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Measuring eco-innovation

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Abstract

In this paper we offer a discussion of eco-innovation and methods for measuring it. Eco-innovation is a new concept of great importance to business and policy makers, covering many innovations of environmental benefit. Past research and measurement activity primarily focused on pollution control and abatement activities or on the environmental goods and services sector. We argue that eco-innovation research and data collection should not be limited to such environmentally motivated innovations, but should encompass all products, processes, or organizational innovations with environmental benefits. Attention should be broadened to include innovation in or oriented towards resource use, energy efficiency, greenhouse gas reduction, waste minimization, reuse and recycling, new materials (for example nanotechnology-based) and eco-design. Research should cover the drivers, patterns, and benefits of eco-innovation for each of these applications, since these factors are likely to differ. For measuring eco-innovation, no single method or indicator is likely to be sufficient. In general, one should therefore apply different methods for analyzing eco-innovation – to see the "whole elephant" instead of just a part. More effort should be devoted towards direct measurement of eco-innovation outputs using documentary and digital sources to complement the current emphasis on innovation inputs such as R&D or patents. Innovation can also be measured indirectly from changes in resource efficiency and productivity. These two avenues are underexplored and should be given more attention in order to augment our rather narrow knowledge basis.

Keywords: eco-innovation, measurement, indicators, data needs. JEL codes O1 en O3

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[1] The paper was written for the Directorate of Science, Technology and Industry (DSTI) of the OECD. It is partly based on research by others for the MEI (Measuring Eco-Innovation) project funded by the European Commission (http://www.merit.unu.edu/MEI/). We acknowledge the contributions from others involved in the MEI project.

1. Introduction

In this paper we examine and discuss methods for measuring eco-innovation. Before doing so, we consider the question *why should we be interested in eco-innovation and its measurement*? The first answer is of course the expected environmental benefits. The second answer is that faced with rising costs for producing goods and managing waste products, the competitiveness of firms, countries and even regions is increasingly linked to their ability to 'eco-innovate'. However, very little is known about the growing global trade in environmentally beneficial goods and services as eco-technologies have been largely neglected in economic statistics. Nor do we know much about the adoption of innovations to reduce the environmental impacts of companies, sectors and nations, and the environmental improvements achieved thanks to the use of eco-innovations.

This paper partly adopts the OECD definition of eco-innovation as "the *creation* of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which - with or without intent - lead to environmental improvements compared to relevant alternatives" (OECD, 2008 p 19). We do not completely adopt this definition because it conflicts with the Oslo Manual definition of innovation, which includes the *implementation* of a new technology that was developed by a different firm or institution. For example, following the Oslo Manual, a firm can innovate (or eco-innovate) by purchasing cleaner production technology from a supplier and implementing the technology into its production line. The Oslo Manual is important here because it is the guidebook for the official innovation surveys of almost all OECD countries.

Eco-innovation is not limited to environmentally motivated innovations, but includes "unintended environmental innovations". The environmental benefits of an innovation can be a side-effect of other goals, such as to recycle heavy metals in order to reduce costs. Institutional innovations such as changes in values, beliefs, knowledge, norms, and administrative acts are also included, as are changes in management, organization, laws and systems of governance that reduce environmental impacts (OECD, 2008). The definition provides a weak conceptual demarcation. Almost all firms who innovate will be eco-innovators, which could appear to be a problem for some analysts. However, this is the same 'false problem' that has been discussed in reference to the Oslo Manual on measuring innovation, with some researchers objecting that the Manual defines innovation so broadly that almost all firms should be innovators. This is true, but the solution is to use available data to identify *how* firms *eco-innovate* and the *different drivers for these various 'modes' of eco-innovation*.

Part of the definitional problem is due to the fact that innovation is a relative concept. The first-time company use of a pollution control device is an innovation from the adopter's point of view, but not an innovation from the manufacturer's point of view. For the manufacturer, a significant change in the pollution control device or the creation of a new technology counts as an innovation. When measuring eco-innovation one should thus make clear whether one is measuring the creation of product innovations or the implementation of products, technologies, services and practices. Other distinctions are whether the innovation is an incremental improvement of something that exists or entirely new.

The structure of the paper is as follows. Section 2 discusses reasons for measuring eco-innovation and aspects to be measured. It discusses the benefits of measuring eco-innovation, eco-innovation categories, and drivers and barriers. Section 3 examines the usefulness of different measures of eco-innovation, offering suggestions for use. Section 4 examines the use of surveys for collecting data on eco-innovation activities, drivers, barriers and effects. It offers a review of existing surveys on eco-innovation and discusses the eco-innovation module of the Community Innovation Survey 2008 of the European Union. Section 4 also offers suggestions for developing future eco-innovation surveys. Section 5 contains conclusions and recommendations.

2. Why measure eco-innovation?

2-1. Benefits of measuring eco-innovation

Measuring eco-innovation helps to evaluate progress within various categories of eco-innovation; to assess which nations are leading; how much progress nations are making to decoupling growth from environmental degradation, and it allows for an analysis of the drivers of eco-innovation and of the economic and environmental consequences. The benefits of measuring eco-innovation can be described as five-fold:

- Helping policy makers to understand, analyze, and benchmark the overall trend of eco-innovation activity (increasing, decreasing, transitions in the nature of eco-innovation such as from end-of-pipe towards cleaner production and increased recycling and reuse); as well as trends in specific product categories (such as wind turbines).
- Helping policy makers to identify drivers and barriers to eco-innovation. This information can inform the design of effective policies and framework conditions such as pollution taxes.
- Raising awareness of eco-innovation among stakeholders and encourage companies to increase eco-innovation efforts based on an analysis of the benefits for companies, sectors and nations.
- Helping society to decouple economic growth from environmental degradation.
- Making consumers aware of differences in the environmental consequences of products and life styles.

It is important to note that thus far eco-innovation has helped to achieve a *relative* decoupling, with emissions levels falling relative to economic growth, but increasing in an absolute sense in almost all nations for many pollutants. What is needed is an *absolute* decoupling. This shows that there is an important issue of scale. One should look not only at reductions achieved at the micro level thanks to the adoption of eco-innovation but also look at economic growth and rebound effects from cost-saving eco-innovation. For instance, savings from reduced consumption of material inputs frees up capital and income for additional consumption of different commodities. The net effect can be no decrease in material use and associated environmental impacts at all.

2-2. Aspects to be measured

This sub-section explains the aspects of eco-innovation that should be measured at the macro level. These aspects are as follows:

- Nature of eco-innovation and scale of use
- Drivers & barriers of eco-innovation
- Effects of eco-innovation

Nature of innovation
Each eco-innovation is unique in some sense. Different attempts have been made to construct a classification system for eco-innovations. Table 1 provides an example from the Measuring Eco-Innovation (MEI) project for the European Commission, which focuses on the purpose of different types of technology. An alternative version developed by the OECD follows the Oslo Manual by dividing eco-innovations into product, process, organizational, marketing and institutional innovation (Machiba, 2008). It also includes *how* firms introduce eco-innovations, for instance through modifying existing technology or creating entirely new solutions (OECD, 2008).

From a wider system point of view, eco-innovations may be categorised as sustaining and disruptive innovations. An example of a sustaining innovation is the catalytic converter, which supported the continued use of the internal combustion engine. An example of a disruptive innovation is the battery electric vehicle (Christensen, 1997).

There exist several classifications of eco-innovation. A synthesis of what exists is needed. One attempt at synthesis is made in the MEI project which created a classification based on the purpose or objective of the innovation. It makes a distinction between environmental technologies, organizational innovations for the environment, product and service innovations that offer environmental benefits, and green system innovation.

Another list is the list of environmental goods prepared by the OECD (see OECD, 2001) based on the following categories:

A. Pollution management
o Air pollution control
o Wastewater management
o Solid waste management
o Remediation and clean-up of soil and water
o Noise and vibration abatement
o Environmental monitoring analysis and assessment

B. Cleaner technologies and products
o Cleaner/resource-efficient technologies and processes
o Cleaner/resource-efficient products

C. Resource management group
o Indoor air pollution control
o Water supply
o Recycled materials
o Renewable energy plant
o Heat/energy saving and management
o Sustainable agriculture and fisheries
o Sustainable forestry
o Natural risk management

o Eco-tourism

Reaching a broad, international agreement on the definition of environmental goods has been found difficult, mainly because many candidate goods have a range of use *besides* environmental protection (Johnstone and Hascic, 2008a, p. 7). More significantly, environmental goods are often designated as such in relation to *a conventional alternative, which may well be included in the very same classification* (an example is spark-ignition international combustion piston engines). It is even entirely possible that the classification may include goods which well be the "dirty substitute" for eco-innovations! These things lead Johnstone and Hascic (2008a) to the important conclusion that **commodity classification cannot be used to develop indicators of eco-innovation.**

Table 1. MEI classification of eco-innovation

A. **Environmental technologies**

- Pollution control technologies including waste water treatment technologies
- Cleaning technologies that treat pollution released into the environment
- Cleaner process technologies: new manufacturing processes that are less polluting and/or more resource efficient than relevant alternatives
- Waste management equipment
- Environmental monitoring and instrumentation
- Green energy technologies
- Water supply
- Noise and vibration control

B. **Organizational innovation** for the environment:

- Pollution prevention schemes
- Environmental management and auditing systems: formal systems of environmental management involving measurement, reporting and responsibilities for dealing with issues of material use, energy, water and waste. Examples are EMAS and ISO 14001.
- Chain management: cooperation between companies so as to close material loops and to avoid environmental damage across the value chain (from cradle to grave)

C. **Product and service innovation** offering environmental benefits:

- New or environmentally improved products (goods) including eco-houses and buildings
- Green financial products (such as eco-lease or climate mortgages)
- Environmental services: solid and hazardous waste management, water and waste water management, environmental consulting, testing and engineering, other testing and analytical services
- Services that are less pollution and resource intensive (car sharing is an example)

D. **Green system innovations:**

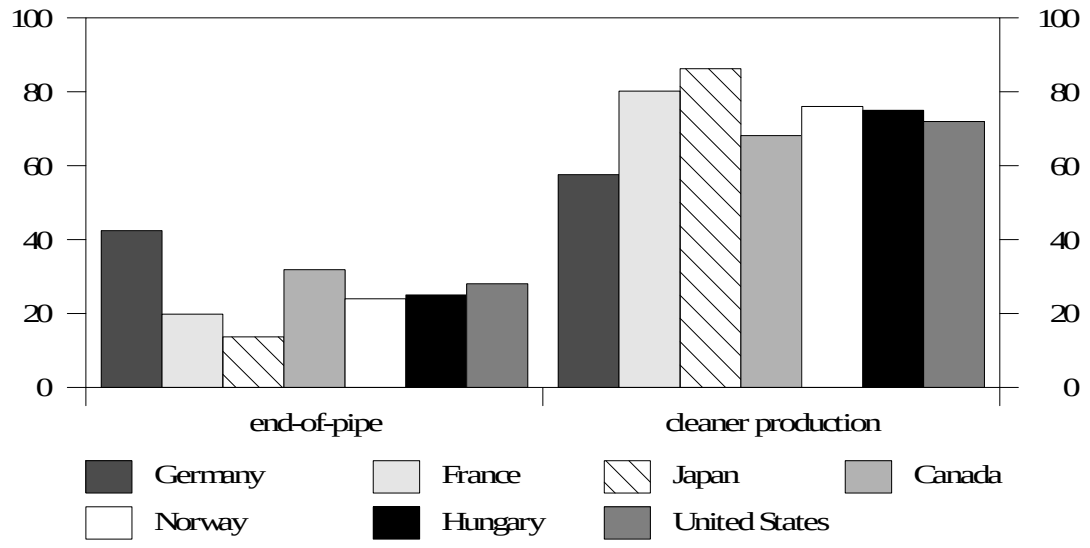
- Alternative systems of production and consumption that are more environmentally benign than existing systems: biological agriculture and a renewables-based energy system are examples

Of these four main categories, green system innovations are the most difficult to measure. They are not about identifiable innovations but about evolving systems involving multiple changes. The other types of innovations can be measured in principle and thus inform policy makers about changes in the nature of eco-innovation, for example whether there is a shift from curative solutions (that treat pollution) to preventive solutions. Cleaner production processes and products are preventive solutions.

Information on investments in pollution abatement and cleaner production technologies is collected in the Pollution Abatement and Control (PAC) survey of the OECD (discussed in 4.3). Such figures may be used to measure eco-innovation but only include expenditure on environmentally *motivated* technologies. The OECD statistics on pollution abatement and control expenditures do not provide information on the proportion of all environmental technology investments that were due to end-of-pipe and cleaner production technologies.

In a special project for the OECD of 3,100 establishments in seven industrialized countries[2], projects to introduce environmental technology were assigned to end of pipe technologies or to cleaner production technologies. The latter accounted for between 57.5% (Germany) and 86.5% (Japan) of the total, as shown in Figure 1. For the seven countries together, more than 75% of the respondents reported that the majority of their projects to adopt environmental technologies were for cleaner production technologies. These results also indicate that end-of-pipe technologies are typically introduced to cope with regulatory compliance, while the implementation of cleaner production technologies is driven by the potential for increasing manufacturing efficiency and reducing costs of operations.

Figure 1: Types of environmental technologies implemented in 3,100 establishments (facilities) in seven OECD countries (In percent)

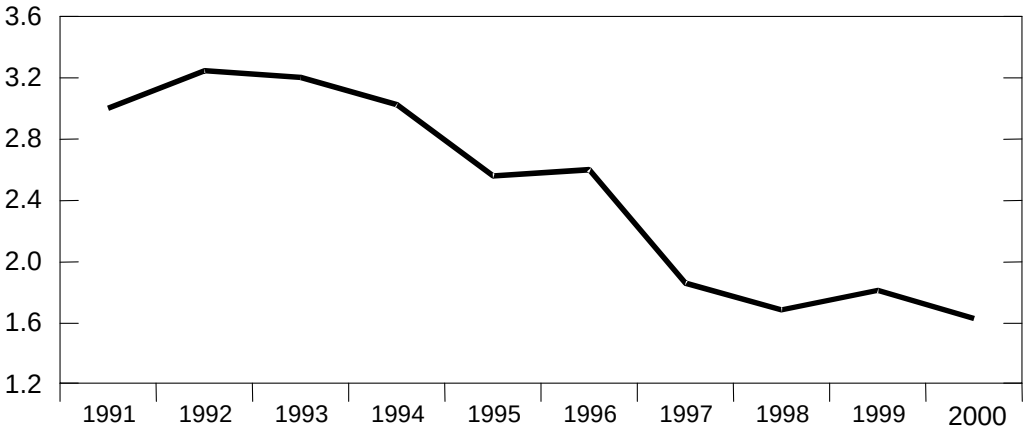


Source: Frondel et al. (2004; 2007)

[2] The seven countries include Canada, France, Germany, Hungary, Japan, Norway and the United States.

Whereas in some countries (such as Germany) investment in end-of-pipe technology has fallen (see Figure 2), in newly industrializing countries (such as China) it can be expected to be growing. Whether the share of cleaner production is also rising in newly industrializing countries, we don't know. There are no statistics on that.

Figure 2: Investments in end-of-pipe technologies in German industry in the1990s (billion Euros)



Source: Becker and Grundmann (2002).

We lack good statistical information about investments and innovation rates for cleaner production, eco-efficiency, the use of lifecycle thinking and eco-design, closed loop production and industrial ecology (see Machiba, 2008 for a discussion of these categories). Statistical offices have only counted investments in end-of-pipe technologies or the extra costs associated with cleaner production. Although international statistical offices such as the OECD and Eurostat agreed to add cleaner production to environmental protection activities, official international statistics on the use of cleaner production technologies are still unavailable. For example, the ECOTEC (2002) report on the employment and export potential of eco-industries within the EU still focuses on end-of-pipe technologies.

We also don't know what part of eco-innovation is environmentally motivated and whether the innovations are incremental or radical. These issues are discussed in Section 3 below.

Drivers

Five drivers for eco-innovation are regulation, demand from users, capturing new markets, cost reduction, and image (Rennings and Zwick, 2003). Determinants for different kinds of eco-innovation have been studied in the IMPRESS project[3], based on 1594 telephone interviews with randomly selected industry and service firms in eight sectors[4]. The interviews were conducted in

[3] IMPRESS stands for the IMpact of Clean PRoduction on Employment in Europe: An Analysis using Surveys and Case Studies. The project was led by ZEW (project leader Klaus Rennings).

4 The NACE Code is a European industry classification system. The IMPRESS survey covered Manufacturing (D), Electricity, Gas and Water (E), Construction (F), Wholesale/Retail-Trade (G), Hotels and Restaurants (H),

2000 in five European countries (Germany, the United Kingdom, Italy, the Netherlands, and Switzerland). Firms active in other sectors such as mining, agriculture or public administration were not been included in the sample. The survey focused on environmental innovation and included questions about the types of environmental innovations that had been introduced in the previous three years, the motivations for doing so, and it asked specific questions about the firm's most important environmental innovation.

The survey found that there are many more important reasons--besides complying with regulations--for introducing an eco-innovation. These are: improving the firm's image, reducing costs, achieving an accreditation, and, for product and service innovations, securing existing markets and increasing market share. Compliance with environmental regulations was more important for pollution control innovations than for the other types of eco-innovation, especially service, distribution, and product innovations. Process innovations and recycling were often introduced in response to the need to comply with regulations, but many of them were also introduced to obtain cost savings (not environment-related) or to improve the environmental image of the firm.

Barriers

ETAP (the European Commission's Environmental Technologies Action Plan)[5] identifies the following barriers to environmental technologies:

- **economic barriers**, ranging from market prices which do not reflect the external costs of products or services (such as health care costs due to urban air pollution) to the higher cost of investments in environmental technologies because of their perceived risk, the size of the initial investment, or the complexity of switching from traditional to environmental technologies;
- **regulations and standards can also act as barriers to innovation** when they are unclear or too detailed, while good legislation can stimulate environmental technologies;
- **insufficient research efforts**, coupled with inappropriate functioning of the research system and weaknesses in information and training;
- **inadequate availability of risk capital** to move from the drawing board to the production line;
- **lack of market demand** from the public sector, as well as from consumers.

A more elaborate list of barriers is offered by Ashford (1993), making a distinction between the following types of barriers:

1. Technological barriers:

- Availability of technology for specific applications.
- Performance capability of technology under certain economic requirements and process design standards.
- Lack of (some) alternative substances to substitute for the hazardous components.

Transport, Storage and Communication (I), Financial Intermediation (J), Real Estate, Renting and Business Activity (K).

[5] COM(2004) 38 final. Communication from the Commission to the Council and the European Parliament. Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union.

- Higher degree of sophistication with operation of some waste reduction technologies.
- Skepticism in performance of certain technologies and therefore a reluctance to invest.
- Process inflexibilities.

2. Financial barriers:

- Research and development costs of technology.
- Costs related to risk of process changes with regard to consumer acceptance and product quality.
- Noncomprehensive cost evaluations and cost-benefit analysis as well as cost calculation method.
- Lack of understanding and difficulty in predicting future liability costs (e.g., of waste disposal).
- Short-term profitability calculations resulting in low tolerance for longer payback periods of equipment investment.
- Alleged drawback in competitiveness as other companies are not investing in waste reduction technologies.
- Lack of capital investment flexibility due to low profit margin.
- Economies of scale preventing smaller companies from investing in waste reduction options (e.g., in-plant recovery technologies).
- Possibilities that investment in process modification can be inefficient for old companies.
- Company financially (and even technically) tied up due to recent investment in wastewater treatment plant.
- Actual cost of current technologies masked in operating costs.

3. Laborforce-related barriers:

- Lack of person(s) in charge of management, control, and implementation of waste reduction technology.
- Reluctance to employ trained engineers for the alleged time-consuming design of waste reduction technologies.
- Inability to manage an additional program within the company and, therefore, reluctance to deal with a waste reduction program.
- Increased management requirements with implementation of waste reduction technologies.

4. Regulatory barriers:

- Disincentives to invest in reuse and recovery technologies due to RCRA permit application requirements for recycling facilities in addition to compliance requirements, application costs, and so forth (work-intensive).
- Depreciation tax laws.
- RCRA waivers available only for hazardous waste treatment technology or process.
- Uncertainty about future environmental regulation.
- Regulatory focus on compliance by use of conventional end-of-pipe treatment technology (may result in investment in those treatment technologies rather than waste reduction technologies).
- Compliance with discharge standards, thus having "EPA off your back" provides no incentive to invest in waste reduction.

5. Consumer-related barriers:

- Tight product specifications (e.g., military purposes).
- Risk of customer loss if output properties change slightly or if product cannot be delivered for a certain period.

6. Supplier-related barriers:

- Lack of supplier support in terms of product advertising, good maintenance service, expertise of process adjustments, and so forth.

7. Managerial barriers:

- Lack of top management commitment.
- Lack of engineering cooperation to break hierarchical separation of areas of responsibility (e.g., production engineers do not cooperate with environmental engineers in charge of the treatment and disposal of hazardous substances).
- Reluctance on principle to initiate change in the company ("Uncle John did it this way; therefore we are doing it the same way!").
- Lack of education, training, and motivation of employees (e.g., in good housekeeping methods or operation and maintenance of recovery technologies).
- Lack of expertise of supervisors.

The barriers are interrelated. For instance a lack of top management commitment might be caused by various factors: (1) lack of information from the financial department to top management concerning the profitability of waste reduction technologies in general; (2) lack of confidence in performance of new technologies; (3) lack of managerial capacity and capital to deal with the transition costs of reorganizing the production process, educational programs, consumer demands, or discharge waivers; (4) lack of awareness of long-term benefits of waste reduction approach, resulting in waste reduction being a low-priority issue (Ashford, 1993).

Effects of eco-innovation

Eco-innovation helps to deal with the tradeoffs between economic growth and environmental protection. The *economic* effects, in terms of the effect of eco-innovation on growth and employment, are not straightforward and likely to vary, depending on the type of innovation and the context in which it is used. Eco-innovation creates jobs and wealth in the producing sector, but if the innovation increases costs for users, jobs in the eco-technology sector may be insufficient to compensate for the loss of jobs elsewhere. Germany has a flourishing solar and wind power industry, thanks to feed-in law establishing high prices for green electricity fed into the grid, but as a result, German consumers and industry pay more for electricity than they otherwise would. The higher electricity costs could hamper the competitiveness of other sectors that are intensive users of electricity.

The IMPRESS study analysed the economic effects of the *most important environmental innovation* introduced by the company in the last 3 years. In addition to asking about the effects, the survey asked about the nature of eco-innovation (using a list of seven categories), the year of introduction, who developed the innovation (the establishment itself, other firms, or through a cooperative effort), the investment costs, whether they had received financial support from government, the percentage of total innovation expenditures spent on this innovation, and motivations for the innovation.

The IMPRESS survey also asked about the effect of the innovation on sales, prices and costs for energy, materials, waste disposal and labour. The questions used the following format:

Did this innovation directly increase or decrease **total** unit **sales**?

Increase sales ☐
Decrease sales ☐
No effect ☐
Don't Know ☐

Would you estimate the percentage [increase/decrease] in sales:
Less than 5% ☐
5% to 25% ☐
Over 25% ☐
Don't know ☐

The survey also inquired into *indirect* effects, such as whether it replaced a previous production process or end-of-pipe pollution control equipment, if it required a major reorganization of the production system, and if it replaced sales (if so by what percentage).

The analysis identified both positive and negative economic effects, but the number of companies experiencing positive employment effects and positive economic effects was higher than the number of companies experiencing negative effects.

Being innovative is not a predictor for success. For assessing future competitiveness, innovation expenditures and relative patent advantages (RPA) may be used, but neither of these is a reliable predictor because future competitiveness also depends on institutions, infrastructure, education, the macro economy, regulation and education. The quality of these can be measured through the Global Competitiveness Index, the Business Competitiveness Index) and the Competitiveness Scoreboard,[6] provided special attention is given to things that are especially important for eco-innovation.

Whereas companies are mostly interested in micro-effects, policy makers are interested in meso (sector) and macro (national) effects. Meso effects can be estimated by aggregating micro-

[6] The Global Competitiveness Index (CGI) measures the competitiveness of nations. The rankings are calculated from both publicly available data and the Executive Opinion Survey, a comprehensive annual survey conducted by the World Economic Forum together with its network of Partner Institutes. The measure of realised innovation is international patenting registration. The Business Competitiveness Index (BCI) was developed by Michael Porter. It ranks countries by their microeconomic competitiveness, identifies competitive strengths and weaknesses in terms of countries' business environment conditions and company operations and strategies, and provides an assessment of the sustainability of countries' current levels of prosperity. It is stated that the BCI explains more than 80 percent of the variation of GDP per capita across the wide sample of countries covered, a confirmation of the critical importance of microeconomic factors for prosperity. This shows that the BCI complements the GCI in an important way. The World Competitiveness Scoreboard (CS) presents the overall ranking for the 55 countries covered by the World Competitiveness Yearbook. The economies are ranked from the most to the least competitive and performance can be analyzed on the basis of time-series. The basic assumption is that wealth creation takes place at enterprise level (whether private or state-owned) but that enterprises operate in a national environment which enhances or hinders their ability to compete domestically or internationally. The WCY divides the national environment into four main factors: Economic Performance; Government Efficiency; Business Efficiency; infrastructure. Each of these factors is divided into 5 sub-factors which highlight every facet of the areas analyzed. Altogether, the WCY features 20 such sub-factors, which comprise more than 300 criteria (MEI final report. 2008, pp. 88-93)

effects. The **links between micro and macro effects are complex** with many cross-sectoral effects and feedback loops:

- Cost-saving eco-innovations generate wealth that will be spent on goods and services that can have negative environmental impacts, creating second order environmental burdens.
- Cost-increasing eco-innovations are likely to contribute more to an absolute decoupling but at the expense of lower economic growth.
- Many normal innovations are de facto eco-innovations (by being more environmentally benign than relevant alternatives), but overall environmental gains will be impaired by economic growth produced by those innovations.
- To assess the impacts of eco-innovation one should look at what happens within and across value chains from resource extraction to waste management.
- Micro-behaviour is affected by macro-factors (taxes, regulations, etc.)

3. How to measure eco-innovation

This section evaluates how the *process* of eco-innovation can be measured and gives examples for each methodology. Eco-innovation can be analysed using the following four categories[7]:

- **Input measures**: Research and development (R&D) expenditures, R&D personnel, and innovation expenditures (including investment in intangibles such as design expenditures and software and marketing costs);
- **Intermediate output measures**: the number of patents; numbers and types of scientific publications, etc;
- **Direct output measures**: the number of innovations, descriptions of individual innovations, data on sales of new products, etc;
- **Indirect impact measures** derived from aggregate data: changes in resource efficiency and productivity using decomposition analysis.

There are two ways of obtaining data: using existing sources of statistics and conducting specially designed surveys. This section reviews the methodologies for using existing statistics, while the next section reviews the survey methodologies.

3-1. Input measures

R&D statistics are widely used in innovation research, although they have a few limitations. They tend to capture formal R&D, typically within formal R&D laboratories, and underestimate R&D conducted by smaller firms, which is often done on a more informal basis (Kleinknecht et al, 2002). Also R&D cannot cover non-technological innovation such as marketing, organisational and institutional innovations and cannot capture the efforts of service sectors

Data for environmental R&D are extremely limited in scope. The only consistent data across OECD countries is for government budget appropriations or outlays allocated to R&D (GBAORD) in “control and care for the environment”. These refer to budget provisions instead of to actual expenditure. The data include both current and capital expenditure and cover not

[7] The first three categories are from Acs and Audretsch (1993, p.10).

only government-financed R&D performed in government establishments, but also government-financed R&D in the business enterprise, private nonprofit and higher education sectors, as well as abroad.[8] It will be interesting to analyse to what extent they correlate with private environmental R&D.

In reference to the private sector, environmental R&D can be defined in two ways: the part of R&D that is environmentally motivated and the part that is environmentally relevant in reducing environmental burden either in the company or elsewhere (at the point of use). Both types of statistics are of value, but create problems of interpretation. The OECD project, Environmental Policy and Firm-Level Management, asked what part of the R&D budget was for environmental conservation (Johnstone, 2007).

Overall, 9.3 per cent of facilities in the OECD study reported investments in environmentally related R&D.[9] Of the seven countries in the study, Norway had the highest percentage of facilities that performed environmental R&D (just under 15%) and Germany the lowest (3.6%). The probability of performing environmental R&D increased with the size of the facility and varied by sector. The sectors with the highest percentage of facilities reporting environment-related R&D budgets were recycling (25%); petroleum, coke and other fuel products (14%); chemicals and chemical products (13%); motor vehicles (12%); electrical machinery (12%); rubber and plastics (11%); metal products (10%) and non-metallic mineral products (10%).

The survey also elicited information on R&D expenditures used for environmental purposes. In Japan, environment-related R&D expenditures accounted for 16.6% of total R&D in the manufacturing sector. The researchers compared the figure with the results from the survey on Research and Development in Japan and found that the OECD figures were biased upwards: 16.6% versus 3.4% (Arimura et al., 2007). This shows the importance of comparing the results of one's survey with the results of other surveys.

To be more meaningful for research and possibly also to companies (for whom the term environment may be too general), the term environment has to be broken down into meaningful categories such as waste reduction, reductions in resource use, pollution prevention and control and so on. To our knowledge, this has not been done to date. Company research efforts on toxic air emissions have been studied in the survey by Scott (2003), which is the only study that goes into the specifics of environmental R&D through the use of questions such as:

- *Is your company conducting research on any toxic air emissions?*
- *Approximately what part of your company's total R&D efforts for environmental projects is for research on toxic air emissions?*
- *Approximately what part of your company's total R&D efforts for all projects, not just environmental ones is for research on toxic air emissions?*
- *Is your company conducting R&D to develop new processes lessening toxic air emissions (yes/no)*

[8] See http://www.estatisticas.gpeari.mctes.pt/archive/doc/Government_budget_appropriations_or_outlays_on_R_D_0.pdf

[9] It is unclear what question is used for environmental R&D.

- *Is your company conducting R&D to develop new products lessening toxic air emissions (yes/no)*
- *Is your company's R&D on new products to lessen toxic air emissions for*
  - ✧ *Products produced with cleaner process technology*
  - ✧ *Products that will have lower toxic air emissions when used*
  - ✧ *Process technology embodied in a producers good to be sold*

One might ask additional questions on the use of eco-design, environmental chain management and the attention given (or research efforts made) to the reduction of greenhouse gas emissions, energy efficiency, resource use, material substitution, and waste reduction.

3-2. Intermediate output measures

These consist of patents and scientific publication and citations. Patents are the most commonly used data to construct intermediate indicators (Dodgson and Hinze, 2000, p. 103) for *inventions*. A patent is an exclusive right to exploit (make, use, sell, or import) an invention over a limited period of time (20 years from filing) within the country where the application is made. Patents are granted for inventions which are novel, inventive, and have an industrial application (OECD 2004, p.8), but patents do not need to be commercially applied. Consequently, they are not direct measures of innovations. Furthermore, the standard of novelty and utility for granting a patent is not very high. The European Patent Office (EPO) grants about 70% of patent applications while the US PTO grants about 80% of patent applications.

Patents have several advantages over R&D expenditures: (*i*) they explicitly give an indication of inventive output, (*ii*) they can be disaggregated by technology group, and (*iii*) they combine detail and coverage of technologies (Lanjouw et al., 1998). Moreover, they are based on an objective and slowly changing standard because they are granted on the basis of novelty and utility (Griliches 1990).

Patent counts can be used as an indicator of the level of innovative activity in the environmental domain. In the same way as for innovation in general, patents covering *eco-inventions* can be used to measure research and inventive activities and to study the direction of research in a given technological field. Whether something is an eco-innovation depends on the environmental effects. To be picked up as an eco-patent, the environmental gain must be described or there must be pre-existing data on the environmental benefits of a patent class. Otherwise, environmental inventions with non-intentional side effects will not be identified in patent analysis.

An important new development is the EPO/OECD PATSTAT database, a new database, containing 60 million patent applications from over 80 national and regional patent offices, going back as far as the 1880s in some cases (Johnstone and Hascic, 2008a, p. 8). In this database not only inventions in end-of-pipe technologies but also inventions in "more integrated technological innovations" (such as fuel cells for motor vehicles) may be identified according to Johnstone and Hascic (2008a, p. 8).

With the new database, possibilities for measurement are increased. Yet, there are a number of additional limitations of patents that need to be taken into account. First, patents measure

inventive activity, not real innovation. Second, not all eco-innovations can be usefully analysed through patent analysis. Eco-patents mainly measure identifiable inventions that underlie green *product* innovations and *end of pipe technologies*, whose environmental impacts are specific aims and motivations of the inventions. For these kinds of eco-inventions and the innovations that result from them it is acceptable to use patent analysis, provided they are carefully screened (for which one may use the four-step method described below). Citation analysis helps to select relevant patents and eliminate patents that have no commercial application. For other types of innovation, such as organizational innovation and process changes, patent analysis is less useful because many of these innovations are not patented. Third, patent classification systems do not provide specific categories for environmental patents and there is also no widely accepted agreement in the literature as to what constitutes an environmental technology. The practical solution around this problem is to use relevant search terms. Words such as "environmental" or "environment" are not helpful because they may be overly broad or may refer to non-ecological aspects.

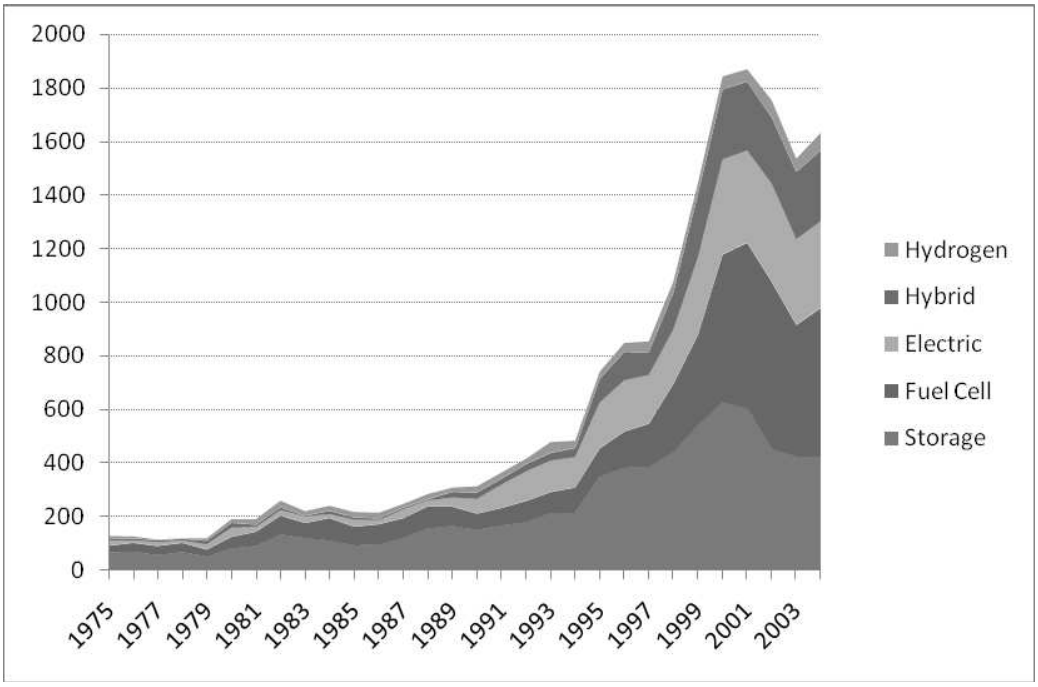
For patent analysis the MEI project proposed the following four-step method[10]:

- Step 1: Choice of relevant parameters (could be the pollutant under consideration, for example, SO_2, or an environmental technology, such as wind power).
- Step 2. Patent search using keywords – based upon relevant environmental technology aspects – in order to generate a set of *potentially* relevant patents
- Step 3. Screening of the abstracts of the patents generated in order to determine whether it indeed was a relevant patent. Irrelevant patents are excluded.
- Step 4. Retrieval of patent families. These are the patent applications the inventor filed in countries other than the home country. This helps to exclude patents of minor importance.

The OECD has been very active in the creation of "innovation" statistics based on patent analysis. IPC classes have been identified for selected eco-technologies: alternative vehicle propulsion, climate change mitigation technologies and a long range of environmental technologies. Whereas past research focused on pollution control technologies, recent research focuses on renewable energy technology and alternatively fuelled vehicle technologies. Figure 3 gives the results for AFV. They are based on claimed priorities worldwide, avoiding double counts and representing quality patents (poor patents are unlikely to filed worldwide).

[10] The 4 step method was developed by de Vries and Withagen (2005).

Figure 3. Development of Inventions with Respect to AFVs
(Claimed Priorities World-wide, 1975-2003)



Source: Johnstone and Hascic (2008a, p. 11)

A deeper analysis revealed that new car manufacturer countries (Korea and China) and specializing in relatively more frontier inventions than some of the traditional car manufacturing countries (including Italy, Germany and Japan) (Johnstone and Hascic (2008a, p. 12).[11]

Patent analyses can also be used for measuring technology transfer. Possibilities for this have been investigated by Johnstone and Hascic (2008b), preparing the ground for future work on "economic globalisation and environmental innovation within the 2009-2010 Programme of Work of the OECD Working Party on National Environmental Policies. The idea of using ***patent data*** to measure international technology transfers arises from the fact that there will be a partial "trace" of the 3 identified channels of technology transfer (trade, foreign direct investment and licensing) in patent applications (Johnstone and Hascic, 2008b, p. 5). It is proposed to use "duplicate patents" (obtained in several countries) as a measure for technology transfer. A positive correlation is found between duplicate patents and export for wind power technologies (Johnstone and Hascic, 2008a, p. 6).

Similar methods can be applied to the scientific publications of firms. These can signal scientific competence and/or interest in getting involved in scientific communication in the specific area. Direct collaboration between scientific and industrial institutions can be measured by co-publication of either publications or patents (Dodgson and Hinze, 2000, pp. 103-104).

The value distribution of patents is highly skewed. A few patents are commercially valuable whereas the majority have little value. Hence the usefulness of simple patent counts is limited, as

[11] Whether these countries are also actually commercializing these inventions remains to be analysed.

they give equal weight to patents of very different values. Different methodologies can be used to evaluate the value of patents. For example, one can ask patent owners about past returns and the potential market value of their rights, look at the renewal of patents, or use number of citations as a proxy for commercial value. Here the development of the OECD Triadic Patent Family database is of great interest since it provides a database of "high quality" inventions. The use of *patent families* - i.e. filings of the same patent application (which share the same priority date) in different countries – enables the researcher to focus on the most valuable innovations. Indeed, because of the added costs of filing abroad, the less valuable patents are usually filed only in the inventor's home country.

The use of patent data for research questions also poses methodological issues. How does one allocate patent data organized by firms or by substantive patent classes into economically relevant industry or product groupings? The OECD Technology Concordance (OTC) presented in Johnstone (2002) may be used to transform IPC-based patent data into patent counts by sector of the economy, but this does not work well for patents used in multiple sectors. With the firm identifiers from PATSTAT there is no need for sectoral concordance (information from Nick Johnstone).

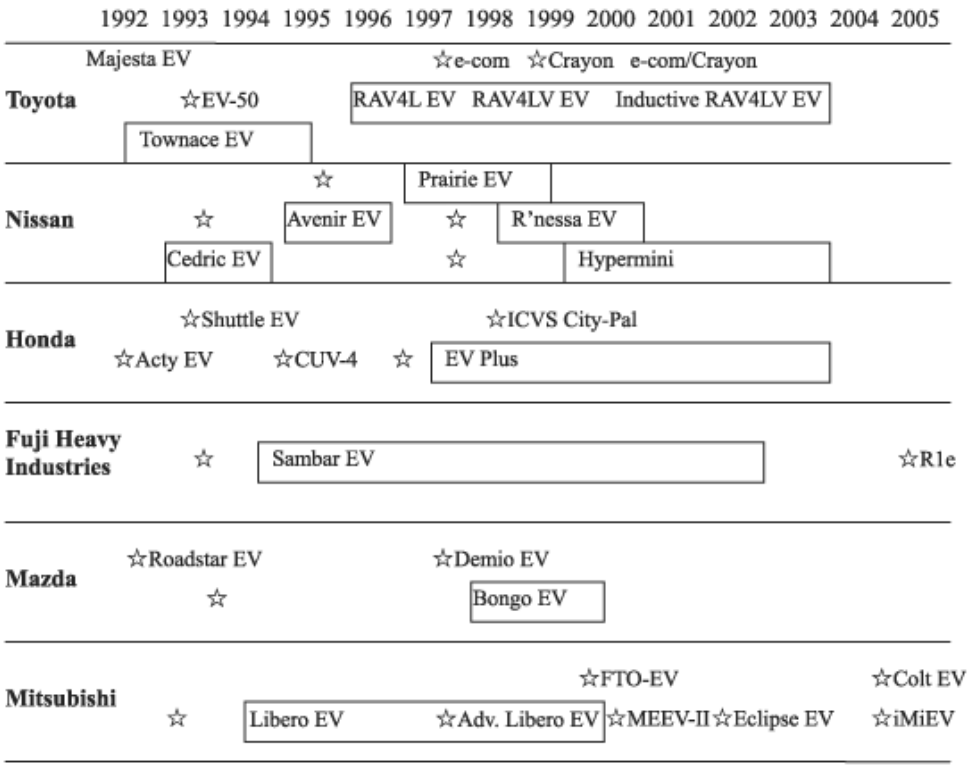
3-3. Direct output measures

A direct output measure of eco-innovation can be obtained from announcements in trade journals[12] and product information databases. An example is the green car database established by Yahoo.

Figure 4 shows the chronological development and commercialization of electric vehicles by the major auto companies, using industry announcements. The results indicate that commercial production almost stopped in the early 2000s. Recently, however, major auto makers have announced that they plan to develop and commercialize plug-in electric vehicles, including hybrids that can use electricity stored at home.

[12] A trade journal or trade magazine is a periodical, magazine or publication printed with the intention of target marketing to a specific industry or type of trade/business. Trade refers to business, not to exports and imports.

Figure 4. Development and commercialization of electric vehicles by major Japanese auto makers



Source: Yarime et al (2008) based on data from Center for Electric Vehicles (2006b) http://www.idrc.ca/en/ev-132155-201-1-DO_TOPIC.html#Ch10Fig2

A real problem is that there are few product databases with environmental information. For specific products, a database of eco-innovation output could be created by sampling the 'new product announcement' sections of technical and trade journals or by examining product information provided by producers. The strengths of the product announcement sampling method are that: [13]

- They measure *actual* innovations introduced in the market place
- The indicator is timely: announcements times are close to the date of commercialization.
- The data are relatively cheap to collect and do not require direct contact with the innovative firms. Students can collect the data without bothering firms with time-consuming questionnaires.
- From the description, it is possible to infer information about the innovation, for instance whether it is a radical innovation, and what the performance characteristics are.

Some limitations are[14]:

- Adequate journal selection is a necessary precondition in order to ensure comprehensive coverage.

[13] Based on Coombs et al. (1996) and Kleinknecht (1993).
[14] Based on Coombs et al. (1996) and Kleinknecht (1993).

- In-house process innovations are rarely reflected in the technical and trade journals. Direct innovation surveys probably provide superior indicators for environmental process innovations.
- Although literature-based innovations can be objectively counted, they can only be subjectively valued in importance.

Information from trade journals can be available digitally. Digital information about products can also be available from the internet – allowing researchers to track the evolution of performance characteristics for selected products. Digital new announcement and consumer information databases are a neglected source of innovation output indicators, which should be used more often. Such research is aided by product disclosure requirements in the EU, where manufacturers have to provide information to consumers on various environmentally relevant aspects such as the kind of materials used and energy efficiency. This information is printed on special product labels which can be analysed.

3-4. Indirect impact measures

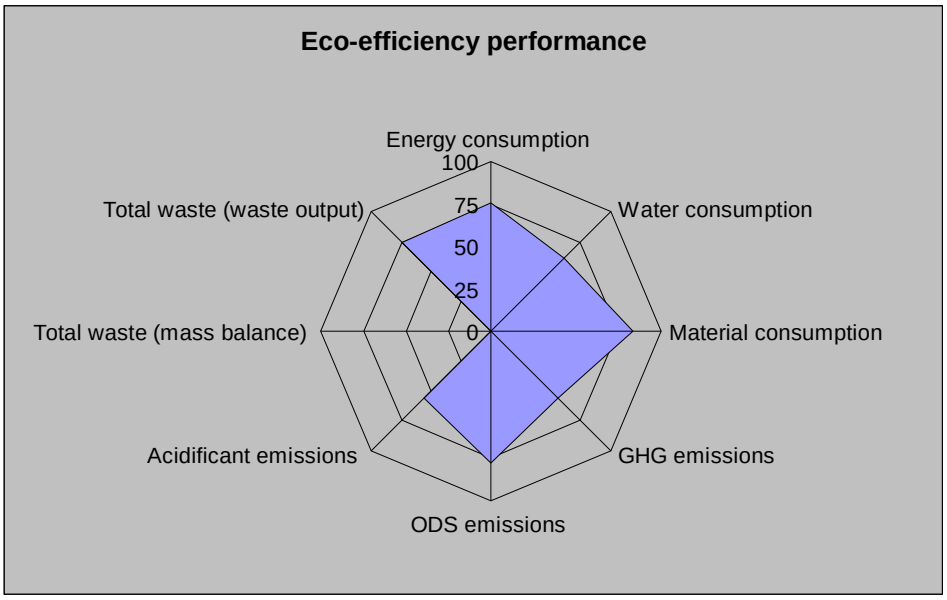
Eco-innovation can be indirectly measured on the basis of eco-efficiency performance data or data about changes in absolute impact. Eco-efficiency is a broad concept that is usually measured at the product or service level. Eco-efficiency means *less environmental impact per unit of product or service value* (WBCSD, 2000).

$$\textit{Eco-efficiency} = \frac{\textit{product or service value}}{\textit{environmental impact}}$$

An improvement in the ratio of value added and emissions is indicative for eco-innovation. Such ratios can be determined for company processes, company products, sectors and for nations.

The MEI project developed and pilot tested a benchmark indicator for eco-innovation on the basis of company environmental performance and innovation data. The indicator is based on company information about innovation and environmental performance obtained from a survey. Seven indicators are plotted in a polygon, as shown in Figure 5. The bigger the polygon area, the better the eco-efficiency performance.

Figure 5. MEI example of eco-efficiency performance benchmarking



Source: Final report MEI (2008, p. 65)

A challenge for benchmarking is to cover environmental aspects over the entire value chain. This requires combining data from different companies. Data from single companies have to be broken down for functional units (a product or production process) to be meaningful.

The following are relevant components of eco-efficiency:

- Quantity of product produced or sold, net sales or value added as output indictors
- Energy consumption, from renewable sources and non-renewables
- Water consumption.
- Greenhouse gas (GHG) emissions: these include carbon dioxide (CO2), methane (CH4), nitrous oxide (N20), hydro- and perfluorocarbons (HFCs, PFCs)
- Other emissions to air: nitrogen oxides, sulphur dioxide etc
- Total waste, broken down in toxic and non-toxic waste.

Eco-efficiency can also be studied at the **sector** level and **national** level, using data for value added and emissions from national environmental accounting.

Innovation indicator research could assist in explaining changes in eco-efficiency, whilst accepting that there is no simple causal relation between innovation and eco-efficiency, as changes in eco-efficiency reflect sectoral changes and non-innovative price-based substitution. Instead of focusing on eco-efficiency one can also focus on resource productivity or on ecological footprints (see Moll and Gee, 1999; Machiba, 2008).

3-5. Overall evaluation

Although some methods are better than others, no single method or indicator is an ideal measure of eco-innovation. To understand overall patterns of eco-innovation and the drivers for those patterns, it is important to view different indicators together, possibly by mapping data, listing headline indicators or developing a composite index.

In particular, more effort should be devoted towards *direct* measurement of innovation output using documentary and digital sources. The advantage is that they measure innovation *output* rather than innovation *inputs* (such as R&D expenditures) or an intermediary output measure (such as patent grants). Innovation can also be measured *indirectly* from changes in resource efficiency and productivity. These two avenues are underexplored and should be given more attention to augment the rather narrow knowledge basis.

Methods for innovation measurement should be combined. Concrete suggestions for combining measures and methods are:

- Contact a sample of inventors and ask questions about the patents, for example to what extent they are spurred by specific regulations, environmental concerns, economic gains for the inventor, etc.
- Compare patent patterns with R&D patterns and data about innovation output collected through documentary and digital source analysis. This would help assess the value of patent analysis and obtain more robust research findings based on multiple data sources.
- Combine meso and macro information on eco-efficiency with micro data from companies about organizational and technological eco-innovation to better understand the links between micro and macro measures.
- Combine information on general innovation investments with information on eco-innovation and environmental performance.

Marrying different databases allows for better analysis. For example, “by marrying assignees in PATSTAT to the firm identifiers in ORBIS [a date set with company information], it will be possible to assess the links between eco-innovation and profitability, employment, etc.” (Johnstone and Hascic, 2008a, p. 32).
This work will serve as a contribution to the Environment Directorate’s work on the environment and competitiveness (Johnstone and Hascic, 2008a, p. 32).

For understanding eco-innovation there is a need to go beyond the use of existing statistics, because their scope is limited and because they are not specially set up for the purpose of measuring eco-innovation, which is not an official statistical category in patent analysis, in R&D statistics or in trade journals. New dedicated surveys can help to collect data on the nature of eco-innovation, its drivers and micro-effects. When this is done internationally on the basis of the same questions, we are creating a new and special knowledge base for research and policy, allowing us to check the robustness of analyses based on existing data, and allowing us to do a much better analysis on for example the drivers and micro-effects from (different) eco-innovations.

4. Use of surveys

Surveys on the eco-innovation activities of firms can obtain information on investment in different types of eco-innovation, on the drivers, and on the effects, permitting econometric analysis of the effect of different drivers on outcomes. Survey results at the level of the enterprise or establishment can also be aggregated to provide regional or national statistics. This section reviews the different approaches taken by surveys of eco-innovation and evaluates their strengths and weaknesses. It also discusses the types of surveys questions that could be introduced in the future.

Currently, due to limitations with R&D, patent, and other data sources, surveys are possibly the best method for monitoring eco-innovation and evaluating drivers and outcomes. Unfortunately, most national innovation surveys based on the Oslo Manual have offered few insights into eco-innovation. The next CIS, covering innovation activities between 2006 and 2008 inclusive, will partly overcome this problem, as it includes an optional one-page set of questions on environmental innovation.

4-1. Review of existing surveys on eco-innovation

Surveys of environmental innovation can be used to collect interval, ordinal and nominal data. A question using an interval scale is: how much did your firm invest in environmental R&D? An ordinal version would provide response categories, such as under 100,000 dollars, 101,000 to 250,000 dollars, over 250,000 dollars etc. A binary version would be: did your firm conduct environmental R&D? (yes or no). For questions that can be asked on an interval scale, there is a tradeoff between precision and the ability of respondents to answer the question accurately. In many cases, ordinal or nominal questions can provide higher quality results.

Some survey questions can involve a highly subjective element but nonetheless be important to ask. For example, the 'strictness' of environmental regulation is very difficult to determine on the basis of objective data as there are many different parameters. Emission requirements can also differ by production process and enforcement may be uneven. Instead of using objective emission data, one can use subjective information from respondents about the strictness of regulations, using an ordinal importance scale. Ideally, when proxies are poor, one should multiple indicators to obtain robust results.

There are two basic sources of survey indicators.[15] The first source consists of official, large-scale innovation surveys that sample thousands of firms and which are performed on a regular basis. The second source consists of smaller 'one-off' surveys by academics or government agencies. These usually focus on a limited region or set of sectors.

Large-scale national innovation surveys in Europe, Canada, Australia, New Zealand, Korea and Japan include a few questions of relevance to environmental innovation. For example, the 2006 Community Innovation Survey in Europe asks about the importance of the 'effects of your product and process innovations' to 'reduce materials and energy per unit output' and to 'reduce environmental impacts or improve health and safety'. Unlike the PACE data (and many patent analyses), these questions provide information on the prevalence of innovation with environmental

[15] Part of this section draws on Arundel et al. (2006).

benefits without limiting the results to intentional environmental innovation. Furthermore, the information on environmental innovation can be linked to other firm-level innovation strategies and characteristics. The main disadvantage of these surveys is that, so far, they have only collected data on a reduction in material and energy use and 'reduced environmental impacts' in general. What is worse is that the last question is combined with a possibly unrelated effect on health or safety.

Several smaller surveys, summarized in Table 2, have gone into environmental innovation in far greater depth.[16] Most of these surveys have not queried firms about their own in-house innovative activities, but are included because they covered the adoption of environmental technology (pollution control technologies or cleaner processes). For each survey, Table 2 describes the target population of firms, the number of responses and the response rate, and the types of questions asked in each survey. For example, Table 2 notes if the survey included questions about the type of innovation (management system, adoption of technology, or technology developed in house), the motivations or drivers for eco-innovation, the economic effects of eco-innovation, and the source of knowledge or barriers to eco-innovating. As shown in Column 3, many specialized environmental surveys suffer from low response rates and cannot match the response rates of official innovation surveys. Low response rates reduce confidence in the accuracy of prevalence rates (for example the percentage of firms that report cost offsets). One option to address this problem is to conduct a non-response analysis to determine if the non-respondents differ in any significant way from the respondent firms. To date, this technique has rarely been used in environmental innovation surveys.

Of the surveys in Table 2, four focus specifically on environmental innovation (Green et al., 1994; Lefebvre et al., 2003; Rennings and Zwick, 2003; Johnstone, 2007), while the fifth covers biotechnology but asks a large number of questions on environmental innovation (Arundel and Rose, 1999). These are the only five studies that differentiate between innovation as a creative and adoptive process. The first survey to make this distinction was the 1993 survey by Green et al. (1994), which was sent to a sample of 800 firms that had expressed an interest in the UK Department of Trade and Industry's Environmental Technology Innovation Scheme (ETIS).

Most of these small surveys focus on the motivation and drivers for environmental innovation, followed by economic impacts on costs, employment, or skills. All three studies on employment and skills (Pfeiffer and Rennings, 2001; Getzner, 2002; Rennings and Zwick 2003) are from Europe. None of these three studies obtain interval level data on employment effects (such as percentage changes in job gains or losses) because respondents can rarely provide accurate estimates. Instead, the survey questions obtain either categorical data (employment increased or decreased with percentage categories such as between 10% and 25%) or nominal level data (employment increased or decreased, yes or no). As an example, Pfeiffer and Rennings (2001) report that between 84 per cent and 91 per cent of German firms (depending on the type of environmental innovation) found that the innovation had no effect on employment, while less than 5 per cent reported a decrease in employment.

[16] Three very small surveys are excluded from Table 1 (Williams et al. 1993; Garrod and Chadwick 1995; Pimenova and van der Vorst (2004). Doyle (1992) only surveys environmental equipment manufacturers and is of less interest here.

Knowledge sourcing and impediments to environmental innovation have received the least attention in environmental innovation surveys. One exception is the survey by Andrews et al. (2002), which asked if firms shared their own knowledge and experience of cleaner production with other firms and with industry associations. This is a valuable area for future research if combined with data on licensing behaviour, because the policy goal of encouraging knowledge sourcing could conflict with a strategic interest for the firm to keep cleaner production methods secret.

The Statistics Canada survey (Arundel and Rose 1999) of biotechnology applications is the only study to cover all four policy areas. The respondents were asked if their firm currently used or planned to use one of five carefully defined environmental biotechnologies. Users of one or more of these technologies were then asked a series of questions on investment, their motivations for adopting the technology, difficulties with implementation, results from their use, and the principal internal and external sources of information to assist the adoption of environmental biotechnologies (Arundel and Rose 1999).

The two biggest special surveys on eco-innovation are IMPRESS and the OECD survey on Environmental Policy and Firm-level Management. IMPRESS is a European survey covering 1594 establishments in manufacturing and service sectors in 5 European countries (the UK, Germany, Switzerland, The Netherlands, and Italy). The OECD survey surveyed the link between government environmental policies and environmental management, investments, innovation and performance in private firms in manufacturing sectors in 7 OECD countries (Japan, France, Germany, Hungary, Norway, Canada, and the United States) (Johnstone, 2007, p. 2). The study is "particularly rich with respect to the characterization of the public environmental policy framework", using measures such as perceived stringency of the policy framework, number of inspections of the last 3 years, and the reported presence of targeted measures to encourage the use of environmental management systems or tools (Johnstone, 2007). It is one of the few studies to look into the aspect of environmental R&D, for which the following questions are used:

Does your facility have a budget for **research and development** specifically related to **environmental matters**?

Yes
No

If yes, what percentage of your total budget for research and development has been allocated to environmental matters in the last three years? _____[17]

Of the approximately 400 facilities reporting that they had a budget, there were 275 answers to the quantitative question (Johnstone, 2007, p. 25).

An interesting avenue for future research on environmental innovation is to develop panel surveys that gather information from the same firms over time. An example is the Mannheim innovation panel of ZEW[18], which includes more than 1800 German-based firms with at least some new product development activities. It is a biannual survey that provides important information about

[17] http://www.oecd.org/dataoecd/36/15/37265779.pdf

[18] ZEW (Zentrum für Europäische Wirtschaftsforschung (Center for European Economic Research). The survey is conducted in cooperation with INFAS (Institute of Applied Social Science).

the introduction of new products, services and processes, the expenditures for innovations and how the economic success achieved with new products, new services and improved processes. In addition, the survey gives information about the factors which promote and also hinder innovation activities of enterprises. The innovation survey covers the areas of mining, manufacturing, energy, construction, producer services and distributive services in Germany.

The results of such surveys would permit sophisticated analysis of the effect of motivations and management systems on different types of environmental innovation.

Table 2. Environmental innovation surveys

Reference	Target firms	Responses (response rate)	Type of innovation	Motivations & drivers	Economic effects	Knowledge sourcing / impediments
Steger, 1993	German manuf. & service firms	592 (not given)	A	✓	C	
Green et al, 1994	UK firms interested in Government support programmes	169 (21%)	A, CR	✓		
Arundel & Rose, 1999	Canadian firms in sectors with potential biotechnology applications	2,010 (86%)	A, CR	✓	C	K, I
Blum et al, 2001	German & UK pharmaceutical firms	32 (21%)	M	✓		I
Pfeiffer & Rennings, 2001	German manufacturing firms	400 (45%)	A	✓	E, S	
Getzner, 2002	EMAS/ISO firms in Austria, Germany, Netherlands, Spain, Sweden	407 (16%)	A	✓	E, S	
Andrews et al, 2002	SMEs in Australia	145 (29%)	M, A		C	K
Lefebvre et al, 2003	SMEs in four industries in Canada	368 (quota sampling)	M, A, CR	✓		
Rennings & Zwick, 2003	Manuf. & service firms in the UK, Germany, Switz., Netherlands, Italy	1,594 (not given for all countries)	A, CR	✓	C, E, S	
Scott, 2003	Manuf. firms in the US	132 (16%)	RD	✓		K
Zutshi & Sohal, 2004	ISO 14001 firms in Australia and New Zealand	143 (46%)	M	✓		
Johnstone 2007	Companies in all manufacturing sectors with more than 50 employees	4200 (25%)	M,A, CR, RD	✓	C	K, I

1. Type: M = **management systems**, A = **technology adoption**, CR = **technology creation** (innovation developed in firm RD: Environmental R&D; Economic effects: C = **costs**, E = **employment**, S = **skills**; ✓ = **motivations/drivers examined**. Knowledge sourcing/impediments: K = **knowledge sourcing**, I = **impediments to adoption**.

Source: Arundel, Kemp and Parto (2006) in Handbook of Environmental Technology and Management, updated with reference for Johnstone (2007)

4-2. CIS 2008 Eco-innovation module

Figure 6 gives the eco-innovation module developed for CIS 2008, developed in collaboration between the CIS Task Force of Eurostat, DG Environment, several academics in the MEI project, and UNU-MERIT.

Question 10.1 asks respondents if they have introduced an innovation with one or more environmental benefits. Six types of environmental benefits occur during the use of the innovation by the enterprise and three types of benefits can occur during the use of the innovation by the end user. This is an important distinction because environmental benefits can occur within the enterprise itself, such as through reduced pollution or from material savings etc., or the benefits could be obtained through its use by the end user, in many cases a final consumer. For instance, the environmental benefits of low energy consumer appliances are obtained during their use by the consumer. The introduction to the question also specifies that an environmental innovation can be introduced intentionally, in order to reduce environmental impacts, or the environmental benefits can be side effect of other innovation goals.

Question 10.2 asks about different drivers, including current regulations, expected regulations, grants or other financial incentives, expected demand, and voluntary codes of practice. Question 10.3 asks if the enterprise has procedures to identify its environmental impacts.

All questions are asked on a simple 'yes or no' basis, with no measure, for instance, of the importance of specific drivers in question 10.2. The simple format of the questions resulted from two rounds of cognitive testing with the managers of 20 enterprises, representing small, medium and large firms in eight EU countries and six sectors, including service sectors (Arundel et al, 2008). The first round of cognitive testing led to major changes in both questions 10.1 and 10.2 to ensure that the questions were correctly understood and answerable. In particular, alternative versions of question 10.2 that asked for more detailed information on different types of government incentives for eco-innovation were not understood by the respondents. An earlier version of question 10.1 asked if the enterprise had obtained each type of environmental benefit, and if yes, if this was an objective of the innovation. This question also failed in cognitive testing. These results highlight the importance of full testing of eco-innovation questions, not only through small scale pilots, but also with in-depth interviews with managers.

Figure 6 Eco-innovation module of the European Union CIS 2008

10. Innovations with environmental benefits

An environmental innovation is a new or significantly improved product (good or service), process, organizational method or marketing method that creates environmental benefits compared to alternatives.

- The environmental benefits can be the primary objective of the innovation or the result of other innovation objectives.
- The environmental benefits of an innovation can occur during the production of a good or service, or during the after sales use of a good or service by the end user.

10.1 During the three years 2006 to 2008, did your enterprise introduce a product (good or service), process, organisational or marketing innovation with any of the following environmental benefits?

	Yes	No
Environmental benefits from the production of goods or services within your enterprise		
Reduced material use per unit of output	☐	☐
Reduced energy use per unit of output	☐	☐
Reduced CO_2 'footprint' (total CO_2 production) by your enterprise	☐	☐
Replaced materials with less polluting or hazardous substitutes	☐	☐
Reduced soil, water, noise, or air pollution	☐	☐
Recycled waste, water, or materials	☐	☐
Environmental benefits from the after sales use of a good or service by the end user		
Reduced energy use	☐	☐
Reduced air, water, soil or noise pollution	☐	☐
Improved recycling of product after use	☐	☐

10.2 During 2006 to 2008, did your enterprise introduce an environmental innovation in response to:

	Yes	No
Existing environmental regulations or taxes on pollution	☐	☐
Environmental regulations or taxes that you expected to be introduced in the future	☐	☐
Availability of government grants, subsidies or other financial incentives for environmental innovation	☐	☐
Current or expected market demand from your customers for environmental innovations	☐	☐
Voluntary codes or agreements for environmental good practice within your sector	☐	☐

10.3 Does your enterprise have procedures in place to regularly identify and reduce your enterprise's environmental impacts? (For example preparing environmental audits, setting environmental performance goals, ISO 14001 certification, etc).

☐ Yes: implemented before January 2006
☐ Yes: Implemented or significantly improved after January 2006
☐ No

Source: Eurostat, Final harmonized CIS-2008 questionnaire

4.3 The PAC survey

One survey of potential relevance to eco-innovation is the PAC survey on Pollution Abatement and Control Expenditures. Since 1996, the PAC questionnaire has been used jointly by OECD countries and by Eurostat (OECD, 2003). In most countries, the survey is limited to firms with more than 20 employees.

PAC activities are defined as *purposeful activities aimed directly at the prevention, reduction and elimination of pollution or nuisances arising as a residual of production processes or the consumption of goods and services* (OECD, 2003, p. 9). This definition excludes unintentional environmental benefits (OECD, 2003). PAC activities consist of two types: purchase of end-of-pipe technology and cleaner production (integrated process changes) (OECD, 2003).

A major limitation of PAC is that it focuses on all capital expenditures. An unknown fraction of these expenditures will be for the adoption of innovations, whereas other expenditures will cover extensions, as when more of the same equipment is purchased to expand production. The PAC survey covers supporting activities such as innovation expenditures, but these specifically exclude capital expenditures and wages for research[19]. The survey is not a harmonized OECD survey, and it is important that it becomes one (we owe this point to Nick Johnstone).

4-4. Developing future innovation surveys

The eco-innovation module for the CIS does not cover many issues of importance to measuring innovation, while the PAC survey does not differentiate between investment in innovation and line extensions. In the former case, serious space constraints limited the eco-innovation module to one-page. This was to ensure that the full CIS 2008 questionnaire did not place a larger burden on respondents than the previous CIS 2006 questionnaire. With minor adjustments, the PAC survey could provide a useful vehicle for collecting data on the adoption of environmental innovation and possibly on investment in innovative activities associated with capital expenditures on end of pipe technology and cleaner production. However, it could be more difficult to collect R&D and other innovation activities using PAC surveys, since many firm managers responsible for capital investments (the target respondent) may not be responsible for innovation.

In an ideal world, what types of questions should and can be included in an innovation survey, for instance in a survey that only covers eco-innovation? The primary goal should be to include questions that are relevant to developing policies that will encourage firms to invest in eco-innovation and also inform policy makers of possible problems and benefits, such as the effect of eco-innovation on competitiveness. We suggest that the following topics should be covered:

- Cover both creative innovation (the enterprise itself invests in developing eco-innovations) and technology adoption (the enterprise purchases relevant technology from external sources) and a means to distinguish between the two.
- Where possible, a few questions on creative innovation should ask about R&D

[19] For example, the 2005 PACE survey for the United States (implemented in 2006), states that the survey covers ‘all related support activities, including but not limited to monitoring and testing and environmentally-related administrative activities’, but elsewhere the survey specifically excludes research (US Dept Commerce, 2006).

investment in creative innovation, the number of personnel active in research on eco-innovation, and intermediate outputs such as relevant patents.

- Cover different types of eco-innovation (products, processes, and organizational innovation, plus recycling, pollution control) in order to identify where, in the value added chain, eco-innovation is occurring.
- Include both intended and unintended eco-innovation to determine where policy incentives should be focused and where they are unnecessary.
- The types of policies and organizational methods that the enterprise has in place to identify and correct environmental impacts. This information is valuable to assessing whether or not these policies make a difference and if yes, the sectors where governments need to focus efforts to encourage more firms to adopt pro-environmental policies.
- Obtain data on the economic effects of eco-innovation on sales, production costs, and employment in order to identify the effects of eco-innovation on competitiveness and possible wider implications for the macro economy.
- The appropriation methods used by the firm to financially benefit from eco-innovation.[20]
- The drivers of eco-innovation, including both policies (subsidies, mandates, regulations) and other incentives (exploiting new markets, image, etc.)

It is also useful to obtain results for a specific innovation, such as whether or not the innovation was introduced in response to a specific policy. General questions on drivers or effects are useful, as noted above, but frequently the design of good policy requires information on the effect of a specific policy on a specific type of innovation and the economic effects of this innovation. These types of issues can be addressed by asking respondents to select their most important eco-innovation in terms of its environmental benefits, and including a series of questions on this specific question. Good questionnaire practice would require including space for the respondent to briefly describe the innovation, which can be categorized later by the survey organization[21].

It would also be useful to obtain basic data on the environmental impacts of the enterprise's products and production processes, but this might be sensitive information that would reduce the survey response rate. These types of questions would need to be thoroughly piloted to determine what is and what is not possible to ask.
Where possible, a survey of eco-innovation should be linked to official data registers to obtain high quality information on control variables and on financial information, such as the enterprise's profits, employment, and sales over time. In many countries this is not possible, particularly for surveys by academic organizations. In these cases, the following types of control variables will need to be asked in the eco-innovation questionnaire:

[20] Appropriation methods refer to strategies companies may employ to protect an innovation against imitation by competitors. Secrecy and intellectual property right protection (patents, licensing) are the most important strategies.
[21] This method is widely used by both academic surveys and by national survey organizations. For instance, Statistics Canada regularly asks respondents to its innovation survey to identify their most important innovation and to answer a few questions on it. This approach was followed in the IMPRESS study for eco-innovation (see Rennings and Zwick, 2003)

- Firm-level attributes (sector, employment, sales or other output measure).
- Commercial conditions (scope of the firms' markets (where and what it sells), level of competition, and if possible, profitability).

5. Conclusions & recommendations

Eco-innovation is a new concept of great importance to business and policy makers. It is about innovations with lower environmental impact than relevant alternatives. The innovations may be technological or non-technological (organizational, institutional or marketing-based). Eco-innovations can be motivated by economic or environmental considerations. The former includes objectives to reduce resource, pollution control, or waste management costs, or to sell into the world market for eco-products.

Eco-innovation comprises many innovations of environmental benefit. Past research and measurement activity has focused on pollution control and abatement activities. Eco-innovation research and data collection should not be limited to products from the environmental goods and services sector or to environmentally motivated innovations but should cover all innovations with an environmental benefit, with research inquiring into the nature of the benefits and motivations for it. Attention should be broadened to include innovation in or oriented towards resource use, energy efficiency, greenhouse gas reduction, waste minimization, reuse and recycling, new materials (for example nanotechnology-based) and eco-design. The drivers are related but different and the patterns of eco-innovation activity are likely to be different as well.

The subject of eco-innovation is a rich and untapped field of research. One area for future research (besides measuring what companies do in terms of eco-innovation) is the macro-effects of eco-innovation, to complement studies on the micro-effects. Measuring the greenness of national systems of innovation (green taxes, education, collaboration, venture capital, subsidy schemes, environmental standards, education relevant to green issues) constitutes another important avenue for research.

For measuring eco-innovation, **no single method or indicator is likely to be sufficient**. In general, one should therefore apply different methods for analyzing eco-innovation – to see the "whole elephant" instead of just a part. In particular, more effort should be devoted towards direct measurement of innovation output using documentary and digital sources. The advantage is that they measure innovation output rather than innovation inputs (such as R&D expenditures) or an intermediary output measure (such as patent grants). Innovation can also be measured indirectly from changes in resource efficiency and productivity. These two avenues are underexplored and should be given more attention, in order to augment our rather narrow knowledge basis. A positive development is the inclusion of three questions on eco-innovation in the next Community Innovation Survey of the European Union, which by 2010 will produce important information about the nature of eco-innovation and its determinants.

It would be of interest to develop a scoreboard for eco-innovation. A first attempt was made in the MEI project, which came up with a list of 24 indicators for five categories: i) firms, ii) conditions, III) linkages, IV) radical/incremental innovation indicators, and V) overall performance (see appendix). The indicators draw on current innovation theory and are

adaptations of existing indicators. This list is not proposed as a definitive set of indicators of eco-innovative capacity; it only represents a first attempt. Given the deep involvement of the OECD in innovation measurement, this presents an interesting avenue for innovation indicator research that can build on available strengths and competences.

To get a better understanding of the different biases of various innovation measures, we propose a **research programme** into measuring eco-innovation activity in a particular domain (automobile manufacturing, electricity production, waste management) **using different methods**: patents (citations), government-funded R&D, private R&D, innovation expenditures, eco-efficiency improvements and direct innovation output measures (such as innovation announcements) – to see whether the methods lead to similar results. We expect significant differences between time series of eco-patents as a measure of invention and eco-innovation expenditures (especially expenditures for the adoption of technologies developed elsewhere); between government-funded R&D for the control of the environment and environmental R&D undertaken by private companies; between environmental R&D in waste, discharges into water, resource/energy use and emissions to air; and between eco-efficiency improvements and input & intermediate output statistics. Information on these differences could assist innovation researchers and policy makers by identifying possible measurement biases and margins of error. This would hopefully lead to a more careful application of the measures, the combination of different measures in research, and more research into direct measurement of innovation.

We would also propose a pilot project on company environmental performance data and eco-innovation activities. Panel data would be very suited for this.

National surveys on pollution abatement and control expenditures could inquire into R&D and other innovation expenditures and differentiate between investments on innovation and line extensions. Such surveys could also examine motivations, such as to reduce resource costs, improve products so that their use leads to lower environmental impacts and innovation offsets (gains from the introduction of environment-saving measures). Additions to the PAC surveys would provide a relatively easy way of augmenting the international knowledge base on eco-innovation. This could offer information for benchmarking nations and sectors within nations, such as on the degree to which nations are shifting to cleaner production and waste reduction. It may also help to change mind sets which see eco-innovation as a cost.
Finally, we propose a more careful use of language. Invention should be carefully differentiated from innovation. Too often the two are used as synonyms, especially in “innovation studies” that rely on patents as the only source of information. Patents are a measure for invention, which may or may not lead to innovation, whereas the majority of innovations are not based on inventions that were developed within the innovating firm itself.

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Appendix. List of proposed eco-innovation indicators for scoreboard (developed in MEI project)

	Indicator	Data Source
	The Firm	
1	R&D expenditures for environmental protection in industry.	STATCAN currently collects this information
2	% of firms with EMAS or ISO14001	Numbers collected by German Federal Environmental Agency
3	% of firms with environmental mission statements and/or officers	Would need to survey for this.
4	Managers opinion of eco-innovation	Possibly for inclusion in CIS
	The Conditions	
5	'Green Tax' as a percentage of government budget	OECD data
6	Government expenditures on environmental R&D as: • % of total R&D expenditure • % of GDP	GBAORD data
7	Uptake of environmental subsidies for eco-innovative activity	Government data
8	Financial support for eco-innovation from public programmes	OECD data
9	Demand for eco-innovative products.	Measure demand using survey techniques.
10	Environmental expenditure in college/university research	National Science Foundation collect this for US. EU source unknown
11	Number of environmental graduates, MScs or PhDs	EIS & IRCE report
12	Waste management costs (landfill tariff etc)	Government data
13	Executive opinion on environmental regulation (Stringency and transparency).	For possible inclusion in CIS
14	Attitudes towards eco-innovation	Eurobarometer data
	The Linkages	
15	Frequency of eco-innovation workshops/conferences and number of people attending.	Web based searches
16	Value of "green funds" made available by financial institutions for innovating companies.	SRI fund service data
17	Managers perception of overall quality of environmental research in scientific institutions.	For possible inclusion in the CIS
	Radical/incremental innovation indicators	
18	Ratio of eco-start-ups to incumbents in the market	Companies house data or European business register.

19	Frequency of new entrants to the market.	Companies house data or European business register
20	Diversification activities of incumbents, investment in smaller operations outside core business.	EUROSTAT entry and exit data
21	Seed and start-up venture capital for eco-innovative firms (investment per 1000 GDP)	IRCE report or interpretation of EVCA data.
	Overall performance indicators	
22	Eco-patents in triadic patent families per million population	US EU and Japan Patent offices
23	Material productivity of eco innovative firms (TMR per capita or GDP)	IRCE report
24	Share of eco-innovative firms as a percentage of all firms (may need to divide into manufacturing and services)	CIS. May need to be reanalysed.

Notes on data sources:

CIS: Community Innovation Statistics. Collected by EUROSTAT available from: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_33076576&_dad=portal&_schema=PORTAL

EIS: European Innovation Scoreboard. Collected by the European Commission available from: http://trendchart.cordis.lu/

Eurobarometer. Available from: http://www.gesis.org/en/data_service/eurobarometer/

EUROSTAT: EUROpean STATistics. Available from: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1090,30070682,1090_33076576&_dad=portal&_schema=PORTAL

EVCA: European Venture Capital Association. Available from: http://www.evca.com/html/home.asp

GBAORD: Government Budget Appropriations of Outlays for R&D. Collected by EUROSTAT available from: http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1073,46587259&_dad=portal&_schema=PORTAL&p_product_code=KS-NS-06-017

IRCE: Impact of RTD on Competitiveness and Employment. Available from: http://cordis.europa.eu/era/benchmarking.ht

SRI: Socialy Responsible Investment. Available from: http://www.eurosif.org/sri

STATCAN: STATistics CANada. Available from: http://www.statcan.ca/.

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