behaviour of firms. For example, a highly educated population should improve both the demand characteristics of individual consumers and the ability of firms to evaluate and successfully implement innovative production and organizational processes.

Education

Educated consumers are more likely to be comfortable with new ideas, demand sophisticated and novel products and services, and evaluate different options. Education can be evaluated by its quality and by the percentage of the economically active population with a tertiary degree. For tertiary education, we use the percentage of the population between 25 and 64 with a tertiary education. The EU countries with the highest quality levels are Finland, Denmark, Ireland, Belgium and Austria, while the highest share of tertiary educated adults are in Finland, Denmark, and Estonia.

In addition, business demand will depend on the ability of talented graduates to work and stay in their countries after they complete their education. A reverse indicator for the 'brain drain' can partly measure this, which is an indicator of the level of domestic opportunities for talented graduates. According to data from The World Competitiveness Report 2006-2007 the two European countries among the 10 top countries globally that are the least affected by brain drain are Ireland and Finland.

Creativity

Florida and Tinagli (2004) created an index to measure creativity that covers three main factors: talent, technology and tolerance. The creativity index was calculated for 14 European countries**.**

Apart from the United States, there is a cluster of European countries formed by Finland, Sweden, Denmark, the Netherlands, and Belgium that have invested in developing "talent" in addition to creating an environment with values and attitudes that facilitates the attraction of talent through immigration.

Income and income distribution

Traditionally, Gross Domestic Product (GDP) per capita has been the most important measure of income. Higher levels of GDP per capita are strongly linked to more sophisticated demand and larger markets for innovations. For this reason, per capita GDP is used as a control variable when we run correlations between demand and innovation activity output indicators and among demand indicators.

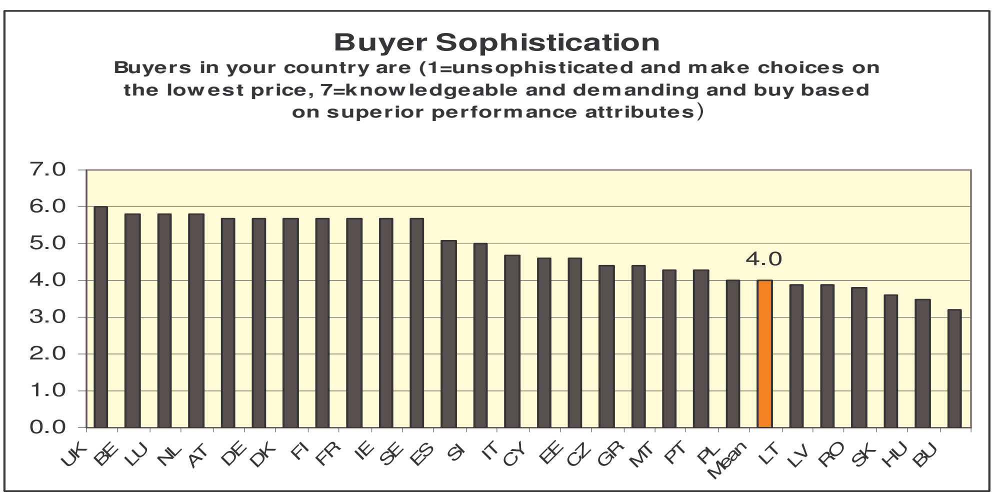
Income distribution is also relevant. Income concentration in a smaller number of consumers allows for higher levels of disposable income in this segment. This could have both positive and negative effects on demand for innovation products. It could increase demand for expensive lead innovations, but decrease overall demand for innovations.

The relevant indicator is the GINI index measure of income inequality (UN, 2006). A low GINI score indicates a higher level of social and economic equality, with a score of zero indicating perfect equality. In the EU, Denmark and Sweden are the two countries with the lowest disparities in income.

The Gender empowerment measure (GEM) captures inequalities between men and women in political participation, economic participation, and power over economic measures. Sweden and Denmark have the highest scores within the EU.

Figure 21 depicts buyers' sophistication. There are 11 leading countries for which the results are very similar. All tend to be high income countries, whereas the countries with the worst performance tend to be lower income countries. From the managerial perspective (the indicator is based on interviews with managers), buyer sophistication could be closely linked to disposable income, which is a drawback to this indicator.

Figure 21.



Note: Mean for all 125 countries surveyed.
Source: The Global Competitiveness Report 2006-2007 – World Economic Forum.

Quantitative demand (market size)

Demographics

Research has consistently shown that younger cohorts are more rapid adopters of new technologies, such as mobile telephones and the Internet, although older cohorts could more quickly adopt health related innovations. Consequently, demographics could play an important role in consumer preferences for specific types of innovative products. Relevant indicators include fertility rates, life expectancy, and the age structure of the population. Market size is also partially dependent on the size of the population (the other main factor is per capita incomes), which will be determined by fertility, life expectancy and immigration rates.

The *fertility rate* is the number of children born per woman in her childbearing years. In Europe, 2.1 children per woman are considered to be the population replacement level. European fertility rates are below replacement level in all countries, ranging from a high of 1.94 in France to a low of 1.24 in Poland. Fertility rates are below 1.5 in 15 EU countries. Low fertility rates will reduce market size in the future if not reverted or replaced through higher immigration or higher incomes.

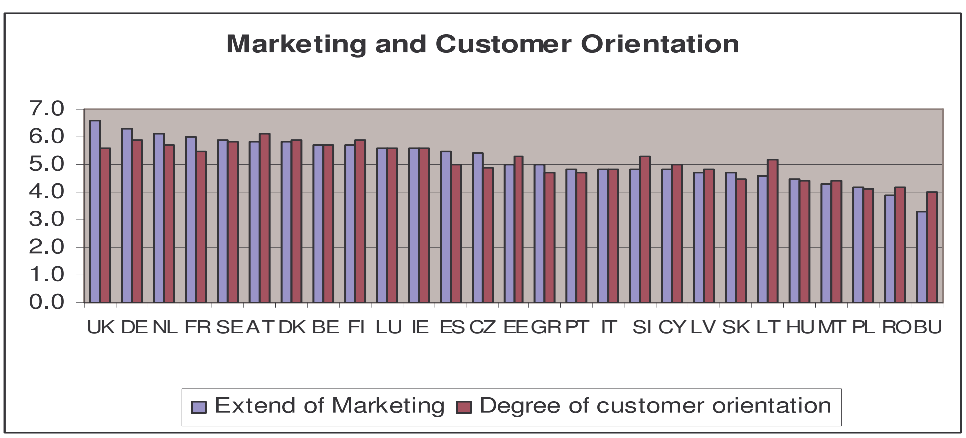
Life expectancy has been increasing for all EU countries over time, with the highest levels in Italy and Sweden (81 years) while Latvia is at the bottom at 71 years. In terms of the *Youth share of the population*, less developed European countries have higher shares than the more developed European countries.

Communication/Advertisement

Marketing is an important mean for creating awareness of new products among potential adopters (Beal & Rogers, 1960) and of influencing the acceptance of novelty (Katz & Lazarsfeld, 1955). The difficulty for developing indicators for marketing is to separate marketing activities for innovative products from activities to market minor improvements in existing products or line extensions.

One of the main objectives for advertising is to increase demand. Unfortunately, there are no reliable indicators for advertisement expenditures for new-to-market products. As a proxy, we explore two WEF indicators: the *Extent of marketing* and the *Degree of customer orientation*. These two indicators, shown in Figure 22, are proxies for the level of sophistication of marketing by country and are highly correlated.

Figure 22.



Extent of marketing
The extent of marketing in your country is (1=limited and primitive, 7=extensive and employ the world's most sophisticated tools and techniques.
Degree of customer orientation
Customer orientation in your country (1=generally treat their customers badly, 7=are highly responsive to customers and customer retention).
Source: The Global Competitiveness Report 2006-2007 – World Economic Forum.

An indicator for communication is obtained from the CIS as the reverse of a 'lack of information on markets' as a hampering factor. In the reverse form, this measures the amount of market information available to firms for their innovative activities.

5.4.2 Foreign demand

Communications / Proximity

Geographical and cultural proximity are possibly important factors for communicating the needs of lead users to firms and information about innovative product characteristics to consumers.

The internet has an ambiguous link with proximity. It can be used to both create international communities and to strengthen local linkages. However, in both cases the internet can facilitate communication and decrease the cost of developing a community of lead users or user-innovators. Von Hippel called this process the "democratization of the opportunity to create".

We use the *broadband penetration rate* per 100 population as an indicator of exposure to more information on innovations. More informed consumers are more likely to demand more sophisticated products and services and also be more involved in the innovation process. There is a large variation in this rate in the EU, from 0.8 in Greece to 22.4 in the Netherlands.

Foreign markets

The ability of firms to exploit national markets gives them access to additional demand. It could also be a marker of the ability of national firms to turn domestic demand into a competitive advantage. Firms based in Germany, Sweden, the United Kingdom, the Netherlands and Austria are best able to access demand in foreign markets and/or use national demand as a source of competitive advantage, according to data from the WEF. An alternative indicator is the percentage of GDP due to exports of goods and services, but the disadvantage of this indicator is that almost all exports could go to one or two trading partners, due to close economic integration.[132]

5.4.3 Role of government

Regulations and standards

Regulations and standards can have a positive effect on demand by reducing uncertainty. Data are available from the World Economic Forum on the stringency of regulatory standards.

Government procurement

There is a lack of indicators for government procurement, even though this is an important factor that can help create new markets or upgrade existing ones. As a proxy for government procurement, we use a WEF indicator that evaluates the role of technical performance and innovativeness in government purchase decisions. Among European countries, France, Germany and Luxembourg tie with the United States on this indicator. The European countries with the lowest performance (procurement based on price instead of advanced technology) were Bulgaria, Latvia and Italy.

5.5 Identifying key demand indicators

Section 5.4 above identified 22 potential indicators[133] for measuring the influence of different factors on demand. The purpose of this section is to identify a limited number of key indicators that can be used to track the effect of demand on innovation and to identify major aspects of demand for which there are no suitable indicators.

Two steps are used to identify a set of key indicators. First, we correlate demand indicators with innovation activity output measurements (described in Section 5.3.4), controlling for GDP per

---

[132] For example, over 80% of Canada's exports go to the United States.

[133] Three indicators are available for both manufacturing and for services sectors, but are counted as a single indicator: information on markets, uncertain demand, and no demand.

capita purchasing power standards (PPS). Controlling for GDP is essential to avoid confounding. This step identifies demand indicators that might be causally linked to innovation activities. Only demand indicators that are positively correlated with three or more of the eight innovation output indicators are selected.

The second step is to reduce the number of key indicators by avoiding repetition, for example by including several indicators that capture the same effect. This is done by correlating the demand indicators with each other. When two or more demand indicators are highly correlated, we select the indicator with the best data coverage and which is available on a regular basis.

In summary, key demand indicators are selected using the following three criteria:

1. Significant correlation with three or more output indicators.
2. Within each major factor category (see Figure 20), the indicator should not be highly correlated (coefficient > 0.8) with other indicators in the same group. If yes, then the indicator that best captures the factor is selected. Furthermore, the indicator must have significant correlation with three or more other demand indicators.
3. If several indicators are highly correlated, the indicator with best data availability is selected.

5.5.1 Correlations: Demand indicators and innovation output indicators

In total, 18 demand indicators from the initial set of 22 indicators are correlated with three or more innovation output indicators.

After controlling for GDP per capita, most of the suggested demand indicators are significantly correlated to the number of EPO patents per million population, employment in high tech services, the share of firms that are strategic and intermittent innovators, and venture capital availability. Demand is not correlated with the share of product sales that are new to the firm and only a few demand indicators are correlated with the share of sales that are new to the market,[134] high tech manufacturing employment, and high tech exports. For a complete view on correlations, please refer to the full report KEI WP 1.4c.

5.5.2 Correlations among suggested demand indicators

There are 18 demand indicators that are significantly correlated with three or more innovation output indicators. The second step is to reduce the number of key indicators by avoiding repetition (including several indicators that capture the same effect). This step is met by correlating the demand indicators with each other, controlling for GDP per capita PPS.

Of the total 18 demand indicators, only the indicator GINI (a measure of inequality) is not statistically significant correlated with at least three other demand indicators, so we drop this indicator. For a complete view on correlations, please refer to the full report KEI WP 1.4c.

5.5.3 Key demand indicators

Domestic demand – Quality

Lead users and lead markets

All proposed indicators for Lead users / Lead markets (*Extent of market dominance, Effectiveness of antitrust policy* and *Intensity of local competition)* proved relevant and significantly correlated with innovation activity output, in particular with Venture capital availability. Lead markets were highly correlated with entrepreneurship activity, indicating that lead markets / lead users tend to attract new and innovative firms willing to take risks to come up with more innovative products.

[134] The lack of positive correlations between the demand indicators and the innovative sales share (either new to market or new to the firm) could be due to a drawback to these two output indicators. What is 'new to the market' in advanced countries such as Finland or Germany probably differs from firms in the new member states. Many firms in the former countries will have global markets, while firms in the latter countries could have local markets. In addition, the indicator for new to firm sales will be affected by the rapid catch up strategies of firms in the new member states.

Furthermore, the three indicators for Lead markets (*Extent of market dominance*, *Effectiveness of antitrust policies and Intensity of local competition)* were not only correlated with most other demand indicators, but they were also highly correlated with each other, indicating that they were capturing the same effect. More specifically, effectiveness of antitrust policies was highly correlated with the other two indicators and could be dropped from the analysis, as it is also measuring the intensity of local competition (if antitrust policies are effective, then local markets should be more competitive) and the extent of market dominance (if antitrust policies are effective, then markets are not dominated by only a few firms).

We keep two indicators for this category: *Extent of market dominance* and *Intensity of local competition.*

Sophisticated buyers

Buyer sophistication was significantly correlated with innovation output indicators and with most demand indicators, in particular with *extension of marketing*, which measures the use of sophisticated marketing tools. As seen, the existence of buyer sophistication goes hand in hand with the use of more sophisticated marketing tools.

When disaggregating sophistication into education, creativity and income distribution, the following observations can be made: *Quality of the education system, Population with tertiary education* and *reverse brain drain* were significantly correlated with innovation output measures. The indicator for *reverse brain drain* has the highest correlations, clearly indicating the need to not only educate but to keep highly skilled individuals in the country to engage in innovation activity.

The three indicators were only weakly correlated with each other, with the exception of the moderate correlation between *reverse brain drain* and *quality of education*. These indicators measure three different aspects of education relevant to innovation outputs, so we keep the three indicators in this category.

Creativity measured by the Euro Creativity Index was also significantly correlated with innovation activity output indicators. But most relevant, the Euro Creativity Index was the proposed demand indicator that showed the highest levels of correlation with innovation activity (EPOs patents, employment in high tech manufacturing and sales new to market). It was the only proposed demand indicator that significantly correlated with new-to-market sales share, which measures the introduction of new products on the firm's market.

Moreover, the creativity index was significantly correlated with several demand indicators. The most significant correlation was a negative relationship with GINI, which measures inequalities. As previously discussed, countries where most of the innovation activity takes place are the ones where there are less inequalities. They display larger domestic markets with the necessary income to acquire novel offerings. The creative class could be responsible for both the production and the consumption of innovative products.

Income distribution, as measured by the GINI coefficient is also significantly correlated with innovation output indicators. Within Europe, innovation activity is stimulated by less variation in individual income, although the effect is partly due to low income inequalities and high innovation outcomes in the Scandinavian countries. These have small domestic markets, with all Scandinavian countries being export oriented. When correlating demand indicators among each other, the GINI indicator was only significantly correlated with the Euro Creativity Index. Consequently, we dropped this indicator, following the criteria that to be relevant, each demand indicator should be significantly correlated with at least three other ones.

We also tested *Gender Empowerment Measure (GEM)* as a proxy for income distribution. Countries where males and females tend to be more equal in terms of political and economic participation, as well as power over economic measures were significantly correlated with innovation activity output measures. GEM had the highest number of significant correlation with all innovation output measures. Of note, GEM was negatively correlated with exports of high tech products, possibly due to branch plants in high technology manufacturing in new member and Mediterranean member states.

Moreover, the GEM index was significantly correlated with most demand indicators, indicating that more developed societies, where innovation activity is more dynamic, are also societies where women share economic and political power with men.

Domestic demand - Quantity

Demographics

Demand is not only relevant for its quality related aspects, but also in terms of quantities. It is necessary to have enough demand to recover R&D investments. Furthermore, economies of scale are necessary to reduce costs.

Birth rates were significantly correlated with several innovation output measures. A country's capacity to replace its present demand matters in terms of making sure demand will be sustained in the future. This is specifically relevant for European countries, with all of them below population replacement levels. *Life expectancy,* after controlling for GDP per capita, was not significantly correlated with any of the proposed innovation activity indicators. One possible explanation could be that the elderly consume fewer innovative products, except for services (insurance and health). This argument is in line with the idea that younger populations are more receptive of novelties, while older ones are more reluctant to adopt new and more sophisticated products.

The *Youth share of the population* was significantly and negatively correlated with innovation outputs, possibly due to a lack of buying power. The key could be the share of the population that is economically active and consequently with above average disposable incomes. This group could drive the population of sophisticated buyers.

Both birth rates and youth share of the population were significantly correlated with several other demand indicators, but not correlated with each other. Consequently we keep both indicators as relevant for measuring different aspects of demand.

Communications- Advertisement

We assumed that firms can influence demand levels by increasing advertisement expenses, thus creating a broader awareness for their new products. Firms would consequently engage in marketing activities to better know their potential clients and to target advertising campaigns to influence such segments of the population. Surprisingly, adequate *information on markets* was not positively correlated with innovation outputs. This could be because market knowledge might not matter for many types of innovations that are developed as a result of technology push. It would be relevant to differentiate between disruptive and incremental innovation to better understand the role of marketing and advertising in demand creation. Sectoral effects could also play a role here.

On the other hand, the other two indicators in this group (*Extent of marketing and Degree of customer orientation*) were significantly correlated with several innovation outputs. Furthermore, both of these indicators were significantly correlated with each other, indicating that only one of them is necessary to capture the effect of marketing as a component of demand. Of the two indicators, customer orientation has a better fit with theory as it measures the responsiveness of firms to customer requirements.

Foreign demand

Both *Broadband penetration and Breadth of international markets* were significantly correlated with innovation activity output measures. Broadband penetration allows for a better flow of information between foreign and local markets, with a positive outcome in terms consumer awareness and sophistication. It is through this bridge between local and foreign markets that countries are able to customize their offerings to a broader range of markets, with gains in terms of economies of scales, stimulating R&D activity.

Both indicators were significantly correlated with most other demand indicators. Of note, Breath of international market was highly correlated with Presence of demanding regulatory standards. This indicates that demanding regulatory standards at home helps firms to compete on foreign markets, perhaps by improving the quality characteristics of their products.

Broadband and Breath of international markets were weakly correlated with each other, measuring different aspects of a country's relation to foreign markets, and are both relevant to innovation outputs, so we keep the two indicators in this category.

Role of government

Both government related indicators*, Presence of demanding regulatory systems* and *Government procurement* were significant correlated with several innovation output indicators. Not only the need for regulations and the use of standards are necessary for innovation to take place, but government procurement appears to play an important role in promoting innovation activity. Government procurement showed higher correlations than presence of demanding regulatory systems with both Innovation mode and Venture capital availability. When government procurement is relevant, firms tend to be strategic or intermittent innovators, as they have a strong motivation to develop R&D in house.

Moreover, government related indicators (*Presence of demanding regulatory standards* and *Government procurement* for advanced technology products) were significantly correlated with most other demand indicators. The two indicators were weakly correlated with each other, and consequently both are relevant for measuring demand, as they relate to two different aspects of government influence: the first deals with setting up regulations and standards to protect both producers and consumers, while the second one refers to government as a buyer, a consumer of innovative goods and services.

5.5.4 Missing indicators

Even though we know that innovation activity is *sector* oriented, we lack indicators to measure sector specific demand conditions. We also lack indicators to measure *demand structure*. Theory suggests that both *polypsony* and *oligopsony* demand structures are beneficial for innovation activity, but we do not have indicators to measure either structure.

We also need to better understand the role of segmentation and niche markets. We do know that income inequalities tend to create market segments. But we also know that demand conditions are only favourable when individual incomes are high enough to absorb new and more sophisticated products, which are more expensive due to R&D costs (plus patent protection).

Furthermore, more needs to be known about economically active adult populations. Although less receptive of novelties when compared to the youth, adult populations have the necessary income to consume more expensive and sophisticated products. Consequently, more indicators related to this specific population bracket should be developed.

Marketing is a demand driver, but we do not know how effectively it can be used to create demand for innovation products. In the future, the addition of new questions on marketing to the CIS could help to overcome this limitation.

Finally, firms can use foreign markets as lead markets or as a source of sophisticated consumers. Currently only one demand indicator is available for foreign markets and it does not fully capture how firms are able to replace domestic lead markets with foreign lead markets.

5.6 Conclusions

Demand conditions are influenced not only by domestic quality aspects, such as the existence of lead users made up of sophisticated buyers, but also by quantitative aspects including the actual numbers of consumers in such markets. The sophisticated buyers were named by Richard Florida as the “Creative class”, which is constituted by highly skilled and educated people, whose higher incomes are a reflection of their level of education. This share of the population consists of prime age adults with the disposable income and interest to purchase sophisticated products.

Furthermore, demand can be created if firms can make use of sophisticated marketing tools to capture customers’ needs and desires. Unfortunately, we are not able to measure the effect of advertising in creating demand due to a lack of data. But it would be relevant to quantify the impact of advertisement in demand creation while breaking down innovation into disruptive and incremental innovation. As most innovations consist of minor improvements, advertisement might play an important role in demand creation. This is certainly an area lacking adequate indicators.

Table 7 in Section 5.1 lists thirteen key indicators for demand for innovative goods and services that were found relevant to measure demand conditions.

However, there are large gaps in indicator availability. The missing indicators include indicators on the different effects of demand by sector, demand structure (monopsony, polypsony and oligopsony), the role of niche markets, the ability of firms to use foreign markets to replace limited domestic markets and the impact of advertisement in creating demand. Table 7 also includes such missing indicators.

References

Adams, R. H. Jr. 2003. International migration, remittances and the brain drain – A study of 24 labor-exporting countries. *World Bank Policy Research Working Paper.* No. 3069. Washington, DC: World Bank.

Anderson, R., House, D. and M. Ormiston. 1981. A Theory of Physician Behaviour with Supplier-Induced Demand*, Southern Economic Journal*, July, pp 124-133.

Ankli, R. E. 1992. Michael Porter's Competitive Advantage and Business History. In *Business and Economic History*, Second Series, Vol. 21.

Archibugi, D., Michie, J. 1998. *Trade, Growth and Technical Change*. Cambridge, United Kingdom: Cambridge University Press.

Arimura, T.H., Hibiki, A. and N. Johnstone, 2007. An empirical study of environmental R&D: What encourages facilities to be environmentally innovative? In *Environmental policy and corporate behaviour,* by N. Johnstone (Ed.). Cheltenham, UK: Edward Elgar and Paris: OECD.

Arundel, A., 2005. *Lessons from innovation indicators: What can we ask in a survey?* Maastricht: MERIT.

Arundel, A., Kemp, R. and S. Parto, 2006. Indicators for environmental innovation: What and how to measure, in *The international handbook on environmental technology management*, by Marinova, D., Annandale, D. and J. Phillimore (Eds.). Cheltenham, UK: Edward Elgar.

Auriol, L. 2006. *International mobility of doctorate holders: First results and methodology advances*. Paper presented at the Blue Sky II conference 'What indicators for science, technology and innovation policies in the 21st century?' in Ottawa, 25-27 September, 2006.

Balsdon, R. 2003. *The Cultural Mosaic of the European Union: Why National Boundaries and the Cultures Inside Still Matter*. St. Edwards University – Perspectives in Business.

Bannock, G., Baxter, R.E. and Davis, E. 1986. *Dictionary of Economics*, Fourth Edition (The Economist Series).

Beal, G. M. and Rogers, E. M. 1960. *The adoption of two farm practices in a central Iowa community: Ames, Iowa agricultural and home economics experiment station*. In: Special Report 26

Beise, M. and Rennings, K. 2001. *Lead Markets of Environmental Innovations: A Framework for Innovation and Environmental Economics.* Centre for European Economic Research.

Brandi, C. 2002. *A pilot survey of foreign researchers in public research bodies in Italy – Characteristics of recent migrants.* A report within a European Commission project 'Brain drain: Emigration flows for qualified scientists'.

Brown, S. L. and Eisenhardt, K. M. 1995. Product development: past research, present findings, and future directions. *Academy of Management Review*, 20 (2): 343-78.

Brunnermeier, S.B. and M.A. Cohen, 2003. Determinants of environmental innovation in US manufacturing industries, *Journal of Environmental Economics and Management,* 45, pp. 278-293.

Böhm, Davis, Meares and Pearce. 2002. *Global student mobility 2025 – Forecasts of the global demand for international higher education.* IDP Education Australia.

Cai, Y. 2005. The future of European higher education from a Chinese perspective: The internationalization dimension. In *The European higher education and research landscape 2020 – Scenarios and strategic debates* (Enders, J., File, J., Huisman J. and D. Westerheijden, Eds.). CHEPS.

Chartrand, H. H. 2002. *The Competitiveness of Nations in a Global Knowledge-Based Economy*. Paris: OECD.

Choi, H. 1995. *An international scientific community – Asian scholars in the United States*. New York: Praeger.

Christensen, C. 1992. *The Innovator's Challenge: Understanding the Influence of Market Environment on Processes of Technological Development in the Rigid Disk Drive Industry*. DBA diss., Harvard Business School.

Christensen, C. M. 1997. *The Innovator's Dilemma – When New Technologies Cause Great Firms to Fail.* Harvard Business School Press.

Christensen, C. M. and J. L. Bower. 1996. Customer Power, Strategic Investment, and the Failure of Leading Firms. *Strategic Management Journal,* 17: 197-218.

Council of the EU. 2003. *Council Resolution on the profession and the career of researchers within the European Research Area (ERA) - Outcome of proceedings of the "Competitiveness" Council on 10 November 2003 (Note dated 12/11/03).* Brussels.

Council of the EU. 2005. *Integrated guidelines – Broad economic policy guidelines (Note dated 28/06/05).* Brussels.

Council of the EU. 2006. *Brussels European Council meeting 23-24 March 2006 – Presidency conclusions (Note dated 18/05/06).* Brussels.

Cowan, R., Cowan, W., and Swann, P. 1997. A model of demand with interactions among consumers. *International Journal of Industrial Organization*, 15, pp. 711-32.

Dannels, E. 2004. Disruptive Technology Reconsidered: A Critique and Research Agenda. *Journal of Product Innovation Management,* 21: 246-258.

Davis, T. M. 2003. *Atlas of Student Mobility*. Institute of International Education.

Dickerson, M. D., Gentry, J. W. 1983. Characteristics of adopters and non adopters of home computers. *Consumer Res.,* 10 – 225-235.

Docquier, F. and A. Marfouk. 2004a. International migration by education attainment 1990-2000. In *International migration, remittances and the brain drain (Özden, C. and M. Schiff, Eds.)*. Washington: Worldbank and New York: Palgrave Macmillan.

Docquier, F. and A. Marfouk. 2004b. *Measuring the international mobility of skilled workers (1990-2000) – Release 1.0.* (Report accompanying a database).

Doornbosch, R. and Steenblik R., 2007. *Biofuels: Is the cure worse than the disease? Round Table of Sustainable Development, Paris, 11-12 September*. Paris: OECD.

Dutton, W.H., Rogers, E. M., and Jun, S. H. 1987. The diffusion and impact of information technology in households. In P. I. Zorkoczy (ed.). *Oxford Surveys in Information Technology*, Vol. 4, NY: Oxford University Press.

Earl, P. 1986. *Lifestyle Economics: consumer behavior in a turbulent world*. Brigton, Wheatsheaf Harvester.

ECOTEC, 2002. *Analysis of the EU eco-industries, their employment and export potential – A final report to DG Environment.* London: ECOTEC.

Edquist, C. 1997. *Systems of Innovation: Technologies, institutions and organizations.* London and Washington: Pinter.

Edquist, C., Hommen, L., and Tsipouri, L. 2000. *Public Technology Procurement and Innovation*. Kluwer Academic Publishers.

Enos, J. L. 1962. *Petroleum Progress and Profits: A History of Process Innovation*. Cambridge, MA: MIT Press.

Ernst & Young, 2006. *Eco-industry, its size, employment, perspectives and barriers to growth in an enlarged EU – Final report*. Brussels: European Commission, DG Environment.

European Commission, 2001. *European economy, no. 73.* Brussels: EC.

European Commission. 2003a. *Investing in research: an action plan for Europe (COM(2003) 226).* Brussels.

European Commission. 2003b. *Researchers in the European Research Area: One profession, multiple careers (COM(2003) 436).* Brussels.

European Commission. 2003c. *Third European report on science and technology indicators 2003 – Towards a knowledge-based economy.* Brussels: DG Research.

European Commission. 2004. *Europe needs more scientists – Report of the High Level Group on Human Resources for Science and Technology in Europe*. Brussels: DG Research.

European Commission. 2005a. Key Figures 2005 – *Towards a European Research Area: Science, technology and innovation.* Brussels: DG Research.

European Commission. 2005b. *Mobilising the brainpower of Europe: Enabling universities to make their full contribution to the Lisbon Strategy (COM(2005) 152 including separate Annex).* Brussels.

European Commission. 2006a. *Delivering on the modernization agenda for universities: Education, research and innovation (COM(2006) 208).* Brussels.

European Commission. 2006b. *Monitoring industrial research: The 2005 EU survey on R&D investment business trends in 10 sectors.* Brussels: DG Research.

European Commission. 2006c. *Progress towards the Lisbon objectives in education and training – Report based on indicators and benchmarks (SEC(2006) 639).* Brussels.

European Commission. 2006d. *She figures 2006: Women and science – Statistics and indicators.* Brussels: DG Research.

European Commission, 2007. Energy technologies: Knowledge, perception, measures. *Special Eurobarometer 262*. Brussels: EC.

Eurostat. 2005. International migration of the highly qualified in the European Union. *Eurostat working paper and studies*. Luxembourg: Eurostat.

Eurostat. 2006. Analyses on human resources in science and technology by educational field of study. *Eurostat working paper and studies*, August. Luxembourg: Eurostat.

Eurostat, 2007. *Draft compilation guide on environmental sector, version 4*. European Commission, Luxembourg: Eurostat.

Eurydice. 2005. *Key data on education in Europe 2005.* Brussels: DG Education and Culture.

Fagerberg, J. 1992. The Home Market Hypothesis Reexamined: The Impact of Domestic User- producer Interaction on Export Specialisation, in: B.-Å. Lundvall (Ed.), *National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning*. Pinter Publishers, London.

Finn, M.G. 1997. *Stay rates of foreign doctorate recipients from US universities, 1995*. Oak Ridge, TN: Oak Ridge Institute for Science and Education.

Florida, R. and Tinagli, I. 2004. *Europe in the Creative Age.*

Foray, D. 1989. Les modèles de compétition technologique. Une revue de la littérature. *Revue d'Economie Industrielle* 48 (2nd quarter), pp. 16–34.

Foray, D. 2004. *Economics of Knowledge*. MIT Press.

Foxall, G. R. 1989. User Initiated Product Innovations. *Industrial Marketing Management*, 18, 95-104.

Franke, N. and von Hippel, E. 2003. *Finding Commercially Attractive User Innovations*. Working Paper, MIT Sloan School of Management.

Freeman, C. 1968. Chemical Process Plant: Innovation and the World Market. In: *National Institute Economic Review* 45 (August) 29-57.

Freeman, C. 1973. A Study of Success and Failure in Industrial Innovation. In B. R. Williams (ed.), *Sciences and Technology in Economic Growth*. New York: Wiley, pp. 227-45.

Frondel, M., Horbach, J. and K. Rennings, 2007. End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries, *Business Strategy and the Environment,* 16(8): pp. 571-584.

Fukasaku, Y., 2005. The need for environmental innovation indicators and data from a policy perspective, in *Towards environmental innovation systems* by Weber, M. and J. Hemmelskamp (Eds.). Berlin: Springer.

Gaillard, A.-M. 2001. *The* mobility of human resources in science and technology in Sweden. In *International mobility of the highly skilled* (OECD Proceedings, pp. 225-252). Paris: OECD.

Gatignon, Hubert, Eliashberg, J., Robertson, T. S. 1989. Modelling multinational diffusion patterns: An efficient methodology. *Marketing Science*, 8 (3) 231-247.

Georgescu-Roegen, N. 1954. Choice, expectations and measurability. *Quarterly Journal of Economics,* 68, pp. 503-34.

Georghiou, L. 2006. *Effective innovation policies for Europe – the missing demand-side.* Contribution to the project "Globalization Challenges for Europe and Finland" organized by the Secretariat of the Economic Council.

Golder, P. N., Tellis, G. J. 1998. Beyond diffusion: An affordability model of the growth of new consumer durables. *Journal of Forecasting*, 17, 259-280.

Granstrand, O. 1984. *Technology Procurement as a Special Form of Buyer-Seller Interaction in Industrial Marketing.* Department of Industrial Managament, Chalmers University of Technology, CIM-report No: 84:06.

Graversen, E., Lemming, M., Åkerblom, M. and M. Virtaharju. 2001. Migration between the Nordic countries: What do register data tell us about the knowledge flow? In *Innovative people – Mobility of skilled personnel in national innovation systems.* Paris: OECD.

Gupta, D., Nerad, M. and J. Cerny. 2003. International PhDs: Exploring the decision to stay or return. *International Higher Education,* Spring. Center for International Higher Education, Boston College.

Haddon, L. 2002. Information and communication technologies and the role of consumers in innovation. In McMeekin, A., Green, K., Tomlinson, M., and Walsh, V. (eds.), *Innovation by demand, an interdisciplinary approach to the study of demand and its role in innovation*. Manchester University Press.

Hansen, W. 2003. *Brain drain: Emigration flows for qualified scientists – Executive summary and conclusions.* Maastricht: MERIT (A report within a European Commission project).

Haug, G. and C. Tauch. 2001. *Trends in learning structures in higher education II*. Follow-up report prepared for the Salamanca and Prague Conferences of March/May 2001. National Board of Education: Finland.

Helsen, K. and Schmittlein, D. C. 1993. Analyzing duration time in marketing research. *Marketing Science,* 12 (4) 395-410.

Hernesniemi, H. and H. Sundquist, 2007. *Rapidly growing environmental business needs monitoring*. Helsinki: SITRA.

Hollanders, H. and A. Arundel. 2007. *European Innovation Scoreboard 2006.* Brussels: European Commission (DG Enterprise).

Horbach, J., 2006. *Determinants of environmental innovation – New evidence from German panel data sources.* Presentation at the FEEM Nota di Lavoro conference in Milano.

Horbach, J. and K. Rennings, 2007. (Panel-) survey analysis of eco-innovation: Possibilities and Propositions, *Deliverable 4 and 5 of MEI project*. Centre for European Economic Research (ZEW).

ICEDD, Wuppertal Institut and Institute of Social Ecology – IFF, 2006. *Supply of the statistical services in the field of the environment – Final report for the European Commission and Eurostat.*

Independent Expert Group on R&D and Innovation appointed following the Hampton Court Summit. 2006. *Creating an Innovative Europe*.

Institute of Higher Education, Shanghai Jiao Tong University. 2006. *Academic Ranking of World Universities – 2006.* Shanghai Jiao Tong University: China

ISA. 1999. *I huvudet på ett företag. om huvudkontorets roll och lokalisering*. Council of Economic Advisors.

Kamien, M. I. and Schwartz, N. L. 1982. *Market Structure and Innovation*. Cambridge University Press.

Katz, E. and Lazarsfeld, P. F. 1955. *Personal Influence: The Part Played by People in the Flow of Mass Communications*. The Free Press, New York.

Kelo, M., Teichler, U. and B. Wächter. 2006. Toward improved data on student mobility in Europe: Findings and concepts of the Eurodata study. *Journal of Studies in International Education*, 10(3), pp. 194-223.

Kemp, Rene, 2007. *Workshop meeting report for the MEI project*, May. UNU-MERIT.

Kennett, M. and R. Steenblik, 2005. Environmental goods and services: A synthesis of country studies, *OECD Trade and Environment Working Paper No. 2005-3.* Paris: OECD.

Ketels, C. 2004. *European Clusters*. Harvard Business School, Boston, MA, USA.

Khadria, B. 2004. Human resources in science and technology in India and the international mobility of highly skilled Indians. *OECD Science. Technology and Industry Working Papers,* No. 7/2004. Paris: OECD.

Kleinknecht, A., van Montfort, K. and E. Brouwer, 2002. The non-trivial choice between innovation indicators, *Economics of Innovation and New Technology*, 11(2), pp. 109-121.

Knight, K. E. 1963. *A Study of Technological Innovation: The Evolution of Digital Computers*. Unpublished PhD Dissertation, Carnegie Institute of Technology, Pittsburgh, PA.

Lancaster, K. J. 1975. Socially optimal product differentiation. *American Economic Review*, 65 (4), pp. 567-85.

Lanjouw, J.O. and A. Mody, 1996. Innovation and the international diffusion of environmentally responsive technology, *Research Policy*, 25, pp. 549-571.

Lanzendorf, U. and U. Teichler. 2003. Statistics on student mobility within the European Union. *Education and Culture Series Working paper,* No. EDUC 112. Luxembourg: European Parliament.

Legler, H., Schmoch, U., Gehrke, B. and O. Krawczyk, 2003. Innovationsindikatoren zur Umweltwirtschaft, *Studien zum deutschen Innovationssytem,* Nr. 2. Hannover: NIW and Karlsruhe: Fraunhofer Institut.

Lillien, G. L., P. D. Morrison, K. Searls, M. Sonnack, and E. von Hippel. 2002. Performance Assessment of the Lead User Idea-Generation Process for New Product Development. *Management Science,* 48, n. 8: 1042-1059.

Lundvall, B-A. 1988. From user-supplier interaction to national systems of innovation. In Dosi, G., Freeman, C., Nelson, R., Soete, L., Silverberg, G., et al. (eds), *Technological Change and Economic Theory,* London, Pinter.

Mahajan, Vijay, Muller, E. 1994. Innovation diffusion in a borderless global market: Will the 1992 unification of the European community accelerate diffusion of new ideas, products, and technologies? *Tech. Forecasting and Soc. Change,* 45, 221-235.

Marbela, F. 2002. Sectoral systems of innovation and production. *Research Policy,* 31 247-264.

McMeekin, A., Green, K., Tomlinson, M., and Walsh, V. 2002. *Innovation by demand*. Manchester University Press.

Marey, P., de Grip, A. and F. Cörvers. 2001. *Forecasting the labour markets for research scientists and engineers in the European Union.* Maastricht University: Research Centre for Education and the Labour Market.

Marinova, D. and M. McAleer, 2006. Comparison of international strenghts in sustainable technological solutions, in *The international handbook on environmental technology management*, by Marinova, D., Annandale, D. and J. Phillimore (Eds.). Cheltenham, UK: Edward Elgar.

Moguerou, P. 2006. The brain drain of PhDs from Europe to the US: What we know and what we would like to know. *EUI Working Papers*, No. 11/2006. Badia Fiesolana, Italy: European University Institute, Robert Schuman Centre for Advanced Studies.

Morrison, P. D., Roberts, J. H., and von Hippel, E. 2000. Determinants of User Innovation and Innovation Sharing in a Local Market. *Management Science*, 46, 12 (December) 1513-1527.

Morrison, P., Roberts, J., and Midgley, D. 2002. *The Nature of Lead Users and Measurement of Leading Edge Status.* INSEAD Working Papers.

Morrison, P. D., J. H. Roberts, and D. F. Midgley. 2004. The Nature of Lead Users and Measurement of Leading Edge Status. *Research Policy,* 33, n. 2: 351-362.

Muche, F., Wächter, B. and F. Maiworm. 2006. *Perceptions of European higher education in third countries – Final report.* Brussels: European Commission (DG Education and Culture).

National Science Foundation. 2000. *Science and Engineering Indicators 2000.* NSF.

Nelson, R. 1994. The coevolution of technology, industrial structure and supporting institutions. *Industrial and Corporate Change*, 3(1), 47-64.

OECD. 1996. *The Knowledge Based Economy*.

OECD. 2001. *Trends in international migration – Part II (Student mobility between and towards OECD countries: A comparative analysis)*. Paris: OECD.

OECD. 2004. *Internationalisation and trade in higher education: Opportunities and challenges.* Paris: OECD.

OECD. 2005. *Trends in international migration – Part II (Counting immigrants and expatriates in OECD countries: A new perspective).* Paris: OECD.

OECD, 2006. *Compendium of patent statistics*. Paris: OECD.

Oltra, V., Kemp, R. and de Vries, F., 2007. *Patents as a measure for eco-innovation,* report for the MEI project. University of Bordeaux, UNU-MERIT and University of Stirling.

Pavitt, K. and Wald, S. 1971. *The Conditions for Success in Technological Innovation*. OECD Paris.

Peter, V., 2006. *Eco-industries – Scoping paper for the Systematic project*. Technopolis.

Popp, D., 2005. *Using the triadic patent family database to study environmental innovation.* OECD.

Porter, M. E. 1990. *The Competitive Advantage of Nations*. The Macmillan Press Ltd.

Porter, M. E. 1998. *On Competition*. The Harvard Business Review book series.

Potočnik, J. 2005. *Key Figures 2005 on science. technology and innovation - Wake-up call for Knowledge Europe!* Presentation by the Commissioner for Research in Brussels on 19 July 2005.

Purcell, K., Wilton, N. and P. Elias. 2003. *Older and wiser? Age and experience in the graduate labour market.* Research Paper No. 2 of 'Researching graduate careers seven years on'. ESRU, Warwick Institute for Employment Research.

Rehfeld, K.-M., Rennings, K. and A. Ziegler, 2004. Integrated product policy and environmental product innovations: An empirical analysis. *ZEW discussion paper no. 04-71,* Mannheim: ZEW.

Rennings, K., Ziegler, A., Ankele, K., Hoffmann, E. and J. Nill, 2003. The influence of the EU Environemntal Management and Auditing Scheme on environmental innovations and competitiveness in Germany: An analysis on the basis of case studies and a large-scale survey. *ZEW discussion paper no. 03-14,* Mannheim: ZEW.

Riggs, W., and E. von Hippel. 1994. Incentives to Innovate and the Sources of Innovation: The Case of Scientific Instruments. *Research Policy*, 23, n. 4: 459-469.

Rogers, E. M. 1983. *Diffusion of Innovation*. NY. Free Press.

Rogers, E. M. 1995. *Diffusion of Innovations*. 4th ed. The Free Press, New York.

Rothwell, R. and Zegveld, W. 1985. *Reindustrialization and Technology*. Longman, London.

Rothwell, R. 1992. Successful industrial innovation: critical factors for the 1990s. *R&D Management* (22) 3, 221-39.

Ruprecht, W. 2002. Preferences and novelty: a multidisciplinary perspective. In McMeekin, A., Green, K., Tomlinson, M., and Walsh, V. (eds.), *Innovation by demand, an interdisciplinary approach to the study of demand and its role in innovation.* Manchester University Press.

Saint-Paul, G. 2004. The brain drain: Some evidence from European expatriates in the US. *IZA Discussion Paper Series,* No. 1310. Bonn: IZA.

Sasson, A., 2005. Industrial and environmental biotechnology – Achievements, prospects and perceptions. *UNU-IAS Report.* Yokohama: UNU-IAS.

Saviotti, P. P. 1994. Variety, economic and technological development. In Shionoya, Y., and Perlman, M. (eds), *Technologies, Industries and Institutions: studies in Schumpeterian perspectives,* Ann Arbor MI, University of Michigan Press.

Saviotti, P. P. 1996. *Technological Evolution, Variety and the Economy*. Edward Elgar Publishing, Cheltenham, United Kingdom.

Saviotti, P. P. 2001. Variety, growth and demand. *Journal of Evolutionary Economics*, 11 (1), pp. 119-42.

Schmitz, H. 1995. Collective Efficiency: Growth Plan for Small-Scale Industry. *The Journal of Development Studies*, 31(4).

Schmookler, J. 1957. Inventors Past and Present. *Review of Economics and Statistics,* August: 321-33.

Schmookler, J. 1966. *Invention and Economic Growth*. Cambridge, Mass.: Harvard University Press.

Shah, S. 1999. *Sources and Patterns of Innovation in a Consumer Products Field: Innovations in Sporting Equipment*. MIT Sloan School of Management working paper 410 (May).

Sjøberg, S. 2002. Science and scientists: The SAS-study on cross-cultural evidence and perspectives on pupils' interests. experiences and perceptions: Background, development and selected results. *Acta Didactica,* Oslo: University of Oslo.

Solimano, A. and M. Pollack. 2004. International mobility of the highly skilled: The case between Europe and Latin America. *ECLAC Working Paper Series,* No. 1. Santiago: ECLAC.

Stanners, D. and P. Bourdeau (Eds.), 1995. *Europe's environment – The Dobris assessment.* Copenhagen: European Environment Agency.

Steenblik, R., 2005. Environmental goods: A comparison of the APEC and OECD lists, *OECD Trade and Environment Working Paper No. 2005-4.* Paris: OECD.

Stern, N., 2007. *The economics of climate change – The Stern review*. Cambridge University Press.

Taylor, M.R., Rubin, E.S. and D.A. Hounshell, 2005. Regulation as the mother of innovation: The case of SO_2 control, *Law and Policy*, 27(2), pp. 348-378.

Takada, H., Jain, D.C. 1991. A Cross analysis of diffusion of consumer durable goods in Pacific Rim countries. *Journal of Marketing*, 55 (April) 48-54.

Talukdar, Debu, Sudhir, K., Ainslie, A. 2001. Identifying similarities in diffusion patterns across countries and products: A Bayesian variance components approach. *Marketing Science,* 21 (1) 97-114.

Teichler, U. 1989. Research on higher education and work. *European Journal of Education,* 24, pp. 223-247.

Teichler, U. 2000. Graduate employment and work in selected European countries. *European Journal of Education*, 35(2), pp. 141-156.

Teichler, U. 2002. Graduate employment and work in Europe: Diverse situations and common perceptions. *Tertiary Education and Management*, 8, pp. 199-216.

The Economist Intelligence Unit. 2006. *CEO briefing: Corporate priorities for 2006 and beyond.* EIU.

Thurow, L.C. 1975. *Generating inequality*. New York: MacMillan.

Tomlinson, M. and McMeekin A. 2002. Social routines and the consumption of food. In McMeekin, A., Green, K., Tomlinson, M., and Walsh, V. (eds.), *Innovation by demand, an interdisciplinary approach to the study of demand and its role in innovation*. Manchester University Press.

Trade and Development Board, 2003. *Environmental goods: Trade statistics of developing countries.* UN.

TrendChart. 2005. *Innovation Policy in Europe*. Innobarometer 2005. http://trendchart.cordis.lu/scoreboard2005/innobarometer.cfm

Trott, P. 1998. *Innovation Management & New Product Development*. Essex, England: Pearson Education Limited.

United Nations, 2001. *Classification of Environmental protection activities and expenditure (CEPA 2000) with explanatory notes, ESA/STAT/AC.78/5.* UN.

United Nations. 2005. *World Investment Report, 2005 – Transnational Corporations and the Internationalization of R&D.* New York and Geneva.

United Nations. 2006. *World Development Indicators 2006*.

Urban, G. and von Hippel, E. 1988. Lead Users Analyses for the e Development of New Industrial Products. *Management of Sciences*, vol. 34, n. 5, May, 569-582.

Utterback, J. M., and W. J. Abernathy. 1975. A Dynamic Model of Process and Product Innovation. *Omega 3*, n. 6: 639-656.

van der Voet, E., van Oers, L., Moll, S., Schutz, H., Bringezu, S., de Bruyn, S., Sevenster, M. And G. Warringa, 2005. *Policy review on decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries*. Report commissioned by the European Commission.

Vlk, A. 2006. *Higher education and GATS - Regulatory consequences and stakeholders' responses (PhD thesis).* Enschede: University of Twente, Centre for Higher Education Policy Studies (CHEPS).

von Hippel, E. 1976. The dominant role of users in the scientific instrument innovation process. *Research Policy*, 5 (3): 212-39.

von Hippel, E. 1978. Users as innovators*.* *Technology Review*, 80 (3), 30-4.

von Hippel, E. 1986. Lead Users: A Source of Novel Product Concepts. *Management of Sciences*, vol. 32, N. 7, July, 791-805.

von Hippel, E. 1988. *The Sources of Innovation*. Oxford, England: Oxford University Press.

von Hippel, E. 2005. *Democratizing Innovation*. Cambridge, Mass.: The MIT Press.

Walsh, V., Cohen, C., Richards, A. 2002. The incorporation of users needs in telecom product design. In McMeekin, A., Green, K., Tomlinson, M., and Walsh, V. (eds.) *Innovation by demand, an interdisciplinary approach to the study of demand and its role in innovation.* Manchester University Press.

Ward, A. 2002. Social mechanisms generating demand: a review and manifesto. In McMeekin, A., Green, K., Tomlinson, M., and Walsh, V. (eds.), *Innovation by demand, an interdisciplinary approach to the study of demand and its role in innovation*. Manchester University Press.

Wilen, H. 2006. Which are the characteristics of Europe's highly qualified human resources? *Statistics in Focus*, Number 8. European Commission, Eurostat.

World Economic Forum, 2001. *Global Competitiveness Report 2001-2002*. Geneva: WEF.

World Economic Forum, 2006. *Global Competitiveness Report 2006-2007*. Geneva: WEF.

Yao, L. 2004. *The Chinese overseas students: An overview of the flows change.* Paper presented at the 12th Biennial Conference 'Population and Society: Issues, Research. Policy' in Canberra. 15-17 September 2004.

ZEW, 2001. *The impact of clean production on employment in Europe – An analysis using surveys and case studies (IMPRESS).* Final report, coordinated by K. Rennings, ZEW. Mannheim: ZEW Centre for European Economic Research.