Chapter 3

TECHNOLOGY AND ENVIRONMENTAL POLICY: INNOVATION EFFECTS OF PAST POLICIES AND SUGGESTIONS FOR IMPROVEMENT

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Introduction: technology impacts of environmental policies

There exists a small literature on the impact of actual environmental regulations on compliance innovation and clean technology. This literature consists of the work of Ashford and Heaton in the 1980s in the United States, Kemp (1997) and a number of German studies (Hartje, 1985; Hemmelskamp, 1997; Klemmer, 1999). The focus of these studies is on technical innovation, not on organisational innovation. What these studies show is that the technology responses range from the diffusion of existing technology, incremental changes in processes, product reformulation to product substitution and the development of new processes. The most common responses to regulation are incremental innovation in processes and products and diffusion of existing technology (in the form of end-of-pipe solutions and non-innovative substitutions of existing substances). Often, the new technologies are developed by firms outside the regulated industry, which means that, in the past, industry was reliant upon suppliers, capital goods suppliers and environmental technology suppliers. (This is changing with the growing attention in environmental policy and industry to prevention and product change.) The studies also show, unsurprisingly, that the stringency of the regulation is an important determinant of the degree of innovation, with stringent regulations such as product bans being necessary for radical technology responses. Technology-forcing standards appear to be a necessary condition for bringing about innovative compliance responses. The studies also show that long before the regulations are promulgated there is a search process for solutions to the problem, both by the regulated industry (mostly for defensive reasons), their suppliers and outsiders. This happened in the case of PCBs and CFCs where firms both in and outside the chemical industry were looking for substitutes ten years before the use of PCBs and CFCs was banned (Ashford *et al*., 1985). Of course, the certainty that their product or activity would be subject to regulations was an important factor.

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* This chapter draws on earlier work done by the author on environmental policy instruments and environmental innovation, published in his book *Environmental Policy and Technical Change*, and recent work for two Dutch research projects, PRET and MATRIC.

As to the nature (incremental or radical, product- or process-related) and the source of technological solutions, an internal OECD report established that:

- High volume, mature sectors were resistant to change, although very amenable to environmental monitoring and process controls that improved efficiency. This fits with the Abernathy-Utterback product life cycle model that during the life time of a product a sector becomes rigid, especially those sectors that are capital intensive. An alternative explanation is that such sectors are powerful and able to fight off regulations that require a major change in their process technologies.

- Significant process innovations occurred in response to stringent regulations that gave firms in the regulated industry enough time to develop comprehensive strategies. There is a trade-off between achieving quick results and radical change.

- Smaller firms and potential new entrants tended to develop more innovative responses. A possible explanation for this is that incumbent firms, especially the big ones, are vested in old technologies – both economically and mentally.

- The environmental goods and services industry provided compliance strategies that were at best incrementally innovative but which diffused fast due to their lack of disruption and acceptability to regulators.

- Regulatory flexibility towards the means of compliance, variation in the requirements imposed on different sectors, and compliance time periods were aspects of performance standards that contributed to the development of superior technological responses.

What the studies show is that technology responses are not a simple response to regulatory pressure. Apart from the regulatory stimulus, many other factors exercised influence. This suggests that the stimulus-response model is too simple. For one thing, it assumes that social innovation starts with regulation, which is most often not the case. Regulation is not the be-all and end-all of social innovation. The knowledge for such innovations is usually available, regulations may provide the leverage or some extra stimulus for the exploitation. Regulation is but one of many stimuli. It may, in fact, not be needed for environmental innovation. Many technologies producing environmental benefits are adopted for normal business reasons of reducing costs and enhancing product quality. These options are referred to as eco-efficiency options.[1] However, even for environmentally beneficial technologies that do not combine environmental gains with economic gains, regulation may not be needed. In the case of an environmentally harmful product, there will always be pressures to reduce the harm. These pressures come from a range of actors: insurance companies, banks, customers, employees, environmentalist groups and consumer organisations through product tests that include environmental aspects.[2]

When the early synthetic detergents of the 1960s created very visible environmental problems (foam in surface water), the detergent companies and especially their suppliers developed new processes leading to biodegradable synthetic detergents, without government regulation (although with the expectation that there might be regulation in the future). The voicing of concern and the threat of regulation may be enough to induce industry to look for alternative solutions. This does not absolve the need for regulation. Regulation will be needed for the widespread diffusion of environmental technologies.

One should be careful in using regulation for promoting innovation. Given the information problem of the government, the threat of regulation may be a better means to stimulate technological innovation than actual regulations (Rip and Kemp, 1998). It is hard to craft regulations that are not disruptive in some sense. Environmental innovations like normal innovation must meet a variety of goals: they should be expendable; it should be possible to fit them into existing processes; and, in the case of products, they should meet user requirements in terms of performance characteristics. Water-saving shower heads should be comfortable (have sufficient stream power) and environmentally improved detergents should have good washing performance. User benefits and social performance benefits must be balanced and co-optimised. It is the need for co-optimisation that creates a problem for innovators and for environmental regulators. For example, it proved to be very difficult to develop phosphate-free detergents with equal washing power to the phosphate-based ones. In the search for a phosphate substitute detergent companies spend more than 250 million dollar. The actual regulations on phosphate content co-evolved with the results from product tests (both toxicological tests and tests about washing performance) (Hartje, 1985).

The example of detergents shows that innovations can not simply be “elicited by legal fiat” (Heaton, 1990). This fits with insights from technology studies which say that technology can not be moulded in a pre-defined, socially desirable shape. This is why emission limits are based on assessments about what is technologically possible and economically affordable, and why environmental permits are often based on the concept of Best Available Technology or Best Practicable Means that are specified in BAT lists or guidance notes for permitting agents. There is a dynamic interplay between innovation and regulation, with innovations often paving the way for regulations. The stimulus response model fails to appreciate this dynamic interplay and circular causality.

The obvious implication of all this is that the governance of technical change is not a simple matter. It is difficult to design instruments that do the job and do it well – in the sense that society as a whole is better off. Evaluation studies of environmental policy instruments show that the instruments in themselves are either ineffective in achieving a set goal or outcome, or inefficient in terms of costs or technology choice. An example is the ONO technology used in the Dutch metal-plating industry to control the release of metals in waste water which led to the production of toxic sludge containing heavy metals which had to be treated

The remaining part of this chapter provides a discussion of experiences with various environmental policies, especially subsidies and covenants.

Subsidies

Subsidies are an important element of government policy towards technology. They are a primary instrument of innovation policy. As a politically attractive instrument, they have been an important part of environmental policies. In the Netherlands, several studies have been undertaken into the effectiveness of investment subsidies for environmental technologies. A common outcome of such studies is that subsidies had a limited impact on decisions. This was true for investment subsidies under the “Wet Investeringsregeling” (WIR), which found that investment subsidies for environmental technologies (at 15% of total investment costs) induced only 8% of firms to undertake investments they would not have done otherwise (Tweede Kamer, 1987, p. 39). The same result is found in a study by Vermeulen (1992) which analysed the effectiveness of three types of investment subsidies. The results of this study, based on a questionnaire (like the study of the WIR), are presented in Table 1.

Table 1. **The (non)effectiveness of investment subsidies for environmental technologies**

	PCBs[1]	Silent trucks	Manure storage
Very effective	0%	2%	1%
Reasonably effective	37%	22%	20%
Hardly effective	13%	23%	3%
Not effective	50%	52%	76%

1. Polychlorinated Biphenyls.
Source: Vermeulen (1992, p. 210).

According to the study by Vermeulen, the investment subsidies for the replacement of PCB equipment, quieter new trucks and the storage of manure were effective in only a small number of cases. The subsidies were the primary reason for investing in environmentally beneficial technologies in 2% of cases for silent trucks and 1% for manure storage. For PCB replacement equipment, the figure was even zero. The investment subsidies were reasonably effective for 37% of the firms that used PCBs. In all three cases, other factors were more important than the subsidies. These included: fuel economy, road performance and comfort in the case of silent trucks; health and safety considerations in the case of PCB replacement; and environmental regulations in the case of the manure storage.[3] According to Vermeulen, under the three programmes, NLG 200 million (about USD 125 million) were spent without having any effect on polluter's purchasing decisions.

The same was true for investment subsidies for thermal insulation under the National Insulation Programme (NIP) in the Netherlands, of which the author studied the effectiveness. Econometric analysis was used for this in the form of diffusion models that were fitted to the data. The statistical analysis established that there was only a weak positive relationship between the subsidies for thermal home improvements which totalled NLG 2 billion (USD 0.9 billion at the current exchange rate) and the diffusion of thermal insulation technologies: the coefficients of the dummy variables for investment subsidies were positive but not significantly different from zero at the 5% significance level. This result was confirmed by another study which asked applicants for the subsidy about their motivation for investing in thermal home insulation. Only 11% of the respondents said that the subsidy was the primary motivation for investing in thermal insulation (Beumer *et al*., 1993, p. 42). Cost savings and improved comfort were the main reasons for investing in thermal home insulation.

Other evaluation studies of investment subsidies for environmentally beneficial technologies (including energy conservation, solar boilers and co-generation of heat and power) arrive at similar conclusions. With the exception of the investment subsidy for CHP and, possibly, the subsidy for wind turbines, the effectiveness of the investment subsidies in the Netherlands was small (Evaluatiecommissie WABM, 1992).

In all the above examples, the subsidies provided applicants with a windfall gain. It is unclear to what extent they encouraged technological innovation, but given that the subsidies hardly influenced adopter decisions, the innovation effects are likely to be small. This does not disqualify investment subsidies as such. There are examples of subsidy schemes that were effective. One such subsidy is that for clean automobiles (combined with a tax for cars with high emission levels) introduced in the Netherlands in 1986 to stimulate clean vehicles. The way in which the system worked was that the subsidies for clean cars (equipped with a catalytic converter) were paid out of the extra tax revenues from the sales of highly polluting cars. This policy proved to be very effective: the share of clean cars in new car sales increased from 15% in 1986 to 90% in 1990.[4] The same kind of policy was used to encourage the supply and distribution of unleaded gasoline to protect catalytic converter emission control systems used in cars. Due to a differentiation in excise taxes, unleaded gasoline (initially only regular, but later also super gasoline) became cheaper than leaded gasoline. Oil companies quickly responded to these changes in the tax regime by offering unleaded gasoline for sale.[5]

What about the effectiveness of subsidies for the development of environmentally preferable technologies? Did R&D subsidies stimulate firms to undertake research in environmental technology that they would not have done in the absence of subsidies? This is a question which has not been studied in a systematic way, at least not in the Netherlands. However, the evidence that is available suggests that R&D subsidies in the Netherlands for environmental technology have been of limited effectiveness. According to the study by Olsthoorn *et al.* (1992, p. 18), the "Stimuleringsregeling Milieutechnologie" (STIR-MT) for the development of environmental technology did not elicit new research projects. This conclusion corresponds with the observation by de Jong and van der Ven (1985, pp.78-79) that innovator firms develop environmentally beneficial technologies not because a subsidy is available but because they believe a market exists for the new technology. The conclusion is at odds with two other evaluation studies, quoted in Cramer *et al*. (1990), that find that of the ten projects that received financial support under the Clean Technology programme in the Netherlands, five would not have been initiated in the absence of support. However, it turned out that many of the projects funded under the programme were second-rate projects: of the ten projects, only seven were technically successful and only four were applied in practice. On the whole, the results are not encouraging: it may be that the R&D subsidies accelerated the development of environmental technologies, but this is unclear. There are few examples of successful clean technologies requiring a technology development programme.

The experience with the Danish Clean Technology Development Programme, described in Georg *et al*. (1992) is more positive. Under the programme, industries, private and semi-governmental research institutions could apply for financial aid for developing and implementing clean technology. The programme was oriented at stimulating preventive process solutions and co-operation among technology suppliers, research institutes, consultancy firms and users. The Danish Environmental Protection Agency played an active role in selecting environmentally beneficial projects and in finding the right partner with whom to co-operate. That is, the agency acted as a matchmaker to elicit environmentally innovative solutions, something that previous subsidy programmes had failed to do.[6] According to the authors, the Danish programme was a success. In almost all cases, appropriate technical solutions were found for the environment problems at hand. In more than half of the projects, substantial environmental improvements were achieved at low cost. Some projects led to net economic gains for the polluting firms. In the 1990s the focus of the programme shifted towards generating in-house environmental competence and production innovation. Examples of projects in the Danish textile industry aimed at creating green product markets are described in Hansen et al. (2000). The creation of markets for green products proved to be difficult, far more difficult than finding ways of reducing waste, input use and emissions, in the absence of green demand. There seems to be a need for policy measures to assist in the creation of markets for green products.

Taxes and tradeable permits

What about the experiences with taxes and tradeable permits? Did they promote innovation? There is little evidence of this. The experiences with the tradeable permits for SO_2 are very positive as far as efficiency is concerned. In a first estimation, cost gains of 50% have been reported (Palmer *et al*., 1995). However, there is little evidence that they promoted innovation. The innovation effects of environmental taxes is a topic which has been barely analysed. Nevertheless, as the taxes are usually set at a low level, one should expect the innovation effects to be low.

Covenants

What are the experiences with covenants (environmental agreements between industry and government) in promoting innovation and environmental technology diffusion? Covenants are negotiated agreements between industry and the government in which the industry promises to reduce the environmental burden of their products and activities. They are a relatively new instrument of environmental policy. The effectiveness of eight product-related covenants in the Netherlands is analysed in Klok (1989a). These covenants covered mercury-oxide batteries, alkaline batteries, beverage packages, heavy trucks, and PET bottles, and the use of cadmium in beer cases, CFCs in aerosols, and phosphates in detergents. Most covenants were about the substitution of an environmentally hazardous substance. According to Klok, the effectiveness of covenants was typically small: when environmental improvements were achieved, this was more due to autonomous technological change, external regulations (such as EC guidelines), and the evolution of market demand than to covenants. There is little evidence that the covenants fostered technological innovation. An exception is the KWS-2000 programme in the Netherlands to reduce VOC emissions which stimulated research into low-solvent paints, especially for the housing market. Covenants are now used for achieving reductions in energy use in the Netherlands (and also in Germany), where sectors promised to reduce their energy use by 20% in 2000 compared to 1989 levels. Again, the impact on innovation is likely to be limited as such reductions can be met with existing technology. This demonstrates a disadvantage of covenants. If policy makers want to make greater use of covenants, these should be more oriented towards innovation.

Innovation waivers

One way to promote environmental innovation is through the use of innovation waivers. Innovation waivers are incentive devices built into environmental regulation. Generally, they extend the deadline by which industry must install pollution control equipment to meet emission limitation requirements. They exempt industry from penalties during trial periods and offer the prospect of cost savings derived from superior technology (Ashford *et al*., 1985, p. 444). In theory, innovation waivers seem very attractive for both potential innovators and the regulating agency. They have been used in the United States with little success. The reasons for this had to do with the short and inflexible deadlines which acted as a disincentive for innovation, especially for radical innovation, and shortfalls in the way in which the programme was administered. Under the Clean Air Act, the responsibility of issuing innovation waivers was given to the Stationary Source Compliance Division (SSCD) of the Environmental Protection Agency, a division with limited technical expertise, whose primary task was enforcement. As it turned out, the SSCD narrowly interpreted the waiver provisions and provided little guidance, which explains why the scheme failed to promote innovation.

In retrospect, it is easy to comprehend why innovation waivers were unsuccessful in the above case. This does not disqualify innovation waivers *per se*. There are several remedies to the problems encountered, such as administration of the programme by people trained to interact with industry, the establishment of a technology review panel, delineation of eligibility criteria, and longer time allowances. It does illustrate, however, the difficulties in designing regulations that encourage environmental innovation.

Turning to the topic of best policies to promote the development of environmental innovation and diffusion, there are two ways to approach this issue. One way is to focus on policy instruments and examine for what purposes (stimulation of innovation or diffusion or both) and context in which they may be usefully applied. This is what the author has done in a previous publication (Kemp, 1997). Another way to approach the issue is to take the dynamics of socio-technical change (including processes of assessment and anticipation) as the starting point for a discussion of governance: how can these be modulated into more environmentally benign directions? The second approach has been explored by the author with Arie Rip (Rip and Kemp, 1996) and in the two Dutch projects in which the author is involved: the MATRIC and PRET projects. It uses the evolutionary view described in Dosi *et al*. (1988), Nelson (1994), Freeman (1992), Edquist (1997), Lipsey and Carlaw (1998), Metcalfe and Georghiou (1998), Rip and Kemp (1998), Kemp *et al.* (1997 and 1998), Schot (1998), and Smith (2000).

The pros and cons of environmental policy instruments

This section offers a discussion of the merits and limitations of environmental policy instruments. It addresses the question of what is the best environmental policy instrument to encourage technological innovation and diffusion. As I will argue below, there is no single best policy instrument to stimulate clean technology. All instruments have a role to play, depending on the context in which they are to be used. Suggestions are offered as to the purposes for which specific instruments may be used to obtain environmental protection benefits through the use of technology.

Environmental standards

As the previous section made clear, from an innovation point of view the experiences with environmental policies are mixed, and often negative. Emission standards were often based on available end-of-pipe technologies and provided little incentive for the development of new, more effective technologies; they merely stimulated the diffusion of existing technologies. This demonstrates the danger of using technology-based standards and the importance of taking a long-term view towards environmental protection.

Technology-forcing standards that require the development of new technologies are a better way of encouraging technological innovation, as the regulatory experiences in the United States demonstrate. However, they may impose high costs on industry unless the regulator is willing to soften and delay standards – although this will have a negative effect on the willingness of suppliers to develop innovations. Technology-forcing standards should only be used when technological opportunities are available that can be developed at sufficiently low cost.

In using standards, it is important that the regulator gives industry enough time to develop solutions that are environmentally benign and meet important user requirements. Time may also be needed to examine whether a solution is environmentally benign and does not pose other hazards. One way of dealing with the problem of compliance time is by giving firms innovation waivers that exempt them from regulations during a certain period. If innovation waivers are used, it is important that firms are given sufficiently long time allowances and that the eligibility criteria are clear. Another strategy is the setting of long-term standards that require the development of new technology.

Economic incentives

Decentralised incentive systems (such as taxes and tradeable pollution rights) are an alternative to command-and-control policies. They are favoured by economists and international organisations such as the OECD. The theoretical benefits of incentive-based approaches to reducing pollutant emissions are many. First, effluent fees (or charges and taxes) and tradeable quotas are more efficient because polluters are given the choice between compliance and paying the polluter's bill. The polluting firm cannot be forced to undertake emissions control for which the marginal costs would be higher than the effluent fee. This means that environmental benefits are achieved at the lowest abatement costs.[7] Second, there is a financial incentive to diminish all pollution – not merely up to the level of emissions standards. They create a constant demand for innovation (Stewart, 1981, p. 1373). The economic belief that incentive-based approaches provide a greater inducement to innovate is based on this argument. Third, such a system depends less than standards-based policies on the availability of pollution-control technology and can therefore be introduced more quickly at lower decisional costs by reducing demands on the regulatory process to take decisions on complex, detailed engineering and economic questions (Stewart, 1981, p. 1374). Fourth, the danger that polluting industries fail to develop new technologies for strategic reasons is lower under an incentive-based regime. And, fifth, economic instruments tend to stimulate process-integrated solutions (including recycling technology) rather than the end-of-pipe technologies that have been overwhelmingly applied in the past.

A disadvantage of effluent charges is the uncertainty about polluters' responses. Another disadvantage is that the total environmental costs (abatement costs plus tax payments) are likely to be high, which lowers their political attractiveness, and may induce the regulator to set a low tax (as has happened in the countries in which they are used). Since freely distributed tradeable pollution quotas do not suffer from this, they may work better than taxes or charges in stimulating environmental innovations.

However, there are also other disadvantages to economic instruments. First, in order to be effective, polluters must be responsive to price signals, which is not always the case. For instance, two evaluation studies in the Netherlands showed that price considerations played a limited role in the timing of investments in thermal home improvements. This suggests that price incentives are probably better suited to changing the behaviour of firms than the purchasing decisions of consumers. Second, the price incentive must be sufficiently high to induce firms to develop and implement environmentally beneficial technologies. This was not the case in most environmental policies in which economic instruments were used (an exception is the effluent charge in the Netherlands discussed later on). And, third, in dealing with transnational environmental problems such as global warming, taxes should be used unilaterally only if their introduction does not put national industries at a serious competitive disadvantage. They should be introduced in those sectors where the environmental costs are a small part of total costs or in sectors sheltered from international competition.

Subsidies

Uncertainty about the demand for cleaner technologies, partly related to unpredictable government policy, may call for the use of R&D subsidies or loans. However, the agency responsible for the subsidy programme should be careful not to stimulate second-rate technologies. The use of subsidies should be restricted to environmentally beneficial technologies for which a market does not yet exist, for example, technologies with long development times (as in the case of energy technologies) or technologies for which there are problems in appropriating the benefits of innovation by the innovator (for example, when imitation is easy). R&D programmes may also be used to increase the number of technological solutions when there is uncertainty about environmental solutions. Subsidies for investments in pollution-control technology are less useful. They clash with the polluter-pays-principle and are expensive; in addition, evaluation research in the Netherlands has proved them to be only minimally effective. There is a great risk that such subsidies provide windfall gains for the firms and consumers receiving them. They should be used only when a switch to cleaner technology entails high costs and produces competitive disadvantages due to less strict regulation in other countries.

Communication

Communication instruments can be useful policy tools for addressing information problems related to products and processes. Environmental management and auditing systems in business (required in the Netherlands for large firms), demonstration projects and information campaigns can be useful to ensure that firms make better use of the possibilities available for emission reduction, especially cost-reducing environmental measures. Information disclosure requirements, such as those in the United States, that force firms to communicate environment-related product information are also believed to be useful. They increase pressures on firms to improve their environmental record while enhancing the environmental awareness of firms. Ecolabels are very important for green purchases. They make the market for green products more transparent. Ecolabels offer a stimuli for producers to innovate but the requirements are often not technologically challenging (as noted in Hansen et al., 2000). Information instruments are believed to be useful as additional instruments, not as substitutes for environmental regulations or taxes.

Covenants

Covenants are a new policy instrument within environmental policy in Europe and the United States. Covenants are contracts between industry or an industrial sector and government in which industry promises to progressively reduce the environmental burden of its activities within a certain period (often five to ten years) according to certain targets. They are also referred to as voluntary agreements, as firms belonging to a sector are free to enter the sectoral agreement (if they do not, they will be subject to regular licensing procedures). Covenants are attractive to industry as they provide greater freedom with regard to the method and moment of compliance, thus lowering the so-called regulatory burden. By handing over responsibility for achieving environmental improvements to industry, covenants may stimulate environmental responsibility in firms, which is important for the wider integration of environmental concerns in companies' decisions. From the viewpoint of the environmental control agency, covenants are attractive because they lower the administrative burden and help to establish a better, more co-operative relationship with business.

A clear disadvantage to the use of covenants is the danger of strategic exploitation of the agreements by industrial firms who may engage in free-rider behaviour, or, more likely, may under-exploit the opportunities for innovation by claiming that it is impossible to meet the targets through compliance technology that fulfils important user requirements. Such behaviour may jeopardise the fulfilment of environmental agreements. Further, the softness of covenants, or voluntary agreements in general, means that there is little incentive for third-party suppliers to develop compliance technologies as the market for the new technologies is insufficiently secured. If covenants continue to be used in the future, as they probably will be, they should be more oriented towards innovation. One way of doing this is through technology compacts between public authorities and private firms to implement long-term technological change (Banks and Heaton, 1995, p. 49). In the compact, industry commits itself to performance goals that require new and advanced technology in exchange for enforcement flexibility and guaranteed acceptance of a new technology. The system of technology compacts looks attractive but, as for covenants, it could be exploited by industry who has superior knowledge of what is technologically possible.[8]

This brings us to a more fundamental issue: the ability of the industry to influence and capture the details of environmental policies. Industry is known to have a great deal of influence over the details of environmental policies, especially standards. Thus, an additional criterion on which to judge environmental policy instruments is the possibility of institutional capture of policies by special interests.

Some policy suggestions

This section offers suggestions for the use of environmental policy instruments in different technological and economic contexts. These are summarised in a table in the Appendix. The table describes the effectiveness and efficiency characteristics of different policy instruments, the purpose for which they may be used (to stimulate technological innovation or diffusion), and the context in which they may be applied, based on experiences with environmental policies and studies of environmentally benign technical change. It should be noted that they reflect the views of the author and are not the outcome of a rigorous model.

Economic incentives

Economic incentives have an important role to play in environmental policy. The case for them is strong: they leave freedom as to the choice and moment of compliance, and provide an incentive to go beyond environmental standards. Especially in the case of heterogeneous firms with different production technologies, economic instruments are attractive. They are more economically efficient than standards, providing equivalent environmental improvements at lower costs and thus, in principle, allow policy makers to achieve greater emissions reductions. They should be used more often, although there are limitations to their effective use that are not always recognised in discussions on the design of environmental policy. For example, there is a danger that economic incentives such as taxes and subsidies provide a too weak and indirect stimulus. Many studies of technology responses to environmental pressures take this view. In their study of clean technology in the United Kingdom, Irwin and Hooper (1992) found that state incentives had only a marginal impact on innovation. This and other considerations led them to the conclusion that "a sensitive but firm policy of putting regulatory pressure on waste and pollution output will be more effective in focusing industrial minds". Hartje (1984), in studying the innovation decisions of detergent manufacturers, doubted that a tax policy would have achieved a switch away from phosphate-based detergents. The 50% reduction requirement for phosphates created a market of significant size for phosphate substitutes.

The idea that regulations are more effective in making firms invest in environmental measures is also widely shared by environmental authorities. For example, in the United States, environmental authorities responsible for pollution prevention programmes stated almost without exception that stringent and certain regulatory demands (such as emission, effluent, or exposure standards, or product bans and phase-outs) are necessary to effectuate pollution prevention. Economic instruments are seen as complements to rather than substitutes for regulatory requirements (Ashford, 1993, p. 296). One system which combines the use of standards with economic incentives is tradeable permits, which makes them attractive for use.

In general, economic incentives may be better suited to stimulating technological diffusion than innovation. A clear example of the effectiveness of economic instruments is provided by the diffusion of biological waste-water treatment plants in the Netherlands. The increase in the effluent charge per unit of "population equivalent" (the typical measuring rod) from NLG 5.42 in 1973 to NLG 74.26 in 1991 induced many firms to invest in biological effluent treatment systems. The diffusion speed was considerably higher for indirect dischargers who discharged their effluent into a collective effluent treatment plant than for direct dischargers. A counter example, also from the Netherlands, is the diffusion of thermal home improvement technologies where subsidies and energy prices played a limited role in the timing of thermal home improvements.

R&D programmes

In order to stimulate technological innovation, a more focused approach may be needed. One way of doing this is through R&D programmes for environmental technologies or more environmentally benign energy technologies. However, as noted above with regard to R&D support, there is always the danger that the programmes promote second-rate technologies and provide windfall gains to the recipients.

Technology-forcing standards

Another strategy to promote environmental innovation is specifying strict environmental standards that require the development of new technologies. However, this should be done only in situations where the environmental risks are large and acute, and where there is consensus about the most viable technological solution or trajectory. If there is no such consensus, there is a danger that technology-forcing standards lock industry into overly expensive and sub-optimal technical solutions. In such circumstances, there is a need for further research and experimentation to learn more about the technological possibilities, about the disadvantages of particular solutions (and how they may be overcome), the economic costs and environmental gains of the technologies, and their acceptability to society. In using direct regulation, policy makers should give careful attention to the design of standards: their strictness, differentiation, timing, administration, flexibility and enforcement. The experiences in the United States with innovation waivers and tradeable permits (described in Hahn, 1989) illustrate that the ways in which the instruments are designed and implemented are important determinants of the technological responses of industry. This is also the conclusion of Blazejczak *et al.* (1999) on the basis of German studies. The authors developed a set of hypotheses about innovation-friendly environmental policy, relating to aspects of instruments, policy styles and configurations of actors that are innovation-friendly.[9]

Matchmaking

Another way of encouraging technological innovation is to build a network of technology suppliers, users and research institutes, as was done in the Danish Clean Technology Development Programme. This programme not only provided firms with economic incentives for developing and implementing clean technologies but, more importantly, provided them with incentives and necessary contacts for finding efficient technological solutions to specific environmental problems (Georg *et al*., 1992, pp. 545-546). Of course, such a policy is not easy; it requires special competence on the part of policy makers. They must have a technological understanding of the production processes, the associated environmental problems and possible solutions if they are to act as a "matchmaker" and identify the relevant participants for the development projects. They must also ensure that more radical solutions with potentially larger environmental benefits are developed and used.

Technology compacts

Technology compacts, described in Banks and Heaton (1995), are another way to promote technological innovation by setting an agenda of phased increments of technological change. As with covenants and negotiated rule making, there is a risk of strategic behaviour on the part of industry who may claim that it is impossible to develop technology that is both environmentally superior and economically feasible.

Exploiting synergies between instruments

From the discussion, it should be clear that there is no single best instrument. Generally, policy instruments should be combined with one another to benefit from synergistic effects. A combination of standards with economic instruments is particularly useful since it combines effectiveness with efficiency. A good example of an effective and economically efficient environmental policy are the US corporate automobile fuel economy (CAFE) standards which set progressive fuel economy targets for automobile manufacturers in the 1979-85 period under penalty of a fine of USD 50 per car sold for each mile per gallon of shortfall. Tradeable pollution permits also deserve to be used more as they too combine effectiveness with efficiency. At this moment, a nation-wide market exists for SO_2 in the United States where utilities can trade SO_2 rights at the Chicago Board of Trade. Early results suggest that the tradeable permits for sulphur dioxide emissions will reduce the costs of the 1990 acid rain programme by 50% or more (Palmer *et al*., 1995).

Modulating dynamics of socio-technical change through public policy

This section offers an alternative view on government policy for achieving environmental protection benefits, based on insights from technology dynamics studies. Within the alternative view – which I have termed the "modulation" approach – the starting point for policy and entrance point of government interventions is the capabilities, interests, interdependencies and interactions (games) of social actors around an environmental problem instead of the environmental problem itself and how this problem may be solved through the use of environmental policy instruments. It was seen above that the environmental policies currently being applied were not effective in securing goals (where goals were obtained, it was usually through other developments). The policies were also found not to be efficient: the same results could have been achieved at lower cost; sometimes the costs exceeded the benefits from environmental protection, sometimes it was the other way round. An explanation for this is that the instruments did not fit the economic-institutional context in which they were applied. This context consists of i) the private and public companies and engaged in activities that cause environmental problems and their customers, ii) the actors who could supply a technical solution to the problem (capital good suppliers, government labs, consulting companies and other knowledge institutes, and the problem industry) and iii) other actors such as environmental pressure groups, banks, insurance companies, users, scientist groups and, of course, the government and politicians – each with their own interests, resources, views, assumptions and values. In this context, the environmental problem is typically contested. Reasons for this are uncertainty about the causes and effects of an environmental problem and different world view and values of policy actors. The same holds true for solutions. Different actors favour different solutions. There is a continuing battle over both problem definitions and solutions in an evolving socio-technical landscape.

These battles are not a peripheral thing: they have a significant influence on the choice and practical design of instruments (Hahn, 1989; Majone, 1976; Bressers and Huitema, 1996). According to Majone, the performance of policy instruments depends more on the institutional framework in which they are used than on their technical characteristics: "The actual outcomes of environmental policies are affected more by the institutional arrangements emerging from the political process than by the technical characteristics of the instruments employed; to use a statistical image, the 'within group' effects (the differential results obtained when the same tool operates under different institutional circumstances) dominate the 'between groups' effects (the results of different tools used under approximately equal conditions)", which leads him to the view that "the significant choice is not among abstractly considered policy instruments but among institutionally determined ways of operating them." (Majone, 1976, p. 593).

Economists – more than any other profession – tend to find the influence of societal actors through politics on the choice and design of policy instruments, a nuisance – something that gets into the way of obtaining environmental benefits in an efficient way and elevating society to a higher level of well-being. However, instead of deploring such societal interactions, they should be taken into account. Policy should not be viewed as something that can occur outside a society, especially not a democratic one. The government itself not only accommodates different interests but also houses them. This should not be assumed away. The modulation approach first sketched in Rip and Kemp (1998) and further developed in Rip and Schot (1999) helps to find a way out of this problem by focusing on societal interactions: how the games that occur and the different stakes may be exploited in ways that benefit society at large. Within a modulation view, the task for government is to modulate the dynamics of socio-technical change into desirable directions, to ensure that the outcome of interactions – between firms and other actors in markets and policy arenas – lead to desirable outcomes from a societal point of view. Within a modulation view, the different interests and problem-solving capabilities of actors, their agendas, expectations, ties and dependencies and the rules of the game (for example, the way in which the policy-making process is structured) are the entrance point of interventions.

The modulation view also says that the focus of environmental technology policy should be on all technologies. Any technology which uses less materials and energy is *de facto* an "environmental technology", although some people may object to the use of this word. Such technologies should be an important target point of policy that tries to reconcile economic goals with environmental protection goals. It also says that, apart from changing frame conditions for technical change in an environment-friendly way, there is a need for environmental policy to be explicitly – rather than implicitly – concerned with technical change. Here the main difference lies with economic views on environmental policy.

The overall idea is that of modulating technical change in environmentally beneficial directions. Key terms are alignment, network management, game management and process management. Within a modulation view, government interventions should go beyond changing the cost and demand structure in which technical change occurs. Policies should be concerned with fostering linkages and establishing a guide for environmental investment though, for example, the setting of goals. This should be done in consultation with industry. Policy makers should be forward-looking and less reactive. Policies should take into account technical developments and utilise these for achieving environmental improvements. One way to do this is through foresight exercises involving industry and science. Foresight exercises can help to set challenging goals. Modulating the dynamics also requires interventions; for example, when industry is resistant to exploiting certain possibilities because it has an interest in incumbent technologies. A way to do this is through game management: interventions in the competitive games between private companies and interactions between companies and social groups over problem definitions and appropriate solutions.

The aim of game management is to create a situation in which there is a search for environment-friendly solutions and to select the best one. This can be done in various ways: by changing the "rules of the game" or by changing the way in which the game is played. Examples of game management are: increasing the number of players (bringing in outsider firms with different interests and capabilities); prolonging the game when no satisfactory results are likely to emerge; empowering certain voices; and manipulating technological and economic expectations, for example by securing a (future) market for a new product or by announcing that there will be a ban on a substance if scientific evidence tells or strongly suggests that it is dangerous. Game management seeks to exploit differences in economic interests by changing the stakes. It thus helps to go beyond win-win solutions. The power of markets is utilised by incorporating ecological concerns in the competitive process, for example by allowing only those products that are best from an ecological perspective. This helps to promote a search process for solutions, both by companies who are supplying an environmentally disruptive product and outsider firms operating in a different market. Game management creates winners and losers. Of course, this will create political problems and is not easy. In less conflict-ridden situations, government agencies could act not as a game manager but as a matchmaker by bringing together technology suppliers to work on a problem, promote learning and providing financial assistance. In the case of technological controversies, they could organise discussions between proponents and opponents in order to generate a better understanding of the issues at stake and guide technology developers in their decisions. Here, they act as a mediator or moderator.

In addition to game management, network management and changing the economic and legal framework conditions (through the use of taxes, covenants, standards, subsidies, etc.), there is also a need for policy to be oriented towards capacity building: enhancing the ability of companies to design environmentally improved products and their ability to adopt clean technologies. Lenox and Ehrenfeld (1997) speak about a company's "environmental design capability": the ability to incorporate environmental concerns into product development. This capability depends on the integration of diverse knowledge resources through communicative linkages and on the use of practical tools (such as design for the environment and green accounting) but also on the "interpretive structures" of the actors. In their study on green product development, Lenox and Ehrenfeld found that resources are insufficient if they are not linked with design teams and embedded in interpretive structures that value and understand the environmental information received (Lenox and Ehrenfeld, 1997, p.195). Environmental management systems – which are compulsory for big environmentally intensive companies in the Netherlands – are one tool which can be used to achieve this and were introduced for precisely this reason by the Dutch authorities. Here, we see that governments are already engaged in alignment policies, assuming a role as capacity builder and alignment agent.

The policies of alignment, capacity building and exploiting differences in economic interests through game management are not a substitute for traditional policies. Within a modulation view, there is a need for corrective policies, in the form of taxes, tradeable permits, environmental standards, fines, and so on – policies that change the framework conditions for economic behaviour and technical change. The modulation approach thus does not preclude the use of traditional policies; rather, it shows how such policies may be used in a different way. It helps to identify useful points for intervention and exercise some leverage and helps to fine-tune policy instruments to the techno-economic and institutional contexts in which they are applied. This is important because in order for policy interventions to have a decisive influence they must tip the balance of economic decision making.

A modulation approach thus helps to see new entrance points for intervention for governments and for other actors (like NGOs) who want to further environmental goals. This is important because changing the framework conditions through a pollution tax or regulation may not be sufficient to bring about innovative responses. As noted in structuralist-evolutionary approaches of technical change (Freeman, 1992; Nelson 1994; and Dosi, 1988) – and as any management expert can tell you – economic actors are not automata responding mechanically to changes in cost and demand conditions. What an organisation and the people in it can do technologically is determined by what they have been doing in the past. Organisations have developed strategies and the people in them are equipped with a certain outlook on problems, and certain capabilities and ways of doing things which also act as a shaping factor. At the same time, organisations are not altogether victims of the past. They have developed systems for dealing with change. Companies, especially the multi-billion ones with large capital assets in dynamic markets, are forward-looking, they scan new technological developments and engage in the surveillance of market developments – the outcomes of which inform their research agenda and strategies. It is these things (the expectations, processes of anticipation, but also the capabilities and outlooks) that could become an entrance point for government intervention, or at least an important consideration in the choice and design of government policy. Modulating the dynamics of socio-technical change should be pursued under the label of sustainability policy. This would require the alignment of environmental policy and innovation policy. It is a new frame for old policies but also suggests some new entrance points for intervention.

Examples of such entrance points for modulation policies are described in Rip and Schot (1999), Geels (1999) and Kemp *et al.* (2000). Key entrance points for interventions for governments (but also other actors) to promote environmental goals are:

- Processes of anticipation and assessment (orientation towards the future) that might be improved. Actors do assessments all the time: they make assumptions about where their market is going; they scan possible technological futures and make guesses about the impacts of changes in the socio-technical landscape (such as the emergence of Internet and public call for corporate responsibility) for their sector and company. Existing attempts at assessment might be broadened to include environmental considerations. Discussions on sustainable futures and the development of images of sustainability are one way to bring environmental concerns into the processes of anticipation.

- Networks for learning and interaction could be created with the help of government, either directly or indirectly through the funding of collaborative research.

- Promises-requirements cycles: to assist in the articulation of new technological possibilities, the articulation of problems connected with their use and the articulation of needs and wants. Technology experimentation and agenda building are ways to do this.

- Niches: spaces in which technologies are protected against selection pressures, acting as a learning environment and possible-stepping stone for overall system change.

One tool to improve processes of anticipation and assessment and shape research agendas is the use of scenarios. Geels (1999) has described how the development of socio-technical scenarios (STSc) can contribute to processes of anticipation and alignment, and thus serve as a vehicle for change. He identifies three purposes for which STSc may be used. The first purpose is that of promoting strategic thinking. STSc may help actors think more systematically about the possible impacts of technologies and their role in the co-evolution of technology and society. As noted by Rip and Schot (1999), business decisions and social interactions are informed by "diffuse scenarios". Economic actors are guided by assumptions about the role of humans, artefacts, organisations in future worlds. STS can be used to make the diffuse scenarios explicit and increase their quality.

A second purpose for which STSc could be used is to build "road maps" and explore technological paths and technological "forks", which then serve to inform public and private policy. STSc may be used to identify pathway technologies: technologies that allow one to move away from an existing technology regime to a new one. On the basis of their socio-technical scenarios about future transport systems, Elzen *et al*. (1998) identified light-weight electric vehicles as a possible important stepping-stone towards a more environmentally benign transport systems. Light-weight electric vehicles have a high innovation-cascade potential, and allow for a co-evolutionary learning process in which people's ideas of what a car should do may change.

The third purpose for which STSc may be used is to facilitate processes of mutual understanding between antagonistic actors. The framework on which STSc are built requires that participants make their assumptions explicit, which is a precondition for mutual understanding. Differences in assumption and values may be unravelled through "argumentive scenarios". This has been done by Rip, Smit and van der Meulen (1994) on the issue of long-lived radioactive waste disposal. It would also seems to be potentially useful for biotechnology, a technology that is believed to possess a significant potential for achieving environmental benefits.

The first two purposes have to do with orienting actors to the future and stimulating strategic thinking and thought experiments. The third, with mediating conflicting views and interests.

Socio-technical scenarios are referred to by Geels as "a tool for reflexive technology policy". They do not deliver "silver bullet" solutions or offer ready-made advice in terms of what to do. The same is true for modulation policies. They offer a somewhat different perspective on governance that may be applied in an instrumental way, to achieve desirable outcomes.

An example of a modulation policy is strategic niche management. Strategic niche management (SNM) is a new approach, first suggested by Rip and further developed by Schot *et al.* (1996), Kemp *et al*. (1998) and Weber *et al*. (1999). SNM aims to modulate the dynamics of socio-technical change through the creation and management of spaces (niches) for the use of a new technology. In these spaces, the technology is partly and temporarily protected from the normal selection pressures of business.[10] The creation and management of niches is a way to work towards regime change.

SNM thus involves the real use of technologies in selected settings. The actual use of a new technology helps articulation processes take place and allows lessons to be learnt about the viability of the new technology and builds a network around the product whose semi-co-ordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices. As I have argued, this is important in fostering technological regime shifts.

SNM is especially appropriate for so-called pathway technologies. Pathway technologies are technologies that pave the way for new developments. They may also be called bridging technologies or enabling technologies. They help to bridge the gap between the current socio-technical regime (in which they may be used for certain purposes) and a new and more sustainable one. Pathway technologies are compatible with both the old and new regimes and allow for a cascade of innovations. Energy storage is an example of a pathway technology: the storage of energy is important for the use of renewables but also useful within the centralised energy system as it may serve to deal with peak demand, helping to reduce peak loads. Electric propulsion and transport telematics (such as transit electronic information and reservation systems) are examples of pathway technologies for public and intermodal transport. Both have been supported by public policies through special research programmes and there has been investment from industry in these technologies but there still is a gap between research and diffusion. A special type of support action is needed to bridge this gap. The Zero Emission Mandate of California which required that a certain percentage of new vehicles sold (2% in 1998 and 10% in 2003) should be zero-emission vehicles (at the point of use) is an attempt to cross this gap. It consisted of a forced commercialisation of zero-emission vehicles in the market. It gave a big boost to the development of batteries, electric propulsion systems and quick recharging systems. It did not result in the wide use of BEVs but it forced automobile manufacturers to work on electric propulsion systems and to re-think car design. The attention to alternative fuel vehicles has resulted in the development of hybrid electric vehicles (in which batteries are combined with an internal combustion engine) and fuel cell vehicles. The latter will be introduced in the market in 2003. Hybrid electric vehicles are already for sale.

The advantage of SNM is that it combines elements of push and pull. For example, user experiences are used to inform private investment and government support policies. By carefully choosing an appropriate domain of application, the costs (of discomfort) for the users may be kept low. It exploits windows of opportunity at the local level and sets in motion learning processes that other actors may benefit from. Through SNM, a transition path may be created to a new and more sustainable system in a gradual, non-disruptive way. It helps actors at the local level to negotiate and explore various interpretations of the usefulness of specific technological options and the conditions of their application. Thus, SNM highlights choices and options and makes the introduction process more transparent and do-able for all parties involved, including producers, users and policy makers (Weber *et al*., 1998).

SNM is not entirely new. It has been attempted by companies for radical innovations such as optical fibres, cellular telephones, aspartame, and computer axial topography (CT) scanners (Lynn *et al*., 1996), who probed early markets as a stepping-stone for penetrating mass markets. For government actors, SNM is a new approach – although some government policies such as the ZEM in California and the Danish policy towards wind power could be labelled as *de facto* SNM policies.

SNM is not a substitute for existing policies, but rather a useful addition to existing policies which is appropriate for working towards more sustainable technology systems. It is an example of an "evolutionary" policy, aimed at deliberately creating paths through circles of virtuous feedback through carefully targeted policy interventions, rather than at correcting perceived market failures. It helps to work towards system renewal instead of optimisation.

Final remarks

In this chapter, I have argued for the use of a modulation approach that is aimed at steering processes of co-evolution rather than at achieving particular policy outcomes, such as a specific reduction of pollutants. Examples of modulation policies are game management and the use of taxes. There are two kinds of modulation policies: those that are explicitly concerned with processes of learning and innovation, and those that are not. Taxes, subsidies, standards and covenants fall into the second category as they are not concerned with learning and innovation in a direct way. They have an important role to play in environmental policy as alternative mechanisms for delivering environmental improvement (such as the demand for green products or companies going “green” because they feel that it is the right thing to do) are weak. However, there are limits to what can be achieved with policies that change the economic and legal framework conditions. They are unlikely to bring about an eco-restructuring. They may be used for achieving an “environmental upgrading” of a sector or chain – what Elzen *et al.* (1996) call “system optimisation” – but they are less well-suited to achieving “system renewal” or “eco-transformation” which involves a transformation of existing systems and trajectories of development which according to some is needed for achieving sustainability goals. Achieving system renewal requires a different type of approach: of probing and learning and specific technology support. Support efforts should be informed by technology assessment and foresight exercises and by discussions of where to go to, to get a sense of direction, and involve experimentation at the local level with new technologies. Possible government policies to work towards system renewal include: the creation of spaces for learning about new technologies, the establishment of long-term goals, and indicative, adaptive planning to guide private and public investment in new directions.

This requires a different type of approach to policy making, one that is more inclusive and participatory, and policies that are forward-looking and adaptive. Learning about environmentally advantageous possibilities should be an important aim. This requires monitoring and evaluation of policies and developments. Designing environmental policies that promote innovation and dynamic efficiency (as opposed to the achievement of short-term environmental goals) is not an easy task. This chapter has suggested a number of practical ways of meeting this challenge, using old and new entrance points for intervention.

APPENDIX

Policy instruments to promote the development and use of environmentally beneficial technologies in different contexts

Policy instrument	General inherent characteristics	Purpose for which they may be used	Context in which they may be applied
Technology-based environmental standards	• Effective in most cases (is when they are adequately enforced) • Uniform standards give rise to inefficiencies in case of heterogeneous polluters	Technological diffusion and incremental innovation	• When differences in the marginal costs of pollution abatement are small and economically feasible solutions to environmental problems are available
Technology-forcing standards	• Effective (in focussing industry's minds on environmental problem) • Danger of forcing industry to invest in overly expensive and sub-optimal technologies • Problem of credibility	Technological innovation	• When technological opportunities are available that can be developed at low enough costs • When there is a consensus about the appropriate compliance technology
Innovation waivers	• Same as technology-forcing standards	Technological innovation	• When technological opportunities are available and when there is uncertainty about best solution
Eco-taxes	• Efficient • Uncertainty about industry response • Danger that they provide a too weak and indirect stimulus • Total environmental costs for industry are likely to be high • Limited political attractiveness	For recycling and material and energy saving Technological diffusion and incremental innovation	• In case of heterogeneous polluters that respond to price signals • When there are many different technologies for achieving environmental benefits

Policy instrument	General inherent characteristics	Purpose for which they may be used	Context in which they may be applied
Tradeable permits	• Effective • Cost effective (which means that environmental benefits are achieved at lowest cost)	Technological innovation and diffusion	• Same as taxes • Costs of monitoring and transaction should not be prohibitively high
Covenants and technology compacts	• Uncertainty about whether industry will meet agreements; should be supplemented with penalty for non-compliance • Low administrative costs	Technological diffusion	• In case of many polluters and many technological solutions • When monitoring environmental performance is expensive
R&D subsidies	• Danger of funding second-rate projects • Danger of providing windfall gains to recipients	Technological innovation	• When markets for environmental technology do not yet exist and when there is uncertainty about future policies • When there are problems of appropriating the benefits from innovation • When there are important knowledge spillovers • In case of large social benefits and insufficient private benefits
Investment subsidies	• In conflict with polluter-pays principle • Danger of windfall gains • politically expedient	Technological diffusion	• When industry suffers a competitive disadvantage due to less strict regulations in other countries
Communication (*e.g.* eco-labels)	• Helps to focus the attention of firms and consumers on environmental problems and available solutions to these problems • Little coercive power	Technological diffusion	• When there is a lack of environmental consciousness • When there are information failures
Environmental management and auditing systems (EMAS)	• Enhance environmental knowledge and competence • Little coercive power	Technological diffusion, product improvement and good housekeeping	• In case of lack of environmental knowledge and competence
Network Management	• Creates a platform for learning and Interaction, to stimulate alignment co-ordinate interdependent activities solutions may be tailored to specific needs • Requires technological understanding of processes and products	Technological diffusion and Innovation	• When there are Information failures
Societal debates about environmental		For stimulating mutual understanding,	• In case of controversies about problems and solutions

issues	learning about values and belief systems Improving processes of anticipation

Policy instrument	General inherent characteristics	Purpose for which they may be used	Context in which they may be applied
Sustainability foresight studies	• Broadens processes of assessment • Enhances strategic orientation	For learning about sustainability options (beyond eco-efficiency) For altering fixed ideas and mind sets	
Setting of goals and use of indicative planning	Provides clarity and (strategic) orientation	For shaping business expectations and guiding strategic decisions	
Game management		Radical innovations with significant sustainability benefits that do not offer a win-win solution	• In case of oligopolies engaged in strategic behaviour over environmental issues
Strategic niche management		For learning about radical innovations and to stimulate processes of co-evolution	• For pathway technologies to a more sustainable system • In case of attractive domains of application

NOTES

1. The term eco-efficiency was coined by the World Business Council for Sustainable Development. See Schmidheiny (1992).

2. According to Baynes, an environmental programme manager at Sony, environmental aspects account for about 20% of the score of consumer products in consumer organisation product tests. A discussion of the factors that led to the use of ONO installations for the control of metal discharges is offered in Kemp (1997).

3. Vermeulen also analysed whether the information provided by government authorities about the availability of subsidies and about the adverse environmental effects of existing technologies and practices influenced the decisions of firms to invest in environmentally preferable technologies. This was only found to be the case for PCBs, which not only had adverse health and detrimental environmental effects, but also posed a fire and security risk for PCB-using firms.

4. Evaluatiecommissie WABM (1992, p. 39), based on Klok (1989b).

5. The rapid response of the oil companies was due in part to the fact that the manufacture of unleaded gasoline did not require any technological innovation. The manufacture of (high-performance) unleaded gasoline was something oil companies in the United States had already mastered in the 1970s, to comply with US environmental regulations (Ashford *et al*., 1985, pp. 435-436).

6. The project was more than a subsidy programme: it brought together firms with environmental problems and firms and institutes that could provide solutions to these problems.

7. According to Hahn and Hester (1989, pp. 100-101), the US emission trading programme introduced in 1974 resulted in cost savings in emission control of between USD 1 billion and USD 13 billion. Almost all of these savings resulted from internal trading.

8. Aggeri (1999) offers a discussion of the usefulness of co-operative approaches to promote innovation. He also provides useful suggestions for managing the process of collective learning.

9. According to Blazejczak *et al*., innovation-friendly policy instruments should rely on the use of economic incentives, act in combination, be based on strategic planning and formulation of goals, support innovation as a process, and take account of the different phases of innovation. Innovation-friendly policy styles are based on dialogue and consensus, are decisive, proactive and ambitious, open, flexible and knowledge-oriented. Innovation policy should include network management.

10. The protection of innovations is not unusual. Many innovations depend on research carried out in public laboratories or universities with the help of public money. In addition, companies themselves create a protected space for research by allowing researchers to do particular kinds of research, using office time, space and equipment. Sometimes an entirely new company unit is created in which a new product is developed free from the usual decision calculus. An example is the Smart car, for which a technological niche was created through company subsidies with the hope that the car would be financially viable or that the knowledge obtained would pay off in some manner. Sometimes research in companies is kept secret from the rest of the company either because it may threaten positions within a company or through fear of failure.

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