The Need for Environmental Innovation Indicators and Data from a Policy Perspective

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1. Introduction

Because of the market failure and the systemic difficulty involved in optimising environmental innovation, well-designed public policies are needed. These policies include both environmental policies and research and innovation policies. Environmental policies need to be designed to stimulate innovation. They need to be complemented by research and innovation policies so that the innovative responses are appropriate, adequate and timely.

Sound policy-making needs to be founded on clear understanding of what is going on in the real world. However, systematic information about what drives firms to innovate for the environment, or the knowledge requirements of firms to generate environmental innovation is not yet available. Two types of information are necessary for sound policy making to optimise environmental innovations. One is public and business expenditure in environmental R&D, and how and where the funds are spent. This is needed to assess whether we are investing enough to generate knowledge to understand and improve the environment and whether the funds are being used efficiently. Also, policy makers need to judge if public investments well complement private investments in research. The other is information about the determinants of environmental innovation in industrial firms, how firms assess the costs and benefits involved, how they acquire needed knowledge. Appropriate indicators and methodology need to be developed to collect these types of information to facilitate the design of environmental policies that stimulate innovation and innovation policies that can supply appropriate and adequate knowledge.

2. Harnessing Science and Technology

It is now widely recognised that technology and innovation play a key role in directing our development path toward sustainability. A recent OECD study on sustainable development concluded that harnessing science and technology was a key policy tool in moving toward sustainable development (OECD 2001). In the face of the urgency of many global environmental problems such as climate change, technology is even regarded as easy "fixes" that can bring about sustainability even in the absence of other policy measures. However, there is no easy "techno-

logical fix". Appropriate innovations need long gestation periods guided by public policies that define the demand for and supply of such innovations.

A growing number of studies point to the pivotal role that public policies play in enhancing environmental innovation. These policies range from environmental policy instruments, i.e., regulations, market based instruments, information measures, and voluntary or negotiated agreements to innovation policy tools, i.e., direct and indirect R&D subsidies, public/private partnerships, the use of national innovation system approach such as clusters and networking. Well-designed environmental policy instruments are needed to stimulate innovative efforts in the business sector to generate and take up cleaner options. Innovation policies are needed to complement environmental policies so that the innovative responses are appropriate, adequate and timely. Working out the right mix of policies to enhance environmental innovation is the challenge facing public policy makers[1].

Sound policy-making needs to be founded upon solid understanding of what is taking place in the real world and how it responds to public policy. Relevant information for effective public policy making to enhance environmental information is not easy to find. Moreover, there is no standardised methodology or indicators for compiling environmental R&D or innovation data that can be applied in any country. This results for one thing from the "diffuse" nature of environmental innovations and the scientific knowledge base that contribute to it. Environmental innovations draw upon a diverse knowledge base. For another, it is not always clear to what policy signals firms are most responsive. This could also differ according to the industrial sector, and the country. Business response to public policies can only be known through thorough firm/sector case studies or well-designed surveys. Either type of studies is still relatively few.

The paper first highlights some characteristics of environmental innovation that distinguish it from other types of innovation. It then discusses the issues policy makers face in making effective policies to enhance environmental innovation. The paper then turns to the discussion of the types of information needed to aid policy makers, namely, indicators and data on environmental R&D expenditures and the determinants, cost and benefits of environmental innovation in industrial firms.

3. Characteristics of Environmental Innovations and Obstacles to Stimulating It

Although environmental innovations share many of the characteristics of "innovation" in general, they do distinguish themselves in some aspects that make it more difficult to develop indicators of how the innovation process is taking place and to formulate policies to enhance it. These special characteristics are the market fail-

[1] Need for a mix of policy instruments rather than the application of a single instrument is the conclusion of some major case studies on environmental innovation, for example in the German studies contained in Hemmelskamp et al. 2000.

ure and the systemic difficulties that environmental innovations are subject to and the "diffuseness" of the knowledge base relevant for environmental innovations.

First of all, innovation for environmental sustainability suffers from "double" market failure[2]. It is widely recognised that because of the spill-over effects of knowledge, private (business) investments in R&D remain sub-optimal. Also, because of the "public" nature of environmental qualities, private investments in contributing to improve the environment also remain sub-optimal. In other words, the market failure involved in environmental innovation is more serious than for other types of innovation; therefore, more intensive efforts at the public policy level need to be made to stimulate it.

Knowledge about environmental changes and their impacts as well as innovations that improve it arises from research and development in different scientific and engineering disciplines[3]. Knowledge advances in diverse fields of basic and applied sciences and engineering need to be combined to generate innovations that enhance environmental performance. Relevant knowledge is generated not only by innovating firms themselves, but may also be generated by upstream or downstream firms, universities or other public research institutions. Environmental innovations often require inter- or multi-disciplinary approach to research as well as inter-firm or inter-institutional co-operation in R&D. The research and innovation systems in many countries are still not well adapted to enhance inter-disciplinarity or inter-sectoral co-operation. This subjects environmental innovations to what may be termed as "systemic" difficulty.

The systemic difficulty implies that the knowledge base that potentially contributes to environmental innovation is diverse and diffuse. Any body of scientific or engineering knowledge and technology can be applied for environmental objectives. Also, a wide range of "organisational" innovations can enhance efficiency and hence improve environmental performance. The growing importance of cleaner processes and products as opposed to end-of-pipe technology is adding to the diversity of the knowledge base for environmental innovations. This also makes it more difficult to define the boundaries of environmental goods and services sector which now is defined to include cleaner processes and products (OECD/Eurostat 1999). Inclusion of cleaner technology implies that firms not necessarily producing environmental goods and services including those in emerging areas such as ICT, biotechnology and nano-technology, probably have a great

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[2] Some experts call this the double externality problem of environmental innovation. "...neither innovators nor those investing in environmental protection can automatically secure returns on their actions. There is a danger that the actual level of environmental innovation will lag behind that which is economically desirable..." (Lehr and Löbbe 2000).

[3] For example, a recent article in Nature discusses the rise of bio-monitoring, the use of living organisms to scientifically assess the impact of environmental pollution and changes on living systems, which may be used as complements or substitutes to more conventional chemical monitoring (Whitfield 2001). It is clear that this branch of environmental R&D needs to combine biology, chemistry and ecology.

potential and do in fact contribute in an important way in supplying needed technology to user industries in enhancing environmental performance.

These characteristics of environmental innovation make it difficult to gather needed indicators and data for effective policy making. The boundaries of environmental innovation itself as well as the boundaries of the pool of knowledge that contribute to this type of innovation are difficult to define. However, because of the seriousness of the market failure and the systemic difficulties involved, there is a need for effective policies to enhance environmental R&D and innovation. There is a need to better understand how industrial firms generate environmental innovation and what their knowledge needs are. Only an adequate understanding of this could contribute to designing of policies (both environment and research/innovation) that can stimulate the demand for environmental innovation and assure the supply of useful knowledge for that purpose.

4. The Issues Policy Makers Need to Address in Formulating Effective Policies

Then what are the issues public policy makers need to address in formulating effective policies? In order to simplify discussion, it is assumed that environmental and innovation policies play different roles. Environmental policies largely define the *demand* for environmental innovations and determine the *direction* of technological and innovative change, whereas research and innovation policies define and manage the *supply* of knowledge for innovation, hence determine the *rate* of technological change and innovation. It is to be noted that this distinction is somewhat artificial, since to a certain extent each determinea both the rate and direction of innovative efforts. Also, policy coherence and integration between these policy domains is an issue in itself. However, the distinction has its own merits, in that in most governments, environmental policy making and research and innovation policy making remain distinct and separate policy areas.

4.1 How to Regulate to Stimulate Innovation – The Issues for Environmental Policy Making

Since environmental innovations are generated in industrial firms, policy makers need to know what drive business firms to innovate to enhance environmental performance. A closely related question is what are the barriers to environmental innovation encountered by firms and industries. Obviously, environmental regulations are the most direct drivers for firms to improve environmental performance through regulatory compliance. Then the policy issue is how to regulate so that firms are stimulated to search for the means of compliance through innovation.

4.1.1 Reglatory Design that Stimulates Innovation Flexibily, Cost-effectively and Continuously

In this context, studies undertaken so far have shown that regulations differ in their effects on innovation (OECD 1999; Kemp 2000; Hemmelskamp et al. 2000; Environmental Law Institute 1999). These studies find that regulations based on technology specifications tend to stifle innovation, although the diffusion of the specified technology option is stimulated. The instruments that are favoured from the point of view of stimulating innovation are performance standards and market-based instruments[4]. Also, regulatory stringency and enforcement strategies are considered important factors in stimulating innovation (Ashford 2000).

Whether or not policy instruments stimulate innovation is not the only relevant policy issue. Some more key policy considerations need to be addressed. These include whether the policy instruments stimulate innovation in a *flexible* manner (i.e., the choice of innovative response is left up to the polluter), whether they do this *cost effectively* and in the *long range*. The flexibility, cost effectiveness and continuity considerations imply that cleaner process and product innovations, where appropriate, are normally to be stimulated rather than end-of pipe solutions.

4.1.2 Where and How Large are the Win-win Opportunities?

These considerations also open up the debate that the well-known Porter hypothesis (Porter and van der Linde 1995) has sparked. This argues that regulatory compliance presents "win-win" opportunities for firms and stimulates environmental innovation that increases their competitiveness. Environmental innovations "offset" the cost of regulatory compliance through innovations that reduce cost to the firm by increasing resource efficiency. The study presents numerous case examples revealing such win-win situations. Because the cost of regulatory compliance is normally higher, the more stringent the regulation, Porter's study as well as others argue that the win-win pie is larger, and can stimulate more significant innovative response, the more stringent and focused the regulations (Ashford 2000).

The Porter hypothesis was in part supported by theories of competitiveness, but the evidence presented was for the most part anecdotal firm level evidence. It did not provide systematic, statistical evidence; consequently, it encountered criticisms both from environmental economists and other management researchers. These criticisms present statistical or anecdotal evidence that regulatory compliance incurs cost to the firms, and/or that these costs varied according to industries or plants (Palmer et al. 1995; Walley and Whitehead 1994; Environmental Law Institute 1999).

Therefore, the central policy issue of how to regulate so as to stimulate innovation requires an understanding of the interrelationship between changes in production costs, R&D inputs on one hand and process and product innovations on the other. This requires disaggregated data on costs and benefits of environmental in-

[4] Product bans also stimulate innovation, but clearly the applicability of this instrument is limited.

novation, which in turn requires systematic work on indicators and data on drivers of environmental innovation, their costs and benefits. The debate surrounding the Porter hypothesis raises the issue of the general paucity of indicators on environmental innovation (Kemp and Arundel 1998). Also, the inter-industry or inter-plant differences in compliance costs imply that "win-win" opportunities are not distributed evenly. There is little doubt that significant "win-win" opportunities do exist, but how large they are in the aggregate or where they are found in the industrial sector are not clear (Norberg-Bohm 2000). These are policy issues that need to be addressed. Again, more systematic understanding of the cost and benefits of environmental innovation is needed.

4.1.3 Central Role of Incentives: Designing Effective, Market-based Instruments and Making Voluntary Agreements Work

The debate surrounding the Porter hypothesis highlights the importance of incentives in stimulating firms to innovate for the environment. The importance of incentives is the main *rationale* behind the increasing use of economic or market-based instruments (taxes, tradable permits, pollution charges, deposit-refund schemes), and the policy advice to enhance their use[5]. Empirical analysis of US situation in the past few decades demonstrates the strategic usefulness of properly designed and implemented regulation complemented by economic incentives (Strasser 1997).

However, the implementation of effective market based instruments has not been easy. The difficulty mainly stems from the frequent resistance to their adoption, especially energy or environmental tax, notably from the industrial firms. The main lesson to be drawn from past experience is that market-based instruments are more effective when applied in combination with other policy instruments, especially regulatory standards, in a policy mix, rather than independently. It may be noted that the optimum mix differs according to industry.

The industrial aversion to market-based instruments, seems to be inducing a proliferation of voluntary agreements in many industries and many countries[6]. Like market based instruments, voluntary agreements normally are applied in the context of existing or new policy mixes. Theoretically, they are flexible as they leave industry more freedom with regard to the method and moment of compliance. They have been criticised on the basis of the danger of free-riding and under-exploitation of opportunities on the part of the industry as well as the frequent

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5 Some policy advice organisations recommend more extensive use of these instruments, such as the OECD (see OECD 2001).

6 There are numerous examples, such as the chemical industry's Responsible Care Program, voluntary agreements to reduce perfluocarbon compound emissions in the aluminium industry. These programmes involve several countries. An example of a major national programme is Japan's Keidanren Voluntary Action Plan to reduce CO2 emissions, which involves a major part of the industrial sectors through participation of industrial associations.

absence of technology forcing targets (Kemp 2000; OECD 1999). But recent experiences suggest that voluntary agreements do stimulate innovation[7].

4.1.4 Interplay of Drivers of Environmental Innovation, but Inter-industry and Cross Country Differences

The existence of win-win opportunities and the importance of incentives imply that for industrial firms, the regulatory driver is often translated into commercial driver to generate environmental innovations. Some recent environmental surveys show this correlation clearly (Malaman 1996; Green et al. 1994; Cleff and Rennings 1999). In addition, some of these surveys show that the social awareness factor is also an important driver, and interact with other drivers as well. Firms want to demonstrate social awareness by being innovative in environmental performance. This in turn improves the image and the performance of the firm in general. It may also be noted that these surveys demonstrate significant inter-country differences in the relative importance of the different drivers.

Numerous surveys of environmental innovation in business firms have been undertaken. These surveys have been conducted at the national level with diverse methodologies, and reveal the incentives that drive firms to innovate for the environment. Although the studies identify regulations, cost considerations and social awareness as drivers, there are clear differences between the relative importance of these drivers according to countries. For example, the UK study showed that anticipation of regulation, the fear of rival products, and the threat to market share were important drivers. However, a German survey revealed that "maintaining market share" or "expected future legislation" were drivers of relatively low importance (Green et al. 1994; Cleff and Rennings 1999). It is difficult to draw conclusions as to whether these results represent genuine cross national differences in firm behaviour, or the divergent results are caused at least in part by the difference in the survey method.

It is equally conceivable that there are significant inter-industry differences in the relative importance of drivers. For emission intensive ("dirty") mature sectors like steel, regulatory driver is likely to be the most important. But for further downstream industries whose products sell directly to consumers, the social awareness driver could well be more important. Environmental policy making need to take into account these important cross-country and inter-industry differences.

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[7] Such as Keidan Voluntary Action Plan to reduce CO2 emissions in Japan, and aluminium industry's efforts to reduce perfluocarbon compounds emissions in several countries. See OECD 2001.

4.1.5 Working out the Best Mix of Policy Instruments Adapted to Industry or Country Specificities

The most widely recognised conclusion about the design of environmental policies that stimulate innovation is that a mix of policy instruments need to be worked out within a regulatory framework adapted to the specificities of the national regulatory regime (Hemmelskamp et al. 2000; OECD 2000).

To work out this policy mix, there is a need to better understand firm behaviour and the ways they respond to signals that policies provide, since policy makers have to assess the relative merits of the different policy instruments from the viewpoint of stimulating innovation. The effective policy mixes differ according to the industrial sector, the country and over time. Policy makers need to be ready to tailor policies to diverse contexts. Hence, there is a need for better indicators and data on drivers and barriers to environmental innovation, and how these factors interact; also, the costs and benefits of environmental innovation for industrial firms. Also sensitivity of business firms to the various environmental policy instruments or the combinations of policy instruments need to be assessed and documented. These require more systematic surveys and information gathering of business attitudes and strategies towards environmental innovation. Standardised environmental accounting methods and standardised survey methods on environmental innovation would enable compilation of relevant information.

4.2 Issues for Research and Innovation Policy Making

If environmental policy making addresses the issue of *why* firms innovate for the environment, *how* firms do it is the central question for research and innovation policy. Once business firms decide to innovate for the environment, they would invariably turn to R&D to search for knowledge required for innovation. Some statistical studies demonstrate the correlation between environmental (compliance) expenditures and R&D expenditures or patenting (Lanjouw and Mody 1996; Jaffe and Palmer 1996). A recent survey by the World Business Council on Sustainable Development indicates that when firms decide to adopt "sustainable development" as part of their corporate strategies, links with R&D and innovation management becomes important. For these "sustainable" firms, improved technology and better engineering skills are the essential tools for supporting "sustainable development" strategy, and the considerations of sustainable development have helped them to launch new products and improve existing products and processes (Dearing 2000).

4.2.1 Making the Case for the Key Role of Research and Innovation Policy for Environmental Objectives

If research is crucial to environmental innovation, active research and innovation policies would facilitate business efforts in the search for needed knowledge. The seriousness of the market failure for environmental innovation discussed previously justifies public support of research. However, two counter arguments arise.

One is that if environmental policies are well designed they would be sufficient to induce appropriate research and innovation. This is probably not the case. For one thing, even if environmental policies send the right signals, it normally takes a long time for the appropriate innovative response to emerge. R&D efforts typically require long time horizons especially for radical innovations. Also, firms may favour less costly (in the short term) incremental innovation to more radical innovations which in the long range may be more cost effective. Network dependent technologies such as energy supply and transport are examples. In other cases, the assessment of the impact of an environmental issue may change constantly, resulting in considerable time lag for appropriate environmental policies to be implemented. Some environmental problems may become irreversibly aggravated by the time proper policies are in place. Climate change is the case in point. Reduction of CO2 came on the policy agenda more than ten years ago, but some of the key policies to address it, such as the Clean Development Mechanism, is yet to be fully designed and implemented. Finally, it is a widely accepted view in research and innovation policy, that demand side factors alone do not determine innovation. Supply side factors play a crucial role. For example, medication for infectious diseases must have been in great demand since the dawn of history, but effective drugs were only developed after advances in bio-medicine since the late nineteenth century. Policies to enhance research and innovation would be needed to address the time lag factor, and to facilitate the development and adoption of appropriate innovations.

Another argument against active public support of research and innovation that often arise in economic policy making, is that public support for R&D, especially public funding of technology programmes, tends to "pick winners". This is viewed as conducive to "locking in" technological development paths which may later be judged sub-optimal from the viewpoint of environmental sustainability or economic efficiency. Some power generation technologies and transport technology are cases in point. This view generally tolerates support to "basic" research at best, but opposes public support to the development of specific technologies.

4.2.2 Importance of Public Support to Broad-based Basic Research

While the market failure factor and the time lag factor involved in innovative response justify public support to environmental R&D, how best to do it is a difficult question that research and innovation policy makers face. The first question that needs to be addressed follows from the winner picking issue: Do we need more than support to "basic" research in order to enhance environmental innovation? If so, how should the focusing be done so as not to pick winners?

It was pointed out previously that the on-going general shift from end-of-pipe solutions to cleaner process and products approach broadens the range of innovation and technology that can be applied for environmental objectives. This first of all, indicates that environmental innovations would benefit from knowledge advances in many scientific and engineering areas, as well as social and behavioural science areas providing knowledge base for organisational and managerial innova-

tions. In a survey of American firms in the environmental technology sector[8], a major R&D issue was the lack of long-term basic research. Two thirds of the companies indicated that at least 90% of their research has a short-term focus, because of economic pressure which make their research market-driven and oriented to developing specific products, with a correspondingly short time frame. Also, nearly half of the firms developed their technology from basic research not oriented specifically to solving an environmental problem (Environmental Law Institute 1997).

These results show the importance of the public funding of basic research to complement business environmental R&D and innovation. It also shows the importance of the serendipity factor in environmental innovation; hence, the basic research that needs to be publicly funded need also to be sufficiently broad-based. It is not easy to foresee which lines of research would lead to environmental innovations.

4.2.3 Inter-sectoral and Inter-country Diversity in R&D Requirements

The above survey also demonstrates differences in the R&D requirements between the different segments of the environmental technology sector. First of all, the share of revenue devoted to R&D differs according to the segment. Water and air technology firms spend an average of 2.5% and 3% respectively, instrument manufacturers 8%, and process and prevention technology firms invest 25%. Also, air and water companies finance 80% of R&D from its own capital and instrument companies 60%, but the share of government funding of R&D is larger for the process and pollution prevention segment.

These results show that the R&D requirements of firms differ considerably even within the environmental technology sector. The difference seems to depend on the maturity of the segment, with the relative importance and the public dependence for financing of R&D higher, the less mature the segment.

Also, another study shows that one sector, paper and pulp sector in US, Japan, Sweden and Germany take different approaches to R&D and innovation (Blazejczak and Edler 2000). The difference stem from the type of regulatory regime and the differences in approaches to innovation.

4.2.4 Ways to Focus Need to be Worked out According to the Sector and the Regulatory Regime?

These inter-country and inter-sectoral differences imply that it is extremely difficult to answer the question of how much R&D investment is adequate in either the public or the private sector as a whole. The answer probably differs according to

[8] This was an interview survey of 45 small to medium sized firms exclusively dedicated to developing environmental technologies distributed between four principal categories of air pollution control equipment, water pollution control equipment, monitoring instruments and process and pollution prevention technologies. (Environmental Law Institute 1997).

the sector and the country. The sectoral differences reflect the diversity in the technological base of industries, and the differences in the innovative paths that these technologies will take in the future, while country differences are likely to arise from the diversity in the environmental policy framework as well as national research and innovation systems.

4.2.5 Focusing without Picking Winners: Partnerships and Involving Multiple Stakeholders in Research and Innovation Decisions

It may be noted that recent changes in innovation policy are addressing the question of focusing public research investments without picking winners. This is seen in the shift away from large publicly supported technology programmes towards the use of networking approaches, especially public/private partnerships in funding and executing research. The important element is the involvement of both public and private actors in research and innovation decision making and taking part in funding of research. The partnership approach leverages private R&D funds, and pre-empts "free-riding" on public funds by making the private sector commit itself financially. The use of this approach has enabled reduced public R&D funding in some sectors such as energy (IEA 2000).

Public/private partnership approach is already used widely for the purpose of enhancing environmental research in many countries. These programmes involve a variety of public and private actors in collaborative research efforts. Partnerships approach can overcome institutional barriers to facilitate networking and address the systemic difficulties in R&D activities to enhance inter-disciplinary and inter-sectoral co-operation (Fukasaku 1998).

Another innovation policy that enhances networking and multi-stakeholder involvement in research and innovation decision making is the cluster approach. For example the recent Finnish Environmental Cluster Programme provides seed funding for research on new environmental technologies to be carried out by consortia of producers and suppliers, universities and institutes. Projects have been launched which aim at improving eco-efficiency through the application of life-cycle techniques in agriculture, forestry, basic metals and water management (Honkasalo 2000; OECD 1999). Collaborative projects enhance networking among researchers and users and facilitate innovation, without picking winners.

4.2.6 Moving towards Radical Innovations

Experts in research and innovation policy know that inducing radical innovations is much more difficult than incremental innovations. But in pursuing any direction of technological change, it is inevitable that at some stage, adoption of radical innovations becomes necessary. Environmental innovation is no exception. Environmental policies normally induce incremental innovations. Inducing radical innovations by environmental policies is not easy, since if it is to be done through regulations, they need to be extremely stringent. If it is done through market-based instruments, tax or charge levels need to be extremely high. It is unlikely that such

stringent regulations or drastic market-based instruments can be negotiated as acceptable public policy.

In principle, stringent regulations and effective market instruments increase the size of the win-win pie. However, it is pointed out that it is not always easy for firms to exploit the win-win potential when it involves large investments. Public policy, not only in the form of environmental regulation, but also R&D support and other measures are necessary to focus firms on the win-win potential, especially in cases of possible shifts away from incremental process and product improvements and towards radical changes in processes and products (Norberg-Bohm 2000).

Then how can research and innovation policies facilitate the move towards radical innovations? Two innovation policy tools can be identified that can do this. In both the involvement of diverse stakeholders is a key. One is technology foresight. An increasing number of countries use technology foresight processes to set priorities in research. In the technology foresight exercises conducted during 1990s, identification of technologies that potentially contribute to environmental sustainability occupied a major place, and a broad range of future technologies have indeed been identified that in the long range are expected to contribute significantly to sustainability. The list includes applications of biotechnology and information and communication technologies, new materials and micro and nanoscale technologies, new energy technologies, innovative waste treatment and recycling technologies (Fukasaku 1999). Many of these may be categorised as radical innovations.

A recent trend in technology foresight exercises is the involvement of diverse stakeholders, including the research community, government, business and the civil society, in the process. The multi-stakeholder involvement clearly guards against setting priority on the basis of the interest of any one group or industry, and guarantees that where a choice is made, that choice is in the interest of diverse stakeholders in society. The involvement of the research community and business enables the matching of the supply of new knowledge developments and the market demand since long before the actual realisation of innovation. Technology foresight, as an innovation policy tool, can not only identify research areas and technologies that are likely to contribute in an important manner to environmental sustainability without "picking winners", but also enable matching the supply of technologies with business demand by actively stimulating networking and intersectoral collaboration.

Undesirable winner picking and lock-in effects may be avoided if radical innovations of entirely new technology systems are given a chance for experimentation. Such "systemic" innovations that lie beyond incremental innovations can transform large infrastructures that have been built up over the long term. Transportation and power generation infrastructures are the cases in point. It is clear that the existing infrastructures that accommodate increasing traffic and fossil fuel power generation with complex grid infrastructures are probably not sustainable in the long range. An innovation policy instrument that induces systemic innovations by allowing experimentation is strategic niche management.

SNM is a means of trying out new systemic technologies in a selected environment - niches - by real users. In niches the technology is temporarily protected from full selection pressures of the market and acts as a test bed and incubator for the new technology. This has been applied in introducing the use of light-weight vehicles in a Swiss town, and in developing organised car sharing, also in Switzerland (Kemp 2000).

5. The Type of Indicators and Data Needed

Then, what kind of information do policy makers need in order to address the issues and questions raised above? There is already a substantial amount of funds devoted to research and development for environmental objectives in both the public and the private sectors. Also, industrial firms have innovated to enhance environmental performance in various ways. The starting point for designing or reforming policies should be to find out what is going on, i.e., to gather systematic information and data on the inputs and outputs of environmental innovation.

5.1 Input Indicators and Data – Public and Private R&D Expenditures for Environmental Objectives

The most obvious input indicator of environmental innovation is R&D expenditures devoted to environmental objectives[9]. R&D is invested both in the public and private sectors. Public policy makers need to know both, so that policies can be designed to complement business efforts.

5.1.1 Public Environmental R&D

The availability of internationally comparable data on environmental R&D remains very limited. The only available indicator compiled by the OECD is government budget appropriations and outlays in R&D (GBAORD) for environmental objective (table 1). On average, OECD governments appropriate about 2 per cent of their R&D budgets to research for environmental objectives. This share rises to about 5 percent when environment-related research on other objectives is added, such as that on energy and agriculture. Also, since the early 1980s, growth in budget appropriations on environmental research has outpaced most other research areas so that its share of the total has increased by about half a percentage point.

However rapid the increase may be, it is dwarfed by the smallness of the budget appropriation itself on environmental objectives. An OECD study undertaken about ten years ago (OECD 1992) also pointed out that there was considerable "relabelling" of existing activities as environmental in response to the demands on

[9] Another important input indicator is human resources, but this is not discussed in this paper since available data is non-existent.

public policy to respond to environmental issues since mid 1980s. The study also argues that publicly financed environmental R&D does not appear overall, to have increased in line with the increased recognition of environmental threats or even with the development of environmental policies and institutions. In spite of considerable general policy discussion in some countries about an appropriate level of funding, the small share attributed to environmental issues suggests that they have had little influence in wider discussions of S&T funding issues.

The scope of environmental research as defined in the Frascati Manual includes both the identification and treatment of pollution *and* prevention of pollution, but the latter may not entirely correspond to the concept of clean or cleaner technology. Also, data are not normally disaggregated into treatment and prevention. Reporting by objectives, therefore, masks trends at more disaggregated levels, the knowledge of which is important for policy makers.

Table 1. Government Budget Appropriations and Outlays for Environment R&D Levels in Millions of 1995 US$ PPPs and as % of total GBAORD

	Million 1995 US$		198	198	199	199	199	199	199	199	200	200
Australi	199	68	2.7	1.9	3.1	2.9	2.5	2.6	2.7	-	-	-
Austri	200	23	0.4	0.9	1.9	2.5	2.2	2.1	1.9	1.9	2.0	-
Belgiu	199	40	2.8	2.5	1.0	1.7	2.5	2.5	1.9	2.8	-	-
Canad	199	147	1.2	1.9	1.9	3.2	3.2	3.6	3.8	-	-	-
Denmar	200	16	1.8	1.5	3.8	4.4	4.4	2.9	3.7	3.4	2.8	2.0
Finlan	200	27	0.9	1.5	1.4	2.5	2.6	2.3	2.2	2.2	2.3	2.2
Franc	200	229	0.5	0.5	0.7	1.9	2.0	2.1	2.2	1.6	1.8	-
German	200	525	1.8	3.1	3.5	3.6	3.7	3.5	3.4	3.5	3.4	-
Greec	199	14	3.1	3.4	2.8	3.6	3.8	3.4	3.3	3.3	-	-
Icelan	200	3	-	0.1	-	3.4	4.0	4.6	2.9	3.6	3.7	3.9
Irelan	199	4	0.4	0.8	1.2	1.4	1.7	1.6	1.1	1.4	-	-
Ital	199	238	1.8	1.0	2.2	2.4	2.4	2.4	3.4	-	-	-
Japa	200	158	-	-	0.5	0.6	0.6	0.6	0.6	0.7	0.8	-
Kore	199	157	-	-	-	-	-	-	-	3.3	-	-
Mexic	199	19	-	-	1.4	0.6	0.7	0.8	1.0	1.0	-	-
Netherlan	199	118	-	3.2	3.4	3.9	3.7	3.8	4.0	4.0	-	-
New	199	3	-	-	2.6	3.3	-	0.8	-	-	-	-
Norwa	200	26	3.6	2.7	3.2	2.8	2.8	2.9	3.0	3.0	2.8	2.7
Portug	200	45	-	-	3.2	4.4	4.2	4.3	4.2	4.3	4.4	-
Slovak	200	3	-	-	-	2.0	2.4	2.0	1.6	1.4	1.3	1.3
Spai	199	102	0.7	0.4	4.3	2.6	2.7	2.2	2.6	2.6	-	-
Swede	200	21	1.8	1.5	3.2	2.3	2.3	-	0.8	1.6	1.4	-
Switzerla	199	2	2.7	-	1.8	-	0.9	-	0.2	-	-	-
United	199	201	1.2	1.2	1.4	2.3	2.2	2.3	2.5	2.4	-	-
United	200	472	0.8	0.5	0.6	0.8	0.7	0.8	0.8	0.7	0.7	0.6
European	199	1,81	1.4	1.7	2.2	2.9	3.0	2.9	3.0	-	-	
Total	199	2,76	1.1	1.1	1.3	1.7	1.7	1.7	1.7	-	-	

OECD S&T databases, July 2001

For the purpose of policy making other disaggregated data would be necessary. Since public sector research includes most basic research; also, most research done in the universities, indicators and data on how much is being spent on basic as opposed to applied research and how much spent on which areas of environmentally relevant research would be useful. Where the funds are used, universities or in public research institutions or contracts to business is another needed information. If there is significant amount of budget appropriated in environment-related research in other objective areas or generic technology areas, this needs to be more systematically assessed. Also, needed is information about where and by whom the funds are being spent.

5.1.2 Business Environmental R&D

The OECD has very fragmentary data on business expenditures for environmental R&D (table 2). This reveals that for some countries, business expenditures on environmental R&D are larger than government budget appropriations. This implies that business expenditures in the OECD area could well be much larger than public expenditures, since this data set does not include US, Japan and Germany which are the largest producers of environmental goods and services. The business sector in these countries is likely to be investing more than the government. In any case the unavailability of data for these and other larger OECD countries severely limits drawing conclusions about major trends in business environmental R&D.

Table 2. Public and Business Expenditures for Environmental R&D (in Millions 1995 US$ PPPs)

	Business expenditures for environmental R&D		Government Budget Appropriations and Outlays for environmental R&D	
Australia	1998	69.2	1998	67.5
Austria	1981	0.7	1981	2.5
Iceland	1999	0.3	1999	3.3
Ireland	1990	4.0	1990	1.7
Korea	1998	173.1	1999	157.3
Mexico	1995	17.2	1995	7.4
Netherlands	1991	63.8	1991	94.7
Norway	1999	9.0	1999	26.9
Slovak Republic	1999	1.4	1999	3.3
Spain	1999	108.8	1999	102.2
Sweden	1999	3.5	1999	23.9
Switzerland	1996	138.7	1996	12.4

OECD S&T databases, July 2001

For the needs of policy making, business sector R&D indicators and data need also to be disaggregated. Which sectors invest larger share of their total R&D for environmental objectives? How do firms use their R&D, on which environmental problems? How much is spent for research on prevention and how much on treat-

ment? How much is spent on basic research? How much is being spent internally, how much R&D is contracted out, or spent on collaborative research? These are some of the questions that policy makers need to know from appropriate indicators and data on business environmental R&D.

5.2 Output Indicators – Indicators and Data on Environmental Innovation in Business

The second set of indicators and data needed for policy making is determinants of environmental innovation in industrial firms, and the types of innovation generated by firms. More work has been done in this area than for environmental R&D. The main problem regarding these output indicators and data is that methodology used varies considerably, and in many cases comparability of results across sectors and countries is very uncertain.

As discussed above, policy makers need to know the relative importance of the various drivers of environmental innovation in industrial firms, regulatory, commercial or social awareness. They need to know how firms react to various policy instruments. Policy instruments need to be assessed in terms of the extent of incentives for innovation they create for firms. This should include the assessment of industrial preference for voluntary agreements as opposed to regulatory or market-based instruments, even if voluntary agreements are not directly designed by the government.

These types of information can only be obtained by conducting innovation surveys. A number of environmental innovation surveys have been conducted in several countries. The problem is that the methodology used differs considerably as discussed above. Hence in many cases, it is difficult to determine if the differences in results are genuine or if they are caused by differences in methodology. Since policy makers do a lot of learning from experiences of other countries and sectors which they are not directly responsible, designing of standardised methodology is a genuine need for policy makers.

As discussed above, another dimension of environmental innovation in industrial firms that policy makers need to know are the costs and benefits involved in improving environmental performance. It is clear from the innovation surveys conducted so far that whatever the incentives for environmental innovation, firms are ultimately interested in reaping win-win opportunities. Information about costs and benefits of environmental innovation can be obtained if firms conduct environmental accounting. This is being encouraged by environmental policy makers, and in recent years many firms have adopted environmental accounting systems. Here again, standardisation of methodology is an issue that needs to be addressed. Also, it should be noted that an important part of the costs of environmental innovation is R&D investments. Patent data would constitute an important indicator of set of output of environmental innovation.

Innovation surveys also should elucidate the "knowledge value chain" for environmental innovation in various sectors. Who supplies the most relevant knowledge for environmental innovation, downstream or upstream firms, public re-

search institutions? What kind of knowledge are the firms looking for? Addressing these questions are key for policy makers in designing appropriate environmental innovation systems.

6. Conclusion

There is clearly a need for better indicators and data on environmental innovation. At least two types of information is necessary, environmental R&D expenditures and determinants of environmental innovation. Existing indicators are far too insufficient. Indicators and survey methods need to be better defined and better standardised, so that the results can be compared across sectors and countries. There is a need for intensified and co-ordinated national and international efforts in building indicators and collecting data on environmental innovation.