

**Innovating Innovation Policy**  
**Rethinking Green Innovation Policy in Evolutionary Perspective**

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## **Innovating Innovation Policy Rethinking Green Innovation Policy in Evolutionary Perspective**

### **Abstract**

Given the need of green innovation and innovation policies to stimulate green technology, the presented paper suggests a new approach in the design of green innovation policies based on an evolutionary perspective. Taking an example from the Dutch situation, Section 2 of the paper briefly illustrates the limited impact of present green innovation programs. Then, Section 3 tentatively analyses some of the core elements of evolutionary thinking suggested by economists and sociologists. Drawing on both perspectives, it is assumed that innovation is driven by selection logic. However, in the economic process, selection is assumed to be dominated by the service characteristics of a technology and in the science/technology system by the technical characteristics of a technology. The mediating system exchanges both sets of characteristics to innovate technology.

Building on the evolutionary notions of technological change and innovation and drawing on regulation theory, Section 4 suggests a framework for evolutionary based green innovation policies. It is argued that the potential to increase the greenness of innovations depends on the potential to simultaneously affect selection processes not only within the economic and the science/technology systems, but also at their interface (the intermediary system). This can be achieved by affecting the structure, conduct and performances in all three systems, and by using the appropriate policy style - facilitation, initiation, or enforcing. Based on this framework a wide range of policy packages is suggested, able to support the longer-term emergence of new technological regimes, endogenously advancing green technology.

Finally, Section 5 tentatively illustrates the arguments for the cases of the emergence of nuclear technology and wind technology in the Netherlands. The main conclusion from this empirical illustration is that evolutionary-based perspectives on technological change may open new intervention points especially to support the emergence of new technologies, such as renewable based technologies.

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# **Innovating Innovation Policy**

## **Rethinking Green Innovation Policy<sup>1</sup> in Evolutionary Perspective**

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### **1 Introduction**

Whereas the range and extent of environmental hazards challenges industries to adopt green technologies and green product designs, at the same time, public authorities are challenged to “green” their innovation policies and programs. For this reason, many countries develop green innovation programs, in order to support and accommodate the development and diffusion of new, environmentally benign technologies. However, these programs appear to be rather restricted in impact and effects. A closer look at, for instance Dutch environmental innovation programs, reveals rather mixed and limited results. One of the causes seems to be the restricted and deterministic analysis of innovation dynamics underlying these policies and programs, assuming barriers and pitfalls in decision making in industrial firms. Relieving these barriers by incentive based means, such as financial programs and tax measures, is the major aim of these programs, hoping to initiate “desired” innovations by facilitating appropriate decision making at the firm level. Undeniably, these measures do have some impact on decision making but innovations accommodated by such measures turn out to be rather incremental in nature and restricted in reach and scope. Basically, they bring about “stand alone” (smooth) improvements of specific technical artefacts, which by far will not satisfy the technological needs to comply with advanced environmental standards such as “sustainability”. In order to meet such advanced standards, more radical innovations are needed that have the potential to engender “discontinuity” of incumbent environmentally hazardous technological tracks and to induce more advanced green innovation policies and programs able to initiate and support these innovations.

In this paper we concentrate on the *policy-side* of this challenge, *assuming the need of green innovation policies*. In the paper we argue that evolutionary notions on technological change and innovation are most helpful and highly significant for the architecture of advanced green innovation policies. Rethinking and redesigning innovation should draw on evolutionary analysis for a better understanding of the structure and dynamics of technological change and innovation. In this way it would be possible to develop effective strategies to support the emergence of green technologies. Better policies and programs may open new potentials to accomplish the greening of “qualitative change” (Saviotti, 1996) in the economic process, to satisfy both economic progress and environmental quality. To design such policies and programs a clear and comprehensive understanding of the structure and dynamics of socio-technical change is vital. Evolutionary thinking contributed to this understanding and this is why it is valuable for innovating the innovation policies.

We start our argument in Section 2 with a brief discussion of conventional innovation programs and take the example of a Dutch program to illustrate the restricted reach and impact

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<sup>1</sup> This paper conceives of *green* innovations as improvements of technology aiming at a reduction of their environmental impact. *Green innovation policies* are understood as public policies and programs encouraging and supporting the development, application and diffusion of green innovations.

of such programs on innovation. Then, Section 3 briefly discusses some evolutionary notions that are significant for innovation policies. Based on these notions, Section 4 develops a framework for environmentally oriented innovation programs. Section 5 tentatively illustrates the logic and rationality of evolutionary based innovation policy. The technological development in the Dutch electricity supply industry is taken as an example. Finally, Section 6 draws some conclusions.

## **2 Support of environmentally oriented innovation: Dutch example**

In the Netherlands, innovation policy has long been the exclusive domain of the Ministry for Economic Affairs but, currently, the number of ministries running environmentally oriented innovation programs has increased. A selection of these programs has been subjected to research, in the attempt to find ways to improve their implementation and impact.<sup>2</sup> All these innovation programs addressed the individual firm in need of new technology, and applicants were predominantly supported by subsidies. The incentive based nature of the programs underlay the assumptions that innovation is a risky and costly business. These assumptions are otherwise the major reasons why industries hold back from environmentally oriented innovation. Costs and risks are assumed to be serious constraints on innovation, and public money is viewed as helping to relieve these barriers.

The innovation model underlying the programs researched was mainly the linear model. Innovation was assumed to be a well organized and well sequenced set of activities starting with the exploration of the technical and economic feasibility of new technologies, continuing with the development and up scaling of technology, and ending with the application and diffusion of the new technology. These activities are certainly major constituent parts of innovation but, in reality, they tend to be far less well sequenced than it is assumed by such innovation models (Cooper, 1983, Rip, 1992). Nevertheless, innovation programs were structured along the sequenced set of activities with the risk of complicating and harming the innovation process. Applicants were forced to match the activity opened for subsidy to enjoy financial support from the program, no matter the real status of and progress in innovation. They were blocked in moving flexibly from one activity to another and this forward and backward moving turned out to be reality of innovation. Only specific activities were eligible under the programs, because they supported either the exploration, or the development or diffusion, but not all three simultaneously.

Innovations supported by the programs tended to be rather incremental. This is illustrated in more depth by the findings of an analysis of one of the major environmentally oriented innovation programs of the Dutch Ministry for Environmental Affairs, called *Programma Milieutechnologie* (Program Environmental Technology).<sup>3</sup> The Program Environmental Technology (PET) facilitated the development and application of environmental technology. Industries, researches institutes and universities developing and demonstrating innovative

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<sup>2</sup> The content of Section 2 leans heavily on the findings of two research projects investigating a set of environmentally driven innovation programs in the Netherlands. The first project was conducted in 1992 and the second one in 1996. The findings of both projects are only available in Dutch language and can be found in Arentsen, Bosveld and Bressers, 1992 and Arentsen and Hofman, 1996.

<sup>3</sup> The paper does not allow for an extensive discussion of the methodology of the research project, but the findings are based on data taken from 146 technology files financially supported by the Dutch Program Environmental Technology in 1993 to 1995. The Program Environmental Technology is the dominant innovation program of the Dutch Ministry for the Environment.

technologies with improved environmental performance compared to incumbents were financially supported by the PET. To some extent, the program also provided additional services and skills. Innovations supported by the PET were not allowed to fall under the private property regime, and the innovator was committed beforehand to ascertain an unconditional diffusion of innovations.<sup>4</sup> In this respect, the PET was unique among the whole set of Dutch environmentally oriented innovation programs that in general allow the innovator to market its innovation. The PET-supported innovations, however, have been opened for all interested users, in order to facilitate the diffusion of innovation as much as possible.

The PET was basically a financial program consisting of an annual budget of approximately \$ 2.5 million and the program supported projects aiming at exploring the feasibility of an innovation, and developing or applying an innovation. The maximum project's budget ranges from \$ 40.000 to some \$ 250.000. In programming, the PET was highly related to priority problems and goals in Dutch environmental policy and to the so-called prioritized target groups.<sup>5</sup> Between 1993 and 1995, 146 innovation projects were supported by the PET. Table 1 displays some of the basic characteristics of these projects.

*Table 1 Number and type of projects supported by PET between 1993-1995*

	<b>PET (1993, 1994 &amp; 1995)</b>
<b>Number of projects</b>	146
Under target group	44 (30%)
Under policy priority	102 (70%)
<b>Application</b>	
Demand driven	64 (44%)
Supply driven	82 (56%)
<b>Type of project</b>	
Feasibility	56 (38%)
Development	60 (41%)
Application	30 (21%)

The table reveals two important points:

1. The larger part of the projects was initiated by technology suppliers, instead of technology demanders. Consequently, the major part of the project was driven by a "technology pull".
2. The largest amount of the budget was spent on projects aiming at the exploration of the feasibility of innovations and the development of innovation. Relatively less money was spent on the application and diffusion of innovations. Table 2 gives an overview of the motives to apply for a subsidy under the PET.

*Table 2 Motives for application*

<b>Type of motive</b> (more than one answer possible)	
Anticipating regulation	67 (46%)
Problem driven	45 (31%)

<sup>4</sup> The impact of this condition on the diffusion of innovations has not been analyzed in the project.

<sup>5</sup> Target groups are a major structuring feature of Dutch environmental policy. Policy goals and means have been formulated for each target group separately. Target groups are, for instance, different sectors in agriculture and industry, transport, electricity production, owners of large scale combustion plants and the like.

In need of technology	76 (52%)
Others	29 (20%)

Table 2 confirms the tight relationship between environmental policy and the programming of the PET policy priorities. This is reflected in the first and third row of Table 2. A consistent share of innovation projects were indirectly initiated by regulatory authorities, who were pushing industries to comply with environmental regulation. In order to meet the regulatory standards, new technologies were needed and the PET enabled the development of these technologies by means of financial support. The third row of Table 2 confirms the wide support of technology suppliers by the PET, because most of the applicants classified under “in need of technology” actually were technology suppliers. The projects classified as “others” hide a wide range of motives for application, but all sharing the idea of getting extra money for innovative activities that were planned anyhow, with or without additional money from the program. Table 3 reveals the environmental gains of the innovations supported under the PET.

*Table 3 Environmental gains of supported projects<sup>6</sup>*

	Number of projects
<b>Emission reduction</b>	146 (100%)
<b>Efficiency improvement</b>	74 (51%)*
reduction in natural resources	45 (61%)**
extension of recycling	29 (39%)
reduction energy use	13 (18%)
reduction water use	13 (18%)

\* n = 146 \*\* n = 74

The first category, emissions' reduction, was a bottom line condition in the PET criteria. Each innovation should have at least reduced hazardous emissions. Table 3 shows that all projects met this obligation, but only 74 produced additional gains classified as “efficiency improvements”. These improvements are interesting since the greater part of them, directly and indirectly (recycling), improved the conversion factors of natural resources.

Finally, Table 4 displays the diffusion pattern of the innovations supported under the PET, which seems to be incremental and rather limited in reach and scope. The innovations registered between 1993 and 1995 are all rather incremental, in the sense that they predominantly contributed to gradual improvements of incumbent technologies. Also the classification “new technology” in the upper part of the table, should be read with some care. Innovations classified as “new technology” should not be regarded as new inventions, but as ramifications of present technologies, for instance new technological solutions to synthesize chemicals or to clean polluted soil or water. As the middle and bottom part of Table 4 show, these type of “new” techniques have a rather restricted impact, referring to specific processes and branches of industry.

<sup>6</sup> The projects have been classified in more than one category, because the classes partly overlap. For this reason, percentages exceed 100%.

*Table 4 Type of innovation*

	<b>Number of projects</b>
<b>Type of innovation</b>	
A new application of incumbent technology	42 (29%)
Modificaton of current process	36 (25%)
Improvement current technology	30 (21%)
New technology	38 (26%)
<b>Technological reach of the innovation</b>	
Restricted to specific application	79 (54%)
Restricted to specific process	61 (42%)
Restricted to specific machine	6 (4%)
No restriction	-
<b>Economic reach of the innovation</b>	
Specific company only	2 (1%)
Branch	64 (44%)
Mixed branches	16 (11%)
Industrial sector	47 (32%)
Mixed sectors	13 (9%)
No restrictions	4 (3%)

### 3 Technological change

Taking the PET innovation program as an example, the previous section has illustrated the rather limited impact and reach of green innovation programs, by providing additional money to firms in order to facilitate decision making on green innovations. Evolutionary theory, has developed a set of ideas, concepts and theories which are helpful in explaining why innovations supported by programs like the PET, tend to be rather incremental.<sup>7</sup> Evolutionary economists are concerned with the “processes by which the products, technologies and institutions which surround us today have emerged and become part of the economic system.” (Saviotti, 1996, 43). In the evolutionary tradition, firms in need of technology behave in a fashion that makes them resemble “merely the incubators and carriers of ‘technologies’ and other practices that determine ‘what they do’ and ‘how productively’ in particular circumstances” (Nelson, 1995, 68). These routines determine to a great extent the set of alternatives firms tend to choose in solving problems they are facing, or to search for new and better technologies. These routines are basically the result of learning processes a firm has internalized in problem solving and to respond to its (changing) environment. Whether these routines are effective or not is basically decided by the firm’s ability to continue its profitability and to maintain and increase its market position. Firms rely on routines because of the uncertainties incorporated in decision-making processes. In order to reduce these uncertainties and to avoid risk, firms tend to fall back on

<sup>7</sup> Hodgson, 1994; Nelson, 1995 and Saviotti, 1996 provide for detailed overviews of evolutionary thinking.

routines and rely on those alternatives in decision making that have proved to be effective in the past. In other words, firms tend to stick to their own corporate history of routines and practices to respond effectively to their environment. They cannot take any risks in this regard and this basically holds them back from “technological experimentation.” Firms simply cannot afford an extensive and risky search for the best or environmentally most benign technologies, beyond their standard operating procedures and routines.

Naturally, firm’s routines and standard operating procedures are not fixed, but do evolve and change in order to keep track with changes in the firm’s environment. Firm’s ability to match the changing requirements of its environment is vital to survive. But here to, the adjustments tend to be rather smooth and incremental which is reflected in the cumulative character of the firm’s knowledge. Firms develop their own knowledge base in a cumulative way meaning the “learning of newer pieces of knowledge requires a knowledge of the previous ones” (Saviotti, 1996, 171). Because of the risk avoiding nature of the search process, it becomes easier for a firm “...to acquire new external knowledge the more similar it is to the firm’s pre-existing  
ibid, 172). According to Saviotti, as long as the firm’s environment does not provide for a radical change in knowledge, “...firm’s knowledge is likely to be cumulative and to display increasing returns to adoption. This implies that firms wanting to enter a particular technological area would face a knowledge barrier. Conversely, firms having accumulated knowledge in a technological area will tend to be locked in that area. Furthermore, if there are multiple options to the development of a technology, after a firm has opted for one of these it becomes extremely difficult to switch to a different one. In other words, in a number of cases technological knowledge can show increasing returns to adoption and, therefore, display irreversibility and path dependence in its development” (Ibid, 172). These trajectories become harder to change the longer the path of their development is. “Increasing returns” appeal to the cumulative and self-reinforcing advantages a technology may enjoy once it has gained a dominant position (Boschma and Lamboy, 1998). As Nelson expresses it: “...there are dynamic increasing returns, in that the more a particular technology is employed, the greater its attractiveness relative to its competitors” (Nelson, 1995, 74). Or differently stated, “...technology is not chosen because it is efficient, but it becomes efficient because it has been chosen” (Rip and Kemp, 1998, 353-4).

In evolutionary thinking the notion of *selection* is important in the explanation how inventions get nestled in the economic process, and which are the reasons for their success or failure. The evolutionary notion of selection environment is very important for innovation and diffusion policy, because the environment incorporates to a great extent the conditions for the survival of the new technologies. Discussing the survival of firms based on the same evolutionary scheme, Nelson argues that whether firms will be successful or not, is basically decided by “ex post competition”. The same can be extended for the survival of new technologies. It is difficult to predict beforehand the winners and losers among new technologies, because the race is decided by a complex set of factors and dynamics incorporated in the “selection environment”. The firm’s environment may be assumed to consist of organizations grouped as competitors, users/consumers, suppliers of input, equipment, knowledge, human capital and regulating institutions. The environment may have certain attributes, such as complexity, diversity, interactivity and rate of change, both qualitatively and quantitatively (Saviotti, 1996, 174). Organizations in and attributes of the firm’s environment are assumed to influence the

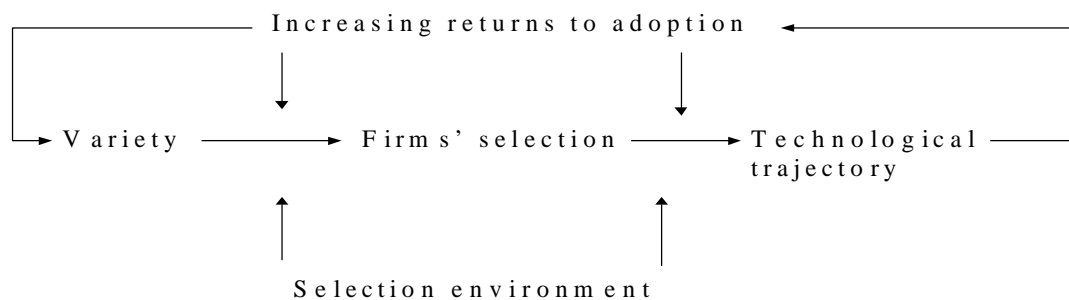
The notion of selection heavily draws upon analogies in biology (Nelson, 1995), explaining the mutation and survival of organisms by their ability to adapt effectively to changing environments. The biological evolutionary theory is based on three principles: the principle of sustained variation, through mutation and recombination, the principle of heredity and continuity, and the principle of selection and survival. The principle of variation draws on the "theory of population thinking" developed by the biologist Ernst Mayr and considers that the evolutionary processes is fueled by the variety of species (Hodgson, 1994). Variety is induced either through mutation or recombination, but it may be also determined by both processes simultaneously. Heredity is the second principle and assumes the existence of a mechanism through which the genes of the predecessors are passed over to next generations. Some theories argue that acquired characteristics are also passed over. The third principle is that of selection and survival of species, which is indicated by three factors: the evolutionary success (in terms of number of species or of stronger developed genes), fitness and adaptation (Hodgson, 1994). The biological theory acknowledges that the results of the selection process depends on the characteristics of the environment but, in that perspective, the selection milieu is basically viewed as static, and exposed only occasionally to few very drastic changes, which are beyond anyone's control, and which result in the metamorphosis of types of species and their distribution. The operationalization of this theory at the technological level should, nevertheless, alter this assumption of a static environment, and acknowledge that the selection environment is dynamic and has a multitude of components and dimensions that interact based on differentiated patterns for the selection of each type of species/technology.

For the operationalization at the technological level of the first principle, one can consider that technological variation is fueled by the multitude of resource processing techniques that have evolved around a certain technological principle. For example, by combining the steam turbine technology with the gas turbine technology, a new technological principle has emerged, called integrated steam gas turbine (ISGT). This processing principle can be altered or enriched by using a series of devices, installations or processes that serve particular purposes. This way, an ISGT can be preceded by a coal gasification installation and the burning processes can be altered so as to reduce NO<sub>x</sub> emissions. Through the integration of the steam turbine technological principle with the gas turbine principle, it can be argued that "recombination" has taken place. Further, the attachment of gasification and NO<sub>x</sub> reduction installations can be equated with a biological "mutation". The result is a new, environmentally friendly coal technology built on the basis of the ISGT principle. This technology can be considered as a "species", that together with other technologies will give the "variation" of electricity technologies (Saviotti, 1996).

In biology, as soon as "variety" is formed, the environment acts on the "species" in order to select the fittest. In the case on technologies, certain components of the environment pre-select one technology from the variety developed. For example this pre-selection force can be only the physical component, but it may be the political one as well. Further, the other components can be reciprocally adjusted, so as to lead to an institutional embeddness of the new technology. The adjustable components are, for example, the market and the knowledge-development sphere. Those technologies that are not pre-selected or fail to be accommodated in the system, because they do not properly meet the portfolio of demands of the more influential components of the environment, are bound to fail and will not survive. After a technology manages to become stable on the market and institutionally embedded, it may evolve in a particular technological trajectory or path (Freeman, 1994). Increasing investments in capital equipment, knowledge expansions and diffusion will lay the basis for the generation

of a new path dependency and the consolidation of a new technological regime. Figure 1 summarizes the core of the evolutionary economist's argument explaining dynamics of technological change.

Figure 1



Drawing on evolutionary economics, sociologically oriented evolutionary approaches developed a different focus and concern in the analysis of technological change processes. Sociologists tend to concentrate on the understanding of the structure and dynamics of technological change processes and are less concerned with their meaning and impact on economic change and development. For this reason, sociologists tend to position themselves as *quasi-evolutionists* (Rip and Kemp, 1998). For sociologists, the “lock in” in certain trajectories and regimes, resembles the idea that today’s technological logic builds upon the heritage of the past and today’s logic may be found, at least partly, in yesterday’s efforts. The dynamics of technological change are assumed to be guided to a large extent by former experiences and learning with technologies in use. The search processes will hardly step outside the technological trajectory that has come into being. “Technology we use today has much in common with that used in the recent past. That is no coincidence. Technology is a body of ideas which solves production problems. To a large extent, the way we go about to solve those problems draws upon what we have learned in the past about how to solve them. For that reason, technological knowledge is cumulative” (Hall, 1994, 10-11).

The concept of technological regime has been suggested to map the collective variant of the idea of cumulative knowledge and technology at the system’s level. According to Nelson this concept has been introduced: “(...) to refer to the set of understandings about a particular broad technology that are shared by experts in a field, including understandings about what a firm needs to be doing to operate effectively in that regime” (Nelson, 1995, 79). A more sociological oriented definition of a technological regime, taking also the “knowledge production side into account”, is provided by Rip and Kemp. They state that “a technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems - all of them embedded in institutions and infrastructures” (Rip and Kemp, 1998, 338). This sociological conception of technological regime is very wide but it nicely points to the “materialized” heritage of technological change and innovation. This heritage incorporates ideas, conceptions, artifacts, routines, habits, customs, skills, standards and institutions that all together determine and shape and condition

present search processes for better technologies. Table 5 tries to cover “the lock in” of the science/technology system, the production side of new technology. Drawing on the biological distinction of “gene”, “individual” and “population”, the table enables to display the multi-layering and multi-dimensionality of novelty creation.

*Table 5 Dimensions of the science/technology system*

	<b>Cognitive</b>	<b>Institutional</b>	<b>Technological</b>
<b>Gene</b>	Scientific laws	Individual scientist/ engineer	Technological principles
<b>Individual</b>	Scientific disciplines	Research institutes	Technologies
<b>Population</b>	Multi-disciplinary Science knowledge- base	Scientific communities	Variety of technology

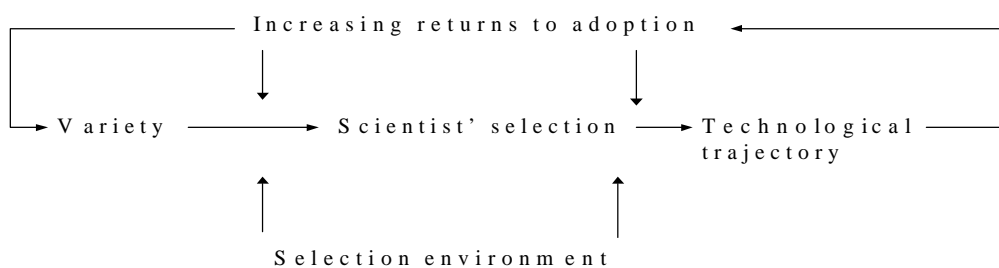
Table 5 covers rather strait-forwardly and, therefore, necessarily simplified, the structure of the “production-side” of innovation. The first column of the table represents the layered building blocks of biology, but here they refer to the layers in the three dimensions of a technological regime: the cognitive, the institutional and the technological dimension. The first, the cognitive dimension, refers to the very elementary base of technology, that is scientific knowledge. This knowledge is cumulative in nature building on centuries of ideas, science and research and encompasses a set of very fundamental scientific laws, such as the laws of thermodynamics, and the theory of relativity. Based on these laws, scientific and technical disciplines have developed, which “produced” the multi-disciplinary science/technology base of technology. The second column of Table 5 reflects the institutional dimension of this process of knowledge production and, this column too, reflects a long-term effort of centuries. The science/technology system evolved over centuries into a highly institutionalized structure of science and knowledge “production” as we know it today in advanced economies. A structure basically constituted by professions, particular organizations and specific science communities. Together they represent the institutional device by which scientific and technological knowledge evolved over time.<sup>8</sup> The third column represents the technological dimension of the regime and refers to the “materialized” knowledge reflected in real techniques and technologies, the artifacts. They represent how the variety of technology is built on particular technologies that have been developed out of a set of technological principles.

Table 5 maps the core-idea that sociologists of technology tend to label as the institutional embeddedness of technological change, especially of science-technology “production”. According to sociologists, the science/technology system has its own logic and dynamics that contributes to the emergence and continuation of certain technological trajectories and contributes to the evolution of technological regimes (Rip and Kemp, 1998). We consider that, like in the economic system, the dynamics within the science/technology system underlay the same elementary mechanisms of variety and selection and scientists and engineers are, like the firm, faced with increasing returns and forced “to obey” the selection environment to survive. Without any ambition to be exhaustive, we formulate a few examples to illustrate this argument. Science has become a highly differentiated, specialized and divisionalized activity, not only among disciplines, but also within disciplines. This not only complicates collaboration in scientific research, but even communication among scientists. Even within disciplines, the high degree of specialization has differentiated the disciplinary idiom. Scientists are obliged to commit themselves to the norms, standards and rules of their own peer group, that becomes

<sup>8</sup> For an extensive analysis on this theme see for instance Schaeffer, 1998.

smaller and smaller by specialization. This may be highly constraining to science and tends to increase the risk-avoiding behavior in science, for instance in the search for totally new directions in research. This risk-avoiding behavior is strengthened by the “institutionalization” of research money. For instance, in the Netherlands, the budgets available for fundamental research are being reduced while competition increases the transaction costs to submit proposals. High transaction costs in combination with a strong commitment to publish (or perish), may contribute to the risk avoiding behavior in science and may enlarge the search for “easy” research money, for instance in industry. This money will not be spent on innovations that are too far from the firm’s existing knowledge. Consequently, the dynamics in the science/technology system are assumed to be driven by the same kind of logic based on which economists tend to explain the selection of technology in the economic system and the emergence of certain technological trajectories and paths. This analogy with the economic system is displayed in Figure 2.

Figure 2



The structure and dynamics of the science/technology system are a minor concern in economically oriented evolutionary thinking. There, innovation, in the sense of “novelty creation”, tends to be “summarized” under the notion of “change event”. Then, the black box is left behind un-opened and the focus of analysis turns back to the real interesting processes, from the standpoint of economists, of selection and nestling of technology in the economic system. In reality, these “change events” hide a whole complex of R&D-activities occurring in highly institutionalized environments and this is where sociologists are interested in. But as Figure 2 illustrates, both dynamics in both the economic and the science/technology system can be understood by the same set of biologically oriented mechanism.

It is at the interface between both systems where economists and sociologists of technology meet. In advanced economies, technoeconomic networks have emerged as bridging devices between the two systems. “The growing knowledge intensity of economies seems to be accompanied by a growing degree of interaction of firms and other organizations” (Saviotti, 1996, p. 12). Technoeconomic networks can be understood as “a coordinated set of heterogeneous actors, (...), which participate collectively in the development and diffusion of innovations, and which organizes via numerous interactions the relationship between research and the market place” (Saviotti, 1996, 197). In advanced economies, there seems to be no longer a clear distinction between the science/technology system and the economic system. Both systems are becoming highly interconnected, while innovation increasingly becomes a joint effort of science, technology and business. As a result of this expanding collaboration,

intermediate devices have developed at the interface between the science/technology system and the economic system (Rip and Kemp, 1998). These devices have become constituent part of the institutional environment in which technology is transmitted. Table 6 tries to cover this interconnection between both systems, drawing again on analogy with biology.

*Table 6 Institutional environment of innovation*

	<b>Cognitive</b>	<b>Institutional</b>	<b>Technological</b>	<b>Bridging device</b>	<b>Economical</b>
<b>Gene</b>	Scientific laws	Individual scientist/engineer	Technological principles	Routines	economic actors
<b>Individual</b>	Scientific disciplines	Research institutes	technologies	TEN	exchange patterns
<b>Population</b>	Multi-disciplinary Science knowledge-base	Scientific communities	Variety of technology	NSI	markets

The added economic dimension in Table 6 tries, in a nutshell, to cover the building blocks of the economic-institutional dimension of a technological regime. The gene's level is represented by individual economic actors, namely producers, consumers, and all other representatives of the functions in the economic process. These actors develop exchange patterns between transactional institutions which represent the individual level, and the whole set of exchange patterns constitute the markets (or the economic system). Both systems, the science/technology system and the economic system are assumed to interact at different levels, which is represented by the "bridging devices" dimension. At the gene's level, both systems are assumed to interact at the level of individual actors and the mediating devices are the routines and habits guiding decision making of "individuals" in both systems. This is the level where individual agents from both systems meet, interact and communicate. This exchange and communication between both systems is structured at the individual level as technoeconomic network (TEN). The configuration of technoeconomic networks is assumed to constitute what is called by evolutionary economists a "national system of innovation" (NSI). Again quoting Saviotti, "this concept, (...), is intended to capture the high degree of specificity which national systems have had up to the present time in generating and adopting technological innovations" (Ibid, 12). Therefore, there are different intermediate devices structuring interaction, exchange, communication and collaboration between the science/technology system and the economic system.

However, not only institutions, agents and agent-configurations act as mediating devices between the science/technology system and the economic system, but also the technology itself. According to Saviotti, technologies/artifacts can be considered as interfaces between inner and outer environments, where the technical characteristics<sup>9</sup> are assumed to represent the inner environment and the service characteristics act at the interface with the outer environment, being the market place. Then the "correspondence (or imaging) between technical and service characteristics, constitutes the coupling of technological knowledge to market demand. The services performed by a given technology determine how closely it can adapt to the environment in which it operates. If the inner environment is appropriate to the outer environment, or visa versa, the artifact will serve its intended purpose" (Saviotti, 1996, 65). Therefore, it can be assumed that technology bridges the science/technology system and

<sup>9</sup> The characteristics of technology are explained in the next section of the paper.

the economic system by exchanging and transmitting knowledge on the technical and service characteristics of a technology. This is displayed in the upper loop of Figure 3.

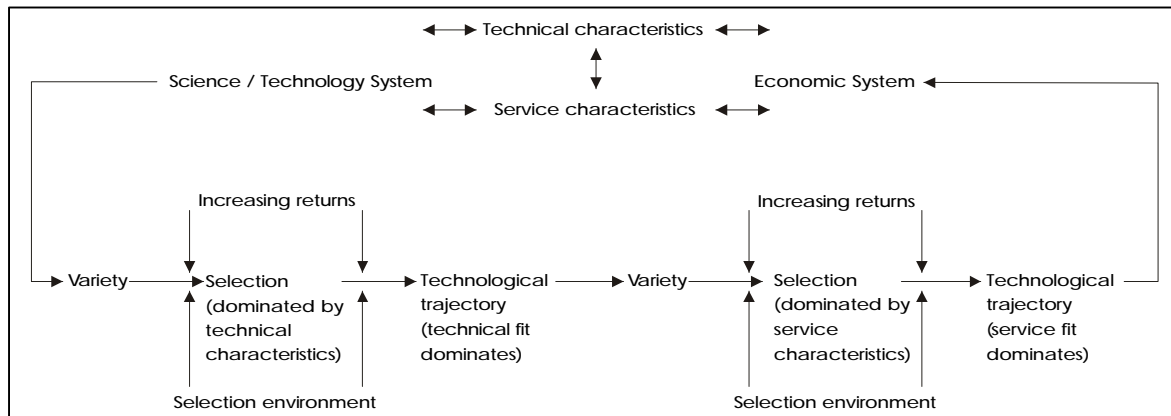


Figure 3

Saviotti's idea of technology being the interface between the inner and outer environment is also helpful in explaining the different logic of "selection" in the science/technology system, on the one hand, and the economic system, on the other hand. In the science/technology system selection is assumed to be dominated by the technical characteristics of technology, whereas in the economic system selection may be assumed to be dominated by the service characteristics of technology. This is illustrated by the bottom loop in Figure 3. In order to survive, both systems exchange knowledge on both the technical and the service characteristics, and this is the way in which technology continuously paves the paths of its development.

To summarize, both economic and sociological analysis are most helpful in understanding how and why technology changes, and how innovations find their way in the economic processes through selection. Both in the science/technology system and in the economic system, the selection of technology is highly institutionalized and strongly influenced by various forces in the selection environment. Neglecting these forces is full of risks, both for the scientist/engineer and the firm, and highly threatening for their continuation. By adapting to "increasing returns", both systems try to reduce these risks but, in this way, they at the same time continue the trajectories along which technology progresses and changes. Innovation not only draws on cumulating knowledge, but also on the cumulating character of the structure and institutions in which new knowledge is "produced", and on the routines that cumulated in these institutions. This may be constraining for the greening of technologies and the emergence of green innovations. A better understanding of the structure and dynamics of technological change and innovation is a first and (necessary) condition to architecture more satisfying green innovation policies. Drawing on both the economists' and the sociologists' contribution to the understanding of the structure and dynamics of technological change, the next section sketches a framework for such policies.

#### 4 A framework for green innovation policy

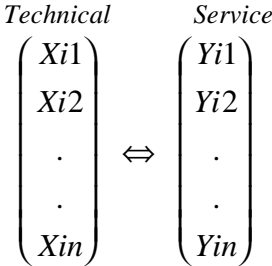
Drawing on evolutionary theory, the challenge to green innovation policy is to find strategies and policies that can result in innovations forming new, self-standing technologies and new technological trajectories that have inherent superior green performances, as opposed to most of their incumbents. And the ultimate challenge of governance is to design policy packages able to support the longer-term emergence of new technological regimes, endogenously advancing

green technology. A first step in the architecture of such policies is to develop a clear conceptualization of green technology.

*Mapping green innovations*

The “greenness” of innovations, meaning their contribution to the improvement of the environmental quality is of minor concern in evolutionary thinking. Theories, especially economically oriented, mainly concentrate on the impact of innovations on the structure and functioning of the economic process. For green innovation policies, the environmental performance of new technologies is, however, the major focus. Therefore, green innovation policy should draw on a clear conceptualization of green innovations. Saviotti (1996) has suggested a twin characteristic representation of technology, and building on his ideas, it is possible to conceptualize the “greenness” of innovation. According to Saviotti a technology may be characterized by two sets of characteristics: technical characteristics constituting the inner structure of a technology, and service characteristics describing the service or functionality for its users (see Figure 4).

Figure 4: Technical and service characteristics of a technology<sup>10</sup>



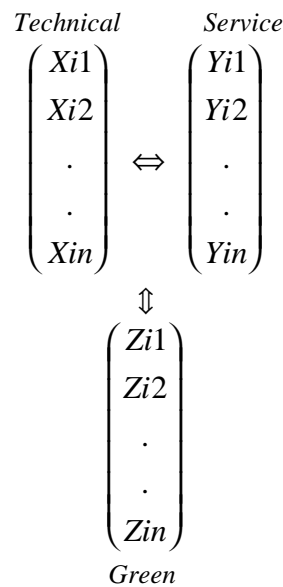
In this way, the differences between technologies can be easily mapped: technologies differ either in their technical or in their service characteristics, or in both. But, more importantly, the twin representation helps to distinguish conceptually between incremental and radical innovations. An incremental innovation is conceptualized as a change in the level or value of technical characteristics, whereas a radical innovation is conceptualized as a *qualitatively* different internal structure of a technology in regard to the previous one, meaning the renewal of the set of technical characteristics.

From the perspective of green innovation policy, the twin characteristics representation of technology suggested by Saviotti, needs to be amended because of two reasons. Firstly, neither the change of technical characteristics, nor a qualitative change of the internal structure of a technology will necessarily improve the environmental performance of a technology. Secondly, service characteristics of technologies may incorporate a real environmental threat, which is strongly illustrated by the automobile example. For these reasons, we suggest to add to the twin characteristics representation of technology, a third one, labeled as the green characteristic of technology (see Figure 5).

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<sup>10</sup> Figure is taken from Saviotti, 1996, 64.

Figure 5: Triple characteristics representation of technology



The green characteristic may either refer to the technical or the service dimension of a technology. With regard to the technical characteristics, they are decided by the conversion efficiency rate of natural resources and the amount of resources incorporated in the technology and, therefore, represent the *internal* part of the green characteristic.<sup>11</sup> The green characteristic of the service dimension is decided by the hazards to the natural environment and therefore represents the *external* part of the green characteristic. The triple characteristic representation of technology enables us to amend the type of innovations distinguished by Saviotti from a green perspective. Table 7 displays the greenness of the different types of innovation.

Table 7 Green innovations

	Technology characteristics	Service characteristics	Internal green characteristics	External green characteristics	Greenness of innovation
<b>Level characteristics changes</b>	<ul style="list-style-type: none"> <li>• yes</li> <li>• yes</li> <li>• yes</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• yes</li> <li>• yes</li> <li>• yes</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• no</li> <li>• yes</li> <li>• no</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• no</li> <li>• no</li> <li>• yes</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• neutral</li> <li>• incremental</li> <li>• incremental</li> <li>• incremental</li> </ul>
<b>Internal structure changes</b>	<ul style="list-style-type: none"> <li>• yes</li> <li>• yes</li> <li>• yes</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• yes</li> <li>• yes</li> <li>• yes</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• no</li> <li>• yes</li> <li>• no</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• no</li> <li>• no</li> <li>• yes</li> <li>• yes</li> </ul>	<ul style="list-style-type: none"> <li>• neutral</li> <li>• radical</li> <li>• radical</li> <li>• radical break trough</li> </ul>

Table 7 illustrates that not every change in the level of technical characteristics or the internal structure of a technology is also a green innovation. From a green perspective, the least helpful innovations seem to be those changing the technical and service characteristics of a technology, or the complete structure of a technology, without any progress in the environmental performance of the technology. From a green perspective, these kinds of innovations should be

<sup>11</sup> This is based on applied thermodynamics. See Cornelissen, 1998.

avoided as much as possible. On the other hand, every change in characteristics, whether, technical or service, that decreases the environmental impact, improves the green profile of the technology and is, therefore, highly “desirable”. The most promising green innovations, however, seem to be those qualitatively changing the internal structure of a technology resulting in progress in both the internal and the external green characteristics of technologies. Examples here are innovations significantly increasing the efficiency rate of conversion of natural resources, or technologies, in the sense of “products”, incorporating significantly less natural resources compared to their predecessors. In advanced economies the challenge is to combine such types of innovations with the maintenance of at least the service level, since consumers are hardly willing to change consumption patterns or to compromise service standards in exchange for environmental quality. The most promising type of green innovation, however, is shown at the bottom line of Table 6. This represents the case of a qualitative change of the internal structure of a technology, improving both the service and the green characteristics of a technology. In this case innovation incorporates a real “break trough”, by setting up a completely new technological trajectory which is intrinsically green in structure and service.

Consequently, Saviotti’s twin characteristic representation is most helpful to grip more clearly the conceptual meaning of green technology. Green technologies are assumed to integrate excellent technical and service characteristics, with excellent internal and external green characteristics, and green innovations are those progresses in technology that contribute to these kinds of technology profiles. Drawing on the idea of Saviotti to consider technologies/artifacts as interfaces between inner and outer environments, green characteristics may be assumed to represent the interface between the technical characteristics of a technology, on the one hand (inner environment), and the service characteristics of technologies, on the other (the outer environment). This is displayed in Figure 6.

*Figure 6 Green Interface between technical and service characteristics of technology*



Therefore, following Saviotti, by assuming the technical characteristics to represent the inner environment of technology and the service characteristics to refer to the outer environment, the green characteristics can be viewed as the mediating device between both environments. Then, at the level of technology, the challenge of green innovation policy should be to support the bridging of both environments, being the integration of green characteristics with both the technical and the service characteristics of technology. In this way, green innovation policy may encourage the longer-term emergence of technological trajectories, while keeping environmental hazards more intrinsically at the minimum. To support such green innovations, the policy repertoire may address basically three points:

- the technical characteristics of a technology, dominating selection in the science/technology system;
- the service characteristics of a technology, dominating selection in the economic system; and
- the exchange of both characteristics, at the interface between both systems.

Drawing on the core argument of technological change and innovation in evolutionary theory, intervention should predominantly use the selection-mechanism as the influencing device, because it is mainly the dynamics of the “selection” processes that shape and influence technological trajectories. Therefore, the potential of green innovation policy to contribute to the greening of innovation and technology depends on the ability to affect “selection”, so as to increase the greenness of variety. This is the core of the lesson taught by evolutionary theory, and green innovation policy is challenged to translate this lesson in effective intervention strategies.

### *Mapping green innovation policy strategies*

The final question to be answered then is how to architecture green innovation policies. The answer to this question needs to bring in another research tradition, regulation theory. For this, the easiest way to provide for an answer to the question is to match, ad randomly, the whole repertoire of strategies suggested by economic and political regulation theory (Mitnick, 1980) with the different opportunities to intervene in the innovation trajectory. A more systematic way to proceed is to architecture policy-packages of interrelated and mutually reinforcing strategies, in order to profit as much as possible from the catalytic effect of the dynamics of technological change and innovation itself. This is what we suggest to do, and with the help of some elementary notions form regulation theory it is possible to clarify the argument.

Taking the neo-classical structure-conduct-performance paradigm as a starting point,<sup>12</sup> the selection of green technology may be encouraged by intervening in structures, conducts and performances of the science/technology system, the intermediate system (mediating networks) and the economic system. Furthermore, the intervention can be more or less coercive for the addressee, meaning that intervention can take different modes or styles, depending on the amount of coercion incorporated in the strategies of regulation (Richardson, 1982, Vogel, 1986). For example, in a purely publicly owned hierarchical organization the style is almost coercive by definition, whereas in a neoclassical free market the coerciveness of regulation is supposed to be minimal, not to disturb the proper functioning of the market. Likewise, public intervention strategies can be assumed to underlie a continuum of coercion (Vedung, 1998), with certain points representing different intervention styles. In this way three basic styles can be distinguished:

- a facilitating style, predominantly supporting the selection of green innovations;
- an initiating style, predominantly encouraging the selection of green innovations; and
- an enforcing style, predominantly forcing the selection of green innovations.

Combining the building blocks provided by evolutionary and regulation theory enables to architecture a framework for green innovation policy. Table 8 displays this framework with examples in each cell of strategies bearing greening of “variety” by intervention of “selection”.

### **Here table 8<sup>13</sup>**

Table 8 displays a set of interrelated and mutually reinforcing strategies to support the emergence of green innovations, drawing on the lessons of evolutionary theory. Firstly, the table distinguishes between the science/technology system, the intermediate system and the

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<sup>12</sup> The structure-conduct-performance paradigm encompasses the basic idea of economic structures determining economic behaviors that result in certain performances.

<sup>13</sup> Table 8 is presented in the appendix.

economic system. Section 3 of the paper has sketched how these systems are structured, how are they reciprocally related and what is their significance for technical change and innovation. Therefore, each of the systems should be included in the intervention domain of green innovation policy. The basic entrance points for green innovation policy in each system are represented in the second row of the table, by “structure”, “conduct” and “performance”. Strategies may address the structure of the systems, the conduct of the agents operating in the systems or the performances of agents. Secondly, the first column of the table represents the three styles of intervention suggested in regulation theory and includes the facilitating, the initiating and the enforcing style. Thirdly, the combination of intervention point and the intervention style has been “translated” in examples of more concrete innovation strategies, policies and programs and this is displayed in the cells of the table.<sup>14</sup> It should be emphasized that the strategies suggested in each cell should be read as examples and not as comprehensive sets of strategies.

Fourthly, the table is basically suggested as a tool for policy makers to design green innovation strategies, policies and programs. The table attempts to convey the complexities of technological change and innovation, to make them more accessible for policy intervention. Therefore, the decomposition of real-life - complexities that are analyzed and explained by both economically and sociologically oriented evolutionary scholars - is one of the main tasks of policy analysts and policy designers. To pursue public goals and interests, policy has to intervene in these complexities and a first and necessary (not sufficient) condition, therefore, is to make these complexities “manageable” for policy intervention.

Fifthly, the table enormously broadens and widens the scope of innovation policies in comparison to the innovation programs briefly discussed in Section 2 of the paper. These programs predominantly address the firms’ conduct in the economic system and, at the best, they provide for additional services regarding cooperation between innovators and firms. In the perspective of evolutionary based green innovation policies the scope of these programs is far too limited to encourage real green technological transitions and the emergence of new green technological trajectories. As Section 2 has illustrated, the results of these programs are rather incremental steps in greening technology and their diffusion potential sticks to the level of firms and branches.

Sixthly, Table 8 illustrates the need of combined strategies incorporating reinforcing logic, both in time and space. Green innovation policy should not be restricted to the short-term intervention of firm’s activities and performances but they should also support and encourage the renewing and greening of the science knowledge base on a longer term basis, to allow for the development and emergence of green technologies. Improvement and innovation of the intermediate system in which technology is communicated and technical and service needs are exchanged may support the emergence of such technologies. Therefore, green innovation policies have to be oriented on the short, medium and long-term simultaneously. In this way, strategies can reinforce each other to support “discontinuity” in the nestled structures and routines of the past, in order to contribute to the emergence of new, green technology. This way, drawing on evolutionary theory, green technology itself will find its way through history by paving its own (green) paths. The next section of the paper tentatively illustrates the core of this argument for the cases of nuclear power and wind technology in the Netherlands.

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<sup>14</sup> It should be emphasized that the table is only meant as a policy-mapping device and not as explanatory scheme of technical change.

## **5 Empirical illustration**

The present section attempts to explain the formation and institutional embeddedness of two new technological regimes in the Dutch electricity industry - nuclear and wind technologies - by using the evolutionary concepts of: "variation" and "selection environment". As the concepts of "path dependency" and "increasing returns" are associated with already formed and self-standing technological regimes, the present empirical analysis will be less concerned with them. In line with the theoretical considerations in Section 3, the selection environment will be viewed in a dynamic perspective and will be considered, in this case, to have six main components: political, normative, economic, social, cognitive and physical. The mission of governance is to be able to come up with the coherent packages of innovation and diffusion policies. These policies should enable the different components of the selection environment to adjust one another in the right sequence, so as to allow for the institutional embedding of new technologies and the consolidation of new self-standing technological regimes. However, not all components are in all cases active in the selection process. This is why, in our analysis differentiated attention will be paid to them. If governmental policies for innovation and diffusion are successful in moulding the selection environment, dynamic increasing returns of technologies will emerge making the new technology acquire a dominant market position. Further, a path dependency is created, which signals the formation of a new technological regime. Our analysis illustrates briefly some of the dynamics accompanying the establishment of two technological trajectories in the Netherlands. Consequently, the analyses will be focused around the concepts of "variation" and "selection environment".

### **Nuclear power technology**

Beginning with 1946, in the Netherlands there was attention for nuclear power generation, based on the feeling that this would become very important in the coming years. Nuclear power was regarded as a promising technology, from which there were high expectations for electricity generation. This feeling arose in spite of the lack of access to nuclear resources in the Netherlands. The first actors involved in the development of nuclear technology were the generation companies, which viewed themselves as main responsible for the construction of nuclear plants. In order to gain the necessary knowledge, they established a joint research institute, the KEMA, which also intended to observe developments in the nuclear field taking place in other countries (especially those in the US, where there was an enormous head start compared to any other country). This can be viewed as the start of the learning processes in nuclear technology in the Netherlands. Other actors involved in nuclear research were the research organization FOM (Foundation for Fundamental Research on Matter), the Ministry of Economic Affairs, and the electricity industry which wanted to obtain a strong position, both nationally and internationally, in this new economically promising field. All these actors were involved in the selection process of nuclear technology.

The government, through the Ministry of Economic Affairs, was interested in the development of a new energy technology with the help of which to ensure national energy self-sufficiency and to acquire a strong position in the international nuclear energy market. Therefore, the political component of the selection environment was a decisive pre-selection force for the emergent technology. In the same time, the electricity industry and the research institutes were also directly interested in the development of nuclear technology, acting equally as absorptive forces in the selection environment.

The Dutch government was, beginning with the 1950's, strongly in favor of nuclear power generation. In 1957, the government was even planning to produce all electricity based on nuclear energy, by the turn of the century. From the start, a difference could be seen in motives driving the efforts of generation companies and the other parties involved. For both the Ministry and the electricity industry one of the main motives was to obtain a strong position on the international nuclear market. To reach this goal, the industry was willing to cooperate at the national level to a certain extent. For generation companies, however, this was clearly not the case and they decided to try to develop nuclear technology on their own, solely for their own purposes.

Because of the high expectations from nuclear energy, nuclear technological development became consistently supported by the government. In 1955, the government established a special national research institute for nuclear energy, Reactor Center Netherlands (RCN<sup>15</sup>). Although all parties involved were supposed to support the institute financially, the electricity generation companies managed to use their contribution for their own nuclear research programs. They even managed to supplement their financial resources with funds from the government and the Euratom (the European Atomic Energy Community). The technological principles researched by the KEMA differed from those researched by RCN. The generators researched, beginning with 1951, the development of a Suspension Reactor (SR), which was quite an apart technological principle, while RCN was researching other principles, which were also on the research agenda of other institutions at international level. Consequently, at that time there were two research programs for different nuclear technologies. Both groups of researchers received funds from the national government and from the Euratom. The generators paid also their own share in the research budget, but in fact there were the consumers who were actually funding the research, by passing on research cost down to the last level in the value chain.

The SR technology had some advantages over other technologies in the field, but also a technical disadvantage, which couldn't be solved, despite the intensive research efforts and investments. Generators built a test reactor, but afterwards it was decided that a prototype reactor would not be constructed. This was because of the high costs, the withdrawal of support from the Euratom, the retreat of industry's support and the choice of Dutch government for two other types of reactor. Moreover, generators considered that knowledge on technical, economic and organizational issues, that are needed when exploiting a nuclear plant, was missing and, based on a risk avoiding strategy, they decided not to commission a SR plant, but to buy a different technology from another country.

Because of the high costs of a powerful reactor, generators decided to buy a smaller plant, with the intention to use it also for continuing their research activities. This made it possible to receive new funds from the Euratom. The electricity industry had meanwhile formed the organization Neratoom, meant to research and gain experience in the nuclear field on a joint basis. Electricity utilities at different levels in the value chain were invited to cooperate in the building of the new nuclear plants, but the Neratoom was kept aside from this business. The first nuclear plant, based on the boiling water reactor technology, was built in Dodewaard. A second plant was also bought from a foreign company and commissioned in Borssele, in 1973. This plant was based on the pressurized water reactor technology.

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<sup>15</sup> Later this institute has been renamed in Netherlands Energy Research Foundation (ECN).

Because generators decided on their own on the technologies to be used for the new power plants, the RCN had no further influence in the selection of the technological principle. The Dutch government, at that time strongly in favor of nuclear technology in general, also had no real influence on what kind of nuclear technology should be used in nuclear plants, because the legislation of the moment did not entrusted the government with decision-making authorities on such matters. The national government was not able to change the course of events because of the autonomous position of generators<sup>16</sup>. The variation of technological alternatives emerged from the national research institutes and from foreign companies. But, in the selection process for the technological alternative, generators were the only actors that played a role, although other actors wished to participate in this process. This happened because the normative component of the selection environment had not been adjusted at the right time, so as to smoothen the emergence and adoption of the new technology. It was only in 1974 when it was decided that the decision-making competence with regard to choosing technologies and building nuclear power plants should be assigned to the Ministry of Economic Affairs.

Citizens became involved in the selection process in the 1970's, manifesting their protest against nuclear energy. The rising public concern for nuclear radiation, the problem of the nuclear wastes and the proliferation of nuclear weapons worldwide began to act, through the social component, against the selection of nuclear energy technology. This social resistance became more and more organized in the Netherlands, throughout the time. In 1978, this opposition became so strong that the Dutch government was forced to organize a national debate about nuclear energy. The debate ended in 1984 with a final report and the report's conclusion was clear: the public considered the expansion of nuclear power undesirable. Nevertheless, it is doubtful how seriously intended the government to take the results of the social debate. The scientific community, supported financially by the government, was still pro-nuclear and the government, through its national energy policy, showed no intention to abandon its nuclear ambitions. The electricity industry was also still in favor of nuclear energy expansion.

Regardless of the outcome of the national debate, the Dutch government was considering to authorize the building of two or three more nuclear plants, when the Chernobyl accident happened. This accident reinforced citizens' rejection of nuclear energy as a technological regime, which placed more pressure on the government to abandon its nuclear program. Consequently, the government decided to postpone the authorization of new plants, although it was suggested that there was no connection with the nuclear accident. This decision was also an indirect consequence of the fact that the national consumption of electricity was at a standstill, due to the energy saving policy, based on environmental reasons. Moreover, the costs of nuclear power were no longer competitive with the costs of fossil-based electricity. There was enough supply of natural gas and it was possible to import electricity at lower prices. In the years to follow, the new governments managed to eschew a clear decision about the future of nuclear energy. For the moment, there is no prospect for the unofficial nuclear moratorium to be lifted, although, some groups, also within government, are still in favor of nuclear energy. In 1993 the Ministry of Economic Affairs presented the Nuclear Energy File in which nuclear energy was qualified as being safe, as a remedy against the greenhouse effect and with manageable waste problems. Subsidies for nuclear research to the NCR continue even nowadays, although in recent years the research orientation at the FOM and the NCR has

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<sup>16</sup> Although provinces or municipalities owned the generators, they acted like private companies.

changed to fusion reactors. This new technological principle is researched from the sole initiative of the political component

As regards the selection process within the economic component, a particularity for nuclear technology in the Netherlands is the interference of utilities/firms - generators, on one side, and the electricity industry, on the other side - with the activities of research institutes. Therefore, nuclear technology did not undertake a sequential selection process, as we described in Figure 3 (Section 3), i.e. a selection dominated by technical characteristics, followed by a selection dominated by service characteristics. Selection was rather a disordered process through the expansion of the economic system in the science/technology system. The expansion process is not a negative development per se, because, as we argued earlier, technoeconomic networks and national systems of innovation are essential for the success of technological innovation. The problem was that the expansion has been made on an adversarial basis, rather than on a cooperative basis. These frictions among actors placed in different components of the selection environment led to the deceleration of the both technological progress and the institutional embeddness of the new technology.

The following conclusions can be drawn from this analysis:

1. nuclear technology emerged based on the decision of the political milieu, and developed based on the consistent financial support from the government, the electricity industry and generators;
2. although there was agreement on the need of nuclear research, there was no consensus on the technological principles to be researched; more actors were involved in research, but there were only the generators who ultimately made the selection of the type of nuclear technology to be used for building power plants, because the legislation of the moment entrusted only them with decision-making authorities;
3. the normative component of the environment was adjusted only with delay to the particularities required by the development and application of nuclear technology, and this had negative effects on the pace at which the new technological trajectory has evolved;
4. due to the rejective forces coming from the social component, and intensified after the Chernobyl accident, nuclear technology finally failed to meet the demands of the environment sufficiently and did not survive the selection process. The major reason of this failure lays in the non-satisfactory "green characteristics" of the new technology, mostly the external green characteristics, consisting of radiation and nuclear wastes.

As concerns the role of the government in the development of nuclear technology, it can be argued that, by stimulating two different lines of nuclear research, the government failed to establish a single coherent and workable technological innovation network. Because of the normative constraints to decide on the building of nuclear plants, the government was not in the position to influence the selection of a certain type of nuclear technology. After legal restraints have been removed, the social component came forcefully on the selection scene and, by exerting pressure on the political component, it managed to obstruct the further development of the nuclear technological trajectory.

## **Wind power technology**

The development of wind power technology in the Netherlands has been spurred during the 70's. After the world energy crisis, in 1973, the Dutch government chose as main goals energy conservation and fuel diversification. The development of renewable energy was seen as one means of attaining the second goal. In order to achieve this, the central government took the role of leading actor in the promotion of wind energy and engaged in two policy lines: intensively funding research, and deploying various financial instruments targeted at specific groups to encourage investments in wind turbines. Therefore, it can be argued that the political component of the "selection environment" has played, also in this case, the role of the pre-selection force for development of a new technological trajectory based on wind energy.

As regards technological variation, when the discussion over the promotion of wind energy started, there were two main technological principles developed, at international level: based on horizontal axis and based on vertical axis wind turbines. Seemingly because of the combined reasons of technical advantages (lower minimum wind speed requirements, lower land take) and traditional use of horizontal axis windmills in the Netherlands, the alternative of horizontal axis wind turbine has been selected by Dutch manufacturers. Currently, there are three main companies manufacturing wind turbines and all of them fabricate horizontal axis turbines. Therefore, in the case of wind technology, the available "technological variation" was poor - only two alternatives - and the selection of the specific alternative was done solely by manufacturers. This selection was based on considerations related to the physical constraints of the environment and, presumably, the traditional use of this system for mechanical applications. Consequently, it can be stated that the group of manufacturers acted as a second pre-selection force.

As stated above, the main actor in the development of wind technology was the central government, through its political decision to widen the basis of energy resources through the use of, among others, wind energy. The question is now, if the other components were properly prepared by the government to accommodate the emergent technology, and to what extent was their adjustment successful, by implementing the two innovation policy lines mentioned in the introduction. To begin with the physical environment, wind resources in the Netherlands allow for the economic generation of electricity. However, the country is densely populated, which makes competition for land use a serious physical constraint for windfarms' development. Hence, the physical environment acted through both absorptive and rejective forces. But, through spatial planning policies, assuming increased interaction between central government, local authorities and local communities, this physical stumble block could be overcome. However, the policy lines adopted earlier by government failed to address the interaction between the political and social dimensions of the selection environment, so as to diminish the physical constraints.

As for the economic component, the central government has tried to re-adjust it, firstly through investment subsidies, until 1996, and later through tax reductions on wind investment projects. The main economic actors who made use of these instruments were distribution utilities, which commissioned approximately 70 % of the installed wind capacity. In order to encourage generators to make use of wind resources, the obligation to buy wind based electricity at a minimum price has been imposed on distribution companies. Later, in 1998, the system of "tradable green electricity labels" has been introduced, applicable for distributors of electricity, but the system has not been put in place yet. For end-users, two policy instruments have been used: the system of MAP levy and the voluntary "green electricity scheme". According to these

schemes, higher tariffs can be voluntarily paid by consumers, in order to stimulate deployment of renewables.

All of these are examples of traditional target group oriented innovation policy instruments that were used by the government to promote wind technology. These policies can, undeniably, play an important role in inducing technological innovation and diffusion, but they are not sufficient in themselves. Besides, they have a sequence which is not entirely driven by the logic of economics. For example, the government was criticized that it replaced investment subsidies with tax reductions too early. This scared off manufacturers that investors will lose interest in wind technology. Consequently, the uncertainty over the future of the market led to the reduction of the research enthusiasm on the part of manufacturers and research centers, resulting in only modest technological progress after the switch between these policy instruments. Besides this, the government understood only later that distributors are not willing to engage in too much wind generation because the capacity credit of wind turbines is low, rising total electricity prices. More research on wind resources assessment, however, is able to improve the capacity credit and encourage further investments (Johansson, 1993). In a nutshell, the way in which the government has moulded the economic component of the selection environment has not been coherent with its action on the research and production centers. Basically, the initiation of real technological innovation networks able to communicate research needs among actors and diffusion timetables has failed thus far.

As regards the cognitive component of the selection environment, research institutes were intensively funded by government in order to develop wind technology at standards that can make the emerging industry internationally competitive. Three national research programs were launched by the government: in 1975, in 1982 and in 1991. As a result of these programs, knowledge on wind resources was refined and higher quality projects were being put forward for utilities and other investors. Research institutes have played, consequently, the role of an absorptive selection force. However, as just mentioned, the facilitation of interaction with other actors has not been a success either because the right connections were missed or because the timing of connection was inadequate. In short, the research efforts were intense but not efficiently channeled. The social component can be considered to include the local authorities and citizens. Local authorities were seen as part of the game in the issue of sitting permits, but a failure was registered in attracting them in discussions in an earlier stage of the project. This has resulted in transforming both municipalities and local communities in strong “breaking” forces of the system, leading to a retarded development of wind based technology.

As concerns the normative component, like in the case on nuclear power, this has been adjusted only with delay. Beginning with 1989 it became possible for private companies to get involved in generation activities, but they chose to invest in cogeneration plants, in joint ventures with distributors. It was only in 1998, however, when it has become possible to connect, to the central high voltage grid, generators with less than 2500 MW installed capacity. If this restriction on central generation had been removed earlier, presumably more wind power would have been installed, as it is more economical to attach wind farms to larger generation pools. The normative component of the environment was, therefore, initially abrasive.

The broad conclusions that can be drawn from this analysis of the selection environment are that:

- 1) the emergence of the wind based technological regime in the Dutch electricity system was decided at the political level, while the selection of type of wind technology (horizontal

axis) was done by manufacturers, without the involvement of political, social or other forces;

- 2) the institutional embeddness of the emergent technology was not a smooth process because of the failure of government to design a coherent innovation policy program able to reciprocally adjust all components of the selection environment in the right time sequence; this process is still taking place as the selection environment awaits for further adjustment;
- 3) because the market position is still very modest, the increase in returns has not taken place yet, which would be the characteristic of a consolidated technological trajectory.

Wind technology is still squeezed between the older deeply rooted fossil technological regimes. By adopting a traditional policy line on innovation, the government failed to break off the path dependencies of the dominant technological regimes. The explanatory schemes and concepts provided by evolutionary theory offer policy analysts valuable tools for the design of innovation and diffusion policies able to

- 1) support the emergence and institutional embeddness of new technologies, through action on the adjustable parts of the "selection environment" and to
- 2) dismantle the dominant and no more desirable technological regimes, by finding and acting on the sensitive junctions of their paths.

The evolution of the wind-based technology in the Netherlands is a case in point for the failure of traditional innovation policy approaches, and for the helpfulness of evolutionary frameworks of thinking in understanding how the dynamics of the socio-technological change and the dynamics of governance can be reciprocally adjusted.

## **6 Conclusions**

The presented paper has attempted to understand the restricted reach of current innovation policies in terms of environmental performances, and to suggest a new approach in the design of green innovation policy based on an evolutionary perspective. Present innovation programs seem to have a restricted impact on the environmental performances of technologies because of a deterministic approach on innovation dynamics. In order to illustrate this, Section 2 has analyzed a selection of conventional innovation programs in the Netherlands. Based on this analysis, it has been observed that Dutch innovation programs consisted mainly of financial incentives, they were focused at firm level, and were based on the assumption that technological innovation is too costly and risky a business for firms to be undertaken without financial governmental support. Projects that received funds were mostly initiated by suppliers of technology ("technology pull") and were generally commissioned in order to find technologies able to comply with the continuously tighter environmental regulations and standards. The outcome of these programs was just a modest, incremental technological change. No radical inventions were produced and no impressive novelties were introduced. Consequently, it has been suggested that, by improving the understanding on innovation dynamics with the help of concepts drawing on evolutionary theory, we can improve the scope and "greenness" of innovation policies.

In this sense, Section 3 has performed a theoretical inquiry in technological change and innovation from an evolutionary perspective. Evolutionary biology is based on three core concepts: variation, heredity and selection. Of these, the notions of variation and selection seem to be most helpful in understanding innovation dynamics and technological change, but they have been interpreted in different ways by various disciplines. The analysis made in Section 3 has been concerned with two of these perspectives: one held by economists of technology, and a second one defended by sociologists of technology.

Evolutionary economists are concerned with the processes underlying the emergence and economic embeddness of new products, technologies and institutions. In order to explain the embedding of technologies in the economic system, they look at firm and argue that firm's behavior is based on routines, which leads to the (re-)enforcement of the adopted technological trajectory. Firms base their decisions on routines because of two reasons: firstly, because of the fear to lose their economic profitability and market position, and, secondly, because of the cumulative character of technological knowledge which brings increasing returns by following a certain knowledge-track. Evolutionary economists are, therefore, more focused on the economic embeddness of innovation and less concerned with the emergence of new products and technologies, which is considered as a "change event", without a further elaboration on underlying mechanisms.

Economists look at how inventions are absorbed in the economic sphere and argue that, after "variation" is formed, certain innovations are selected at two levels: the level of the "environment" as a whole, and the level of the individual firm. Further, the routine mechanism becomes activated and the selected technology evolves in a self-standing technological trajectory. The new technology will begin to display increasing returns characteristics, and this will influence future selection processes at both levels - firm and the general environment. Evolutionary economists explain the emergence of increasing returns mainly through the cumulative knowledge on the use and economics of technology (knowledge on "consumption"-side of innovation) and consider that firms play the most important role in the selection of technological innovation and change.

Evolutionary sociologists have a different perspective and are concerned with underpinning the structure and dynamics of the production-side of innovation, which forms the science/technology system. Therefore, in contrast with economists, sociologists pay attention to the emergence of new products and technologies and argue that the science/technology system has its own internal dynamics leading to the creation and re-enforcement of certain technological trajectories. The underlying mechanisms are the same as those considered by evolutionary economists - variation, selection and routines. But sociologists argue that after variation is formed, scientists play the most important role in the selection of the new technologies. After the technological trajectory has evolved, the increasing returns to adoption arise mainly due to the cumulative character of technical and scientific knowledge, placing the argument of increasing returns on the production side of technology.

Further, Section 3 has elaborated on the interface between the economic and the science/technology system by conceptualizing the institutional environment of innovation along five dimensions - cognitive, institutional, technological, economic, and the bridging device dimension - and looking at the three biological levels - gene, individual and population. It has been argued that technoeconomic networks and national systems of innovation are essential bridging devices, ensuring that innovation becomes increasingly the joint effort of scientists, technologists and firms. Moreover, technology itself appears to be a particularly interesting bridging device between the two systems. In the approach of Saviotti, technologies have two types of characteristics - technological and service characteristics. In processes of innovation and change, knowledge on technological characteristics is transmitted through the science/technology system, while knowledge on service characteristics is transmitted through the economic system. This conduces to a differentiated approach on the dynamics of technological change and innovation, compared to the more traditional perspectives of

evolutionary economists and sociologists. In this new approach, after variation is formed, a first selection occurs in the science/technological system, based on the technological characteristics. Further, the economic system becomes involved in the selection process, where selection is dominated by the service characteristics of technologies. Both selection processes are affected by the environment as a whole, and, after the technological trajectory has evolved, increasing returns are induced by cumulative knowledge on both the technological and service characteristics of technology. This leads to the consolidation of a new technological regime, embedded in the economic and science/technology system.

Following the theoretical inquiry in the dynamics of innovation, Section 4 has attempted to design an innovative framework for innovation policies, which can induce the emergence of new technological trajectories with inherently higher environmental performances. This has been done in two steps: mapping "green" innovations, and mapping policies and strategies that can result in green innovations. The point of departure in mapping green innovations has been the twin characteristic conceptualization of technology by Saviotti. According to Saviotti, innovation can address either certain levels of technological characteristics, or the internal structure of technology. This vision on technology is most helpful in estimating the degree of novelty introduced by innovations, but, unfortunately, it cuts no ice in terms of the "greenness" of innovations. This is why this paper has suggested the introduction of a third characteristic of technologies, namely the "green characteristics", viewed as having an internal part and an external part.

Consequently, the greenness of innovation has been conceptualized and mapped along four dimensions - technological characteristic, service characteristic, internal green characteristics and external green characteristic -, and at two levels of change - internal structure of technology or change in the level characteristics. It has been concluded that, generally, four types of innovations can be differentiated in terms of improvements in environmental performances: neutral, incremental, radical and breakthrough. The radical and break-through green innovations have been found to be those taking place at the level of the internal structure of technology, when at least one part of the green characteristic of technology is affected. These innovations have the real potential to establish green technological trajectories.

The second step in designing an innovative policy framework has been the mapping of policies and strategies for achieving green innovations. It has been argued that the potential to increase the greenness of innovations depends on the potential to simultaneously affect selection process not only within the economic and the science/technology systems, but also at their interface (the intermediary system). This can be done by affecting the structure, conduct and performances of actors involved in all three systems, by using the appropriate policy style - facilitation, initiation, or enforcing. Consequently, the governmental approach can support, encourage or enforce the selection of green innovations. The policy framework proposed has been meant as a tool for improving the design of green innovation policies and reflects the need to arch innovation policies over time and space, in order to secure a wider reach and a more stable outcome of technological innovation and change.

Finally, Section 5 has attempted to explain the processes of emergence and institutional embeddness of nuclear and wind energy technologies in the Netherlands. The main conclusion of these two analyses was that the traditional governmental approach on innovation policy was not helpful in sustaining these two processes, and that the evolutionary framework of thinking, based on the concepts of "variation" and "selection", can improve the visualization of the

intervention points and policy styles, so as to adjust the dynamics of technological development with the dynamics of the selection environment.

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## Appendix

Table 8 A framework for green innovation policies

Style	Science/technology system			Intermediate system			Economic system		
	Structure	Conduct	Performance	Structure	Conduct	Performance	Structure	Conduct	Performance
<b>Facilitating</b>	<ul style="list-style-type: none"> <li>research funding</li> </ul>	<ul style="list-style-type: none"> <li>fundamental long term research</li> </ul>	<ul style="list-style-type: none"> <li>greening of knowledge</li> </ul>	<ul style="list-style-type: none"> <li>network management</li> <li>network money</li> <li>Greening of NSI</li> </ul>	<ul style="list-style-type: none"> <li>supportive infrastructures</li> </ul>	<ul style="list-style-type: none"> <li>rewarding green choices</li> </ul>	<ul style="list-style-type: none"> <li>management of global competition</li> <li>niche management</li> <li>support of emerging green markets</li> </ul>	<ul style="list-style-type: none"> <li>clear and reliable green policy goals</li> </ul>	<ul style="list-style-type: none"> <li>privileging green technologies and products</li> </ul>
<b>Initiating</b>	<ul style="list-style-type: none"> <li>green sciences</li> </ul>	<ul style="list-style-type: none"> <li>Privileging early green adapters</li> </ul>	<ul style="list-style-type: none"> <li>Green knowledge “production”</li> </ul>	<ul style="list-style-type: none"> <li>greening of network infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>discourse on green values and standards</li> </ul>	<ul style="list-style-type: none"> <li>discourse on green of technology</li> </ul>	<ul style="list-style-type: none"> <li>endogenous green transactions</li> <li>convenants and agreements</li> </ul>	<ul style="list-style-type: none"> <li>support of green designs</li> <li>innovation programs</li> <li>providing knowledge and information</li> <li>collaboration among firms (integral change management)</li> </ul>	<ul style="list-style-type: none"> <li>encouragement demand for green technology and products</li> </ul>
<b>Enforcing</b>	<ul style="list-style-type: none"> <li>greening of teaching programs</li> </ul>	<ul style="list-style-type: none"> <li>blocking research trajectories</li> <li>withdrawal of research money</li> </ul>	<ul style="list-style-type: none"> <li>blocking technologies and trajectories</li> <li>conditioning new technological trajectories</li> </ul>	<ul style="list-style-type: none"> <li>participation of green groups</li> <li>access</li> </ul>	<ul style="list-style-type: none"> <li>cooperation among firms and organizations</li> </ul>	<ul style="list-style-type: none"> <li>sincerity of information</li> <li>contractual relations</li> </ul>	<ul style="list-style-type: none"> <li>legitimizing internalization of externalities</li> </ul>	<ul style="list-style-type: none"> <li>annual green business reports</li> <li>collaboration among firms</li> <li>environmental departments in firms</li> </ul>	<ul style="list-style-type: none"> <li>charging pollution</li> <li>environmental regulation</li> <li>best technical means (technologies and products)</li> <li>green performances of technology</li> </ul>

