Paula Kivimaa

The innovation effects of environmental policies

Linking policies, companies and innovations in the Nordic pulp and paper industry

HELSINGIN KAUPPAKORKEAKOULU
HELSINKI SCHOOL OF ECONOMICS

A-329

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Abstract

The importance of technological innovations providing environmental benefits has been highlighted increasingly in political and scientific discussions. For example, following the Lisbon Strategy, the European Commission has launched an Action Plan for Environmental Technology (ETAP). To address the demand for environmental innovations, in the belief that environmental policies could complement ETAP, there is a practical need to analyse how environmental policies actually promote innovations. The effects of environmental policies on innovations have been studied before, but the literature provides partly inconsistent and context specific results. It rarely goes deeper into analysing the implications of the context. Thus this thesis analyses the innovation effects of environmental policies by examining both policy and company levels.

The research examines the mechanisms through which environmental policies affect innovations, and how variation within and between organisations responding to policies influences the policy effects. Thus the thesis endeavours to explain how the context surrounding policies and innovations varies in the Nordic pulp and paper industry, and why environmental policies sometimes fail to support innovation. The thesis also provides information on how policies could better support environmental innovation. To achieve these objectives, a perspective combining policy, technology, and organisation and management studies is adopted.

The policy effects are studied as one among many determinants influencing innovation processes, following the idea of the innovation systems literature. The case study research approach comprises twelve cases of technological innovations and inventions, both processes and products, in the Nordic pulp and paper industry. The innovation cases are complemented by an analysis of how environmental considerations are integrated into product development in four large paper and packaging companies, and by one policy case examining the integration of environmental considerations into Finnish technology policies.

The Nordic pulp and paper industry presents an extremely interesting empirical case for the study as it has been important for the historic and economic development of Finland and Sweden, and has recently experienced significant changes in its operational environment influencing its future innovation potential. The sector is characterised by fairly significant achievements in environmental process innovation, developed collaboratively in networks of public and private organisations, often in response to environmental policy. By contrast, environmental product innovations and the focus of environmental policies on products have been rarer. Recently, internationalisation and consolidation of companies, globalising paper markets, and decreasing R&D investments have transformed the innovation context in this sector.

The findings of the thesis show that the ways in which environmental policies influence innovations can be divided into six categories: responsive effect, anticipatory effect, two-way effect, indirect effect, negative effect and no influence. Variations in how environmental policies affect innovations are explained by the heterogeneity of public policy, the variety of ways in which organisations respond to environmental policies, and changes and inertia in market conditions and technological systems. Thus, factors related to policies, organisations, markets and technological systems have conditioned the innovation effects of environmental policies in the Nordic pulp and paper industry.

Environmental policies alert companies to the environmental improvements required. Yet policy signals are sometimes inconsistent in the type of actions they promote. Environmental policy includes different aims, and their respective realisations may prove partly contradictory. An improvement in one environmental impact may be detrimental to another. Environmental policy also has aims whose realisations may be in conflict with other sectoral policies, such as technology and energy policies. Moreover, environmental policies actually comprise various instruments and characteristics, making it even more varied in the effects it generates.

The organisational dimension is important from the perspectives of environmental policies and innovation. While the target groups of environmental policies are often well defined, the different types of organisations and organisational networks engaging in innovation processes are seldom fully acknowledged by environmental policymakers. This is partly because innovation has rarely been an explicit goal of environmental policies. Even within the defined target group of a specific policy, the differing structures and cultures of seemingly similar companies influence their responses to policies and their innovation capabilities. In large companies, functional disintegration between those following developments in environmental policy and those developing new products may hinder the diffusion of policy signals. Thus, a policy may simply fail to induce innovations because its effects are actually dependent on a complicated route from policy to outcome with a multitude of cause-effect points. The study emphasises the importance of acknowledging organisational variation in policy studies.

Environmental policies have two important roles from an innovation perspective: to facilitate innovation within dominant technological systems, and *also* to keep options open for other innovations to emerge outside the boundaries of the existing systems. Evaluations of current policies and policy systems are needed to identify inconsistent policies and potential barriers to innovation. From an innovation perspective, for example, policies specifying particular technologies to be used, not allowing testing of innovations and having too lax requirements may create innovation barriers. Thus new and revised environmental policies should incorporate flexibility to alternative solutions and should be foreseeable, consistent with other policies and to a degree binding to best support innovation – by enhancing markets for environmentally improved products and technologies.

Key words: environmental policy, innovation, environmental technology, organisations, pulp and paper industry

Acknowledgements

This study originated somewhat unintentionally when I started working for the research project Increasing eco-efficiency – an analysis of factors generating innovations (Ecoinno) in summer 2003 after the project had already began. As most of the empirical work and the thoughts in this thesis are based on work I carried out during Ecoinno, I am most indebted to my colleagues in that project: Mikael Hildén, Per Mickwitz, Matti Melanen and Heli Hyvättinen in the Finnish Environment Institute (SYKE) and Ken Oye, James Foster and Mikael Román in the Massachusetts Institute of Technology. The greatest thanks go also to the former Ministry of Trade and Industry that through the ProACT Research Programme funded Ecoinno and the writing of the four journal articles in this study during 2003-2006. I also thank the Nordic Council of Ministers that funded the Green Markets and Cleaner Technologies project during 2006-2007 which resulted in a research report that is attached as a contribution to this thesis. The Foundation for Economic Education receives my thanks for funding the months in 2007 that I spent on writing the thesis manuscript.

I want to give my warmest thanks to Professor Raimo Lovio in Helsinki School of Economics and Dr. Per Mickwitz in SYKE, who have greatly contributed to my PhD process and been my supervisors. The actual work on the PhD began when, in spring 2004, I went to meet Raimo with a thesis idea. Raimo supervised my work by providing a lot of space to develop my own ideas but has also imposed positive pressure on me to go ahead and get things done. I hope our cooperation continues in future projects.

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Helsinki, 6 April 2008

Paula Kivimaa

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II. Kivimaa P, Mickwitz P. 2006. The Challenge of Greening Technologies - Environmental policy integration in Finnish technology policies. *Research Policy* 35(5): 729-744.*

III. Kivimaa P. 2007. The determinants of environmental innovation: the impacts of environmental policies on the Nordic pulp, paper and packaging industries. *European Environment* 17(2): 92-105.**

IV. Kivimaa P. 2008. Integrating environment for innovation: Experiences from product development in paper and packaging. *Organisation & Environment* 21(1): 56-75.***

V. Kivimaa P, Kautto P, Hildén M, Oksa J. 2008. Green Markets and Cleaner Technologies (GMCT) – What drives environmental innovations in the Nordic pulp and paper industry? *Tema Nord* 2008:512, Nordic Council of Ministers: Copenhagen. ****

Author’s contribution

The author of this thesis has alone produced the summary essay and Articles III and IV.

Article I is a collaborative product written jointly with Dr. Per Mickwitz. Both authors participated in writing all parts of the paper. The author of this thesis took the initiative for the paper and had the main responsibility for collecting and analysing the empirical material.

Article II was also jointly written with Dr. Per Mickwitz. It is based on the authors’ joint work on policy integration, and the basis of the research and the framework and criteria for the analysis were jointly developed. The author of this thesis had the main responsibility for collecting and analysing the empirical data and writing about the relationship between environmental and technology policies. The discussion and conclusions were produced in collaboration.

Article V was written with Mr. Petrus Kautto, Professor Mikael Hildén and Mr. Juha Oksa. The author of this thesis took the initiative for the paper, wrote the first draft and took the main responsibility for the writing. All sections were jointly written with Kautto and Hildén. The literature review by Oksa was used as a basis in the introductory parts. The framework for collecting empirical material was developed jointly with Kautto. The author of this thesis collected and analysed empirical material related to five out of the seven empirical cases, while Oksa and Kautto were responsible for the remaining two cases.

1 INTRODUCTION

1.1 Can obligations promote novelties? Links between environmental policies, companies and innovations

The connection between environmental policies – obligations or incentives imposed by public authorities on companies and people to protect the environment – and technological innovations, novelties, is an interesting one. It deserves further examination for reasons arising from scientific discussion and real life environmental concerns.

Technological development and the extensive use of different technologies have caused many environmental problems. Yet technology has also helped to react to numerous problems, such as ozone depletion and acid rain. In effect, innovation in environmental technologies has been identified as one of the most important ways of solving environmental problems (e.g. Ashford, 1993; Weber and Hemmelskamp, 2005) and various policies have been initiated in support of environmental technology. For instance, following the Lisbon Strategy on economic, social and environmental renewal, the European Commission (2004) launched an Action Plan for Environmental Technology (ETAP) aiming to reduce pressures on the natural environment, improve the quality of life and stimulate economic growth with the help of more sustainable technological change.[1] In addition, for example, the Communication on Integrated Product Policy (IPP) has recognised that product innovations need to be directed for the benefit of the environment (European Commission, 2003). Besides these innovation-directed environmental policies, there is a multitude of other environmental policies with potential, positive or negative, innovation impacts. The actual effectiveness of these policies in supporting environmentally sounder technological change therefore merits attention to better facilitate environmentally sustainable development.

Many have already researched the links between environmental policies and innovations (e.g. Ashford, 1993; Porter and van der Linde, 1995; Jung et al., 1996; Kemp, 1997, 2000; Cleff and Rennings, 1999; Norberg-Bohm, 1999), obtaining interesting but sometimes rather contradictory results that demonstrate the complexity of this relationship. While some have found that environmental policies can indeed result in innovations (e.g. Hemmelskamp, 1997; Norberg-Bohm, 1999; Kemp, 2000; Becker and Englmann, 2005) others have also identified negative effects (e.g. Jaffe and Stavins, 1995; Jaffe et al., 2003). Those agreeing that environmental policies may reap benefits in the form of innovation have had disparate theoretical and empirical results on the type of policy instruments that are best suited for this purpose. The inconsistent results regarding the innovation effects of environmental policies indicate that the relationship needs more thorough examination to explain what causes the inconsistent or context-specific results of environmental policies. Further knowledge of the causal connections between environmental policies, company activities and technological innovations is needed to explain why environmental policy

[1] In 2005, the Lisbon Strategy was refocused on growth and employment, while the development of ETAP still continued.

succeeds or fails in inducing innovations. The two research questions I address in this thesis derive from this problematique:

1. What are the mechanisms through which environmental policies influence technological innovations?
2. Why do environmental policies sometimes fail to support innovations with increased environmental benefits?

Studies on organisations and management have shown that an organisation's environmental performance is a combined result of demands originating from the operational environment and the internal factors of the organisation (e.g. Gunningham et al., 2003; Howard-Grenville et al., 2006). Similarly, organisational factors have been mentioned among the determinants in complex innovation processes, and industrial research and development has especially been identified as a key factor for innovation (e.g. Edquist, 2005; Pavitt, 2005). Yet organisations have varying purposes, structures and cultures, influencing how they engage, or do not engage, in innovating activities. They are composed of different cultures and sub-cultures (Frost et al., 1991; Alvesson and Berg, 1992; Howard-Grenville, 2006), have varying responses to new technology (Orlikowski, 2000) and have differing resources and capabilities to innovate (Rugman and Verbeke, 1998; Christmann, 2000). In addition, the units within organisations have varying functions and ways of working (Frost et al., 1991; Howard-Grenville, 2006). Thus, the ways in which organisations interact with their institutional surroundings differ (e.g. Meyer and Rowan, 1983; Oliver, 1991). Variation in organisational responses to environmental policies and in organisational innovation activities possibly contribute to the mechanisms through which environmental policies affect innovation, leading to the third research question of the study:

3. What role does variation in organisations play in environmental innovation processes from a policy perspective?

Earlier studies on innovations argue that little is known about how public intervention should take place to promote innovation, especially in the changing context of globalising businesses (Chaminade and Edquist, 2006; Hage and Meeus, 2006). Some have called for new theories of innovation and knowledge production to explain the competing views on this field within and between different disciplines (e.g. Hage and Meeus, 2006). I aim to contribute to the development of new theories by explaining some of the mechanisms through which environmental policies impact on innovations and why environmental policies sometimes fail to promote innovation. The connection between public policies and innovations is complex and is mediated through various actors. I therefore seek to explain the context-specific differences in the innovation effects of environmental policies by considering the variation within and between organisations, responding to public policies, and also the heterogeneity of the policies and policy contexts that influence innovation. The study focuses on the interaction between public policy and company levels (Figure

1). The work has a wider relevance, because it relates in general to innovations yielding societal benefits.

As the purpose is to gain more profound knowledge of the mechanisms through which environmental policy does (or does not) affect innovation, the study is carried out from a bottom-up, case study perspective, by first identifying innovations and companies and thereafter analysing which policies have affected them. In examining how policies actually affect innovations, it is also important to assess the significance of the wider context (e.g. other policies, markets, and technologies) in this process. The study mainly focuses on (i) the combined impact of environmental and technology policies on innovation, serving as an example of the wider policy context, and (ii) the variation that the organisational or market factors may bring to the final impact of the policies.

The study relates to the field of industrial innovation (e.g. Hage and Meeus, 2006), and complements earlier studies on environmental innovation in the pulp and paper sector (e.g. Hildén et al., 2002; Berkhout, 2005; Foster et al., 2006). Earlier studies describing environmentally beneficial technological development in the sector have largely been limited to water pollution (Sonnelfeld, 1998; Andersen, 1999; Sæther, 2000; Harrison, 2002; Hildén et al., 2002). To provide a firmer ground for generalisations, this study explores a wider range of cases related to air and water pollution, waste, and resource and energy consumption.

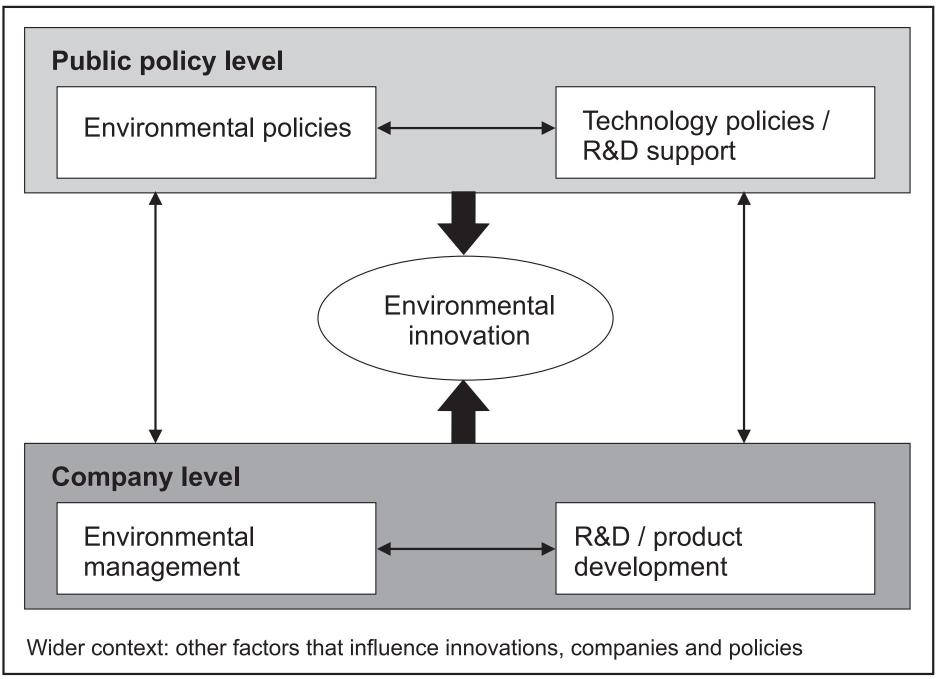

Figure 1: *Scope of the study: The interactions between public policy and company levels influencing technology-based environmental innovation*

1.2 Structure of the thesis

This article-based doctoral thesis comprises three parts. The first part deals with the background of the study: introduction, definition of key concepts, and descriptions of the relevant literature and the research approach. The second part presents an overview of the industrial sector from which the empirical material is drawn. It also draws together the key findings of the articles and goes further in creating an overall view of the policy and organisational factors influencing the innovation effects of environmental policies. The third part includes the five articles and essays.

In the first part, Chapter 2 provides definitions for the key concepts used. First, the concepts 'innovation' and 'environmental innovation' are defined. This is followed by briefer explanations of the policy-related concepts: environmental, technology and innovation policies, and policy integration. The different literatures the study builds on – relating to science and technology studies, organisation and management studies, and policy studies – are discussed in Chapter 3. Although several literatures and disciplines are relevant to innovation research, the chapter focuses on those found most useful for examining the links between environmental policies and technological innovations from a case study perspective. Chapter 4 describes the research approach and methodology, emphasising case studies.

In the second part, Chapter 5 describes the source of the empirical material, the Nordic pulp and paper industry. Moving on to the findings of this thesis, Chapter 6 examines the heterogeneity of environmental policy and the concept of policy integration from an innovation perspective. Chapter 7 takes an organisational perspective by contemplating the differing roles of organisations in responding to policies and the variation in organisations, explaining problems related to the transfer of policy information within companies. Chapter 8 links the findings to technological systems literature and to market conditions influencing innovation. The theoretical, methodological and practical conclusions are presented in Chapter 9, also including recommendations for policymakers.

2 KEY CONCEPTS

2.1 Innovations

The word 'innovation' has had various meanings in scientific literature referring, for instance, to new technologies, products, services, organisational reforms or applications of technology. Joseph Schumpeter (1927: 30) first introduced the concept of innovation as '*changes of the combinations of the factors of production as cannot be effected by infinitesimal steps of variations at the margin.'* Schumpeter (1928) saw innovation as consisting of either producing a new commodity to 'the public' or producing at a smaller cost and changing the supply system.

More recently technological innovation has often been defined as the first commercial (or practical) application of an invention (e.g. Norberg-Bohm, 1999). Schumpeter (1928), however, took the view that innovation often involved no invention in the form of scientific novelties. Following Schumpeter, some have taken a wider approach on innovation, defining it, for example, as *'novel ways of doing things better or differently, often by quantum leaps versus incremental gains'* (Perrin, 2002) or rather *'as a creative process than an end-state'* (Nonaka and Peltokorpi, 2006). This means that innovation can be used to mean practically anything new and creative. This study, however, focuses on technological and product innovations because, as noted in the introduction, they can have significant positive or negative impacts on the environment. Thus, the definition offered by Tushman and Anderson (2004: xi) is well suited for the purposes of this thesis:

> *'An innovation is more than an invention. It advances a novel idea to the next level, reducing it to practice in a way that creates economic value for some group of customers. An innovation may lower the cost of producing what a company already produces, enhance the value of the company's output, or allow the company to reach new customers.'*

Innovations have often been categorised according to their degree of incremental or radical change. Incremental innovations have been described as *'innovations that push the existing technological trajectory for existing subsystem and linking mechanisms'* (Tushman and Smith, 2004: 6). Radical innovations (sometimes referred as discontinuous innovations), in turn, have been perceived to break system boundaries or create technological discontinuities. Even though radical innovations may establish new systems, they are often improvements over earlier, similar inventions that failed to develop into innovations (Hughes, 1987). Some have claimed that the categorisation of innovations into radical and incremental is incomplete, and have proposed further categories for architectural and modular innovation (e.g. Henderson and Clark, 2004). Architectural innovations link existing technologies in novel ways, at most re-enforcing the core concepts (e.g. Tushman and Smith, 2004; Meeus and Edquist, 2006), while modular innovations are the opposite by changing the core concepts of technologies but maintaining the existing linkages between components (Henderson and Clark, 2004).

Another distinction is made between product and process innovations. Product innovations result in product differentiation and/or an increase in product quality, whereas process innovations result in a decrease in the cost of production (Damanpour and Aravind, 2006). New products often require distribution channels and suppliers different from those that serviced the old products; process innovation usually makes the product better and cheaper without necessarily disrupting upstream and downstream linkages (Anderson and Tushman, 2004). A specific innovation may involve both product and process changes (e.g. Berkhout, 2005). For instance, a novel way of producing transport biofuels in pulp mills involves process innovation in production technology and product innovation in the form of a new type of fuel.

System innovations go one level above individual product or process innovations, and have been called for to achieve more radical changes in society, for example, to overturn the current environmentally detrimental production and consumption structures (e.g. Weber and Hemmelskamp, 2005). They are described as comprising a combination of new and old components and their novel combinations (Kemp and Rotmans, 2005). System innovations are not the focus of this study. Yet as they combine elements from incremental, radical, architectural and modular innovation, the innovations described in this study may cumulatively contribute to future system innovations.

2.2 Environmental innovations and environmental technologies

The concept of 'environmental innovation' is based on that of an innovation involving additional characteristics. In this study, I discuss environmental innovations and environmental technologies as interlinked concepts due to my focus on technological and product innovations. Innovation can, however, mean much more than mere technology and is usually linked to a specific point in time (e.g. commercialisation), whereas technology in general maintains its status as technology over time.

The term 'environmental technology' has traditionally referred to so-called 'end-of-pipe technologies' that have been added to production processes in order to purify water discharges or air emissions. Later, integrated technologies intentionally producing environmental benefits through, for example, reduced consumption of water, energy or raw materials, have also been considered as environmental technologies. Subsequently, both innovation research and political arguments have widened the concept of environmental technology to include all kinds of technologies that have reduced environmental impacts in comparison to existing technologies serving the same purpose as the environmental technology in question. For instance, a new paper machine resulting in reduced water emissions and energy consumption as a side-effect of technological development can be regarded as environmental technology. The current definition of the Environmental Technologies Action Plan (ETAP) of the European Union adopts the wider concept and defines environmental technologies as *'all technologies whose use is less harmful than the relevant alternatives'* (European Commission, 2004: 2).

The term 'environmental innovation' has also been defined in different ways. Some have described it as those innovations that specifically aim at reducing the negative environmental impacts (e.g. Hemmelskamp, 1997) or where a significant environmental pressure has influenced the development of the technology (e.g. Berkhout, 2005). These definitions tend to exclude innovations that have produced environmental benefits as a 'surprise' or side-effect of technological development. Given that environmental improvements produced as side-effects may have a significant role in environmental protection, others (e.g. Norberg-Bohm, 1999; Kemp, 2000) have taken environmental innovations to be any new technologies or products that provide environmental benefits. The difference between the two definitions lies in the intention behind the technological development (Figure 2). The wider definition is more pleasing, because many environmental improvements have been achieved with the help of new technologies that have included environmental improvements as positive side-effects. It also offers new opportunities for technology-based environmental policy. The wider definition, however, also creates problems through less precise boundary conditions for defining environmental innovations.

I adopt the wider definitions of environmental technology and environmental innovation in this thesis regarding environmental innovations as *'new products or process technologies that have reduced some negative impact on the environment either intentionally or as a side-effect of the development'*. However, I also acknowledge that these terms must be used with caution. Environmental innovations and technologies may also have negative effects on the environment, and their environmental effects compared to those of existing alternatives depend on the time when they are used, on the geographical conditions surrounding the place of use, and on how the technologies are used.[2] Furthermore, if

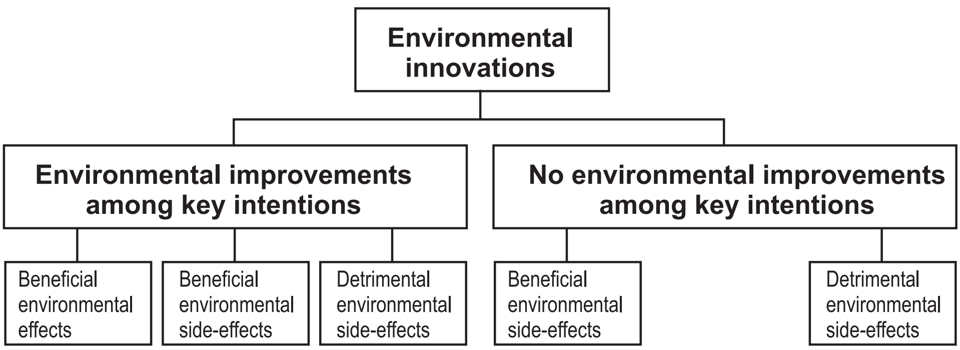

***Figure 2:** The intentions based definition of environmental innovations and the effects on the environment (modified from Article I)*

[2] Work on best available technology (BAT) in the pulp and paper industry has yielded important observations regarding the environmental effects of technology. First, it has found that it is impossible to have best values in all environmental impact categories (air emissions, water emissions, energy use, water use and waste) and still produce a competitive product. Second, smooth and safe running of machines and processes can be a better way to reduce emissions than further end-of-pipe investments. (Nilsson et al., 2007)

the environmental impact is reduced through efficiency improvements, a simultaneous incentive to use more of the new technology or product (than was used of its predecessor) due to improved production efficiency could override the positive environmental effects by increasing the total use and thus the total environmental impact (e.g. Saviotti, 2005). Therefore, the absolute eco-efficiency of a technology is determined both by the technological characteristics and the use of the technology.

Environmental innovations differ in the types of environmental improvements they generate. They may involve one or many of the following improvements (an improvement in one of the following may also impair performance with respect to the others):

- Process technologies
  - Switching to less harmful resources (e.g. chemicals, fuels)
  - Improved resource efficiency (e.g. raw materials, chemicals)
  - Improved energy efficiency
  - Reduced water consumption
  - Reductions in water or air emissions
  - Improved by-product utilisation and reduced waste
- Products
  - Selection of environmentally less harmful raw materials (e.g. renewable)
  - Removal of hazardous or toxic substances
  - Reduced raw materials per unit
  - Improved energy-efficiency
  - Improved durability
  - Improved recyclability
  - Improved end-of-life management. (Articles III, V)

A time-bounded element is also related to environmental innovations and technologies. As the criteria for allocating the labels of environmental innovation or environmental technology for specific products or processes are often based on their environmental impacts compared to other existing technologies, these labels will expire through further technological development and as further knowledge about technologies is gained. For instance, the use of black liquor in energy production in pulp mills and the re-use of water in paper mills have involved several subsequent improvements, where a new technology has always replaced older technology as 'the environmental innovation'.

2.3 Environmental, technology and innovation policies

Environmental policy

The term 'environmental policy' has been used to refer to policies executed by both public and private organisations. I use the general term 'environmental policy' to refer to public policy having key aims related to environmental protection. Environmental policy carried out by public authorities fundamentally aims at reducing the anthropogenic environmental impacts and at conserving natural resources (Article II). In practice, I have mostly focused on those policies coordinated by environmental authorities. In cases where policies executed by private organisations are concerned, I call them 'corporate environmental policy'.

Technology and innovation policy

The fundamental aim of national technology policy is frequently defined as seeking competitive advantages for the country in question, and as increasing productivity growth (e.g. Lemola, 2002; Russell and Williams, 2002). In high income countries the focus of technology policy may be on establishing capacity in producing the most recent science-based technologies and applying these innovations, while in other countries it may be a question of absorbing and using new technologies as they come on the market (Lundvall and Borrás, 2005). Technology policy as a whole covers a variety of different activities, such as laws governing intellectual property rights, support for new businesses, and the funding of basic and applied research.[3] Due to research and technology –based policies proving to be partly ineffective in delivering successful technological advances (e.g. Russell and Williams, 2002), many countries have adopted more innovation-oriented technology policies that have, in addition to R&D support, paid attention to markets and commercialisation.

Recent academic discussion has called for a shift from traditional technology policy (and from innovation-oriented technology policy) towards innovation policy embedded in a broader socio-economic context and overarching different sectoral policies (Lundvall et al., 2002; Smits and Kuhlmann, 2004; Pelkonen, 2006). Thus the concept of innovation policy is often perceived as being much wider than merely technology policy. For example, Chaminade and Edquist (2006: 142-3) define innovation policy as:

> *'public actions that influence innovation processes: that is, the development and diffusion of (product and process) innovations. The objectives of innovation policy are often economic ones, such as economic growth, productivity growth, increased employment and competitiveness. However, they may also be of non-economic kind, such as cultural, social, environmental or military. The objectives are determined in a political process… be specific and unambiguously formulated in relation to the current situation of the country and/or in comparison to other countries.'*

2.4 Policy integration

Public policies have different, sometimes conflictual aims, such as national economic growth or environmental sustainability (e.g. Lafferty, 2004; Pollitt, 2006). The discussion on policy coordination and policy integration springs from concern that inconsistent

[3] Here, the examination and discussion of technology policy is mainly focused on R&D funding activities, where the policy output concerns project funding decisions (Article II).

policy goals may impair the efficiency of policies (e.g. Pollitt and Boucaert, 2002; Pollitt, 2006). Policy integration, i.e. integrating specific policy objectives such as environmental protection or gender equality into other policy sectors, is one way to coordinate policies and to address the problems of goal conflict and inefficiency (Article II). Economic policy has been viewed as a prime example of successful policy integration (e.g. Lafferty, 2004). Underdal (1980: 162) defines a perfectly integrated policy as:

> *'one where all significant consequences of policy decisions are recognised as decision premises, where policy options are evaluated on the basis of their effects on some aggregate measure of utility, and where the different policy elements are consistent with each other.'*

Environmental policy integration (EPI) has been mentioned as means to improve the effectiveness of environmental policies and environmental protection (e.g. Lenchow, 2002; Lafferty and Hovden, 2003; Nilsson and Persson, 2003). According to Lafferty (2004), the basic notion of environmental policy integration as a goal of governance is to bring policymaking closer to such an ideal situation where non-environmental sectors are similarly responsible for meeting the environmental norms and targets as the environmental administration. Lafferty and Hovden (2003) define the ideal type of environmental policy integration in the national governance for sustainable development as:

- The incorporation of environmental objectives into all stages of policymaking in non-environmental policy sectors, with a specific recognition of this goal as a guiding principle for the planning and execution of policy.
- Accompanied by an attempt to aggregate presumed environmental consequences into an overall evaluation of policy, and a commitment to minimise contradictions between environmental and sectoral policies by giving principled priority to the former over the latter.

An environmental innovation can in some cases be regarded as an intermediate outcome of innovation, technology or environmental policy. In this study, I, therefore, explore environmental policy integration as a potential facilitator of environmental innovations (Article II) and the lack of it as a potential barrier. Figure 1 in Article II demonstrates how environmental policy integration can take place at different levels of technology policy, including policy strategies, policy instruments and policy outcomes. The extent to which it occurs in these levels may influence the innovation outcome. However, I also acknowledge that policy integration alone may not be sufficient to promote innovation.

3 DETERMINANTS OF CHANGE IN TECHNOLOGICAL SYSTEMS AND INNOVATION PROCESSES

3.1 Socio-technical change surrounding innovation

Socio-technical systems and technological transitions have been much discussed in relation to both innovation and sustainable development (e.g. Geels 2002, 2004; Berkhout et al., 2004; Elzen et al., 2004; Tushman and Anderson, 2004; Smith et al., 2005; Weber and Hemmelskamp, 2005). In the systems literature, it has been emphasised that the opportunities and pressures for innovation are specific not only for each sector but for each socio-technical regime that forms around particular system-based functions in society (e.g. Berkhout, 2005). Here I will focus on two separate but similar ideas about technological change at system level: technology cycles and technological transitions.

Technology cycles have been described in organisations and management literature to surround the emergence of innovations (e.g. Anderson and Tushman, 1990; Rosenkopf and Tushman, 1994; Anderson and Tushman, 2004; Tushman and Smith, 2004). The cycles have four phases – technological discontinuities, eras of ferment, dominant designs, and eras of incremental change – where the discontinuities and the dominant design events mark the transitions. A dominant design refers, for example, to the large-scale power plant dominating the organisation of the electricity system in many countries. According to Tushman and Smith (2004), rival technologies compete with each other and with the existing technological regime during ferment, whereas the selection of a dominant design is followed by a period of incremental and architectural change.

Technological discontinuities enabling the era of ferment and, thus the emergence of more radical innovations have been described as relatively rare and unanticipated events (Tushman and Smith, 2004). When technological discontinuities do occur, they create space for transitions from one dominating regime of a technology system and its surrounding network of actors, institutions, norms and assumptions to another. The invention and diffusion of automobiles and mobile telephones are examples of discontinuous changes.

In the era of ferment, the dominant technological designs selected from among the alternatives are seen to emerge from a negotiated logic enlivened by actors with interests in competing technical regimes rather than technical logic (Rosenkopf and Tushman, 1994). It can also be described as a struggle between alternative technological trajectories that are initiated and pushed by competitors, alliance groups and governmental regulations (Tushman and Smith, 2004). After the dominant design has been selected, subsequent technological change is driven by the logic of the selected technology (Tushman and Smith, 2004). Thus, the era of the technology cycle determines the possibilities for more radical or incremental innovations to occur, and may also determine the extent to which environmental policies can impact on technological innovation.

Technological transitions (TT) is a more recent concept than technology cycles and has links to policy studies. TTs have been defined by Geels (2002: 1257) *'as major technological transformations in the way societal functions such as transportation, communication,* *feeding, are fulfilled'*. TTs do not only involve technological changes but also changes in elements such as user practices, regulation, industrial networks, infrastructure and symbolic meaning. With respect to energy generation, a TT would imply a transition in the whole system of energy supply and consumption including the regulatory systems and networks of different actors behind it, rather than just tackling single issues, such as air pollution, with new technologies. This somewhat corresponds to the idea of discontinuous change in technology cycles. The TT approach examines how a new paradigm emerges, while the technology cycles approach has not specifically focused on what factors cause change from one phase to another. Technological transitions, however, have sometimes been criticised for focusing exclusively on emerging from the niche level (e.g. Berkhout et al., 2004).

The existing legislation is often seen as constituting a barrier to transitions, since regulations are usually tuned to an existing regime with specific characteristics (Elzen and Wieczorek, 2005). Geels (2004) has identified cognitive, normative and formal rules that control people's behaviour and hinder changes away from the existing systems. Overall, the sets of rules of different social groups that influence technical trajectories, including engineers, users, policy makers, suppliers, scientists, banks and NGOs, create socio-technical regimes supporting the existing technological paths (Geels, 2002). Although environmental policies together with other regime factors may often hinder transitions and support more incremental change, they also have the potential to create pressure for system-level change (e.g. Smith et al., 2005).

Though transitions are characterised by non-linear behaviour, the process has been claimed to be gradual and estimated to last between 25-50 years (Kemp and Loorbach, 2003). Yet some transitions, such as the shift to the mobile phone society, have occurred much faster. Both technology cycles and technological transitions literatures are somewhat unclear about what really constitutes a shift in the socio-technical regime. A regime shift from one perspective, such as that of an industrial sector, may be viewed as a mere incremental change in inputs for a higher level regime, such as the organisation of industrial production as a whole (e.g. Berkhout et al., 2004).

While the technology cycle model describes the changes in the dominant designs and the networks of organisations, i.e. the transitions, as something unpredictable and uncontrollable, some scholars (e.g. Rotmans et al., 2001; Kemp and Loorbach, 2003; Kemp and Rotmans, 2005) argue that the transitions could be triggered by policy in the form of 'transition management', based on experiments initiated at niche-level with a guiding vision that could subsequently result in wider changes in the level of socio-technical regimes. For instance, Kemp and Loorbach (2003) claim that the direction and speed of a transition could be influenced and the prospect of a transition occurring could be increased while transitions as such cannot be controlled. It has, however, been argued that the niche-based model of transitions is rather limited, because it does not take into account other sources for change (Berkhout et al., 2004). Social aspirations, rarely articulated in a way resulting directly in technological innovation, are more likely to exert influence through the macro-level, where they may channel into market or policy signals promoting innovation

(Berkhout et al., 2004). In effect, the nature of transformations will depend on the contexts in which they occur (Smith et al., 2005).

Related to the above discussions on technological change, path dependency has been named as something that guides change in socio-technical systems in specific directions and limits other kinds of solutions (e.g. Teece et al., 1997). Path dependency relates to technology cycles and technological transition literatures, in that it concerns not only technology but also ideas and practices (Garud & Karnøe, 2001; Smith et al., 2005) that improve the stability and support change not deviating too strongly from the existing systems. Path dependency also varies across different societies, nations, business sectors, organisations and technologies (e.g. Gartland, 2005; Smith et al., 2005; Hollingsworth, 2006).

In a simplistic form, path dependency means that the actions taken today shape the actions of the future. Path dependency does not hinder innovation as such. Rather it dictates easier conditions for those innovations to emerge that support the dominant technological design or the dominant socio-technical system emerging from past events. This means that more radical or discontinuous innovations encounter considerable barriers in path-dependent systems (Markard and Truffer, 2006).

The phenomenon of technology lock-in is also related to the concept of path dependency (e.g. Unruh and Carillo-Hermosilla, 2006). It implies that once a particular product, technical standard, production process or service has been adopted, the barriers to switching to an alternative technology may be prohibitive (Jaffe et al., 2003). In the era of incremental change of the technology cycle, the dominant design presents a technology lock-in that continues until technological discontinuity is triggered. For example, the dominating papermaking process involves barriers to alternative technologies. The various technological paths also afford different options for actors to influence the path and to innovate, in that they have different patterns of actor involvement (Garud and Karnøe, 2003). This could in part explain the context specific effects that environmental policies have on innovation.

3.2 General models of innovation drivers

In the context of technology cycles or technological transitions smaller-scale incremental innovations having a variety of drivers and barriers emerge and diffuse. Traditionally, the models of specific technological innovations have been based on simple linear chains of activities. In the technology push model, basic scientific R&D is followed by an invention, its development, commercialisation and diffusion. The market pull model departs from market needs met by technology development, its commercialisation and wider adoption. (Article III)

In effect technological development experiences both push and pull from different directions (Article III). The linear models of the innovation process have indeed often been criticised for being arbitrary or simplistic (e.g. Pinch and Bijker, 1987; Freeman, 1996; Nightingale, 1998). The policies relying on the technology push model have also been claimed to fail to take into account the inherent uncertainties of innovation (Russell and Williams, 2002). Some have extended the traditional models by adding elements such as regulatory push and pull (Cleff and Rennings, 1999; Rennings, 2000). Others have illustrated learning based models for innovation (e.g. Lundvall, 1992). An approach adopting a system perspective on innovation has developed to complement and replace the linear innovation models.

The variety of factors affecting the innovation process has often been conceived of as constituting an innovation system[4] (e.g. Lundvall, 1992; Lundvall et al., 2002; Chaminade and Edquist, 2006). Narrowly defined, the innovation system is composed of those institutions which deliberately promote the acquisition and dissemination of knowledge, such as the formal R&D system and technical education (Freeman, 1996, 2002). The recent literature, however, also proposes that while innovation depends on scientific knowledge it is not a direct result of science (e.g. Nightingale, 1998; Jordan, 2006). A broader approach to innovation systems recognises that the narrow institutions are embedded in a wider socio-economic system in which political and cultural factors influence the rate and success of innovation activities (Freeman, 2002). In this broader sense, innovation systems have been described as bringing together a number of market and non-market factors (Meeus and Edquist, 2006) and having public standards, norms and laws and public and private investments in supporting infrastructures as its integral components (Kuhlmann and Shapira, 2006). For instance, public policies related to environmental protection that may or may not have specific innovation objectives are thus part of the innovation system.

The national innovation system concept especially has been widely discussed in the literature (e.g. Lundvall, 1992; Freeman, 1996, 2002; Lunvall et al., 2002). Innovation systems have coevolved together with national political systems and have country-specific characteristics (Kuhlmann and Shapira, 2006). The innovation systems surrounding the Finnish and Swedish pulp and paper industries, for instance, differ somewhat from each other, and both differ greatly from that of the United States. I examine the interaction between companies and environmental policies as a sub-section of the (national) innovation systems in Finland and Sweden. The research framework thus incorporates a perspective in which environmental policies impact on innovation within the context of other affecting factors.

[4] The concept 'innovation system' is different from the concepts 'technological system' or 'socio-technical system', introduced in Section 3.1. They apply different logics. Socio-technical systems comprise technologies and institutions that have formed around an existing dominant technological design. In contrast, innovation systems consist of institutions and organisations deliberately created to support innovation – directly or indirectly. The aim of innovation systems is thus to induce change in the existing technological systems. Yet they may also include institutions (with no deliberate innovation effects) embedded in the wider, surrounding socio-technical systems.

3.3 Environmental policy effects on innovation

Research on the interlinkages between environmental policy and innovations can combine approaches from many social science fields, such as policy studies, science and technology studies, economics or organisation and management studies. Here, the most important perspectives from the point of view of this study are presented.

Environmental economics has frequently been the starting point of theories on this topic (Downing and White, 1986; Milliman and Prince, 1989; Jaffe et al., 1995; Porter and van der Linde, 1995; Jung et al., 1996; Kemp, 1997). While some authors have focused on the impacts of policies on innovation, others have examined policy as one among the many determinants of innovation. Rennings (2000) and Cleff and Rennings (1999), among others, have taken regulatory push and pull into account as a significant determinant of environmental innovation in addition to technology push and market pull. They argue that new environmental technologies can be subsumed under technology push factors, such as attempts to improve material and energy efficiency and product quality, while preferences for environmental products or image can be subsumed under market pull factors, including customer demand and new markets for environmental innovations. Since the factors of technology push and market pull alone are not strong enough environmental innovations need specific regulatory support to emerge and diffuse. The strong and enduring support of government policies has, for example, been found to be important in the emergence of radical innovations in the electricity sector by shaping organisational routines for investment and strategy formation (Markard and Truffer, 2006).

The effects of environmental policies on technological innovation have received specific research interest since the late 1990s (e.g. Ashford, 1993, 2005; Porter and van der Linde, 1995; Freeman, 1996; Jung et al., 1996; Hemmelskamp, 1997; Kemp, 1997, 2000; Norberg-Bohm, 1999; Jaffe et al., 2003). Environmental policies have been found to drive improved environmental performance of companies in different business sectors, for instance, in the pulp and paper industry (Hildén et al., 2002; Gunningham et al., 2003) and the chemicals industry (Becker and Englmann, 2005). The discussion on the innovation effects of environmental policies has also sometimes been connected more generally to the drivers and incentives for environmentally sounder technological change (e.g. Milliman and Prince, 1989; Freeman, 1996; Jaffe et al., 2003). Yet more often it has focused solely on the different types of policy instruments best suited to support innovation.

Environmental policy for innovation has been defined to include more typical environmental policy instruments, such as regulation, economic instruments, public procurement and information programmes, as well as instruments improving technology push, including investment tax-credits and funding for R&D and demonstration (Norberg-Bohm, 1999). Frequently economic instruments have been perceived to be the best in promoting innovation due, for example, to the flexibility they offer in the choice of response or technological solution (e.g. Palmer et al., 1995; Porter and van der Linde, 1995; Jung et al., 1996). Many studies have claimed that they are more likely to prompt innovations than regulations (Jung et al., 1996; Milliman and Prince, 1989; Hemmelskamp, 1997). Another commonly held view in the policy instrument discussion is that stringent regulations are more likely to produce innovations than lax regulations (Porter and van der Linde, 1995; Kemp, 2000), although opposing arguments have also been evinced, portraying innovations resulting from stringent policies as rare and special cases (Palmer et al., 1995).

Overall, the research on different policy instruments, especially empirical research, presents somewhat contradictory results on the actual effects of environmental policies on innovation. Some have argued that environmental regulation is likely to stimulate innovation and technology adoption that will facilitate environmental compliance (e.g. Porter and van der Linde, 1995; Jaffe et al., 2003), while others have found that emissions standards are often based on the technology available with little incentive for innovation (e.g. Palmer et al., 1995; Kemp, 2000). Moreover, regulation has sometimes been found to inhibit investment and slow down productivity growth (Palmer et al., 1995; Jaffe et al., 2003). A later study has proposed that stringent regulations are more important for end-of-pipe technologies than for cleaner production technology (Frondel et al., 2007). It has also been claimed that public R&D may play an important role for environment-related science and technology (Jaffe et al., 2003), but that subsidies have had a limited impact on decisions regarding investments in environmentally beneficial technology (Kemp, 2000).

The inconsistent results on the innovation effects of environmental policies have been partly explained by the fact that the dynamic effects of environmental policy instruments in practice differ from the ideal instruments in theoretical studies (e.g. Hemmelskamp, 1997). However, the literature does not usually go deeper into explaining what causes the context-specific differences in policy effects. The evolutionary approach sheds some light. It assumes that firms are not rational actors and that it is difficult for them to make optimising R&D decisions (Jaffe et al., 2003). For example, Porter and van der Linde's (1995:99) argue that:

> *'the actual process of dynamic competition is characterized by… highly incomplete information, organisational inertia and control problems reflecting the difficulty of aligning individual, group and corporate incentives.'*

Thus, according to Porter and van der Linde (1995), environmental policies can benefit companies and lead to innovation by *improving information transfer* to aid decision-making by (i) signalling companies about likely resource inefficiencies and potential technological improvements, (ii) increasing corporate awareness through informational policy instruments, (iii) reducing uncertainty and making those investments that address the environment valuable, (iv) creating outside pressure that motivates innovation and progress and overcomes organisational inertia, (v) ensuring during a transition period to innovation-based solutions that one company cannot opportunistically gain by avoiding environmental investments, and (vi) improving environmental quality in cases where innovation does not offset the costs of compliance. I have adopted the information perspective as a basis for examining organisational responses.

In sum, earlier studies show that the ways in which diverse policy interventions promote environmental innovations are complex and that the effectiveness of various policy instruments is heavily dependent on the context in which they are used. Thus, the discussion on the suitability of specific environmental policy instruments for promoting innovation seems rather outdated. Rather, one should move on to discuss the features of the mix of policy approaches and instruments that can be in place in different contexts. (Article III) Indeed, the literature indicates certain characteristics of environmental policies that would be more likely to support innovation. Combining the results of different studies portrays characteristics such as sufficiently stringent regulation (Ashford, 1993; Kemp, 2000), predictable policies that reduce long-term uncertainties through anticipation (Ashford, 1993; Porter and van der Linde, 1995; Norberg-Bohm, 1999), and flexible policies creating maximum opportunity for innovation (Porter and van der Linde, 1995; Norberg-Bohm, 1999). With these observations in mind, the characteristics of policies supporting innovations are examined through empirical material in Article III and the discussion in Section 6.2.

The link between environmental policies and innovation can be characterised by a complicated two-way relationship, where the direction of cause and effect will vary over time. While regulations have been found to influence innovation either by hindering or promoting it, new technologies have equally been found to pave the way for new regulations (e.g. Kemp, 2000; Peltola, 2007a). Thus, innovation can also serve as a basis for lobbying for stricter environmental policies that would support the diffusion of a particular innovation.

Environmental policies have been found to affect long-term market expectations, opportunity recognition and selection, and the competitive strategies of companies, but not to induce significant process innovations on their own (Foster et al., 2006). Therefore, the conditions in which innovation processes initiate and develop in companies merit further examination. The literature on environmental policy sometimes refers to managerial practices but does not discuss what really happens in organisations (e.g. Ashford, 1993, 2005). The literature on corporate environmental management has examined the differing environmental practices in companies (e.g. Gunningham et al., 2003; Howard-Grenville et al., 2006) but it often examines policies from some distance. More general organisation and management studies, such as those focused on organisational culture or institutional requirements posed on organisations, discussed briefly below, could reveal more about the link between environmental policies and innovation.

3.4 Organisational structures influencing policy responses

> *'[The] effectiveness of firms in originating, developing, and implementing technical innovations is viewed as a function of three sets of factors: (1) characteristics of the firm's environment, (2) internal characteristics of the firm itself, and (3) flows between the firm and its environment'.* (Utterback, 1991: 75)

In organisation and management studies, it has been recognised that organisational factors, such as the structure and culture of an organisation, are important in determining how companies interpret external conditions and how they develop solutions to address the problems identified (e.g. Howard-Grenville et al., 2006). The formal and informal structures of organisations influence who makes decisions, how decisions are made, and the degree of autonomy that individual facilities hold in decision-making (Howard-Grenville et al., 2006). Organisational cultures affect how organisations respond to different issues as a whole and how organisational members think and act (e.g. Frost et al., 1991; Alvesson and Berg, 1992). The existence of a variety of sub-cultures within an organisation is commonly assumed (Alvesson and Berg, 1992).

The discrepancy or complementarity of formal and informal structures is related to how an organisation is capable of responding to external requirements, such as environmental policies. It has been argued that the discrepancy between organisational goals and institutional requirements, posed by external constituents on organisations, may lead to situations where the publicly stated principles of the organisation do not match the activities carried out (e.g. Meyer and Rowan, 1983; Oliver, 1991; Brunsson, 1993; Westphal and Zajac, 2001). Profound differences between organisational policies as formally adopted and actual organisational practices have indeed been observed (e.g. March and Sutton, 1997; Westphal and Zajac, 2001). Principles may differ from action, either intentionally or accidentally, when organisations face multiple conflicting pressures from their stakeholders (e.g. Oliver, 1991) or when they lack the capacity (e.g. knowledge, time, financial or human resources) to conform (Article IV). The likelihood that an organisation will truly conform to institutional pressures, such as those caused by public environmental demands, depends according to Oliver (1991: 166) on:

> *'the degree of discrepancy between organisational goals and institutional requirements (consistency), the likelihood that institutional constituents create conflict for the organisation in meeting incompatible goals simultaneously (multiplicity), and the degree of organisational dependence on the pressuring institutional constituents for its legitimacy or economic viability (dependency)'.*

Formal organisational structures determine which groups or departments interact with which external groups (e.g. Lawrence and Lorch, 1967). This means that the formal rules establish with whom environmental managers officially come into contact (Howard-Grenville et al., 2006) and with whom R&D or product development personnel interact. When contacts with actors external to an organisation have been divided among the organisation's different units and sub-units, the interaction within the organisation determines how signals are transferred between certain external constituents and those parts of the organisation that have no direct contact with the external actors. Thus, a so-called functional integration within an organisation (Lawrence and Lorch, 1967; Fryxell and Vryxa, 1999) mainly determines how, for instance, environmental signals are transferred from environmental managers to R&D or product development personnel. Functional integration can be carried out on an organisation level by maintaining cooperation between different units. Alternatively functional integration can be realised on a project level. Cross-functional project teams including members from more than one functional area (e.g. engineering, manufacturing, and marketing) have in effect been argued to be among the key elements in product development (Brown and Eisenhardt, 1995).

4 CASE STUDY AS THE RESEARCH APPROACH

4.1 Introduction to case studies

Innovations have been studied in different ways through quantitative, qualitative and a combination of methods. I chose a qualitative case study approach to examine the causal mechanisms surrounding those innovation processes that result in improved environmental technologies or products. While case studies by many (even some case study researchers) are not perceived as a tool for gaining generalised knowledge they, nevertheless, often produce knowledge that is relevant in a wider context than merely that of the cases studied (e.g. Stake, 1995; Gerring, 2004; Flyvjberg, 2006; Eisenhardt and Graebner, 2007). In effect, Eisenhardt (1989) has shown that theory construction from case studies is possible.

According to Gerring (2004) case studies have a double function, where they are studies of the unit itself as well as case studies of a broader class of units. Case studies of individual technologies have been criticised because a focus on micro-level changes in technology is liable to miss the dynamics across a wider technological system that may be more significant (Berkhout, 2005). Examining multiple cases within the context of the same sector, the pulp and paper industry, also enabled focusing on the macro-level changes in the sector and their connections to the individual innovation cases. Theory building from multiple cases is argued to be more robust and generalisable than using a single case research approach (e.g. Eisenhardt and Graebner, 2007).

I chose the case study approach to retain theoretical flexibility, so that I would not be bound by a particular paradigm or theory. I perceived this to be crucial, because otherwise combining different strands of literature would have been too difficult, if not impossible. When I began the research I was unsure about the eventual make-up of the series of case studies, what it would actually look like and what they would present as findings. The first selection of cases and the findings they yielded affected the selection of the subsequent cases due to the queries and information gaps they raised. Indeed, a central feature of theory-building case study research is the freedom to make adjustments during the data collection process (Eisenhardt, 1989). An article based thesis enabled different kinds of sequences following from the initial findings. The approach meant that I did not know what I expected to find, or even research, when I embarked on this journey.

'Case studies' or 'cases' have been referred to in many different contexts, so it is useful to define more precisely what they mean. Whereas Stake (1995:2) has defined a case fairly vaguely, as a *'specific, functioning thing'*, Gerring (2004) offers a much more precise definition:

> *'...for methodological purposes a case study is best defined as an in-depth study of a single unit (a relatively bounded phenomenon) where the scholar's aim is to elucidate features of a larger class of similar phenomena. ... A unit connotes a spatially bounded phenomenon – e.g. a nation-state, revolution, political party, election, or person – observed at a single point in time or over some delimited period of time.'*

Stake (1995) divides case studies into three different categories: intrinsic (a case is given to, not chosen by, the researcher), instrumental (a case is chosen specifically to answer a research question) and collective (several case studies are carried out with coordination in between). To me these categories opened up different interpretations. From one perspective, my study explores the findings of an overarching case – environmental innovation in the Nordic pulp and paper industry – which is created with the help of smaller case studies of specific technological, environmental innovations. In other words, the study has 'cases within cases' and, thus, as described by Stake (1995), it is a collective case study. However, the overarching case of this study was also an intrinsic case study from my perspective. In 2003 a senior colleague asked me to start working for a research project looking at environmental innovation in three already chosen sectors. Therefore, I did not select the case that ended up forming the major part of this thesis on the basis of some research question I had in mind. Yet the case was chosen by others in the research group, which made it instrumental in responding to their research questions. Furthermore, the cases within cases, i.e. the environmental innovations studied, I selected to respond to my research questions, thus making them instrumental.

4.2 Data collection – exploring the unknown

Gerring (2004) argues that the case study method is a particular way of defining cases, not a way of analysing cases or a way of modelling causal relations. It is a research approach where different methods of data analysis can be used. Case study research does not require, and rarely involves, random sampling of cases (e.g. Eisenhardt, 1989; Gerring, 2004). Rather, case selection is dependent on the theoretical insights the researcher wants to generate. Case study research design is well suited to exploring the drivers of environmental innovations, because innovations are by nature surprising and one never knows what will be found and where the findings will lead. It has been argued that for theory-building research, it is legitimate to alter and even add data collection methods during the study, because, if a new line of thinking emerges during the research, it makes sense to take advantage of it (Eisenhardt, 1989). My research evolved in a series of steps that followed from the questions that the previous findings posed (Figure 3).

Three types of cases presented in Table 1 form the basis of the empirical analyses: (1) twelve cases of technological inventions and innovations (i.e. the innovation cases), (2) four cases of product development in major paper and packaging companies (i.e. the company cases), and (3) a case of public technology R&D funding in Finland (i.e. the policy case). The innovation cases that form the main empirical material represent diversity: innovations intended to provide environmental benefits and innovations that were developed for other reasons; process and product innovations; diffused innovations and inventions still to become innovations. Some of the cases involve longer processes, where the first developments may have failed to be commercialised giving indications of factors that hinder innovation. Trade journal reviews of *Pulp and Paper International* (reviewing first the issues between 1993 and 2003 and later between 2004 and 2006), e-mail questionnaires and interviews with pulp and paper industry experts were made to identify suitable cases.

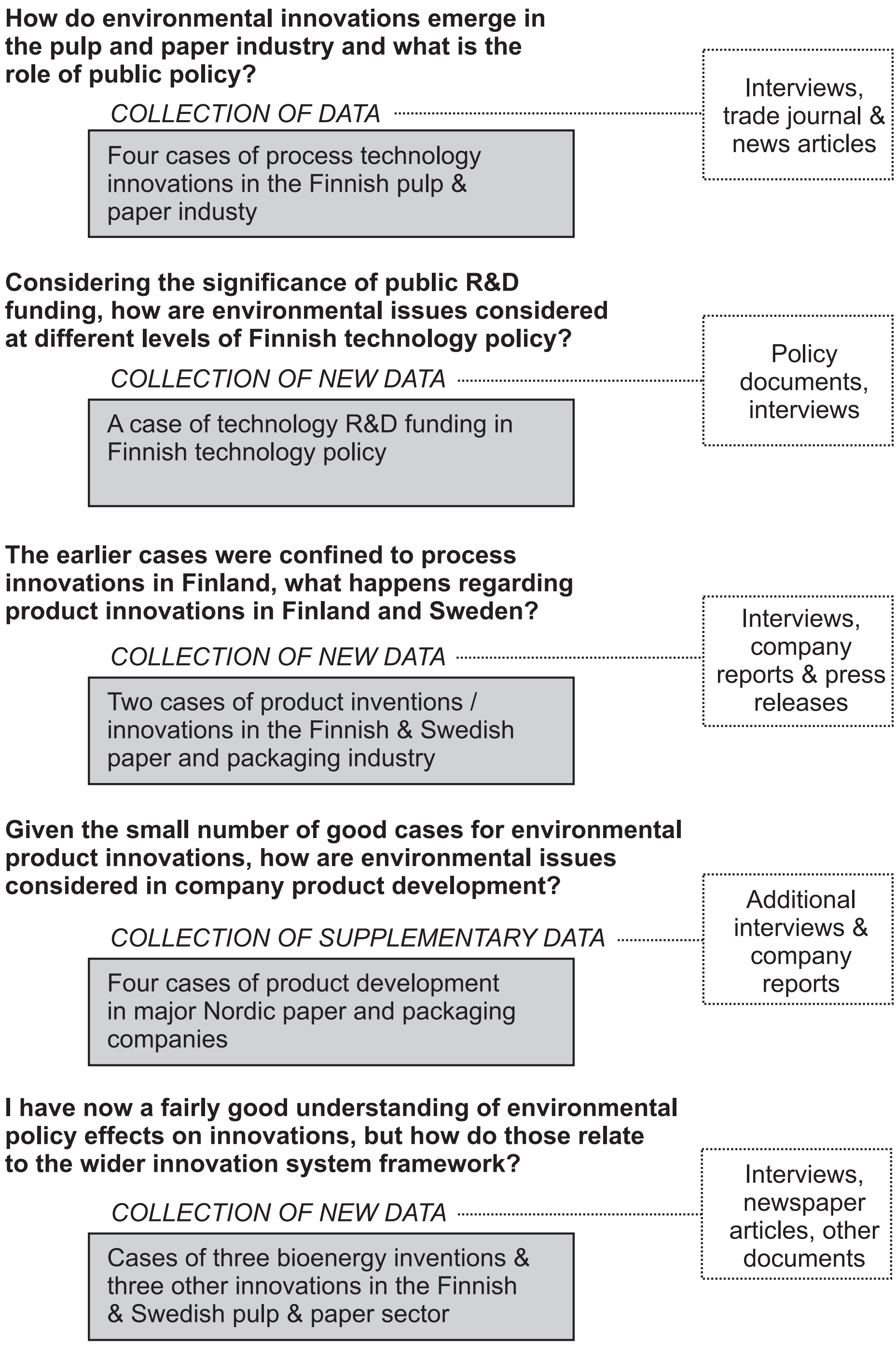

Figure 3: *The process of data collection, presenting the sequence of questions and case studies collected. The findings of each step are presented in a scientific article or essay, the five articles/essays forming part of this study.*

Table 1: Innovation and company cases forming the empirical part of the study

Case study	Environmental impacts	Described in
Process and product innovations in the pulp, paper and packaging industries		
POM-technology – air removing pump system for paper machine	Improved energy-efficiency, reduced water consumption, effluent discharge and waste.	Articles I and III
BCTMP – mechanical pulp producing process with superior efficiency and a higher level of whiteness in end-products	Uses less chemicals and energy than the sulphate pulp process (excluding the heat & power generated from sulphate pulping). Reduced wastewater load, an almost closed water cycle. Indirect energy savings in transport due to reduced weight of products.	Article V
Conox-process – effluent concentrate combustion system	Reduced water discharges, development towards closed water cycles, improved energy efficiency.	Articles I and III
Black liquor dry content increase over 80% in recovery boilers	Reduced air emissions, especially sulphur, and more efficient energy supply.	Articles I and III
Black liquor gasification for electricity	Reduced air emissions, more efficient energy generation than BL combustion.	Articles I, III and V
Black liquor gasification for transport biofuels	Reduced CO_2 emissions compared to fossil fuels, better efficiency than other biofuels technologies.	Article V
Biomass gasification for transport biofuels	Reduced CO_2 emissions compared to fossil fuels, higher efficiency than agriculture-based biofuels technologies.	Article V
LignoBoost – extracting lignin from pulp making to produce biofuels	Reduced CO_2 emissions compared to fossil fuels.	Article V
Ecological paper – replacing mineral components of paper with starch	Options to combust waste sludge from paper recycling to bioenergy, reduced emissions from transport due to lower weight.	Article III
Tetra Recart – retortable carton package	Recyclable and renewable material replacing tin cans and glass jars, reduced emissions from transport due to lower weight.	Article III
Recycled packaging – recyclable and biodegradable moulded fibre packaging from recycled paper	Reduced material and energy use, reduced amount of waste.	Article V
Radio freq. identification (RFID) tags and inlays – attachable to products for storing & remotely obtaining stored data	Reduced transportation due to improved logistics, reduced loss of products, more efficient waste management and recycling, decreased amount of waste.	Article V
Research and new product development in pulp, paper and packaging companies		
Stora Enso		Article IV
SCA		Article IV
M-real		Article IV
Tetra Pak		Article IV
Public technology policy focusing on R&D funding for the pulp and paper industry		
Technology policy strategies in Finland and R&D funding by Tekes		Article II

I used different types of material – interviews, public documents, news articles, company reports, transcribed workshop discussions and email communications – for building up descriptions of the innovation and company cases. The empirical approach that combines different data sources is called data triangulation (e.g. Stake, 1995; Vedung, 1997). According to Eisenhardt (1989) the grounding of theory that emerges from case study research is strengthened by triangulation of the evidence. Data triangulation responded to a degree to the problems created by lack of depth and reliability of findings. The use of multiple data sources had the potential to reveal inconsistencies and avoid gaps in the case descriptions.

All together the interview material comprised 28 interviews with 32 interviewees representing six pulp, paper and packaging companies (14 interviewees), three equipment developers (4 interviewees), three consulting companies (3 interviewees), two research organisations (7 interviewees), two universities (2 interviewees) and a public technology agency (2 interviewees). In addition, Article III used as data recorded focus group discussions including three groups of 4-5 experts each representing pulp and paper producers (3), an industrial association (2), government (3) and university and research (5).

Collecting data for the innovation cases of this study showed that the triangulation of data is often more important from the point of view of an innovation case study than the number of interviews, as long as the overall data used is sufficient. A thorough analysis of the innovation cases required a combination of data sources. While the interviews were used to re-construct an outline of the innovation process and its significant turning points in hindsight, information in news articles, books, company annual reports and technology programme reports was needed to provide more specific information on some parts of the process and also portrayed the innovation process at another point in time. E-mail communication, on the other hand, was used to ask specific questions on relevant issues that did not become clear in the interviews or written material.

In the policy and company cases the role of the interviews varied. In the policy case of Article II, the interviews were complementary to the written documents that were the key data source. By contrast, in the four company cases of Article IV, interviews were the key data source and provided the viewpoints of both environmental and research personnel on how environmental issues are integrated into company R&D and product development. With the aid of interview data the study framed important questions pertaining to how environmental information travels and is produced and how policies are recognised, interpreted and potentially acted on within companies. The questions formulated in this study could be further studied by deep cases, perhaps through extensive interview data or ethnography, to obtain more detailed knowledge of the different integration and interaction mechanisms that organisational members in product development and environmental management departments use.

4.3 Methods for analysing data and building theory

If one wants to examine the mechanisms through which environmental policies (undetermined at the beginning of the study) influence specific innovations and their diffusion, a bottom-up approach is useful for identifying the role and timing of the different factors affecting the innovation process. Innovations as the starting point take the focus away from particular policy instruments and look at policies as one among the many potential determinants of environmental innovations within the innovation system. I used the bottom-up approach to analyse the policy-innovation linkages through case studies of innovations.

I re-constructed process descriptions of the innovation cases by analysing the contents of interviews and relevant written material (e.g. news articles, company reports, book chapters and technology programme reports) and by identifying key features, change events and factors promoting or impeding the emergence, development and diffusion of the technology or product. Coding of the data was used to mark the different types of drivers and barriers identified.

In autumn 2003, I analysed the descriptions of four process innovation cases from the Finnish pulp and paper industry using an inductive approach (Article I) to see what findings emerged from the data. The additional empirical material collected in 2005-2006 focused on product innovation cases and product development in Finnish and Swedish paper and packaging companies using wood fibre as a raw material. Following from this, in Article III, I compared the process and product innovation cases by analysing the role of technology push, market pull and regulatory push/pull (Cleff and Rennings, 1999; Rennings, 2000) in the innovation processes.

With the aid of the innovation systems literature (Section 3.2) and prior knowledge gained from studying innovations, to better take into account the wider context of innovations, a case study framework was developed in 2006 to be used in forming interview questions and analysing the findings presented in Article V. Article V involved six new process and product innovation cases as well as innovation cases presented in Articles I and III and in the relevant literature. This was done to have a larger number of cases to find more general conclusions and to include more recent developments as the operational conditions of the Nordic pulp and paper industry had significantly changed in the last few years (see e.g. Häyrynen et al., 2007).

The innovation cases could not provide enough information on what happens and how policy signals travel within large innovating organisations, because they largely covered process innovations developed by inter-organisational networks or SMEs, and the number of suitable product innovation cases with environmental benefits was found to be small in the sector. Thus, two articles examined the integration of environmental considerations into public R&D funding (Article II) and into company research and product development (Article IV). Environmental (policy) integration was of interest, because it could offer an alternative way, instead of specific environmental policies, to promote environmental considerations in innovation processes. The analyses highlighted different routes through which policy signals may come to the knowledge of innovators and various problems related to integrating environmental issues into innovation processes.

Using the ideas of Underdal (1980) on policy integration and of Lafferty (2004) and Lafferty and Hovden (2003) on environmental policy integration (Section 2.4), a three-level analytical framework was created to examine environmental policy integration in Finnish technology policy, focusing on R&D funding. The three-level approach was applied to analyse environmental policy integration in policy documents on policy strategy and policy instrument levels. Environmental policy integration in policy outcomes was explored more tentatively. (Article II)

The integration of environmental considerations into innovation activities in companies was explored through company case studies (Article IV). Four company cases, constructed by interviewing separately both environmental managers and R&D people (to account for potentially differing views) in selected paper and packaging companies, acted as the empirical base. Most interviews were carried out in spring 2005, while three additional interviews were conducted in autumn 2006. The additional interviews were undertaken to strengthen the empirical base and to test the conceptual map developed on the basis of the initial findings. The interview data regarding the case companies was supplemented with a content analysis of company reports from 2005.

In summary, the thesis draws the relevant findings from each article to answer the research questions. Thus, I revisited the articles and the empirical material to see what they collectively and inductively reveal about the research problem.

5 THE EMPIRICAL CONTEXT: THE NORDIC PULP AND PAPER INDUSTRY

5.1 The Nordic pulp and paper industry

The Nordic pulp and paper industry is of empirical interest, because it has historical importance for the economic development of Finland and Sweden, and the sector is still important for their national economies, the two countries being among the world's largest exporters of paper. Moreover, the sector has been a major contributor to some environmental problems and undertaken many innovative responses to solve these.

The pulp and paper industry was established at the end of the 19th century and developed to be the largest exporter and industrial employer in Finland, Sweden and Norway. During the latter half of the 20th century, although exports had been growing, other industrial branches assumed the dominant position, high-tech electronic companies gaining increased export volumes (Ali-Yrkkö and Hermans, 2002). The pulp and paper industry has nevertheless remained valuable for the economies of Finland and Sweden. Pulp and paper contributes 22 percent and 11 percent of the value of total export in Finland and Sweden. In Norway the sector has divested itself of its prominent status and plays only a minor role, producing two percent of the total value of exports, and in Denmark the importance of the sector is even smaller.[5] Finland and Sweden each produce close to 12 million tonnes of pulp annually. Nearly 90 percent of the paper produced in the Nordic countries is exported, the total production amounting to 28 million tonnes in 2004. All together the Nordic countries produce 16 percent of the world's pulp and eight percent of the world's paper, while they contribute to 20 percent of the world's paper produced for export. (Finnish Forest Research Institute, 2006)

The internationalisation process in the late 1980s and in the 1990s created major consolidation among the companies in this sector (Moen and Lilja, 2001). The concentration resulted in only six pulp and paper producers operating in Finland compared to over 20 independent companies at the beginning of the 1980s and around 30 companies in the middle of the 20th century. The three largest corporations in Finland, Stora Enso, UPM-Kymmene and Metsäliitto Group, constitute approximately 98 percent of the pulp and paper production capacity as well as being internationally significant actors. (Article I) In Sweden, companies such as Assi Domän, MoDo Paper and Södra have either merged with or sold their operations to other companies. Consolidation has crossed national borders, and in 1998 the Swedish company STORA merged with the Finnish company Enso. Concentration and internationalisation has also occurred among companies developing and producing process technology for pulp and paper mills. Large equipment manufacturers operating in the Nordic countries tend to be multinational companies, and even small firms develop equipment for world markets.

[5] Thus the empirical cases and discussion in this thesis have mostly focused on pulp and paper industries in Finland and Sweden.

International corporations dominate the forest products market. The Swedish-Finnish Stora Enso, Swedish SCA and Finnish UPM-Kymmene are among the largest producers of pulp and paper in the world. The Norwegian Norske Skog and the Finnish Metsäliitto are among the largest paper producers in Europe. (Finnish Forest Research Institute, 2006) The Swedish Tetra Pak is an internationally significant producer of wood fibre packaging machinery for the food industry. Of the international corporations, the innovation or company cases in this study directly involved Stora Enso, SCA, UPM-Kymmene, Tetra Pak and M-real (partly owned by Metsäliitto).

The Finnish and Swedish pulp and paper sectors have over the last three decades invested in R&D and participated in public research and technology programmes. According to the OECD classification system of manufacturing industries, however, the pulp and paper sector is a low technology industry (OECD, 2005), and the R&D investments of pulp and paper producers have been clearly less than one percent of turnover.[6] In effect, much of the innovation has occurred in production processes, less in products. In process-based innovation pulp and paper companies have cooperated with the medium and high technology sectors, including process equipment, chemicals and information technology (Article V). Therefore the Forest Cluster, of which the pulp and paper sector is a part, cannot be strictly characterised as low technology (Autio et al., 1997).

Suppliers, especially small and large equipment developers, have been a central part of process innovation in the sector. In developing process innovations, equipment developers' joint R&D projects with universities, research institutes, pulp and paper producers and chemicals producers have improved the use of different types of knowledge and information flow (Articles I, V). Process technology development has often benefited from cooperation with pulp and paper producers, the users of the potential innovations, and information on end-of-pipe solutions has been quite freely exchanged between mills (Article I). Smaller companies developing new equipment have been jointly established by consulting companies, equipment manufacturers and others. In addition, several public technology programmes perceived by the Finnish Funding Agency for Technology and Innovation (Tekes) to be a major technology policy instrument and a means to allocate public R&D funding, have both motivated and required cooperation between different actors (Articles I, II, V). During the 1980s and 1990s, for example, two equipment manufacturers were able to create a competitive advantage through intensive cooperation (Article I). By contrast, the development of new paper and packaging products has mostly been carried out internally by their producers, and the various actors in the innovation system depicted in Table 2 have played a smaller role in environmental product innovation.

Overall, innovation in the sector can be characterised by a larger focus on processes than products, heavy involvement of public sector actors (universities, R&D funders and environmental authorities), and networks of actors surrounding innovation commercialised by equipment manufacturers. In addition, more radical innovation cases have involved entrepreneurial individuals thinking beyond the current systems and pushing the

[6] News articles in Tekniikka & Talous, 14 September 2006 and 13 September 2007.

Table 2: The innovation system for Nordic pulp & paper sector from an actor perspective (Article V)[1]

	National	International/EU
Public	• Science, technology, innovation policy councils • Ministries (trade, innovation, environment) • Regional/ local environmental authorities • Governmental research institutes • Governmental innovation agencies (e.g. Vinnova, Tekes) • Governmental energy agencies (e.g. Swedish Energy Agency) and advisory bodies (e.g. Finnish Motiva and Swedish Swentec) • Universities (mostly public) • R&D funding foundations (e.g. Mistra, Sitra) • Venture capital (government owned)	• The EU – DG Enterprise – DG Research – DG Environment – DG Energy and Transport – Joint Research Centre – European Science Foundation
Public-private partnerships	• Development finance companies (e.g. Finnfund) • Forest Cluster Ltd	• Forest-based Sector Technology Platform • Biofuels Technology Platform • Biofuels Advisory Council
Private	• National industrial federations (SFIF, FFIF) • Sectoral research companies (STFI, KCL) • Small equipment developers/manufacturers (e.g. Chemrec, POM) • Energy producers (mostly national) • Customer companies (e.g. food producers, printing houses) • Venture capital (privately owned) • Private research foundations	• Confederation of European Paper Industries • Pulp and paper producers • Large equipment developers/manufacturers • International consultancies (ÅF, Pöyry) • Chemical companies • New cooperators in automotive and electronics sectors • Customer companies (e.g. food producers, printing houses) • Energy companies • Venture capital (privately owned)

[1] The national level actors are generalised based on the operating conditions of the Finnish and Swedish pulp and paper sectors. Slight differences between countries are likely.

development forwards. The diffusion of some process and pollution control technologies has followed environmental policies, whereas in other cases competitive or cost benefits to customers have been crucial.

During the past decade, the historically stable position of the Nordic pulp and paper industry has been replaced with future uncertainty. The operating conditions of the sector have changed, including globalising paper markets, stagnating demand for traditional paper products in Europe and North America, and decreasing R&D investments. International competition in paper markets has grown, also meaning a growing threat of losing markets and customers (Siitonen, 2003). Globalising paper markets have allowed investments, capital and emerging technologies to move easily into regions where they are expected to be particularly productive, eliminating the ties between forest processing and locations, such as Finland and Sweden, with abundant natural forests (Bael and Sedjo, 2006). Globally on-going trends in the paper industry may reduce future investments on innovation by the Nordic pulp and paper sector.

5.2 Environmental problems and technological development in the sector

Environmental problems originating from the pulp and paper industry began to attract extensive public attention during the second half of the 20th century in the Nordic countries (Andersen, 1999; Sæther, 2000). Although the development of filters for particle emissions from pulp mills already began in the 1930s (Kuisma, 2004) and the mills had polluted local environments prior to that, water pollution and deteriorating water quality were first seriously noted in the middle of the 20th century. Sweden had enacted the Water Act in 1941 setting requirements for the discharge of both municipal and industrial wastewaters based on the concept of best reasonably available technology (Westerlund, 1996). In 1969, the control of wastewaters from stationary sources was transferred under the Environmental Protection Act to be integrated with air pollution control (Westerlund, 1996). In Finland, between 1962 and 2000 the Water Act controlled all water-resource related sectors of legislation, including pollution. The enactment of water and environmental protection laws in the Nordic countries initiated a period where the Nordic pulp and paper industry has been innovative in achieving environmental improvements, for example, in water emissions and consumption, air emissions and resource-efficiency.

The first significant environmental improvements made by the pulp and paper industry followed regulation on water discharges, the total discharges of the sector declining rapidly despite fast increasing production (e.g. Harrison, 2002; Hildén et al., 2002). Significant process changes were made in the 1970s to reduce water consumption (Kettunen, 2002). In the 1980s, biological effluent treatment was introduced in connection with pulp mills, resulting again in a dramatic reduction in discharge volumes (Hildén et al., 2002). In the mid-1980s as water pollution from chlorine bleaching gained increased attention (Halme, 1997), two technologies solving this problem, elementary chlorine-free and totally chlorine-free pulping, were developed following strong market demand (e.g. Mickwitz, 2003). R&D efforts carried out together with industry and research organisations have continuously reduced water consumption and emissions (Figure 4). For example, the freshwater consumption of Metso's paper machines declined from 7.5m^3 per tonne of paper to 2.5m^3 during the 1990s, partly because of research carried out in a public technology programme (Haavanlammi, 2001). Three innovation cases of this study – POM, Conox and BCTMP – have had positive environmental impacts in the form of reduced water consumption and effluent discharge and developments towards closed water cycles.

Air emissions from industry, especially sulphur dioxides and nitrogen oxides, began to attract attention worldwide in the 1970s. International discussions and agreements, such as the Geneva Convention on Long-range Transboundary Air Pollution signed in 1979, as well as the following national legislation on air emissions affected the development of new technologies reducing acidifying air emissions from industry (Article I; Kuisma, 2004; Mickwitz and Kivimaa, forthcoming). The pulp and paper industry significantly reduced its sulphur dioxide emissions, for instance, by closing down sulphite pulp mills (Hildén et al., 2002; Kettunen, 2002) and by developing more efficient recovery boilers to combust

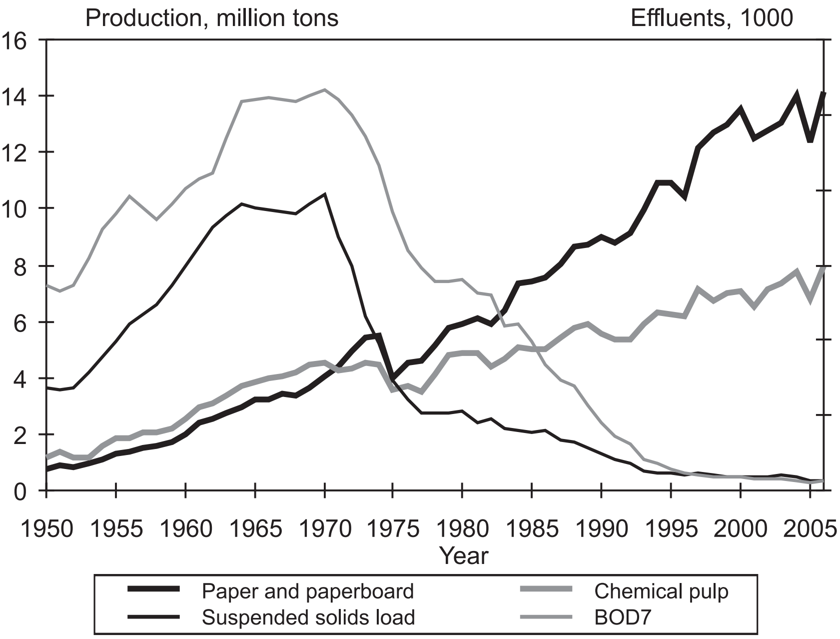

***Figure 4:** Decoupling of production and some water discharges in the Finnish pulp and paper industry (Sources: the Finnish Forest Industries Federation and the Finnish Environmental Administration)*

the pulp industry by-product, black liquor (Article I). For nitrogen oxide emissions the development has been more modest. Two innovation cases of this study – black liquor combustion and the early development of black liquor gasification – responded to concerns about air emissions.

In the 1990s, the focus of environmental issues moved from emissions to resource issues, such as recycling (Halme, 1997) and forests (Mikkilä, 2006). In the early 1990s, Germany took a pioneering step in reforming its waste legislation, including quotas for the collection rate of each packaging material. As Germany was a large market for the Nordic paper industry, Finnish companies were forced to react to new customer demands. (Halme, 1997) EU and national legislation in the Nordic countries followed suit. Following tightening recycling policies and customer demands, the companies developed collection systems for paper and packaging and increased the use of recycled fibre (Halme, 1997; Articles III, V). Improvements in sustainable forest management and the use of forest resources anticipated and followed market demands and legislation (Mikkilä, 2006). The product innovation cases – Tetra Recart, ecological paper and recycled packaging – were responses to recycling demands.

Reporting on carbon dioxide emissions also started in the 1990s (Kuisma, 2004) when climate change attracted widening public recognition. The Nordic pulp and paper industry early on produced power and heat for internal needs and improved the efficiency of these processes. Yet climate policies together with energy policies and high oil prices increased the production of bio-based energy in the sector. In some production facilities, the production of electricity even exceeded the internal demand and it was sold to the market (Article I). In total, however, the forest industry has not reached self-sufficiency in energy and purchases both fuels and electricity (Helynen et al., 2007). Between 1992 and 2005, the share of wood-based fuels used by the Finnish forest industry increased from 62 percent to 74 percent; simultaneously the carbon dioxide emissions from fossil fuels and peat reduced by 30 percent (Finnish Forest Research Institute, 2006).

All the innovation cases studied relate to some energy aspect. Five cases, black liquor combustion, black liquor gasification, biomass gasification, LignoBoost and ecological paper, provide opportunities for bioenergy production. Four other cases, POM, Conox, BCTMP and recycled packaging, provide improved energy efficiency of processes. BCTMP, ecological paper and Tetra Recart aim at lighter weight products that indirectly reduce emissions from transport and RFID provides opportunities for more efficient logistics.

5.3 Brief descriptions of the environmental invention/ innovation cases

The empirical material is largely based on 12 innovation or invention cases from the Finnish (8), Swedish (3) and Danish pulp and paper sector (1) (Table 1).[7] The cases have been addressed in the articles on which the thesis is based. For the benefit of the reader, the key features of the cases are summarised here.

POM

The development of a more efficient and compact paper machine wet end was started and driven by the inventor's interest in simplifying the papermaking process to reduce costs and increase the flexibility of papermaking in the early 1990s. It received public R&D funding in several phases of the innovation process, some of the funding entailing environmental criteria. The Finnish Funding Agency for Technology and Innovation, Tekes, provided product development support at the beginning and, with the help of additional funding from Tekes and risk capital from the Start Fund of Kera, the first four POM systems were installed in German and US paper mills in the late 1990s. Funding from Tekes and other public sources reduced the investment risks and made the commercialisation phase possible. Environmental policy as such had no role in reaching commercialisation. POM was adopted by paper manufacturers in different countries mainly for reasons of cost and competitiveness. An exception out of 20 installations by 2003, environmental policy was one of the reasons for a paper mill in Spain to acquire POM. POM enabled the mill to meet the short term maximum limits in the water permit and reduce emissions below the legal requirements set up by the municipality. In 2006 a Japanese company Aikawa Iron

[7] No cases initiated in Norway were studied, because the efforts made to identify suitable environmental innovation cases did not yield any Norwegian cases to study.

Works Co. Ltd became the sole owner of the previously Finnish-owned POM Technology. (Articles I, II, III)

BCTMP

The development of the Bleached Chemi-Thermo-Mechanical Pulp (BCTMP) mill, started in the late 1990s from awareness within M-real, a Finnish pulp and paper manufacturer, that the company's existing pulp mills were getting older, producing too little pulp and too inefficiently. Its main aims were to increase the capacity of mechanical pulp production, improve its cost-efficiency and achieve economies of scale. Energy-saving was a clear need from the beginning, because it was assumed that energy prices would increase in the future. Later customer needs and M-real's long-term goal to produce lighter paper that maintained the functional qualities of heavier paper were intertwined with the project. One of the driving forces was that BCTMP pulp could be used in product groups that had previously used only chemically produced pulp, the new product being competitive because it weighed less due to the nature of the mechanically separated fibre. Paper with reduced weight offered cost benefits for the customers, for example, due to lower transportation costs. (Article V)

Conox

The Conox process was originally designed to reduce organic pollutant load on water by attacking the chemical oxygen demand in bleaching plant effluents. It was created by a small Finnish company set up jointly by a consultancy, an environmental technology company and a chemicals producer in anticipation of increased regulatory measures for closing the bleaching processes. The anticipation rose due to the issue receiving a lot of attention from the Central European paper buyers and NGOs, such as Greenpeace, during the early 1990s. In contrast to the expectations of the developer, in the late 1990s, interest in the chlorine issue diminished in Western and Northern Europe due to reduced organic loads, and the anticipated regulatory action did not occur. In 2003, despite public R&D support for the development, Conox had not been demonstrated in Finland. The development halted for several reasons, including an interpretation that the environmental policies concerning discharges of heavy metals were not strict enough to make pulp and paper producers interested in this technology. Later the concept was applied to black liquor from non-wood pulping and, during 2003 Conox was adopted by small mills in Spain and China. These mills faced regulations that they needed to comply with for the mills were allowed to stay in operation. The patents were later bought by an international company Siloxy Ltd. (Articles I, III)

Increasing the dry solids content of black liquor

Innovations increasing the dry solids content of black liquor, a by-product of pulp making, originated from basic scientific research and attempts to achieve more economic thermo-technical solutions for black liquor combustion in the 1970s. Following this, the developers surprisingly noticed that sulphur emissions after the process were practically non-existent. During the 1980s and 1990s, the process was further developed in Finnish technology programmes with environmental aims, and by major technology companies, Tampella Power (now Aker Kvaerner) and Ahlström (now Andritz). Air emissions received increased emphasis in further development, due first to the anticipation and later to the implementation of new air pollution policies. R&D was carried out and some pilot installations were built prior to the 1987 Council of State Decisions for the first time setting national guidelines for sulphur emissions in Finland, while the need to reduce the emissions had already been discussed in the 1970s preceding the Convention on Long-Range Transboundary Air Pollution in 1979. In many instances R&D and environmental policy progressed simultaneously. In addition to permit limits for manufacturing plants on air emissions, the opening up of the Finnish electricity markets in 1995 increased the diffusion of new, more efficient black liquor recovery boilers by creating an incentive for the pulp and paper companies to produce electricity in excess of their own needs. (Articles I, III)

Black liquor gasification for electricity

In the 1980s some began viewing gasification as a more efficient solution than recovery boilers to produce electricity from black liquor. The incentive to develop black liquor gasification for power production stemmed from the low power to heat ratio of the existing technologies. Subsequently, the efficiency of recovery boilers increased, and the development of black liquor gasification for electricity faced many difficulties, including technical uncertainties, large investment costs and a lack of benefits perceived by the pulp and paper companies. In Finland, black liquor gasification was researched in several technology programmes in the late 1980s, but by the early 1990s the recession reduced investments in research, the value of electricity was low and a fairly efficient already existing alternative, the recovery boiler, offered a competitive alternative. In Sweden, the development work conducted by Chemrec since the mid-1980s was also slowed down by financial and technical difficulties but it never stopped, partly due to the financial and administrative support provided by the Swedish Energy Agency. Technical universities in Finland still do some black liquor gasification research, mainly supporting the Swedish effort. New black liquor recovery boilers reached commercialisation by being fairly risk-free incremental innovations on the existing system, whereas black liquor gasification is a technology requiring more significant system changes and has therefore yet to be commercialised. (Articles I, V)

Black liquor gasification for transport fuels

Chemrec's development of black liquor gasification began in the 1980s when engineers with backgrounds in two sectors deliberated that the gasification technology used for oil and gas could be applied to black liquor. Chemrec was established in 1987 to develop the idea further, the ownership changing several times in the course of 20 years. Technical and financial difficulties and pulp and paper companies' lack of interest hindered the development along the way. Financial and administrative support from the Swedish Energy Agency was crucial when the interest of private investors was low. Wider interest was not stimulated until the early 2000s, when a directive for the promotion of biofuels for transport (2003/30/EC) was being prepared by the EU. It required a minimum proportion of two percent of biofuels in the energy content of transport fuels by 31 December 2005 and 5.75 percent by 31 December 2010, creating a market for new technology, while the increased price of oil spurred on the competitiveness of biofuels. Although initially Chemrec looked at black liquor gasification for electricity, following the new demand for transport biofuels an engineer working at Chemrec thought of combining syngas and black liquor gasification to produce dimethyl ether (DME) for transport fuel. Another driver was the energy tax relief for renewable fuels in Sweden that made the net payback time quicker. Chemrec also initiated cooperation with Volvo who had developed a truck motor using DME as fuel and anticipated a future with stringent requirements for emissions from heavy duty diesel engines. Volvo, now a co-owner of Chemrec, is starting the commercial production of DME engines in 2011 and wants to have the fuel commercially available. (Article V)

Biomass gasification for transport fuels

The Technical Research Centre of Finland and the Helsinki University of Technology began researching biomass gasification in the 1970s, and the Finnish Funding Agency for Technology and Innovation, Tekes, started funding gasification projects in the 1980s. Later, a consortium of researchers and companies was formed to jointly develop biomass gasification in integrated pulp and paper mills. Despite these efforts, low oil prices kept many research results unutilised until recently, and the interest of the forest industry was low. Finland recently adopted the requirements of the EU Biofuels Directive, and the globally sinking price for paper products and an increased price of fossil fuels have increased pulp and paper producers' interest in biorefineries. The extensive R&D background meant that suitable technology was near commercialisation to respond to the Directive. In 2006 UPM made the first move among Finnish paper producers, stating that it would start the production of DME through gasification in connection with its pulp mills in Finland and in other European countries. Soon after, Stora Enso also announced a co-operative venture with Neste Oil to start the production of biodiesel. (Article V)

LignoBoost

The research and consulting company STFI began developing the LignoBoost process in the mid-1990s for extracting lignin, a chemical compound of wood, from the pulp making process for producing biofuels. A strong driving force for LignoBoost was that by removing lignin from black liquor, the pulp capacity of the mill could be increased with low investment costs. The system could also extend the age of existing recovery boilers up to 8-10 years, simultaneously saving 50-70 percent of the investment costs required to rebuild a recovery boiler. When the development leading to LignoBoost began, research in STFI was based on the vision that a pulp mill could be a major supplier of energy to society, while at the time many people in the pulp and paper industry viewed the vision as unrealistic, partly because of low oil prices. LignoBoost was developed further in cooperation with companies and universities, and with support from the Foundation for Strategic Environmental Research (MISTRA) and the Swedish Energy Agency. Later increased oil prices heightened investors' interest in LignoBoost. Two energy companies have been actively involved and licences for the technology have been pre-bought by interested customers. (Article V)

Ecological paper by VTT

At the turn of the millennium, VTT, the Technical Research Centre of Finland has developed natural materials from raw starch enabling the making of high-quality paper that is fully recyclable and called 'ecological paper'. With the help of this technology and without changes in paper machinery, starch can replace the mineral rock-based filling and adhesive materials typically used in papermaking. The development started as an idea to reduce the weight of paper and produce printing paper with as little fibre as possible, aiming at improved resource efficiency. Improving both the environmental and technical aspects of paper regarding recyclability and surface strength increased the researchers' interest in developing the idea further. The companies M-real, Stora Enso, Metso Paper and Ciba Specialty Chemicals co-financed the research together with the Finnish Funding Agency for Technology and Innovation, Tekes. The technology was ready for commercial trials in 2006. No environmental policies were identified as having affected the research, despite its potential environmental benefits related to logistics, printing and recycling. Environmental policy trends, especially those related to recycling, have in general terms had some influence. (Article III)

Tetra Recart

In the late 1990s Tetra Pak developed a carton material that is moisture-resistant and heat-resistant. This means that the Tetra Recart package can go through a heating process after it has been filled with food to enable a long shelf-life. It provides an alternative to tin cans and glass jars for storing food. The development consisted not only of the packaging itself but also of the system sold to food producers for packaging the food and heating it for longer preservation. Improvements in the logistics of packaged food, cost reductions and the need to develop something innovative were behind the invention. Expectations of potential new markets and of environmental benefits through savings in materials, energy and non-renewable resources simultaneously influenced the development. More generally, the recyclability of packaging has been important in Tetra Pak's new product development, following both increased demands from customers and the EU Directive on packaging and packaging waste (94/62/EC). (Article III)

Recycled packaging by Hartmann

Hartmann has manufactured recyclable and biodegradable moulded fibre packaging from recycled paper for decades. Environmental arguments were first used in the 1990s in marketing the packaging products. Since then extended producer responsibility based systems for packaging and packaging waste created new markets for the increased use of recyclable and recycled packaging. This development took place despite less ambitious goals set in the Directive for recycling of plastic than fibre packaging. In addition, a tax on packaging favoured fibre packaging over plastic in some EU countries. Increased pressure on those packaging their products to use fibre instead of other packaging materials made Hartmann's moulded fibre packaging an 'environmental' innovation. Increased oil prices have also increased the price of plastic, thereby supporting the growth of moulded fibre packaging market. (Article V)

Radio-frequency identification (RFID) tags and inlays

For several reasons, especially due to increasing outsourcing of manufacturing, the need to improve supply chain management has been stressed in many industrial sectors. Radio-frequency identification (RFID) refers to a method for automatic identification, in which so-called RFID tags or transponders are utilised for storing and remotely obtaining stored data. Tags can be attached to products, animals or people in support of supply chain management. The development of RFID has mainly been carried out in other sectors than the pulp and paper industry, and the development of RFID technology in the sector has arisen by combining technologies from different industrial sectors. In connection to its label stock business, UPM Raflatac developed RFID tags and inlays in order to create new business in response to needs to improve supply chain management. The EU Directives on extended producer responsibility (EPR) for electronics (2002/96/EC) and end-of-life vehicles (2000/53/EC), however, have also created pressures to enhance the waste management and recycling in the industries targeted by the directives. They have thus created new potential markets for RFID based solutions that also provide environmental benefits. The new markets may also enhance the demand for RFID tags and inlays developed in the pulp and paper sector. (Article V)

6 HETEROGENEITY OF PUBLIC POLICIES RELATING TO GOALS, CHARACTERISTICS AND INNOVATION EFFECTS

6.1 Different goals of environmental policies

Empirical research has shown that the effects of environmental policies on innovation tend to be partly context dependent and partly dependent on policy design. This chapter explores the different ways in which environmental policies affect environmental innovations based on empirical examples from the Nordic pulp and paper industry (Articles I, II, III, V). Furthermore, conditions in which environmental policies are most likely to promote innovation are proposed as a result of the empirical study.

Environmental policy is not a homogenous concept, because the word 'environment' has a wide meaning. Thus, while environmental policy has a uniform general aim to protect the natural environment (Section 2.3), it includes several different environmental aims that sometimes have conflicting outcomes. At times, technology improving the achievement of one environmental policy aim impairs the achievement of another (Article III). For instance, increasing the recycling of paper may increase the use of energy in the recycling process or in related transport. In a good case, different environmental policy aims complement each other. Such is the case, for example, when climate policies promote energy technologies that also reduce the emissions of sulphur and nitrogen oxides into the air.

The environmental policies of Finland and Sweden have several different aims, including:

- curbing climate change
- protecting the ozone layer
- controlling air pollution
- noise abatement
- controlling water pollution and water quality in surface and ground waters
- reducing wastes and improving waste management
- soil protection
- controlling risks related to chemicals
- controlling risks related to genetically modified organisms
- conserving nature and biological diversity

Environmental innovation is rarely mentioned as an explicit objective of environmental policy but it is related to achieving improvements in environmental protection. Yet in some cases specific decisions have been made that, for example, environmental permit decisions cannot anticipate technological development and must rather be based on existing technology (e.g. Similä, 2002). In these cases, environmental policy cannot directly promote innovation by requiring it. Even in these cases, however, permit decisions may play an important role in the diffusion of innovations, when newly commercialised technology makes it possible to fulfil the permit conditions more effectively or cost-efficiently than older technologies (Article I). Permit requirements in Finland have been found to facilitate the testing and diffusion of new technologies by allowing relaxed conditions during trials and issuing emission limits that do not specify the use of any given technology in meeting the requirements (Hildén et al., 2002; Mickwitz et al., 2008).

Environmental innovation rarely being a specific aim of environmental policy has further consequences. As environmental policies are often not primarily intended to promote innovation, many policies fail to encourage it. (Article III) Yet despite the limitations of environmental policies in promoting innovation, the empirical cases of this study show that they have played some part in the innovation processes in the Nordic pulp and paper industry. The studied innovation cases have been affected by at least four of the ten policy areas identified above:

- Air pollution policies, e.g. the United Nations Convention on Long-Range Transboundary Air Pollution 1979, and Decree 160/1987 of the Finnish Government on general guidelines for limiting the sulphur emissions of sulphate pulp plants. (Article I)
- Water pollution policies, e.g. national-level water emission limits in Finland and Spain. (Article I)
- Waste reduction and management policies, e.g. Directive 94/62/EC of the European Parliament and of the Council on packaging and packaging waste and national-level waste policies in Germany, Sweden and Finland. (Articles III, V)
- Climate change policies, e.g. Directive 2003/30/EC of the European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport, and national-level support for renewable energy sources in Finland and Sweden. (Article V)

While the environmental policies above have contributed to innovations responding to these specific environmental concerns, the resulting product and technological innovations may exacerbate some other environmental aspects, such as energy use or biodiversity. The whole pulp and paper industry extending beyond the empirical cases of this study also experiences influences from chemical, biodiversity, soil and noise policies.

6.2 Different instruments and characteristics of environmental policies

Various policy instruments have been applied in the context of environmental policy, including regulation (e.g. emission limits enforced through permit conditions), economic instruments (e.g. pollution taxes and tradable emission quotas) and informational or voluntary measures (e.g. eco-labels and voluntary agreements for energy-saving). Some R&D funding is allocated through environmental ministries but, in the context of the pulp and paper industry, other funding agencies (e.g. other ministries, energy agencies and technology agencies) have been more significant sources of funding for environmental innovations (Articles I, V).

The innovation case studies showed clear effects from regulatory policy instruments on innovations, while the contribution of economic and informational instruments was absent or remained unclear in most cases. There are several possible explanations for this. First, the effects of regulations are easier to pinpoint compared to those of economic or informational policy instruments, because certain technological changes have been made specifically to comply with regulations. By contrast, for example, an environmental tax does not force technological change as the companies may choose to pay the tax rather than engage in innovating or in purchasing new technology. Yet other studies have been able to find causal connections. For example, local emission standards of harbours have encouraged innovations reducing NO_x emissions from ships (Hyvättinen and Hildén, 2004; Mickwitz et al., 2008).

The second explanation for the significance of regulatory instruments is that the pulp and paper sector has had most policy pressure from regulations on air and water emissions and recycled content of paper rather than other policy instruments (Articles I, III, V). Few economic or informational instruments have been imposed on this sector.

The third explanation relates to the observed weakness or newness of those economic policy instruments that have related to the pulp and paper industry in Finland. The energy tax has been found to have only marginal impacts on industry because it is at a low level and includes exemptions for energy-intensive industry (Määttä, 2000; Mickwitz et al., 2008). The emissions trading scheme, by contrast, is too recent an instrument for its definite impacts on technological change to be discernible.

Earlier I argued (Section 3.3, also Article III) that due to disparate results from several empirical studies, the discussion on the suitability of specific policy instruments in supporting environmental innovation is outdated, and one should move on to discuss the elements of policies that may be shared between different types of policy instruments. In light of the empirical cases, three important characteristics of environmental policy can be identified that are more inclined to support innovation, including 1) foreseeability of policies; 2) flexibility of policies; and 3) gradually more demanding policies (Figure 5). These correspond quite closely to Porter and van der Linde's (1995) early ideas on how environmental policies should be designed to support innovation. Furthermore, these elements have been put forward by others (Section 3.3) but not systematically combined together.

Anticipation of future policy has a decisive influence on innovation (Articles I, III, V). When companies anticipate environmental requirements, they may act in advance to gain leeway to respond to different policy and market situations (Article I). The case studies show that technological developments, such as Conox and black liquor combustion, have partly been induced by certain environmental issues being high on the policy agenda, which has foreshadowed forthcoming policies (Article I). Similar results have been found in the manufacture of ship engines, where the innovations have been created in anticipation of international policies on NO_x emissions (Hyvättinen and Hildén, 2004; Mickwitz et al.,

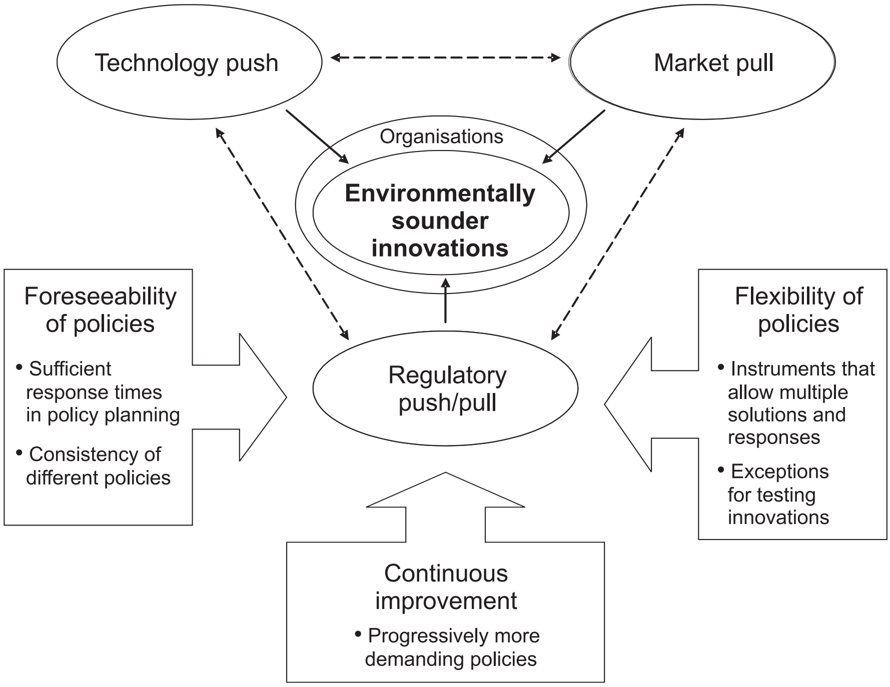

Figure 5: *Intervention model for environmentally sounder innovation, expanded from Rennings's (2000) model of the determinants of eco-innovation (Article III)*

2008). Yet policy anticipation may also fail, as the Conox case illustrates. The anticipated regulatory measures for closing the bleaching processes of pulp mills did not materialise; luckily a new market application for the technology was found in China (Article I). Planned policies that are credible and predictable to companies are more likely to promote innovation prior to implementation (e.g. Mickwitz, 2003).

There is also a dynamic effect related to policy anticipation. While technological development reacts on foreseeable policies, the policy decisions are influenced by technological advances. This has been explicit in the development of recovery boilers increasing the dry-solids content of black liquor, where the technology was developed in anticipation of new air pollution policies and the policy conditions were detailed on the basis of recent technological development (Article I). Further support for the argument can be found in another study that showed the importance of domestic technologies for the setting of standards for SO_2 emissions from large combustion plants in Finland (Mickwitz and Kivimaa, forthcoming). More recently, policy measures to increase the use of bio-based fuels in transport would have very little chance of being implemented had not the technologies making this available been developed since the 1970s (Article V).

Flexibility in regard the choice of technological solution for meeting environmental requirements and the testing new technologies is important. Economic policy instruments are often seen as inherently flexible, because they allow action or non-action to different extents by companies that are the target groups of the policies. Thus, economic instruments are often favoured at least in theoretical discussions (e.g. Milliman and Prince, 1989; Jung et al., 1996). This is because *'the desired outcomes are assumed to be achieved'*, while in effect those targeted by the instruments can freely choose their actions, which may continue to be less desirable (Similä, 2007).

By contrast, regulatory instruments have often been characterised as inflexible (e.g. Palmer et al., 1995) but the innovation cases also revealed examples of flexible features of regulation (Article I). Inflexibility is mostly associated with technology forcing regulation that chooses a particular technological option to be installed. An example of this could be the height of chimneys in manufacturing plants (Hildén et al., 2002). By contrast, general guidelines for emission limits are only indicative and have allowed permit officials to consider context-specific circumstances of industrial installations. General guidelines for air emissions of the Finnish pulp and paper industry fostered the development and diffusion of new black liquor recovery boilers (Articles I, III). Allowing temporary increases in water discharge limits, in turn, enabled the testing of activated sludge installations in Finnish mills (Mickwitz, 2003; Mickwitz et al., 2008). The flexibility of guidance allows permit decisions tailored for individual installations and may help to avoid efficiency problems related to the rigidity of technical standards; the implementation of guidelines, however, has been claimed to be a more costly form of decision-making (Similä, 2007). Even specific emission standards in regulations, unalterable by permit officials, allow flexible responses in terms of the technology chosen by the organisation to which the permit applies.

While companies often object to gradually more demanding policies, policy development may provide benefits to innovative and technologically leading companies, altering the competitive situation of companies. In the development of technologies using black liquor, tightening environmental regulation for air emissions brought these issues to the attention of pulp and paper producers, who then knew to require improvements from the technology developers and became enthusiastic about the developers' solutions (Article I). More demanding transport fuel policies have enabled the commercialisation and diffusion of black liquor and biomass gasification technologies that have been close to commercialisation for quite some time (Article V). The most positive response is received by those environmental innovations that also result in efficiency, cost or competitive benefits for the companies using them. The black liquor technologies, for instance, also improve the mill's opportunities to produce power and heat for internal or market purposes, thereby reducing the total cost of pulp and paper production (Article I). Financially the more traditional end-of-pipe technologies benefit at least their manufacturers but also others if regulatory, trading or tax costs are avoided.

In sum, foreseeability, flexibility and continuous improvement are the key elements of environmental policies that appear to best support innovation. By combining the three elements derived from this study with Rennings' (2000) model of the determinants of environmental innovation, an intervention model for environmental innovation was developed (see Figure 5). In evaluation research, the concept of intervention theory/model refers to the presuppositions regarding what the intervention is designed to achieve and how (Vedung, 1997). The intervention model for environmental innovation presents how, in principle, environmental policy could be directed to support innovation. Environmental policies requiring continuous improvements in a predictable direction and offering several response options can (i) directly provide incentives to companies to innovate, (ii) signal or inform research and development or the markets about potential inefficiencies or need for improvement, or (iii) create new markets for innovations. Technology and markets offer feedback for environmental policymaking on the prevailing problems and available solutions. (Article III)

6.3 Differing policy effects on innovation

In reality, environmental policy has many different types of effects on innovation, not always representing the ideal type presented above, and these effects are not limited to the way that the traditional 'policy cycle' is described (Articles I, III, V). Environmental policy effects on innovation can be divided, in the light of the empirical findings, into six different categories (based on Article III):

1. *Responsive effect* after policy implementation on (a) innovation and/or (b) diffusion.
2. *Anticipatory effect*, where innovations are developed or commercialised in expectation of future policies that potentially create new innovation markets and impose requirements.
3. *Two-way effect*, where policies and technological innovations develop simultaneously influencing each other.
4. *Indirect effect*, where the influence on innovation and diffusion occurs, for example, through the heightened awareness of customers (demanding better products) and technology developers (creating new alternative solutions).
5. *No influence*, because the motivation for innovations stems from other factors and/or policy has targets achievable with existing technology at little cost.
6. *Negative effects*, where policy impedes innovation, for example, by prescribing a specific technological choice, by controlling the other environmental impacts too strictly, or by allowing no flexibility for the testing of new technologies or products.

The first type of effect, innovation being developed or diffused in response to environmental policy adheres to the idea of the traditional policy cycle, where policy initiates or enforces a subsequent change. For example, POM technology was adopted by a Spanish paper mill, because it enabled the mill to meet short term maximum limits in the water permit (Articles I, III). Some pulp mills in Finland adopted new black liquor recovery boilers only after their permit conditions for air emissions tightened (Article I). Similarly new activated sludge technology was adopted in Finnish mills following tightening conditions in the water permits (Mickwitz et al., 2008). In this study, the responsive effect was more common for the diffusion than the actual emergence of innovations. However, in the case of developing black liquor gasification, the end-use of black liquor in the technology developed by Chemrec was applied to transport fuels partly due to the EU Directive 2003/30/EC on the promotion of the use of biofuels for transport (Article V). The use of recycled fibre in packaging also increased after the implementation of EU and national level policies on packaging and packaging waste (Articles III, V).

As described above (Section 6.2.) the anticipation of environmental policies played a significant role in the environmental innovation cases in this study. The innovators expected policy-created markets promoting the adoption and diffusion of new environmental technologies or products. This was the case especially for several process innovations, including increasing the dry-solids content of black liquor, Conox, and black liquor and biomass gasification technologies. On the product side the EU Directive on Packaging and Packaging Waste includes clear signals of forthcoming improvements, further enforcing technological development (Article III). The two-way effect, where policies and technologies develop interactively, was also described above (Section 6.2).

The indirect effect of environmental policies is harder to establish due to the complex causal mechanisms surrounding innovation. For instance, a new policy when discussed publicly may bring new information to the attention of the customers of the pulp and paper industry, who then may require improved environmental performance even exceeding the policy requirement. For example, policies have highlighted the significance of water pollution, while customers of paper companies have actually posed more stringent requirements (e.g. on chlorine use) than the policies in place (e.g. Mickwitz, 2003). A policy may also exhort technology developers and inventors to produce even better products and technologies. Such was the case with air pollution policy and the development of black liquor recovery boilers in Finland. A policy may also occasion achievements in one sector, and the technology can then be modified and transferred to the use of another sector. This happened when CHP production developed in the pulp and paper sector was transferred to be used in district heating (Middtun and Koefoed, 2005). In the cases studied indirect effects may have emerged from anti-nuclear discussions, renewable energy policies and the EU emissions trading scheme (Articles I, V). For example, an anticipated increase in energy price, partly influenced by the EU emissions trading scheme, affected the design of M-real's BCTMP mill (Article V).

Environmental policies are not the only reasons behind improvements in new technologies or products, and often innovations with environmental benefits as side-effects have emerged entirely for other reasons. For example, POM technology was created to achieve cost reductions through improving the efficiency of the paper machine, simultaneously resulting in environmental improvements, such as reduced water consumption (Articles I, III). The early development stages of 'ecological paper', LignoBoost and the BCTMP mill likewise had no direct links to specific environmental policies (Articles I, III, V).

Environmental policies may also have negative effects on technological development. Some of the cases studied, such as some stages of black liquor gasification and early development of Conox, showed that environmental policies presented too lax conditions from the perspective of the commercialisation and diffusion of these inventions. More general barriers arise when policies specify the technology to be used to solve the problem thereby preventing more innovative solutions, or when a policy allows no flexibility to test new technologies or products in practice. Environmental policy may also contribute to the emergence of more complicated systems, when improvements are added on top of the existing systems. To examine the extent to which these barriers occur would require detailed scrutiny of cases of failed inventions.

As the references to the empirical cases show, a case can incorporate more than one type of policy effect during different stages of innovation development. Table 3 illustrates the type of policy-effects occurring in the cases studied. The same policy may likewise have different types of effects on different innovation cases, depending on the focus of the policy and the environmental improvements that the innovation involves.

Environmental product innovations by pulp and paper producers have been fewer than environmental process innovations by equipment developers. Many paper producers have been risk averse towards investments in new business areas, and the product information flow between companies has been small. Environmental product innovation has largely been dependent on demands from paper or packaging buyers, whereas process innovation has also involved environmental policy pressure targeted at paper producers. In effect, much of environmental policies and customer pressures in the sector have targeted production, not products (Article III). This is due partly to the fact that the environmental impacts of the sector have been greater from production, although product and process improvements in this sector are linked to a degree (see Section 2.2).

The effect of environmental policies on innovation is more complicated than initially appears. This supports arguments in the favour of properly evaluating both existing and planned policies using multiple criteria (e.g. Mickwitz, 2006), of which promoting innovation could be one.

6.4 Integration between 'policy fields'

As innovation systems are composed of a variety of factors, including the policy sphere, environmental policies are not the sole determining factor in the emergence and diffusion of innovations. Even within the policy sphere, policies from different areas tend to influence, either promote or hinder, the development of innovations (Figure 6). The findings from the empirical cases show that environmental and technology policies frequently have a combined impact on the emergence and diffusion of environmental innovations in the pulp and paper industry (Articles I, V). For instance, the development of black liquor dry content increase was a combined result of air pollution policies and R&D funding programmes (Article I).

The findings of this study also show that energy policies have overlapping effects, positive and negative, on those innovation cases that improve the energy efficiency of production or provide new solutions for energy production in pulp mills (Articles I, V). In the 1990s, the deregulation of the Finnish electricity markets increased the diffusion of new, more efficient black liquor recovery boilers, because it created an incentive for

Table 3: Nature of policy effects in the innovation/invention cases studied

Invention/ innovation case	Responsive effect	Anticipatory effect	Two-way effect	Indirect effect	No influence	Negative effect
POM	diffusion (water permit in Spain)				invention & development	
BCTMP				development (emissions trading increasing energy price)	no direct influence on development & adoption	
Conox	commercialisation & diffusion (regulation in China)	development (reg. closing bleaching processes)				commercialisation (expected regulation did not occur)
Black liquor dry content increase	diffusion (air emission limits in Finland)	development & commercialisation (reg. for air emissions)	development (simultan. with Finnish air pollution policy)	development & diffusion (energy policies)		
Black liquor gasific. for electricity				development (energy policies)		commercialisation (no policy stimulus in the 1990s)
Black liquor gasific. for transport biofuels	development & demonstration (EU Directive for transport biofuels, renewable energy subsidies)	development (renewable energy policies)	development (simultan. with bioenergy policies)	development (emissions trading)		
Biomass gasification for transport biofuels	commercialisation (EU Directive for transport biofuels)	development (renewable energy policies)	development (with bioenergy policies)	development (emissions trading)		
LignoBoost				development (energy policies)	invention	commercialisation (support systems for existing renewable energy)
Ecological paper				development (recycling policies)	invention	
Tetra Recart				development (recycling policies)	invention	
Recycled packaging by Hartmann	new use & diffusion (policies on packaging/ packaging waste)				invention	
RFIF tags and inlays				development & diffusion (extended producer responsibility)	UPM Raflatac's products	

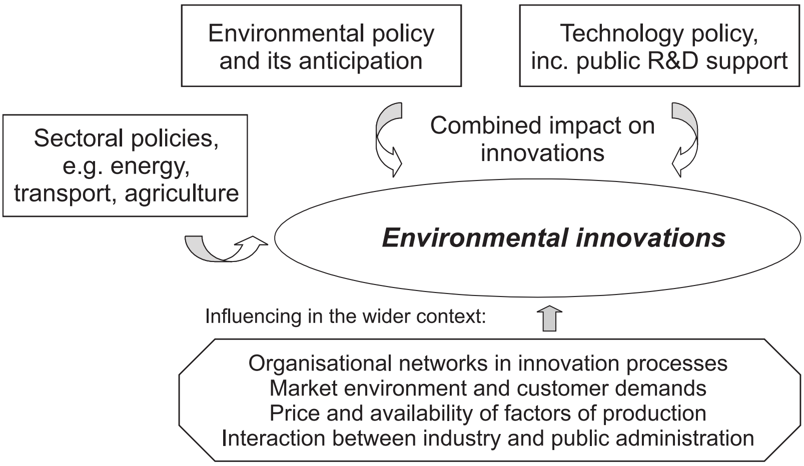

***Figure 6:** Different policy fields have combined impacts on innovation, causing both synergies and conflicts when influencing within the wider context*

pulp and paper companies to produce electricity in exceed of their own needs (Article I). By contrast, the Swedish green certificates scheme has slightly dampened investments in LignoBoost due to the profitability of producing electricity from excess steam in pulp mills by existing processes (Article V). In addition, energy policies may have indirect effects on product innovations: for instance, as fossil-fuel based packaging has become more expensive, new fibre-based packaging solutions have been developed (Article V).

Although different policy fields in combination may have positive effects on the innovation process in question, the policies themselves may have contradictory goals. Specific policy fields have several different goals that do not always yield consistent outcomes. The multiple objectives of environmental policies were discussed above (Section 6.1). The public funding of technology likewise tends to be supported by several different goals. For example, black liquor related R&D has received financial support motivated by environmental protection, enhancing the competitiveness of domestic industry, and supporting the use of domestic fuels (Article I).

The two most important policy fields for environmental innovation, technology and environmental policies, are in synergy when they both promote domestically developed environmental technology and products. However, when potentially more efficient environmental solutions are developed abroad, the interest from the perspective of innovation-oriented national technology policy is reduced. Actual goal conflict may occur in areas where R&D support is allocated to technologies that subsequently have negative environmental side-effects, or where an innovation is dependent on a substance or operation later prohibited or circumscribed by environmental policies (Article I). Case studies of inventions, failed to become innovations, would yield more insights into the contradictory effects of different policies.

The idea of 'policy integration' (Underdal, 1980; Section 2.4) is of interest in the context of promoting environmental innovation for two reasons. First, the innovation cases themselves show that, since multiple policies affect innovations, they should somehow be coordinated. If, for example, environmental policies are not designed to incorporate flexibility allowing the testing of new technologies, technological potential may remain unexploited (Article II). If environmental policy bans a newly developed technology outright, R&D funding allocated to it will be wasted (Article II). Second, harmful environmental effects are often caused by activities such as transport, agriculture and energy production, which are extensively influenced by public policies (Article II). Consequently, it has been argued that the environmental damage could be reduced if environmental aims were taken into account in the design and implementation of public policies (e.g. Weale, 2002). If environmental goals were well integrated, for example, into innovation and technology policies, the negative effects of new technologies could be anticipated and reduced (Article II) and environmental opportunities of R&D projects carried out for other reasons could be better recognised. In light of the earlier discussion, the opposite could also be argued. If innovation goals were better integrated into environmental policies, more efficient environmental improvements promoting economic development could result (Mickwitz and Kivimaa, 2007).

Article II presents an empirical evaluation of environmental policy integration (EPI) in Finnish technology policies focusing on R&D funding, whereas the integration of innovation objectives into environmental policies is explored in another article by Mickwitz and Kivimaa (2007). Article IV examines environmental integration within companies, focusing on R&D and product development, but also provides useful findings regarding the organisational perspective of policy integration. Together the findings indicate that the integration of new objectives or principles into organisations can mainly occur through two routes: people and procedures (Article IV). A vertical 'from strategies to projects' application of either, however, is not necessary to achieve environmental policy integration at the local level of R&D projects or innovations, because integration of ideas can occur locally without links to strategies (Article II). From the environmental innovations perspective, integration towards the end of the policy process is crucial (Article IV). A connection between the strategy and local levels, however, means that the choices made regarding the pursuit of environmental improvements emerge systematically from strategy, and that different programmes or projects follow a similar strategy (Article IV). National level strategies are indeed important in achieving coordination between different policy sectors, in highlighting issues that are important to society and policy-making, and in gaining support for environmental policy integration (Article II). To promote environmental innovation, strategies must be followed by actions influencing idea generation and technology development in research organisations and companies.

A mere occurrence of integration does not indicate any practical relevance. Rather the extent to which integration has occurred and the actions it promotes are relevant from the perspective of achieving environmental innovations. The necessary conditions when evaluating the extent of environmental policy integration are: 1) the inclusion of the environmental aspects in policy strategies, policy instruments, and policy outputs and outcomes, 2) the consistency of the environmental aspect in relation to other aspects, 3) the weighting given to the environmental aspect with respect to other aspects, and 4) reporting on the achievement of integration (Article II). These can be used as criteria in evaluating policy strategies and documents or equally in examining the processes that people participate in and the activities that people conduct as part of policymaking. Article II focused on evaluating policy strategies and documents, and showed how to use the criteria in such an evaluation. On the people dimension, the weighting could be measured as representation of environmental experts in working groups or committees or as the way in which environmental issues are presented in the discourse during meetings and other activities. Coupling between organisation's principles and the actual practice (Oliver, 1991; Brunsson, 1993; Westphal and Zajac, 2001), functional integration within organisations (Fryxell and Vryxa, 1999) and the existence of informal networks supplementing formal networks within organisations (Howard-Grenville, 2006) are likely to influence the effectiveness and outcomes of implementing environmental policy integration in public organisations.

When examining policy outcomes such as the contribution of technology funding programmes to environmental innovations, the results of EPI can only be examined tentatively, since innovation processes are affected by a variety of driving forces (Article II, Section 3.2). Yet, the empirical study shows that many of the public technology programmes carried out during 1988-2002 in Finland have contributed to processes that have resulted in environmental innovations (Articles I, II, V). The developers of POM did not have key intentions relating to reduced environmental impacts, but the project received funding from an environmentally oriented technology programme. The technology ended up having environmental benefits and it was in one case purchased specifically due to its environmental credentials. (Articles I, II) The results thus imply that environmental objectives as part of R&D funding can contribute to the development of environmental innovations, but the extent to which EPI affects innovation could not be quantitatively measured in this study.

As noted above, EPI could play an important role in transforming more general innovations into environmental innovations, i.e. to innovations that have environmental benefits in addition to competitive benefits for businesses. Article II, however, shows that in practice systematic assessments of both the negative and the positive environmental impacts of funded R&D projects have been rare in Finland. Furthermore, there is no pre-screening of the overall environmental impacts of the activities promoted by the technology policies. Because observing the long-term effects of technological developments on the environment takes decades and environmental policies are essentially reactive, consistency or inconsistency between policies will not become apparent until time has elapsed (Article II).

A more thorough integration or coordination between different policy fields could find those environmental elements that could fairly easily be integrated into ongoing R&D projects. Since the anticipation of future environmental policies has been a major component for many environmental innovations (Section 6.3), the integration of environmental concerns into other policy fields could also, if based on developments in environmental policies, facilitate the information flow of forthcoming environmental policy concerns to researchers and technology developers. More effective promoting of environmental innovations includes also developing and adopting evaluation and monitoring mechanisms to support environmental policy integration.

7 VARIETY OF ORGANISATIONS AS POLICY TARGET GROUPS AND AS INNOVATORS - IMPLICATIONS FOR POLICY EFFECTS

7.1 Networks of organisations taking part in innovation

Most of the innovation cases studied show the involvement of a variety of organisations in the innovation processes. Networks of organisations have more commonly surrounded the development of process technology than paper and packaging products. New process technologies have often been created, developed and tested in cooperation with equipment manufacturers, pulp and paper producers, chemical companies, consultancies, universities, and public and private research organisations (Articles I, V). Conox Ltd was jointly established by a consultancy, a chemical producer and an environmental technology company to go forward with the invention behind the Conox process, and the technology was developed in cooperation with two large pulp and paper companies (Article I). Cooperation between equipment manufacturers and users of new equipment has been crucial for creating innovations in the complex industrial system. By contrast, new products of the pulp and paper producers have often been created within the companies but may have also been influenced by research in universities and research institutes (Articles III, V). Product innovations such as Tetra Recart have mostly been created internally for competitive reasons (Article III). Some product inventions also requiring new basic research, such as ‘ecological paper’, have been developed by research institutes (Article III).

Organisational networks involved in the innovation processes have frequently originated from publicly funded R&D (Articles I, V). In Finland and Sweden, R&D to promote innovation has often been carried out in joint public and private funded technology programmes. For example, the Finnish Funding Agency for Technology and Innovation, Tekes, has both required and motivated the cooperation of organisations in its technology programmes, influencing, for example, the development of BCTMP, biomass gasification and black liquor recovery (Articles I, V). The co-operation of equipment manufacturers with public research institutes through technology programmes has been crucial to advance black liquor related R&D in Finland (Article I), and it has been argued that:

> *‘the Finnish situation, where two major technology developers have co-operated in the same projects and research programmes has been unique from the global perspective, and this has created positive competition on the level of basic know-how… the know-how of both has clearly increased and they were clearly distinguished from their American or Japanese competitors.’* (Interview comment in Article I)

At the same time, inter-organisational cooperation has not been fully realised in all innovation projects funded by the technology programmes. Although public technology programmes are often intended, compared to independent project funding, to provide added value through information sharing, some SMEs have experienced this to be of little value:

> *'…certain large companies invested in their own development projects and, regarding information access and participation, we did not gain participation in those seminars that covered these results and did not become sharers of others' results, but we did present our own results.'* (Interview comment in Article I)

Some others have also viewed this kind of 'forced cooperation' negatively. Public funding schemes may strongly prefer companies to have a university or a research institute as a partner in R&D projects, and a company may have to co-operate with a governmental institute in order to obtain funding even when the same research service could be obtained from a consultancy at half the price (Mickwitz et al., 2008). Cooperation may also turn out to be costly in other ways. The bureaucracy, common activities and seminars required especially by EU projects have been criticised by the participants for requiring too many resources (Mickwitz et al., 2008).

Organisational networks have also originated on the market side (Article V). The development of technologies related to new product value chains has motivated some paper producers and equipment developers operating in the forest cluster to cooperate with companies in other sectors. The development of bioenergy technologies in connection with pulp mills has involved cooperation with energy and automotive companies (Article V). The development of RFID tags and inlays has involved combining wood fibre with electronics (Article V). The changing operational context of the Nordic pulp and paper industry and the search for innovations in new product value chains (Peltola, 2007b) further highlight the need to improve cooperation with companies operating in other sectors.

Although generally innovation in the Nordic pulp and paper industry can be characterised as cooperative, in some cases cooperation has been limited or lacking. The development of black liquor gasification by Chemrec was delayed due to a lack of investment interest on the part of pulp and paper producers, the potential users of the technology (Article V). In other cases, such as Conox, POM and LignoBoost it has also been difficult to get Nordic pulp and paper producers to take an interest in investing early on. The perceived ratio between risk and expected benefit has been too undesirable for most pulp and paper companies in these cases.

The examples above show a range of organisations potentially responding to policies targeting one industrial sector. Ideas are generated and research is carried out in a diversity of organisations, including universities, research institutes and companies alike. Often small companies, such as POM, Conox and Chemrec, are set up to take an innovative idea forward. For more radical inventions, such as black liquor gasification, obtaining the first customer, crucial for getting a reference to prove that the new technology works, can be an extremely difficult task involving a lot of negotiation with different parties. In other cases, the first customer may be actively developing the technology or product together with the innovator. Companies having differing roles in innovation processes are also likely to follow up environmental policy development differently and have varying responses to environmental issues.

Table 2 (Section 5.1) depicts actors in the innovation system surrounding the Nordic pulp and paper industry, showing that the organisations involved extend beyond those actively carrying out R&D or adopting new technologies. The innovation system also includes many public organisations promoting innovation (e.g. innovation agencies, R&D funding foundations and government owned venture capital). In addition, so-called shared organisations between industrial actors, such as industrial federations and sectoral research companies owned by companies in the forest cluster, have influenced innovation in the sector.

7.2 Different roles of organisations in responding to environmental policies

According to Oliver (1991) company responses to institutional pressures, such as environmental policy, range from acquiescence and avoidance to manipulation, where the latter refers to power over institutional processes. In the categorisation by Oliver manipulation has a negative tone. She does not mention the potentially positive effects of societally beneficial innovation that may be reached by exceeding policy demands to gain first mover advantage and by aiming actively to guide the policy design in a more stringent direction. For example, recovery boilers increasing the dry solids content of black liquor were partly developed in anticipation of air pollution policy, subsequently influencing the air emission limits set in legislation (Article I). The Finnish and Swedish forest clusters have actively promoted the diffusion of some environmental technologies by taking part in the preparation process of the Reference Document on Best Available Technologies in the Pulp and Paper Industry (European Commission, 2001). For example, Chemrec's black liquor gasification was mentioned as among the emerging technologies in kraft pulp production. In the electronics sector, large companies such as Nokia have actively aimed to influence the preparation process of the EU Directive on the eco-design requirements of energy using products (Kautto, 2007). The active influence on policymaking may benefit those commercialising innovations.

The empirical cases showed that innovating organisations have differing roles regarding their responses to environmental policy, including:

- responding to policy demands regarding own performance or products
- anticipating policy demands regarding own performance or products
- creating solutions to policy demands on the performance or products of others
- creating solutions in anticipation of policy demands on the performance or products of others

- increasing policy demands by innovating ahead of any expected policy
- increasing policy demands by posing requirements on others ahead of any expected policy

In this study, pulp and paper producers were usually those that responded to or anticipated policy demands regarding their own performance or products. They anticipated and responded, for instance, to water and air pollution and waste management policies by testing newly developed technology, by purchasing commercially available new technology and by setting up recycling and waste management schemes for their products (Articles I, III, V). Equipment developers, research institutes and universities created solutions to the policy demands of others, or increased policy demands by innovating ahead of anticipated policy. For example, the equipment manufacturers Ahlström, Tampella and Chemrec together with Nordic universities and research institutes worked for decades on various black liquor technologies both ahead of and in response to air pollution and climate change policies (Articles I, V). The Central European paper buyers, in turn, imposed requirements for the paper producers prior to or exceeding the requirements of policies, for instance, on water emissions and recycling related issues. This has spurred on both process and product innovation. (Articles I, V)

More recent innovation cases, however, have showed that the pulp and paper sector, including paper producers and equipment manufacturers, have also responded to policy demands in other sectors. For example, the development of gasification technologies relates to policies targeting energy production and transport. UPM Raflatac's RFID tags and inlays, in turn, respond to policies regarding extended producer responsibility, for instance, in electronics.

Managers of environmentally regulated companies have argued that it is hard to innovate because policymakers are unpredictable and policies often change unexpectedly, motivating companies to de-emphasise risky strategies such as innovation (Meeus and Edquist, 2006). Yet the preparation of new policies and amendments to existing policies takes a long time, and during this process many stakeholders are usually consulted. Larger companies are often more actively involved in policy development than smaller ones. For smaller companies with limited resources following many policy developments can be difficult. In effect, companies' responses to policies are likely to be determined by how actively policy developments are followed and how signals travel within companies from those who follow policy to those who carry out different operations (see Section 7.3). Moreover, the predictability of the details of the anticipated policy will affect whether and how companies respond (e.g. Mickwitz, 2003). Uncertainty about the eventual makeup of policies is likely to reduce actions in anticipation of future policy.

7.3 Dissimilarities in how organisations integrate environment into innovating

Environmental innovations in companies are enabled or limited by the organisation's general structures and capabilities for supporting innovation (e.g. Hatchuel at al., 2006) and the mechanisms through which environmental considerations are fed into innovation processes (Article IV). It has been argued that often there is too much focus on mere on networks between organisations, while the greening of industry projects should pay more attention to internal networks in companies (Williander, 2006). Therefore, although it is important to acknowledge the diversity of organisations taking part in the environmental innovation processes, processes within organisations also merit attention.

As noted in Section 3.4, a multitude of often conflicting institutional requirements imposed on organisations forces them to make choices between different goals and activities (see also Article IV). Organisations can use different processes in implementing their goals in practice. Processes within organisations determine, for example, how environmental policies are in effect followed up by companies and how policy signals transfer from one part of the organisation to another.

Organisational tasks are carried out to achieve organisational goals and respond to the variety of institutional requirements. The empirical cases show two potentially important organisational tasks from the perspective of environmental innovation, namely corporate environmental management and R&D (Articles III, IV). R&D aims to create new competitive advantages for the company and typically liaises with customers and marketing departments. Corporate environmental management in turn coordinates environmental issues in the corporation. Environmental policies, for example, create demands for corporate environmental management that modifies internal operations within the confines of the overall context and company culture. Customer demands, in turn, are often communicated to R&D and product development via marketing departments. (Article III)

Interaction between company departments is important for the transfer of environmental policy signals and information to R&D. Because different kinds of organisational tasks require different kinds of activities, they may also create different kinds of sub-cultures around them (e.g. Alvesson and Berg, 1992). Thus, there is a risk of functional disintegration (e.g. Fryxell and Vryxa, 1999) between the different departments and units formed around different tasks. Functional disintegration between company R&D units and corporate environmental management, for instance, does not as such prevent the emergence of environmental product innovations but it affects the intensity with which ideas and information flow between the units (Article IV).

The studied company cases from the paper and packaging sectors support the view that product development is rarely functionally integrated with corporate environmental management. This is illustrated both in the product development cases studied and in how the environmental and R&D personnel interviewed describe the processes. Environmental signals are fed into product development mainly through customer contacts, while developments in process technology are bound by environmental legislation. Functional integration is more common between product development and marketing and sales. Corporate environmental management, in turn, guides manufacture and may participate in process development. Thus the environmental activities of product development are often separated from corporate environmental management, at least in the pulp and paper sector. (Article IV) Interviewees at the case companies identified environmental considerations affecting product development, but did not directly relate these to any pressures external to the company. Environmental managers were aware of external signals but did not have detailed knowledge about the product development process or its drivers. (Article III)

Functional integration between corporate environmental management and R&D units, or coupling of corporate environmental principles via some other route with the R&D practice, may be required for an efficient transfer of environmental policy signals within organisations. Outside the organisation, environmental policy integration into R&D funding (Section 6.4; Article II) provides an alternative route to transfer environmental policy signals into R&D work. While the existing legislation is usually adhered to, a more efficient transfer of policy signals could enable a better utilisation of policy anticipation in company innovation activities. In addition, it could even facilitate the use of information on the expectation or realisation of policies that target other sectors than the company in question.

Fairly similar organisations may differ in terms of their approach to environmental issues. When attention was paid particularly to large paper and packaging producers, a variety of ways to consider environment in relation product development was identified. Article IV presents a study where the integration of environmental aspects into company R&D and product development was compared in four large paper and packaging companies. The analysis was based on a typology of six different forms of environmental integration created on the basis of existing literature. The analysis of the empirical material, in turn, illustrated four different approaches combining different integration forms that the companies used to integrate environmental issues into R&D and product development (Figure 7). The approaches differed from a highly standardised to a case-specific approach.

The standardised approach refers to organisations having standardised and systematic procedures for R&D projects, including environmental criteria defined by corporate management and a central team of in-house environmental experts to assist on R&D projects. By contrast, the case specific approach means that only project specific R&D personnel is involved in R&D projects and no corporate procedures for environmental criteria exist. Thus, environmental issues are considered on a case-by-case basis. In an expertise-based approach, the case-specific consideration of environmental impacts is complemented by a central pool of environmental expertise. In a procedural approach, project specific R&D personnel are bound by environmental criteria in standardised corporate procedures. The four paper and packaging companies studied could tentatively be positioned in Figure 7, showing that all the companies were positioned somewhat differently. (Article IV)

The different approaches to integrate environmental considerations into R&D are likely to have differing effects on environmental innovation and policy follow-up at companies. They may also be an indication of the companies differing views on

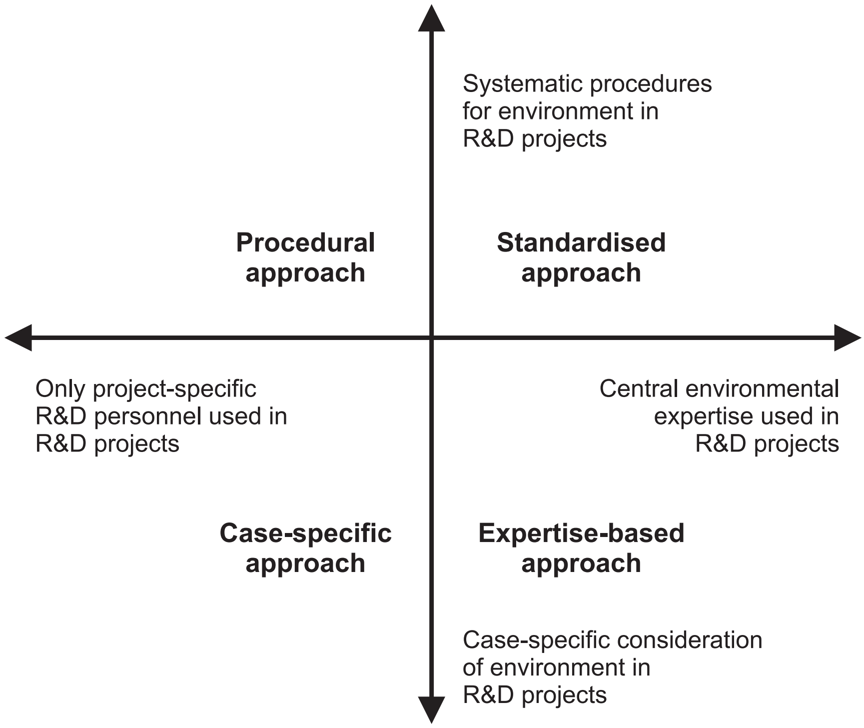

Figure 7: *A conceptual map of different approaches to integrating environmental considerations into company R&D (Article IV)*

innovating. The discussion on the coupling or decoupling of organisational principles and practice sheds some light on this issue (e.g. Oliver, 1991; Brunsson, 1993; Wesphal and Zajac, 2001). The standardised approach to integrating environmental considerations into R&D achieves some coupling between corporate environmental principles and the R&D practice as knowledge is shared through common procedures and key experts. This means that innovation follows a similar strategy throughout the organisation as both tacit and codified knowledge are diffused widely. This type of approach is better suited for achieving incremental innovations.[8] In more case-specific approaches there is a risk of slowly diffusing tacit and codified knowledge important for innovation, because R&D teams tend to work independently. Thus, in these cases R&D practice may be decoupled from corporate environmental principles. (Article IV)

In cases of standardised R&D procedures, functional integration is also more likely than in adopting an approach where the conditions and rules are determined on a case-by-cases basis for R&D projects (Article IV). Therefore, direct responses to environmental policy through innovation become more probable. As policy designs may sometimes be

[8] Even for more radical innovations, decisions coming from top management level can confer legitimacy on the implementation of certain principles to R&D work throughout the organisation (Williander, 2006).

confined to existing technologies or incremental improvements in existing technologies (e.g. Elzen and Wieczorek, 2005; Section 6.1), other approaches to include environmental considerations in company R&D may, however, produce innovations with more radical environmental improvements. In these cases environmental innovations could emerge that exceed the requirements of public environmental policy and offer previously unthought-of solutions with greater environmental benefits. Likewise to case study research that allows the researcher to follow up new tracks as they emerge, case-specific product development permits the finding of surprises and proves that the 'impossible' could be possible.

The case-specific approach allows more flexible conditions for radical and discontinuous innovations to emerge as the teams are freer from the restraints of corporate procedures (Article IV). To support this claim, it has been argued that creativity may be inhibited by structural rigidity and a high degree of formalisation (Hatchuel et al., 2006) and that top-down corporate visions are a poor guide to innovation strategies because of the uncertainties involved in the innovation process (Pavitt, 2005). Sometimes active development requires a departure from the boundaries of corporate rules. For example, every new pulp and paper grade in Metsäliitto has been developed bypassing the system that especially in the early days opposed development (Kettunen, 2002). This, among other things, has enabled the company to create lighter weight and more resource-efficient products for the markets. Moreover, it has been argued that environmental paradigm shifts in companies can actually emerge from experiences and innovations; it does not have to precede them (Halme, 1997). Thus, a more case-specific approach exploring new practices could also result in an environmentally beneficial organisational change.

As innovation processes are complex and affected by many determinants (e.g. Edquist, 2005; Malerba, 2005; Pavitt, 2005), the appropriate strategy for integrating environmental considerations into R&D is dependent on the nature of the organisation and the diversity of institutional requirements it faces. A more centrally controlled approach is useful if the organisation is not too large and allows for the bottom-up flow of ideas. Standard environmental criteria acknowledge environmental impacts from the start. If a company has a wide variety of environmental questions to deal with due to different product areas or environmental contexts, a more case-specific approach may be useful. (Article IV) Even within an organisation different strategies may be needed, as radical and incremental innovations have been found to require quite different organisational capabilities (e.g. Henderson and Clark, 2004; Jordan, 2006). In practice, however, the co-existence of competitive alternatives may be difficult within an organisation. In one of the innovation cases, the development of the invention was hindered because the owner company was also manufacturing an existing technology to which the invention was an alternative.

7.4 Linking policy and company levels

In sum, the diversity of approaches found to be available for integrating environmental considerations into company R&D supports the researchers of organisational culture (e.g. Alvesson and Berg, 1992; Howard-Grenville, 2006), in that organisations are rather loosely coupled and arbitrary, not a homogenous and rationally acting unity. Commonly corporate environmental management follows up and aims to influence developments in public environmental policy (e.g. Kautto, 2007). Yet those working in environmental management on the corporate level may be unaware of what happens in the same company's R&D or product development units (Articles III, IV). This can be explained by functional disintegration at departmental level, creating challenges to the ways in which environmental policy information reaches those who innovate. A similar lack of integration between the environmental and innovation fields may exist on company and policy levels (Figure 8).

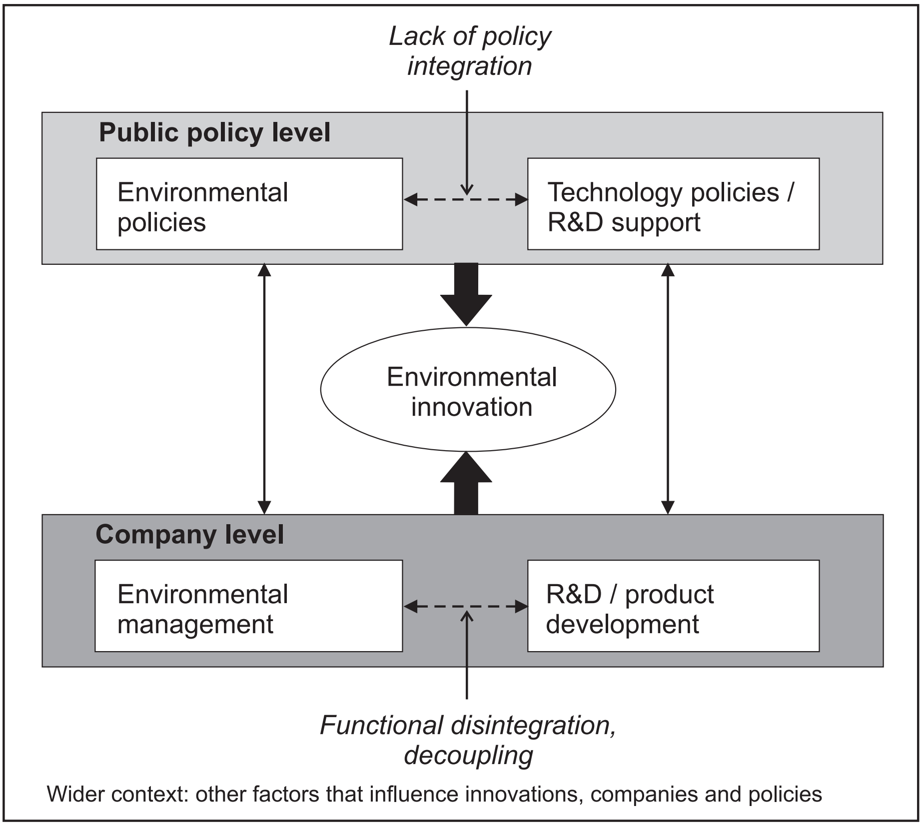

Figure 8: *Lack of integration between environment and innovating, complicating the environmental innovation process*

Public R&D support has a more direct route to innovators, because it is allocated to R&D projects, i.e. those who innovate, in most companies engaging in innovation in the pulp and paper sector. Larger companies and trade organisations also have influence on the design of technology policies and R&D programmes, making information flow both ways. Environmental policy integration, at least on some level, however, is a prerequisite for environmental signals to reach companies through technology policies and R&D funding. Alternatively, companies need internal ways to integrate environment into innovating for environmental innovations to emerge. Functional disintegration between R&D and environmental units and a decoupling of corporate principles from practice may impede the diffusion of environmental signals into innovation activities (Article IV), especially at the absence of environmentally-focused customer demand.

8 LINKING POLICIES TO TECHNOLOGICAL SYSTEMS AND MARKET CONDITIONS

8.1 Technology cycles, technological transitions and policy support for innovation

Dominant designs and path dependency in the Nordic pulp and paper industry

In the cases of several individual innovations, public policy support, especially focused R&D funding and environmental policies, has been found to be important. Yet if a wider systems change perspective is taken along the lines of technology cycles and technological transitions literatures (Section 3.1), other interpretations of the potential role of public policies in technological change emerge. On the one hand, windows of opportunity created by system change or by the stage in a technology cycle determine the options for public policies to promote innovation. On the other hand, policies created in support of existing technological systems may hinder the windows to open that would allow alternatives to the dominant technological design to emerge. For example, energy systems have often been claimed to be highly path-dependent, where discontinuous innovation may be restricted by existing institutions (e.g. Markard and Truffer, 2006; Unruh and Carillo-Hermosilla, 2006).

According to the technology cycles model (e.g. Anderson and Tushman, 1990; 2004), a change in a dominant technological design requires alternative technological trajectories and views of the world to emerge. In the era of ferment these alternatives rival each other and the previous dominant design until a new dominant design is selected (Section 3.1). When the stability of the dominant design is undermined, potential for new technological trajectories may emerge. Below I will examine recent developments in the Nordic pulp and paper industry from the perspective of the technology cycles approach.

Rather than having one particular dominant design, Nordic paper production actually involves several interlinked designs regarding the supply of resources, production and use. The relevance of each depends on the perspective taken. The dominant designs together or separately form the socio-technical regime surrounding paper production, depending on which interpretation of the rather vague regime concept (e.g. Berkhout et al., 2004) is adopted. At least three interpretations of the dominant design involving the Nordic pulp and paper industry can be made: dominant designs based on the socio-technical systems of 1) papermaking, 2) forest use, and 3) information provision (Figure 9). Changes in one design have implications for others. For example, if major paper producers shift their Nordic operations to countries where fast growing trees replace the traditionally used pine and spruce, the dominant system, where forest use in Finland is dominated by pulp and paper production, will also change.

Paper production during the last half century has become the dominant design of the Nordic forest sector on which other forest uses are based. In Finland, particularly printing and writing paper have formed the core products, which has meant that the major producer companies have had a diminishing interest in other product groups or business areas (e.g. Häyrynen et al., 2007).[9] As an illustration, the export share of these paper grades has increased from 20 percent in the 1960s, when a variety of forest products were exported, to 45 percent in 2006 of total forest sector exports (FFIF, 2007). The dominant design of paper production in forest use affects the extent to which alternative uses of wood are maintained and developed. The black liquor gasification case showed, for example, that the interest of paper producers to invest in radical deviations from the current production processes and core business areas has been low.

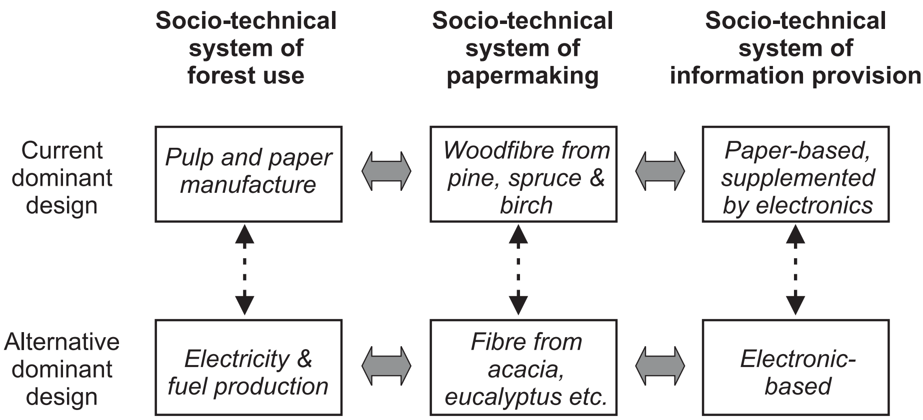

Figure 9: *Three dominant designs influencing the Finnish pulp and paper industry, and how discontinuities in one dominant design could influence the other designs. The horizontal two-way arrows show that the dominant designs surrounding the pulp and paper industry are interdependent. The vertical arrows indicate potential rivals to the current dominant designs. If a new dominant design emerges, it also affects the stability of the other dominant designs and may change them.*

Policies and political structures influencing the Nordic forest sector have also largely been based on the thinking relevant for export-oriented paper production. In the transition management literature, these would be described as a barrier to transitions and systems change (e.g. Elzen and Wieczorek, 2005). Environmental innovation in the Nordic pulp and paper industry shows signs of path dependency. Many technological solutions have been designed to support the existing paper production system and to mitigate its problems. The first environmental policies on pollution control were mainly intended to solve the environmental problems of production by requiring or implicitly promoting end-of-pipe technologies or other add-ons (although these may have also required process changes to function). Even more recently, supporting the view of transition management scholars, those cases where substantial effects from environmental policies have occurred can be

[9] By contrast, the Swedish forest sector has focused its expansion and development efforts also on packaging and hygiene products (Häyrynen et al., 2007).

argued to easily fit within the existing system. More radical innovations, such as RFID, were initiated and developed mostly for other reasons than environmental policy.

The development of black liquor gasification involving a different type of production system, and an end-product of energy rather than paper, is a case in point. Despite extensive research efforts in the 1980s, it was slowed down because it was perceived as a rather radical technology and no significant national environmental policies emerged to support this development in the 1980s or 1990s (Articles I, V). In early 2000, the biofuels policies that finally promoted the adoption of black liquor gasification originated in the EU, less tied by the Nordic paper production regime.

Path dependency related to technological systems has meant that those innovations fairly easily fitting into the existing systems, such as improved black liquor recovery boilers, have encountered fewer barriers to commercialisation. Although the R&D component of the Nordic innovation systems has supported a variety of technological options (all the cases studied), the experiences regarding environmental innovation in the Nordic pulp and paper industry show that other factors of the innovation system are often indispensable complements to the R&D support, without which the commercialisation stage may not be reached.

Potential for discontinuous innovation in the Nordic pulp and paper industry

When a dominant design thrives economically and receives much public support, it is hard for alternative trajectories to gain ground. Recent changes have reduced the stability of the Nordic pulp and paper industry (Section 5.1.) with potentially interesting implications for technology, society and policy. The findings of this study indicate that as the sector is forced to change radically in response to globalised markets and falling paper prices, inventions on the peripheries of the forest cluster receive increasing interest from pulp and paper producers who have previously been low investors in innovation outside their core business areas (Article V).

Much of organisational networking that has traditionally been part of the Nordic forest industry can be described as consensus-based. However, recent research by the Future Forum on Forests, based on a range of expert views on the future opportunities of the Finnish forest sector, constructs four very different alternative outlooks for the future (Häyrynen et al., 2007). A change of the Nordic forest sector from highly consensus-based to alternative outlooks could indicate a window of opportunity for discontinuous innovation in the sector's technology cycle(s).

Recently, however, new consensus-based activities, such as the Forest-based Sector Technology Platform (2006) and the Forest Cluster Ltd, have also been initiated in the sector. A European-level Strategic Research Agenda of the Technology Platform was launched in 2006, and national forest-based research agendas were subsequently published in Finland and Sweden. These common visions appear, nevertheless, to extend beyond paper-based research and innovation. While the forest-based research agenda does not explicitly focus on environmental protection, it may make a significant contribution to it in areas that have not typically been associated with environmental protection, such as intelligent products and biorefineries. The innovation effects of the recent initiatives depend partly on whether alternative voices, with the potential for creating new technological paths, will be heard. There appears to be a struggle between consensus and alternative outlooks, the result of which may determine how radically the existing regime will change. The result partly depends on the consensus-based regime's adaptive capacity to recognise and reduce its vulnerability to competing regimes (e.g. Berkhout et al., 2004).

It has been argued that, given the future uncertainties of the Nordic pulp and paper industry, the public sector may no longer be willing to direct resources heavily in this sector (Häyrynen et al., 2007). At first sight, this appears to weaken the basis for innovations, as national and sectoral innovation systems (including the public sector) have been described as a major component in successful innovation processes (e.g. Freeman, 2002; Lundvall et al., 2002; Malerba, 2005). This could instead, however, support the emergence of alternative trajectories along the lines of the technological transitions approach, if the strong influence of existing policies that may create barriers to discontinuous innovation is reduced. With this in mind the flexibility of policies to a variety of technological and business solutions is crucial (Section 6.2). Policies open to diverse technologies rather than supporting a single technological solution are more likely to admit change events. Yet a challenge for technology and innovation policy remains. A selection of key areas is usually preferred in public innovation policy, when not everything can be funded. Yet selecting particular areas in an era of ferment could create barriers for a more naturally emerging selection of future dominant designs.

Following from different levels of technological change, environmental policies can be seen to have two important roles in promoting more sustainable technological change: (1) facilitating innovation within the dominant designs while (2) simultaneously keeping options open for more discontinuous innovations to emerge outside the boundaries and bridging the gaps created by current systems. This supports the ideas of transition management scholars, in that system change and improvements in systems are not mutually exclusive (e.g. Rotmans et al., 2001). The discontinuous innovation perspective emphasises the need to evaluate current structures and identify components maintaining inertia.

Fulfilling the two roles of environmental policy can be difficult. While path dependent systems create tougher conditions for radical innovations to emerge, they simultaneously maintain predictability – one of the elements supporting innovation. When companies know to expect certain policies, they can innovate in anticipation. If they can expect a continuation of a policy, they will dare invest in innovation. Moreover, as innovation effects were noted to often be mere side-effects of environmental policies, fulfilling even one of the roles can be difficult.

8.2 The importance of market changes and internationalisation in the Nordic pulp and paper industry

The literature on innovation systems shows that several factors are crucial over the duration of the innovation process and for success in reaching commercialisation and adoption (e.g. Lundvall, 1992; Freeman, 2002; Edquist, 2005). The role of knowledge and learning is highlighted by many (e.g. Lundvall et al., 2002; Hage and Meeus, 2006). Apart from the issues covered in Chapter 7, the findings of this study show that the impact of knowledge and learning on environmental innovation tends to be similar to that in innovation processes in general (Article V). This section briefly addresses factors not covered earlier that may be important for environmental policies in generating innovation effects, namely market changes and internationalisation.

In a previous model of innovation drivers (Cleff and Rennings, 1999; Rennings, 2000), environmental policies contribute to the regulatory push and pull that complement technology push and market pull. From another point of view environmental policies could also be seen as creating new market pull for innovations by facilitating the diffusion of process and product innovations (Article V). In Article V, based on the empirical innovation cases and a literature review of earlier studies related to environmental innovations in the pulp and paper industry, three different types of market changes collectively affecting the innovation processes were identified: (1) changes in the existing markets for pulp and paper products, (2) new markets created or enhanced by international, regional or national environmental policies and (3) changes in other sectoral markets, such as energy or electronics (Table 4).

Globalising markets, falling paper prices, stagnating demand for paper products in Europe and North America, and speedier diffusion of information have altered the conditions under which pulp and paper companies operate. Intensified competition with more southern countries with lower resource costs has notably changed the markets for pulp and paper products. In addition to investments in production in southern countries and the closing down of European mills, these developments have increased the pressure for Nordic companies to improve the cost-efficiency of production, create new products for existing markets, and create products for new markets and product value chains. (Article V) The changes have made pulp and paper producers somewhat more proactive towards innovation (see Forest-Based Sector Technology Platform, 2006), and even inventions not in their core business areas have received interest. For some process technologies, such as black liquor and biomass gasification, this means that their operation can be demonstrated in conjunction with pulp mills.

The environmental innovation cases of the 1980s and 1990s were largely affected by national policies on water and air pollution and the opening up of joint Nordic electricity markets (Article I; Hildén et al., 2002). The more recent cases have increasingly been influenced by EU environmental policies on transport fuels and waste management that have created new markets or improved the existing ones for bioenergy, RFID tags and inlays, and recyclable or recycled products. Requirements for the use of biofuels and CO_2

trading have been important drivers for the use of production by-products for energy, while extended producer responsibility (EPR) based policies on packaging and packaging waste have been a driver for recyclable and biodegradable packaging from recycled paper. (Article V)

Table 4: Influence of three types of market change for environmental innovation in selected cases (Article V)

Technological change	Time period	Changes in existing p&p markets	New markets created by environmental policy	Changes in other markets
Changes in the early 21st century				
Biorefinery innovations E.g., black liquor & biomass gasification, LignoBoost (Article V)	2000 -	Pressures to improve cost-efficiency and to create business in new product value chains	EU requirements for transport biofuels, national & EU support for RES, EU CO_2 emissions trading	Rising oil prices, transforming electricity markets, new vehicle types
RFID innovations (Article V)	2000 -	Pressures to create business in new product value chains	EU policies for extended producer responsibility for electronics and end-of-life vehicles	Need for more efficient logistics, longer and more complicated supply chains, improved RFID technology
Changes during the 1990s				
Development of CTMP and BCTMP pulp to replace conventional mechanical pulp (Article V, Kautto et al. 2002)	1990s -	Pressures to improve cost-efficiency and provide more competitive products	Extended producer responsibility system especially in Germany	Anticipated higher electricity prices in the Nordic power market
Packaging from recycled materials (Article III, Andersen 1999)	1990s -	Rising price of wood fibre in Denmark	Extended producer responsibility for packaging, packaging taxes	Higher (oil and) plastic packaging prices
POM – paper machine wet-end (Article I, III)	1990s -	Improved efficiency, expansion of production to China and other 'new' countries	(water emission limits in Spain)	
Conox – effluent concentrate combustion (Articles I, III)	1990s -	Expansion of production to China and other 'new' countries	Expected national regulation for water emissions	'Discovery' of paper industries with higher organic content in effluents than in modern wood based paper industries.
Changes during the 1980s				
Energy from black liquor through combustion or gasification (Articles I, V)	1980s -	Improved thermo-mechanical efficiency	SO_2 and NO_x emission limits in Finland	Low electricity price and regulated markets (hindrance)
Activated sludge (Hildén et al. 2002)	1980s -		Water emissions regulation in Finland	
Filters for air emissions (Hildén et al. 2002)	1980s -		National limits for air pollution	

Changes in other markets, such as energy or electronics, have amplified the search for efficiency improvements and new product markets in the pulp and paper sector. Rising oil prices have created new markets for bioenergy to replace oil-based fuels and for fibre packaging to replace plastics. In addition, the globalising supply and distribution chains in electronics and other sectors have created needs for new types of tracking and packaging solutions. (Article V)

The three types of markets show that international developments have clearly influenced the innovation cases. Although market areas outside Finland have always been important to the Finnish forest industry (Article I), the formation of innovation markets is increasingly dependent on international developments (Article V). The findings related to the Europeanization of environmental policies and internationalising markets are relevant from the point of view of the national innovation systems discussion (Section 3.2).

Public policies have been described as an integral component of national innovation systems (e.g. Kuhlmann and Shapira, 2006), and the empirics of this study also showed the importance of other than technology or innovation policies. Therefore, the shift in environmental policymaking to the EU level, where policy designs are no longer made from national perspectives, may weaken the 'national' innovation systems. The deduction of the special features of Finnish and Swedish environmental policymaking has potential implications for environmental innovations, for example, through reduced flexibility and cooperation at the level of environmental permit allocation.

By contrast, due to the ongoing internationalisation process it has become easier for even small and medium-sized companies to sell their products in other parts of the world than where they were designed or produced. This feature is especially important for companies in knowledge-intensive sectors where production does not require a lot of capital. For both POM and Conox technologies, the main markets have been outside the Nordic countries. Moreover, innovation spin-offs may emerge if the company has access to information about developments in other countries, as the Conox case illustrates. This benefits both the domestic technology sector and the environment through more rapid international transfer of new environmental technologies. (Article I) Improved international market potential for environmental innovations may also reduce the negative impacts of policy uncertainty. If the anticipated policy in one region fails to materialise, companies may find alternative markets in other countries.

9 CONCLUSIONS

9.1 Innovation Effects of Environmental Policies

In this thesis I aimed to explain the mechanisms through which environmental policies influence innovation. I argued that while several factors influence the innovation process, the interaction between company and policy levels is especially relevant from the viewpoint of promoting environmental innovations. In addition, I noted, partly supporting the literature on technological system transformation, that inertia and change in the relevant socio-technical and market systems influence the formation of innovations in the company-policy context.

My findings from the Nordic pulp and paper industry showed that the ways in which environmental policies relate to innovation can be divided into six categories: responsive effect, anticipatory effect, two-way effect, indirect effect, no influence and negative effect. One policy may have dissimilar effects on different innovation processes, covering several of the above impact categories. In turn, for one innovation case different types of policy effects may alternate during different stages of the innovation process. For example, LignoBoost experienced indirect effects from emissions trading favouring bioenergy and negative effects from renewable energy certificates for existing technologies.

Variations in the innovation effects of environmental policies observed in the empirical cases were explained by the heterogeneity of public policy, the variety of ways organisations respond to environmental policies, and changes or inertia in market conditions and socio-technical systems. Thus, factors related to policies, organisations, markets and socio-technical systems have conditioned how environmental policies have affected innovation in the Nordic pulp and paper industry.

In the thesis, I showed that the heterogeneity of public policy implies both disparities within environmental policy and synergies and conflicts between environmental policy and other policy fields, such as technology or energy policy. Environmental policy encompasses a variety of objectives, such as mitigating climate change and conserving biodiversity, the fulfilment of which may conflict. Furthermore, it is implemented through measures with varying characteristics with regard, for example, to being flexible to different technological solutions and to the strictness of requirements.

Conflict between policy fields, conversely, may occur due to the different logics they apply. Environmental policies address environmental problems, i.e. negative outcomes of past – often industrial – activities, whereas technology or innovation policies are generally forward-looking attempts to improve the value of industrial production. Technology and environmental policies are in synergy when they both promote domestically developed environmental technology. However, when potentially more efficient environmental solutions are developed abroad, the interest from the perspective of innovation-oriented national technology policy is reduced.

The target group of a specific environmental policy may be well defined, for example, to comprise all pulp and paper producers. Yet the number and types of organisations that actually act in response to this policy may be far greater. In the case of the Nordic pulp and paper industry, equipment developers especially have been a central part of process innovation that has responded to environmental policy requirements on paper producers. Different types of organisations and organisational networks engaging in innovation processes, however, are seldom fully acknowledged in environmental policymaking. One of the reasons for this is that innovation *per se* is rarely a key goal of environmental policies. Even when the actual target group of a policy largely corresponds to the intended target group, differing structures and cultures within the organisations targeted may not be accounted for. For example, four large paper and packaging companies were found to integrate environmental considerations in very different ways into their product development activities, supporting the view that organisations are not homogenous – although they are often treated in policy as such.

My findings, thus, indicate that there are different ways in which environmental information (originating from public policy, customers or experts) travels to 'innovators', responding to the research question on the role of organisational variation in environmental innovation processes. In the sector studied, those working in corporate environmental management were usually aware of developments in environmental policy, but some of them were unaware of what happens in the same company's R&D or product development units. This kind of functional disintegration between environmental and R&D units creates challenges to the ways in which environmental policy information reaches those who innovate. In contrast to environmental policy, public R&D support has a clearer route to innovators in the pulp and paper sector because it is directly allocated to R&D projects in most companies. Environmental policy integration into public R&D support, however, is a prerequisite for environmental signals to pass along to companies through technology policies and R&D funding.

Policy integration, especially the integration of environmental objectives into technology policies, could promote an improved diffusion of environmental policy signals into R&D. The more conceptual analysis of this study showed, however, that mere integration is not sufficient to promote environmental innovation. The actual effects of policy integration depend, for example, on the extent to which environmental policy objectives are integrated into different levels of policymaking (policy strategies, instruments and outputs), the weighting given to environmental objectives in cases of conflicting objectives, and whether the people working in the relevant public organisations are willing and able to adopt new practices. The findings of this study showed that, although environmental considerations have been well integrated into technology policy strategies, the integration has not in all cases extended to policy outputs.

In sum, the empirical findings from the Nordic pulp and paper industry show that the effects of environmental policies on innovation depend on:

1. The aims and characteristics of an individual policy measure
2. Synergies and conflicts with other policies both within environmental policy and with other policy fields
3. The timing of the policy effect in relation to the innovation process (in anticipation, during, after)
4. The route through which policy signals reach innovation (direct/indirect)
5. The recipient, i.e. the organisations that form the policy target group
6. The responses of organisations not targeted by the policy
7. Information transfer mechanisms within organisations affected by the policy and in inter-organisational networks
8. The nature of the innovation (process, product)
9. The wider context in which the policy effect occurs (markets, system dynamics), and
10. Synergies or conflicts between policy and market changes on a global scale.

The list above responds to the first research question on the mechanisms through which environmental policies influence technological innovation. In response to the second question, a policy may simply fail to induce innovations because its effect is dependent on a multitude of factors forming complex networks where both synergies and conflicts exist. The greatest pitfalls of policies include: from the environmental innovation perspective "wrong" policy aims or characteristics, too many conflicting policy aims, a complicated route from policy to outcome with a multitude of cause-effect points, functional disintegration in organisations, the inability of policymakers to address the heterogeneity of organisations, and a lack of other factors creating momentum.

When policies fail to promote environmental innovations, opportunities for improved environmental protection and for new businesses are wasted. Some of the pitfalls can be addressed in policymaking. Others require changes in companies. Some external variables (e.g. global market trends and technological lock-in) are difficult or even impossible to change by specific policies alone. The findings of this study emphasise the importance of acknowledging organisational variation in policy studies. This not only reflects on the design and evaluation of policies, but potential learning opportunities that organisation and management studies could offer for policymaking.

9.2 Conclusions on Case Studies and Policy Analysis

This study tested the suitability of the case study approach for analysing the links between environmental policies and innovations. On a general level, case studies of innovations were a good way to analyse policy effects within the context of other factors as it did not make policies stand out in importance. However, to go deeper into the mechanisms through which policies affect innovations, the long routes through which policies affect indirectly were harder to detect, especially within companies, when multiple cases were used. I preferred the breadth of cases – rather than depth – to identify and portray the diversity of effects environmental policies have on innovation. In future studies however, deep cases, perhaps through ethnography, could enhance our knowledge of the ways in which environmental information travels and is produced and the ways in which policies are recognised, interpreted and potentially acted on within companies.

Focusing the case studies on one particular industrial sector, made it possible to capture the influence of macro-level changes, such as general market trends, on the innovation processes and the conditions in which environmental policies affected innovation. It also revealed specific innovation characteristics of the Nordic pulp and paper sector that are important elements of the context in which environmental policies have operated. For example, process innovation in the sector can be characterised by the intense involvement of public sector actors, which means that some policy signals have diffused to innovation processes directly through these actors. By contrast, product innovation often carried out within companies is more dependent on effective knowledge diffusion within organisations.

Difficulty of finding cases of failed innovation projects and inventions was a clear shortcoming of this study. This is partly related to the dominant culture of innovation management, where risky or failed cases are not openly discussed. Fortunately some of the innovation cases involved longer processes, where the first developments failed to reach commercialisation, giving indications on factors that hinder innovation.

The study also contributed to the discussion on policy integration, and it provided an evaluation framework containing specific criteria for evaluating environmental policy integration comprehensively at multiple levels of sectoral policies. The first list of criteria is based on a study analysing policy documents. Further research should be carried out to extend the criteria to include participatory or discursive elements in policy processes.

9.3 Policy Recommendations

In the light of the findings reported in this thesis, I argue that environmental policies have two important roles from an innovation perspective, namely to facilitate innovation within the existing technological systems, and *also* to keep options open for innovations to emerge outside the boundaries of the existing systems.

The improvement of policies to support environmental innovation involves two types of activities: improvements within environmental policy and improvements in the coordination of policy systems. The results of this study indicate actions which would be necessary in designing current policy systems, often based on existing technological systems, to be more supportive of innovations yielding environmental benefits.

Environmental authorities should adopt a wide definition of environmental innovation, including all new products or processes that reduce negative impacts on the environment.

Too narrow a focus, based on intended environmental improvements only, excludes innovations that have yielded environmental benefits as a surprise or side-effect. The wide definition increases the scope of solutions that can be considered in addressing environmental problems.

Policymakers have an important role in establishing mechanisms through which information to SMEs is available already at the policy preparation stage.

The cases studied showed that anticipation of policies plays a crucial role, and that SMEs have been important participants to innovation processes. For small and medium enterprises, however, following policy developments can be difficult.

New policies should be designed and policy revisions should be made that better support environmental innovation and conflict reduction: Policies need to be flexible in supporting multiple technological solutions, foreseeable and credible to organisations responding to policies, and continuously demanding to dynamically promote innovation.

Flexible policies refer both to market-based policies and to regulations based on more general targets. Narrowly targeted policies may be inflexible in excluding other types of solutions. Although the EU Directive on biofuels for transport has been very efficient in supporting the commercialisation of new bioenergy technologies, it offers less flexibility for innovation than would CO_2 reduction targets for transport. At the same time, the directive supports innovation in bioenergy by offering flexibility through quantified overall targets for the share of biofuels rather than specifying or requiring the increase of a particular type of biofuel or its production technology.

Foreseeability of future policies is essential to allow time for the invention, technology development, testing and commercialisation of innovations. It has been considered that too fast an introduction of policy could actually hinder innovation through companies settling for older technologies as the new ones are not yet sufficiently available. For example, without prior R&D on the second generation biofuels technologies, the implementation of the EU Directive on biofuels would have resulted in an increased adoption of the first generation technologies, often regarded as inferior from an environmental perspective. Foreseeability also concerns the longevity and credibility of policies. When investing in new technology in response to a particular policy companies need to see that the same policy goal will still be aimed at in the following years. This means that policies should be long-term actions supporting more profound socio-technical change.

Policies also need to be ambitious enough to support innovation. This means, for example, high enough taxes to provide an incentive in transferring to a more expensive but environmentally sounder new technology or product. It also implies gradual increases in the demands of policies, although the timing needs to be carefully assessed for different product groups and industrial sectors. Sectors with capital intensive investments, such as the pulp and paper industry, cannot renew their production equipment every year or even every decade. By contrast, some rapidly developing consumer products could face a faster schedule, especially if they can be improved without capital-intensive changes in production processes. Thus, an ambitious policy could either introduce a rarer significant change event with sufficient time for technology development in advance or more frequent smaller changes.

To design new policies to be more supportive of innovation, ex-ante evaluation of their potential innovation effects and ex-post evaluation of earlier policies are crucial. The evaluations need to take into account the diversity of direct and indirect target groups of the policy.

The findings of this study showed that many different kinds of organisations take part in innovation processes. Companies responding to policies may actually be creating solutions to policy demands made on the performance or products of other business sectors. Thus, the diversity of companies following up a policy development may often be larger than merely the sector in question. Evaluations need also to consider the influence of predicted market changes on the desired impact of the policy. These two dimensions are not a standard part of policy evaluations, and require further development in policy evaluation techniques.

Sectoral, national and EU policy systems should be re-evaluated to better identify inconsistencies and conflicts in regulatory systems, policy aims and policy instruments from an innovation perspective. These evaluations could highlight areas where differing policy goals could be better managed.

Conflicting policies both within and between policy fields may often hinder innovation. Different policy fields by definition signal different kinds of needs. While environmental policy aims at reducing the negative effects on the environment often by established means, technology policies promote innovation and economic development from domestic premises that may not always be the most environmentally benign options from a global perspective. Moreover, the positive environmental effects of one policy measure, such as an increase in fuel taxes, may be reduced by another policy measure, such as tax exemptions for commuting costs.

Other policy fields should increase environmental policy integration.

As all policy fields have environmental consequences, the extent to which environmental policy integration occurs and the actions it promotes are relevant for environmental innovation. The integration of different objectives, however, is not always straightforward, as decisions have to been made in conflictual situations, for example, between environmental, economic and social aims.

So, is it necessary for environmental policies to promote innovation? The cases where environmental policies fail to promote environmental innovations waste opportunities for improved environmental protection and for new businesses, as noted above. Environmental policy and cooperation between industry and policymakers could in the best case direct research so that more general innovations improving the competitiveness of national and EU industries could be transformed into environmental innovations. In these efforts, knowledge of how environmental policies affect innovations and of the context in which they are implemented is useful.

9.4 What is in this for businesses?

The thesis shows that environmental policies can be a potential facilitator of innovation markets. Therefore some companies could better recognise the opportunities that policies create for innovations and their diffusion, at the same time recognising the obvious threats posed by short-term, uncertain policymaking or conflicting policies. The opportunities and threats of a particular policy are likely to vary even significantly among business sectors, and even among companies operating in the same business depending on their capabilities and key skills. Missed opportunities mean wasted business potential. Moreover, a company not recognising the environmental policy effects in time, when competitors do so, could end up losing competitive advantage.

The most likely innovation advantage from policies is gained by acting in anticipation of a policy, because being first offers both a market advantage and better opportunities to influence policy development. Responding to policies in advance can be risky, but internationalising markets tend to offer alternative markets for environmental innovations in case the initial expectations do not materialise. Thus the potential harm caused by non-implementation of anticipated policies is reduced.

A company that is thinking of engaging in innovating activities in response to a policy can choose between different types of actions, including undertaking R&D, joint developments with other companies, and testing or purchasing new technologies. Innovation-related responses in companies can replace other, from an innovation perspective more negative responses, such as non-action, acquiring older technology, company restructuring or lobbying to change the policies to be less demanding in environmental terms. An assessment of a company's innovation opportunities benefits from pooling knowledge within the company, improving information exchange between different units, and identifying and negotiating with potential co-operators.

Increased attention to climate change and the use of chemicals has created new challenges and opportunities for innovation in the pulp and paper industry, while the actual effects on environmental innovation are still largely to be seen. Climate change policies have increased the production costs of the sector. For example, CO_2 emissions trading has increased electricity prices, influencing the pulp and paper industry due to its energy-intensive operation. Yet it has also offered opportunities to increase energy production from the sector's by-products that offer a CO_2 neutral energy source. Climate policies increasingly favouring bioenergy, however, have also increased competition over the use of forests, thereby raising the price of timber.

Future potential in environmental innovation exists for equipment manufacturers and for pulp and paper companies. Improving energy-efficiency and the use of chemicals are areas for improvement in production processes. Paper producers could find further innovation potential in replacing products made of other raw materials than wood fibre, especially fossil fuel based materials, and reducing the environmental impacts of transport by offering lighter alternatives, gaining market potential from climate policies. Other environmental options involve decreasing product loss through safe and durable packaging and contributing to tracking systems developed in response to extended producer responsibility. In addition, there is a need for more radical innovations in the Nordic pulp and paper sector, when papermaking increasingly shifts to technologies and locations using fast growing trees, such as eucalyptus and acacia.

Recently the pulp and paper industry has responded to new pressures and challenges by refocusing its research and innovation strategies. A change from a highly consensus-based industry to alternative outlooks within the sector could indicate a window of opportunity for more radical transformation in the Nordic forest sector. For instance, the Forest-based Sector Technology Platform aims to increase business from new products. The actual innovation effects of the recent initiatives, however, depend on whether the alternative voices for new technological paths will be heard, and how environmental policy signals (partly targeting other sectors) are in effect followed up and reacted to in this sector.

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Article I

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Driving Forces for Environmentally Sounder Innovations: The Case of Finnish Pulp and Paper Industry

Paula Kivimaa and Per Mickwitz
Finnish Environment Institute

1. Introduction

Moving towards sustainability requires that new environmentally sounder technologies are developed and widely adopted. Policy instruments that advance technological development are necessary, while at the same time it is clear that public policy is far from the only factor affecting the emergence and diffusion of environmentally sounder technological innovations. Other factors influencing the innovation process arrive from company external influences such as market forces or within the company due to desires e.g. for cost cuts.

Even though there is wide spread agreement on the importance of technological innovations, there is still comparably little consensus on the relationship between different types of policies and technological development. Several contradicting claims have been expressed regarding the policy-innovation relationship, yet empirical thoroughly examined evidence is rare.

Some argue that environmental regulation is likely to stimulate innovation and technology adoption that will facilitate environmental compliance (e.g. Porter and van der Linde 1995, Jaffe et al. 2003), while others have found that emissions standards are often based on available technology with little incentive for innovation (e.g. Kemp 2000). Common to these studies has been the view that stringent regulations are more likely to produce innovations than lax regulations (Porter and van der Linde 1995, Kemp 2000). Another commonly held view is that economic instruments are more likely to prompt innovations than regulations (Milliman and Prince 1989, Jung et al. 1996, Hemmelskamp 1997). It has, however, also been found that, according to empirical studies, the dynamic effects of environmental policy instruments in practice differ from the ideal instruments in theoretical studies and that the relationship of policies and innovations may not be as simple as often stated (e.g. Hemmelskamp 1997). Regarding technology policy, it has been stated that public R&D may play an important role for environment-related science and technology (Jaffe et al. 2003), but that subsidies have had a limited impact on decisions regarding investments in environmentally beneficial technology (Kemp 2000).

Innovation has been defined by Freeman (1987) as "the introduction of a new product, process, method or system into the economy". If a broader view including also social innovations is taken, innovations can mean all new elements, practices and applications used in a social system. The term environmental innovation has had many different meanings. Some use it for all innovations with beneficial environmental effects (e.g. Kemp 1997), while others have used the term for those innovations intended to have positive environmental effects (e.g. Hemmelskamp 1997). In this article we focus solely on technological innovation and use the term environmentally sounder innovations to describe any new and innovative technology with less harmful environmental effects than the available alternatives. The term environmental innovations is, in turn, used only for those technologies that have specifically aimed at reduced environmental impacts.

Based on a previous examination of selected claims in the light of the pulp and paper and the marine engine sectors, we have chosen a number of specific innovations in the Finnish pulp and paper sector to further examine the driving forces for innovations and their diffusion. The sector provides an interesting focus because it has long been a target of traditional pollution control measures, while restructuring and globalisation have reformed the industry during the last decades. Three innovation cases, namely the development of black liquor recovery technology, a paper machine pump system, and an effluent concentrate combustion system, were selected to present innovations with reduced environmental impact but different innovation settings.

This article presents a study of how environmental policy and R&D support have affected the emergence and diffusion of these environmentally sounder innovations. It begins by providing a background for the study and introducing the Finnish pulp and paper industry. The impacts of environmental policy and R&D support measures on innovation are analysed empirically, followed by a discussion on their combined impact. The wider innovation setting is accounted for by discussing internationalisation and its influence on innovations. The article ends with a summary of the key conclusions.

2. The starting point and scope of the study

Previously we have examined selected claims on the effects of policy instruments on innovation and diffusion based on empirical experiences from the Finnish pulp and paper sector and a company producing marine engines (Mickwitz *et al.* 2003). The results for the pulp and paper sector are summarised in Table 1. Although the marine engine case is not discussed, it should be noted that the results differ for some of the claims.

Table 1: Summarising the experiences on the policy-innovation claims* (Mickwitz *et al* . 2003)

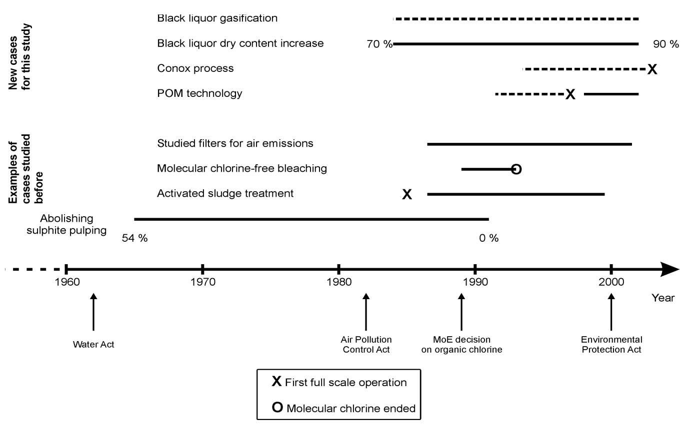
Claim	Supporting experiences	Contradicting experiences
• Environmental regulations (permits, standards, etc.) are often based on existing technology and provide no incentive to innovate but may stimulate diffusion.	• Activated sludge treatment - diffusion was stimulated • Chlorine-free bleaching of pulp • Filters for air emissions	• Activated sludge treatment - innovative application to this sector and these climatic conditions
• Non-binding permit conditions or standards do not provide any incentive to innovate.		• Waste water permits, especially for BOD and phosphorus
• Permit conditions or standards only confirm the development that has taken place otherwise.	• Reduced discharges of chlorine compounds from pulp bleaching • Change from sulphite to sulphate pulp production	• Activated sludge treatment was applied in novel conditions due to strict standards
• Environmental regulations can easily hamper innovations, by directly specifying the technology to use or indirectly making try-outs impossible.		• The flexibility of the Finnish water permits to support try-outs
• Environmental taxes are superior to other policy instruments with respect to innovations.		• The Finnish energy taxation had no effect on innovation in pulp and paper production
• R&D subsidies have limited impacts.	• The share of R&D subsidies is low in the total R&D expenditure of the forest cluster	• The existence of subsidies is important
• Innovations can be promoted by encouraging/forcing co-operation between organizations that would not otherwise work together.		• When networks are traditionally strong, as in the forest cluster, no change may be imposed.

**Some claims are widely supported and others are held by a few. They have all been challenged.*

Our analyses have shown clear effects of policies on the diffusion of environmentally sounder technologies but less on the very emergence of innovations. Furthermore, we have found that the effects of policy instruments on innovations are context specific, e.g. influenced by the cost-benefit distribution of the policy (Mickwitz *et al.* 2003). Various factors such as market demand for new technologies affect also the formation of different innovation settings.

Earlier studies by our research group (Hildén *et al.* 2002, Similä 2002, Mickwitz 2003 and Mickwitz *et al.* 2003) have examined the issues largely from the perspectives of the pulp and paper companies and public authorities. The innovations that were examined in detail were those technologies that have attributed to the drop in traditional water and air emissions, and our focus was largely on the period between the early 1970s to the mid 1990s (Figure 1). Since then the concentration and increased globalisation of the industry have affected for example the investment behaviour of the companies (e.g. Siitonen 2003).

Figure 1: Temporal distribution of some earlier cases and the new cases for this study



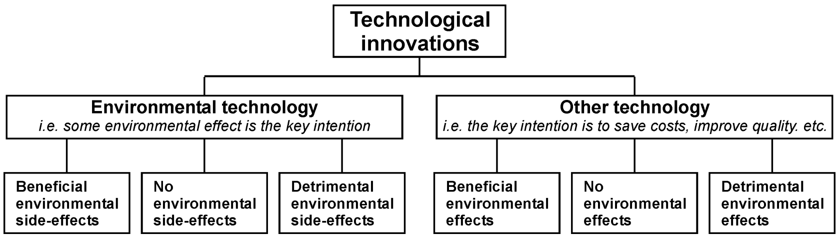
Three new cases were selected to expand our earlier picture of the innovation processes and to bring forth the perspectives of technology developers and researchers within the Finnish forest cluster (Box 1). Two of the cases were chosen to represent very recent innovations, whereas the third case covers innovations development on a wider scale and during a longer time period from the 1980s to the present. Also, the company format differs between the cases covering two small companies, POM Technology and Conox Ltd, and two major machinery developers, Tampella Power and Ahlström.

Box 1: Three additional cases

Technology	Description	Empirical sources
POM technology - air removing pump system for paper machine	**POM** is a compact wet end system for the paper making process, developed by *POM Technology,* and its main component is air-removing centrifugal pump. POM achieves faster and shorter water recirculations in the paper mill and reduces grade change times, resulting in improved energy efficiency and reduced water consumption, effluent discharge and waste compared to the conventional process. This has been regarded by some as one of the most important pulp and paper innovations of the 1990s (Oinonen 2000, HS 2004). The idea was generated in the early 1990s and the first full scale operation started in 1997.	www.pom.fi Interviews: *P. Meinander*, POM Technology Sept. 2003. E-mail quest. to 3 customers Newspaper & trade journal articles
Conox process - effluent concentrate combustion system	The **Conox** process, developed by *Conox Ltd,* is based on pressurised thermal oxidation of process water effluent concentrate. It was originally designed to eliminate organic compounds creating chemical oxygen demand (COD) present in bleaching plant effluents (Myréen *et al.* 2001). Later the concept was applied to black liquor from non-wood pulping. In addition to reduced water discharges, it's a development towards closed water cycles and it somewhat improves energy-efficiency. The idea was generated in the early 1990s and the first full scale operation for non-wood pulping started in 2003.	www.conox.com Interviews: *B. Myréen* & *L. Prepula*, Conox Ltd Nov. 2003. *M. Hupa*, Åbo Akademi University Nov. 2003. *B. Myréen* 2002. Trade journal articles & other documentation
Black liquor recovery technologies - increased dry solids content, gasification	The third case explores the development of various **black liquor recovery technologies** aimed towards increased dry solids content and gasification of black liquor. Efficient black liquor recovery reduces air emissions and increases the plant's energy supply. To a large extent, the significant sulphur emission reduction of the forest industry in the 1980s can be attributed to the increase of the black liquor dry solids content to over 70% (Interview II). These technologies have been developed by *Tampella Power* (now Aker Kvaerner) and *Ahlström* (now Andritz)	Interviews: *E. Vakkilainen*, Jaakko Pöyry Ltd Oct. 2003. *M. Hupa*, Åbo Akademi University Nov. 2003. Trade journal articles & other literature

Common to the selected cases has been reduced environmental impact, but in comparison, the innovations are of different types. Viewed from a purpose perspective, technological innovations can be divided into two categories: *environmental technologies,* where a specific environmental effect has been a key intention of the innovation, and *other technologies*, where the key intentions have not included environmental concerns but e.g. cost reduction (Figure 2). The paper machine pump system POM is a process innovation with beneficial environmental side-effects, whereas the effluent concentrate combustion system Conox was created as an environmental technology to reduce the organic pollutant load to water. Black liquor recovery technology positions itself somewhere between the two, being originally developed for improving the process and saving costs, but further innovative development has also had environmental intentions.

Figure 2: A typology of technological innovations viewed from the environmental perspective



3. The Finnish pulp and paper industry

The pulp and paper industry has had a highly significant role in the Finnish economy since the 19th century. Finland's first paper mill was established in 1873. The significant expansion of the industry began in the 1950s and by 1970s the production of paper had experienced a six-fold increase (VTT 1999, 39). In 2002 the annual pulp and paper production were nearly 12 million tonnes and 13 million tonnes respectively (FFIF 2003). The forest cluster, comprising forestry and the production of pulp, paper and wood products, contributes to about 20% of the industrial value added gross production (Statistics Finland 2002). The forest industry's share of total export value was 26% in 2001 and the largest share, 19% of total export value, can be attributed to the pulp and paper sector (Metla 2002, 284). Although exports have been growing, their share of the total export value has been shrinking with e.g. high-tech electronic companies gaining increased export volumes (Ali-Yrkkö and Hermans 2002).

Concentration of the Finnish pulp and paper industry has resulted in only six companies operating in the sector (Näsi 2001, 13) compared to over 20 independent companies in the beginning of the 1980s (Hagström-Näsi 1999, 88) and around 30 companies in the mid 20th century. The three largest corporations, Stora Enso, UPM-Kymmene Corporation and the Metsäliitto Group, constitute circa 98% of Finland's paper and pulp production capacity (FFIF 2000) as well as being internationally significant actors in the sector.

Also technology companies Metso Paper and Ahlström have developed globally significant market positions as manufacturers of paper and pulp machinery. Much of the technological development occurs in cooperation with pulp and paper producers, technology companies and consultancies, such as Jaakko Pöyry and some smaller actors. In addition universities, e.g. Helsinki University of Technology and Åbo Akademi University, have had important roles in basic and applied research.

The environmental impacts of the sector have been significant due to extensive use of energy and timber as well as emissions to air and water. Technological innovation and development have lead to increased production capacity simultaneously reducing the pollutant load significantly. A change from sulphite pulping to sulphate pulping is an example of a significant process change. In 1965, nineteen of total 35 pulp mills were sulphite mills but by 1985 only three sulphite mills were left and, since 1991, only the sulphate process has been used (Ministry of the Environment 1997, 39). This shift that has taken place mainly for economic reasons has contributed significantly to the decline in water discharges (Hildén *et al.* 2002). Several important developments in environmental technology can be identified in the past three decades, e.g.

chlorine-free bleaching and tertiary waste water treatment. Significant advances have been made to improve the resource efficiency and water consumption of the production processes, the latter developing towards closed water systems within the plant. For example, the per unit water consumption of pulp production has been reduced from 600 m^3 per ton, in the 1950s, to close to 10 m^3 per ton in the early 21st century (Kettunen 2002, 36).

4. The impact of environmental policies on innovations

4.1. Regulatory environmental policy instruments

In Finland permits, designed on a case-by-case basis, have been the main way of controlling point source pollution (Hildén *et al.* 2002, 37-44). Emissions to air and water were controlled separately through different kinds of procedures prior to the implementation of the EU Directive on Integrated Pollution Prevention and Control (IPPC) in 2000. For air emissions the limit values in individual permits were complemented with general norms and guidelines, e.g. regarding air quality, depositions or emissions. Contrarily, for water discharges the permit system has functioned without general standards to explicitly guide individual decisions. Our earlier empirical examinations have indicated that permit decisions have mostly been based on existing technology and have provided no incentive for innovation, and have affected diffusion mainly in relation to activated sludge technology for water treatment and filters for air emissions (Hildén *et al.* 2002, Mickwitz *et al.* 2003). The three cases examined here also reveal diffusion effects of the regulatory instruments.

The origin of innovations increasing the dry solids content of black liquor lies in basic scientific research and in attempts to achieve more economic thermo-technical solutions for black liquor combustion. For example, Ahlström's evaporation technology increasing the dry solids content of black liquor, achieved in the early 1980s, originated from the basic research of lignin not related to energy efficiency or emissions (Kettunen 2002, 88). As a result, it was noticed that sulphur emissions after the process were practically non-existent (Interviews II, III). During the 1980s and 1990s, the process was further developed through large national research programmes and development work by major technology companies. The air emissions received increased focus in the later development phases partly through tightening environmental regulation "*which probably brought forward these issues to the pulp and paper producers, who then knew both to require improvements from the technology developers and to enthuse about the developers' solutions*" (Interview III). Specific permit conditions have in some cases affected the diffusion of the technology, while in others adoption has preceded actual permit regulation. For example, one pulp mill postponed new investments for nearly ten years, and permit conditions effective from the beginning of 1999 finally forced investment in new technology including 80% dry solids content evaporation and recovery boiler with a new system to collect and combust odorous gases (Illi 1999).

For POM technology, environmental policy had no role in the innovation process (Interview I). Also, the diffusion of this technology to various countries, e.g. Germany and Japan, has occurred due to cost and competitiveness factors alone. As an exception out of 20 installations, environmental regulation was one of the reasons for acquiring this technology for a paper mill in Spain. POM enabled them to meet the short-term maximum limits in the water permit and reduce the emissions below the legal requirements set up by the Municipality (Clariana 2003). This together with increased flexibility was considered as an important characteristic when deciding on the investment. By 2003, POM had been installed in only one Finnish paper mill, for process improvement reasons not related to environmental issues.

In 2003, Conox had not reached the demonstration stage in Finland and the progress had halted for various reasons. Some view that the environmental regulations concerning e.g. discharges of heavy metals are not strict enough to awake the interest of pulp and paper producers for this technology, while others argue that competing solutions are more appealing (Interviews III, IV). However, during 2003, the Conox application to non-wood pulping was installed to small mills in Spain and China. These mills faced tight regulations, and non-complying would have closed the mills, resulting in serious conditions for the rural communities dependent on those mills (Interview IV).

4.2. Anticipation of new or tightening regulations

The impact of environmental policies on the innovation process is, in effect, not straightforward and the dynamic nature of both innovations development and environmental policy must be accounted for. The duration of an innovation process in the pulp and paper industry is often more than a decade, and therefore anticipation of future markets is essential. Anticipation of future environmental policies may, consequently, have a decisive role in the innovation process.

The development of the Conox system addressed the issue of water pollution caused by plant effluents. The original idea was spurred by anticipation of increased regulatory measures for closing the bleaching processes. The anticipation rose from the issue being high on the agenda for the Central European paper buyers and NGOs, such as Greenpeace, during the early 1990s (Interviews IV,V). Unexpectedly, in the late 1990s, the NGO and government interest in the chlorine issue diminished in Western and Northern Europe due to reduced organic loads, and the anticipated regulatory action did not happen. Simultaneously water discharges of non-wood pulping, e.g. in China, were discovered to be a significant environmental problem (e.g. WBCSD 1996) and the further development of Conox was redirected to those markets.

The anticipation of future regulation has also played a role in the development of black liquor innovations. Much of the R&D for increasing the black liquor dry solids content had already been carried out prior to the 1987 Council of State Decisions that for the first time set national guidelines for sulphur emissions. Yet the need to reduce forest industry's emissions was already discussed in the 1970s and e.g. Finland's signature for the Convention on Long-Range Transboundary Air Pollution in 1979 was an indication of possible future regulation regarding air emissions. Later, the need to reduce sulphur emissions affected the participation of pulp mills in the try-outs of emerging technologies. For example, this motivated the Äänekoski pulp mill to purchase Ahlström's LHT-system (Interview II), one of the first to achieve over 80% dry content and zero sulphur emissions, in 1990 (Pearson 1993).

In many instances technological R&D and environmental policy have progressed simultaneously, and it is difficult to identify when policy affects technological development and vice versa. For example, in the black liquor case, national air pollution regulations were implemented in permit decisions from 1987 onwards and national technology programmes, including black liquor research, were carried out from 1988.

5. The impact of public R&D support on innovations

5.1. R&D support

During the last decade the trend in Finland has moved from financing individual projects towards focused technology programmes. Also, the public expenditure on

R&D has increased both in monetary terms and as share of the GDP (Prihti *et al.* 2000). At the same time the financial contribution of external R&D support has reduced in the pulp and paper sector. In the 1970s, a large corporation may have received over 25% of its R&D finance from outside (Kettunen 2002, 102) whereas, in 2001, only 3,3% of R&D funding in the sector was received from external sources, less than received by industrial companies in general (4,7%) (Statistics Finland 2003). For example public finance received by KCL, a research company owned by the four largest pulp and paper companies in Finland, has reduced by half from 9,4% of turnover to only 4,6% between 1998 and 2002 (KCL 2002, 24). Although, the share of public finance seems rather low, a former head of research at Metsäliitto Group has stated that the National Technology Agency of Finland (Tekes), after its founding in 1983, has provided funding to every major research project of new technology that the company has undertaken (Kettunen 2002, 104).

Public funding is mainly given out in the form of grants and low-interest loans from Tekes and the Ministry of Trade and Industry (MTI). These constitute to 60% and 36% of external R&D funding respectively (Statistics Finland 2003). Tekes also supports pilot projects and commercialisation. Other sources of public funding include the Finnish National Fund for Research and Development (Sitra), the Start Fund of Kera, and the regional TE Employment and Economic Development Centres. Besides R&D funding for independent projects, there have been six major technology research programmes supporting the development of environmentally sounder technologies relevant to the pulp and paper sector.

With respect to black liquor innovations, it has been argued that technological change would have progressed more slowly without public subsidies that have lowered the barriers and risks to investors (Interview II). Black liquor related R&D has received financial aid motivated by several political goals, including environmental protection, enhancing the competitiveness of domestic industry and supporting the use of domestic fuels. The aid has been especially significant through the two LIEKKI research programmes (1988-1992, 1993-1998), financing projects related to combustion and gasification technology. These created a favourable climate resulting in "two waves": firstly, over 80% dry solids content evaporators focusing on other than sulphur emissions and, second, chemical research and information systems aiding e.g. gasification research (Interview II). The Jalo (1988-1992) and Code (1999-2002) programmes have also covered black liquor research. Code developed numerical modelling of combustion processes dramatically reducing the need for pilot experiments (Interview III). The technology programmes have been crucially important in creating and increasing the necessary knowledge base for black liquor research before specific innovations could be generated (Interviews II, III).

The Conox developer views that public R&D funding is important in the early stages for generating inventions, but for innovations to appear also risk capital and markets are required (Interview V). The general view appears to be that public funding is fairly well available for basic and applied research and technology development, but finding finance for prototypes is more difficult. Black liquor dry content technologies have reached the commercialisation phase because they have been fairly risk-free incremental innovations on the existing system, whereas black liquor gasification is a technology requiring more significant system changes. No demonstration system has yet been created in Finland due, likely, to the high risks and costs involved (Interview III).

POM Technology received public R&D funding in the technology development and the installation phase. Tekes provided product development support in the beginning and, with the help of development support from Tekes and risk capital from the Start Fund of Kera, the first four POM systems were installed in Germany and USA in the late 1990s (Lindén 2000, 1996; Oinonen 2000). Significant funding from

Tekes and other public sources reduced the risk for other investors and made reaching the commercialisation stage possible.

5.2. R&D networks

Co-operation of pulp and paper companies with technology developers, consultancies and research organizations has been characteristic to the industry throughout its history (Hildén *et al.* 2002). Information on end-of-pipe solutions has been quite freely exchanged between mills and often R&D has been undertaken jointly. For example Conox Ltd was jointly established by a consultancy, a chemical producer and an environmental technology company, and the technology was developed in cooperation with two large pulp and paper companies. The development of POM technology involved cooperation with a university and some paper mills, whereas the black liquor R&D has been jointly carried out by several public and private actors. The co-operation of the technology companies with public research institutes has been crucial to advance black liquor related R&D.

> "The Finnish situation, where two major technology developers have co-operated in the same projects and research programmes has been unique from the global perspective, and this has created a positive competition on the level of basic know-how… the know-how of both has clearly increased and they were clearly distinguished from their American or Japanese competitors." (Interview III)

Some public funding schemes require companies to have a university or public research institute as a partner in R&D projects. The critique suggests that the measures used to encourage or even force co-operation and networking between organizations can also have negative effects and that establishing a technology programme is not necessarily the best form of public R&D funding from the perspective of the established players in the field (Mickwitz *et al.* 2003). However, at least Ahlström saw the experiences from the LIEKKI programme positively:

> "The LIEKKI program has improved the availability of information resulting from public research, and it has enhanced the adjustment of the research needs of public organisations and those of industry for better mutual agreement. At the same time it has improved the cooperation between public projects…and the industrial projects aimed at product development" (Hupa 1994, 71).

Also, Tampella stated that the programme enabled international cooperation in black liquor related modelling, but viewed the programme benefiting cooperation only when entering new research areas (Hupa 1994, 73). This view is supported by the fact that POM Technology did not gain any new cooperation for joining the CACTUS programme (1996-1999) three years after patenting its first invention. In the POM case, there has not been a difference between participating in a technology programme and receiving outside-programme public funding since the CACTUS programme only resulted in one way information flow from the project to other participants:

> "…certain large companies invested in their own development projects and, regarding information access and participation, we did not gain participation to those seminars that covered these results and did not become sharers of others' results, but did present our own results." (Interview I)

In many occasions, the additional benefits of a technology programme in comparison to funding for independent projects seem insignificant from the technology developers' viewpoint. However, according to a consultant and former representative of a technology company, technology programmes are necessary to generate and share basic research knowledge, without which even private commercial projects would be difficult to carry out (Interview II). This point is further illustrated in the Conox case, where the developer received technical answers for many uncertainties from the 'combustion technology cluster' created by the LIEKKI-programmes (Interview III).

The impact of public R&D support on innovation may differ between smaller and larger companies. On one hand, smaller companies with fewer resources tend to be more dependent on outside financial support, but large companies benefit from wide access to various research programmes. For example, the role of Ahlström and Tampella has been significant in combustion technology programmes. Their projects, although not all black liquor related research, accounted for 29% of the total expenditure of the LIEKKI programme and received 17% of the total MTI funding (Hupa 1994).

6. Combined impact of environmental policies and R&D support

Although many policy issues of today are so broad and complex that they involve several traditional policy branches and institutions, there is still often a lack of co-ordination. This can result in at least two kinds of problems: aspects of an issue not being covered by any sector and aspects covered by several sectors but potentially in conflicting ways or inefficiently. It has been argued that these types of problems are present in the Finnish central administration (Bouckaert *et al.* 2000). Examining the combined impacts of environmental policies and R&D support can thus be seen as being relevant also in this wider context.

Environmental and technology policy measures are usually directed at very different aims, yet they both influence the emergence and diffusion of innovations affecting the environment. Table 2 lists the environmental policies and R&D support measures having affected the studied innovations. It appears that R&D support has affected all these innovations and environmental policy has acted as a driving force for all but one, namely the development of POM technology. However, the connection between policies and innovations is complex. For example, the CACTUS technology programme financing POM included environmental aims, such as reducing the use of water and the environmental impacts in water, in air and on land (Komppa and Neimo 2000). In turn, the development of the Conox system was partly influenced by the know-how created in the LIEKKI programme.

Table 2: The impact of environmental policies and R&D support on the studied cases

Environmental Policy	Innovation	R&D Support
▪ Generally no impact ▪ Water permit limits affected the adoption in a Spanish mill.	POM	▪ Start Fund of Kera capital & TE loan for company establishment ▪ Independent Tekes finance 1994-95,2000-02 ▪ CACTUS programme 1996-99 ▪ EU funding for first commercial installation
▪ Anticipation of regulatory measures for closing bleaching processes in W. Europe - did not happen ▪ Water discharge limits for non-wood pulping in Spain & China	Conox	▪ Research project partly funded by Tekes 1995-98 ▪ Independent Tekes finance 1999-2002 ▪ EU LIFE funding for a planned prototype in a Finnish mill - not realised ▪ Finnfund a shared owner of Conox Holdings Ltd to finance installations in China
▪ Anticipation of emission limits for sulphur & nitrogen in 1980s - Council of state decisions issued 1987 onwards ▪ Emission limits & technology specifying permit conditions affecting diffusion	Black liquor dry content increase	▪ LIEKKI programme 1988-92 ▪ LIEKKI 2 programme 1993-98 ▪ CODE programme 1999-02
▪ Anticipation of emission limits for sulphur & nitrogen in 1980s ▪ Discussion on the need to prevent the fifth nuclear power plant in the late 1980s and early 1990s by providing more electricity from gasification and biomass combustion. (Interview II)	Black liquor gasification	▪ JALO programme 1988-92 ▪ LIEKKI 2 programme 1993-98

The combined effects of environmental policies and R&D support can be studied more specifically by using the typology of technological innovations introduced in Section 2 (Figure 2). Potential goal-conflicts occur in areas where R&D support is directed at technologies with detrimental environmental effects (Table 3). These environmental effects may be anticipated or unanticipated. In occasions, there can be lack of knowledge transfer between the policy sectors. If an invention is dependent on a chemical that will be prohibited or the use of which will be circumscribed through environmental regulation, it might never be realised and the work done by the innovator and the allocated R&D support could be wasted.

Table 3: Policy intentions vis-à-vis different types of innovations

	Technological innovations					
	Environmental technology			Other technology		
	Beneficial environmental side-effects	No environmental side-effects	Detrimental environmental side-effects	Beneficial environmental effects	No environmental effects	Detrimental environmental effects
Environmental policy	Encourage	Encourage	Encourage / Obstruct	Encourage	Neutral	Obstruct
R&D support	Encourage	Encourage	Encourage	Encourage	Encourage	Encourage
Combination	Potential synergies	Potential synergies	Potential goal-conflict	Potential synergies	No interaction	Potential goal-conflict

While Table 3 only lists the overall intentions of the policies, actual policy practices might differ from these intentions. It is well known that good intentions do not guarantee good results. The adoption of environmentally sounder technologies may in fact be obstructed by environmental policies in force, even though there might be a joint interest to promote the diffusion of such technologies. Policies focusing solely on environmental technologies may delay environmental improvement, because often the non-environmental technologies bring many environmental benefits. This is in line with the results of several other studies, which have shown that a range of technological changes with major environmental performance impacts are not shaped by environmental factors (Berkhout 2003, Hildén *et al.* 2002). In Finland, due to the flexibility of the permitting system, conditions have often been temporarily relaxed during demonstration periods or pilot phases of new end-of-pipe technologies (Hildén *et al.* 2002). Innovations have, therefore, not been hindered in a way that for example emission limit values, in theory, could do.

The studied innovations are all examples of cases where there are potential synergies between the policies, i.e. they have resulted in beneficial environmental effects. For example, the further development of black liquor recovery was simultaneously supported by national emission limits and various research programmes. However, in some instances, the encouraging effect of environmental policies may not be strong enough to support the commercialisation or diffusion of environmentally sounder innovations, especially if the users cannot see the other benefits of the technology. The Conox process was not adopted in Finland because, despite a granted EU LIFE funding for a prototype in a Finnish mill, environmental regulations were not strict enough to keep up the interests of pulp producers to install this technology. In turn, the development and diffusion of some environmentally sounder technologies, such as POM, may occur without the direct impact of public environmental intervention. These are often so called 'win-win' solutions that are driven by other factors bringing also competitive advantage for the companies.

7. Internationalisation and its effects on innovations and policies

Market areas outside Finland have always been important for the Finnish forest industry. Until the 1970s the forest industry exports accounted for more than half of the total exports. Subsequently the forest industry's share of the total export value has decreased from 56% in 1970 to 27% in 2000, despite the real value of forest industry exports doubling during that period (Metla 2002, 295).

The pressures and opportunities caused by increased globalisation of the sector are an important factor behind the concentration of the industry, where a few major international companies control over 90% of the markers, in pulp and paper production as well as in technology development. The largest paper producer Stora Enso is a merger of two previously national companies, the Swedish Stora and the Finnish Enso-Gutzeit. A similar example from the technology side is Aker Kvaerner. There are about 20 companies in the forest cluster that are in foreign ownership, and especially the manufacturers of chemicals, suppliers of systems and equipment and industrial automation companies have attracted foreign capital during the 1990s (Lammi 1999).

One feature of the ongoing globalisation process is that it has become easier even for small and medium-sized companies to sell their products in other parts of the world than where they are designed or produced. This feature is especially important for firms in know-how intensive sectors where production does not require a lot of capital. For both POM and Conox technologies, the main markets have been abroad. Moreover, innovation spin-offs can emerge if the access to global information and markets is present, as the Conox case illustrates. This benefits both the domestic technology sector and the environment, through more rapid international transfer of new, environmentally sounder technologies. The Aracruz pulp mill is another example of the global deliveries of the machinery and plant manufacturing sector, installing equipment from several Finnish companies: Ahlström, Sunds and Rauma (Häggblom 1999, 300).

While globalisation has widened the market and created increased possibilities for companies, it is obvious that international markets mean an increased level of competition. It has also been argued (e.g. Foster *et al.* 2003) that, as a side-effect of globalisation, the company motivation for investing in new, innovative and unestablished technology has decreased. This is because new technology is simultaneously available for pulp and paper producers all over the world if proven successful, and the forerunner's benefit is thus reduced. However, even if technologies are usually available for purchase immediately after commercialisation, in practice technology transfer to other countries can be slower because, for example in Finland, the interaction between companies is more frequent and information transfer is faster than e.g. between Finnish and Brazilian companies (Interview II).

The internationalisation of companies can also have negative effects on the development of innovations. It sometimes becomes more difficult to receive public R&D support, because national organisations may not be willing to finance R&D by companies in foreign ownership (e.g. Interviews II, III). Conox Ltd has a contract for a cooperative project with a German research laboratory, but proceeding in it has been extremely slow perhaps partly due to local decision makers' reluctance to support foreign technology (Interview IV). However, it can also be argued that, generally, company ownership is not as an important criterion for public funding as the effects of the company operations for the country in question. Tampella still continued to be part of the LIEKKI research programmes after being sold to Kvaerner. Andritz and Foster Wheeler, that are not in Finnish ownership but continue to concentrate their research operations to Finland, have still been actively involved in Finnish research programmes after acquiring the Finnish companies (Interview III).

The internalisation of markets can also be observed in many other sectors, some of which may be linked to the pulp and paper industry. Several countries have deregulated the electricity market creating an opportunity for any company to participate, while previously selling electricity has been limited to a government-owned regulated monopoly. The next possible step to deregulation - common markets between countries - is gradually succeeding with plans for a common market for trading electricity within the EU borders and the already operating Nordic market covering four states.

The Finnish electricity market was deregulated in 1995 and Finland joined the Nordic electricity market system, Nordpool, at the start of 1998 (e.g. Pineau and Hämäläinen 2000). The new markets have increased the diffusion of new, more efficient black liquor recovery boilers by creating a incentive for the pulp and paper companies to produce electricity exceeding their own needs. Already three mills have been (re)designed for producing electricity for the markets: Metsä-Rauma in 1995, Joutseno Pulp during 1997-2001 and Wisaforest completed in 2004 (Interview II). For example, the Joutseno mill can annually export 15-30 MW of the electricity produced with the black liquor recovery boiler alone while, prior to the new recovery boiler, it had to purchase around 8 MW of electricity from outside producers (Illi 1999, Interview II). However, generally the short term effects of the electricity market liberalisation have been perceived as reducing the interest of companies for new investments (Interview III). In the future, electricity markets will guide the innovation development through the electricity price. If electricity prices increase, the development and diffusion of energy-efficient technologies will be promoted.

8. Conclusion

The cases studied have reinforced our position that it is equally important when analysing as well as promoting technological change to consider both technologies developed for environmental purposes and technologies with beneficial environmental effects primarily developed for some other reason.

Policy anticipation affects both the innovation and diffusion processes. When companies have reasons to believe that environmental requirements set by public policies will become tighter they often act in advance. By adopting environmentally sounder technologies before required to do so they gain leeway to respond to political and market situations. Our case studies have shown in practice that expectations about future environmental policies can have an important role for the innovation processes of environmentally sounder technologies. Developing innovations is a long-term task focused on future markets, where environmental policies are among the key shapers. However, uncertainties are always involved in future predictions and, in occasions, the anticipated conditions may not arise, as illustrated by the Conox case. If environmental policy does not develop as expected by the innovator, at the absence of alternative markets, the R&D efforts might have been wasted. Although the future will always be uncertain, this stresses the importance of transparent and predictable long term environmental policies.

For a successful environmental innovation to emerge and diffuse, often a combination of R&D support and environmental policy measures is required. While there are areas where the interests of the two policy fields are compatible, there are cases where these interests are conflicting, potentially resulting in both negative environmental impacts and wasted resources. When a technology, that is above all developed to increase competitiveness, has environmental benefits the challenge is to ensure that the intentions are also supported in practice. This stresses the significance of coordination in policymaking, but also emphasises the importance of accounting endogenous technological change when formulating environmental policies. Co-operative networks have been shown here to have a significant impact on innovation, and these could be expanded to include policymakers in order to facilitate information transfer. When environmental policies are well known by those providing R&D support there is a reduced risk of wasted R&D resources for technologies that will be impeded or even blocked by environmental policy measures. Also, when new technologies with negative environmental effects are emerging or when significant environmental improvements can be achieved with new technologies, it is important that the environmental authorities are aware of the development so that policies can be redirected accordingly.

The increased globalisation has at least two important effects on environmentally sounder innovations. Firstly, it increases the potential markets for these innovations. If the anticipation of one emerging market is wrong, there might be market potential for the new technology somewhere else as in the Conox case. Alternatively, if the conditions for the crucial first commercial application are not right in the domestic market it might be carried out elsewhere, as in the POM case. Secondly, when a Finnish innovation is developed because a potential market has been identified, it is likely that a foreign competitor has also seen the opportunity. Competition is thus clearly increased by globalisation.

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The challenge of greening technologies—Environmental policy integration in Finnish technology policies

Paula Kivimaa *, Per Mickwitz

Finnish Environment Institute (SYKE), P.O. Box 140, FIN-00251 Helsinki, Finland

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Abstract

The integration of environmental principles into other policies is perceived as essential in order to combat environmental problems as efficiently as possible. Environmental policy integration in Finnish technology policies is assessed empirically by focusing on technological R&D support at all levels, from policy strategies to project funding decisions. The actors making and implementing technology policies have grasped the idea of environmental protection and environmental issues have been identified especially at the strategy level and in some technology programmes. However, the integration is not overarching and no assessment of environmental impacts is required in funding applications.

Keywords: Technology policy; Environmental policy integration; Evaluation; Environmental technology; R&D funding

1. Introduction

The increased focus on innovation policy instead of research and technology policy implies that the scope has increasingly widened to include societal concerns, such as environmental issues. Harmful environmental effects are often caused by activities, such as transport, agriculture and energy production, which are extensively influenced by public policies. It has therefore been argued that environmental damage could be reduced if environmental aims were taken into account when designing and implementing these public policies (e.g. Weale, 2002, p. 203). Technological innovations and their diffusion have caused most environmental problems but have also resolved many. Technological development is also an example of an activity largely affected by public policy. If environmental aims could be integrated into innovation and technology policies, the negative effects of new technologies could be anticipated and reduced while simultaneously enhancing environmentally sustainable economic development.

The use of science and technology policies to achieve environmental goals constitutes a new focus for technology policy (Freeman and Soete, 1997, p. 414). This has been highlighted, for example, in the Environmental Technologies Action Plan (ETAP) of the European Union based on the Lisbon Strategy (EC, 2004). Environment-oriented technology policy did not exist in many European countries until the 1990s (Sedlacek and Schrama, 2003, p. 231). During the 1990s the focus on environmental issues increased in technology policy, but there has been little discussion on how and in what form they have appeared and affected actual decision-making.

Environmental policy integration is the term used for including environmental aims into other policies.

* Corresponding author. Tel.: +358 9 4030 0994;
fax: +358 9 4030 0382.
E-mail addresses: paula.kivimaa@ymparisto.fi (P. Kivimaa), per.mickwitz@ymparisto.fi (P. Mickwitz).

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Originating from the United Nations Environment Programme in 1972 and strengthened in the Brundtland Report "Our Common Future" in 1987, environmental policy integration or the need to consider environmental issues in all decision-making has developed as part of the wider discussion on sustainable development. The necessity to integrate environmental policies into other policy fields has also been acknowledged in the European Union. Starting with the Third Environmental Action Programme (1983) and strengthened in the Fourth (1987) and Fifth Action Programmes (1993) the need to integrate environmental considerations into the formulation and implementation of all sectoral policies has become a guiding policy principle in the EU (Liberatore, 1997, p. 108). The role of environmental policy integration in EU legislation was strengthened in 1997, when the Treaty of Amsterdam stated in article 6: "Environmental protection requirements must be integrated into the definition and implementation of the Community policies . . .". Despite the recognition of environmental policy integration in policy-making, the decisions have mainly been disappointing (Jacob and Volkery, 2003). The Cardiff process initiated in 1998, aiming to integrate environmental objectives, first, to transport, energy and agricultural policies and, later, to other sectoral policies, has proven burdensome (e.g. Schrama and Sedlacek, 2003) and the actual application of environmental policy integration in sectoral policy-making does not look promising (Lenschow, 2002, p. 220).

Empirical evaluations of policy integration are needed to find out what kind of policy coordination problems are present and to examine the existing examples of policy coherence in order to learn from them and develop the practices of policy integration. Evaluations are also needed to examine the genuineness of the efforts to integrate policies. While policy integration can be an effective way to overcome policy coordination problems, it is also an old way to divert attention and to obliquely resist the political goals supported through integration.

This paper examines to what extent environmental policy integration has been adopted in Finnish technology policy and whether the principle is reflected in different levels of policy-making, focusing on R&D funding. Although the integration of innovation concerns into environmental policies can be seen as equally important and is something we have examined in some detail previously (see Mickwitz and Kivimaa, in press), we focus here on the evaluation of environmental policy integration into technology policy strategies, programmes and R&D funding. However, we also stretch beyond this and explore more tentatively the outcomes of a small sample of technology programmes in terms of generated innovations and their environmental impacts. Since Finland has at the same time been assessed as one of the most technologically advanced countries (UNDP, 2001) and has received top ratings in sustainability (Environmental Sustainability Index, 2005), it is an interesting case to study.

The concept of environmental policy integration and the relationship between environmental and technology policies are first discussed in Section 2. Section 3 describes the framework and criteria used for evaluating environmental policy integration. An empirical assessment of environmental policy integration in Finnish technology policy with respect to R&D funding is reported in Sections 4–7. Section 4 looks at environmental issues in technology policy strategies. Section 5 examines environmental issues at the policy instrument level in specific technology programmes designed to fund and coordinate R&D projects. In Section 6 the policy outputs of the technology programmes, the project funding decisions, are assessed. Section 7 explores a subset of those policy outcomes of technology programmes that fall under environmental innovations. Finally, a discussion of the results and the conclusions are presented in Sections 8 and 9.

2. The relationship between environmental and technology policies

Policy integration, that is integrating specific policy objectives such as environmental protection or gender equality into other policy sectors, is one way to address the problems of goal conflict and inefficiency of policies. Underdal (1980, p. 162) defines a perfectly integrated policy as:

> "one where all significant consequences of policy decisions are recognised as decision premises, where policy options are evaluated on the basis of their effects on some aggregate measure of utility, and where the different policy elements are consistent with each other. In other words, a policy is integrated to the extent that it recognises its consequences as decision premises, aggregates them into an overall evaluation, and penetrates all policy levels and all government agencies involved in its execution".

Environmental policy integration means the implementation of environmental objectives into policy-making horizontally across policy sectors and vertically extending to different levels of policy-making. According to Lafferty (2004, p. 203), the basic notion of environmental policy integration as a goal of governance is to bring policy-making closer to such an ideal situation, where non-environmental sectors are similarly responsible for meeting the environmental norms and targets as the environmental administration. Lafferty and Hovden (2003) define the ideal type of environmental policy integration in the national governance for sustainable development as:

- The incorporation of environmental objectives into all stages of policy-making in non-environmental policy sectors, with a specific recognition of this goal as a guiding principle for the planning and execution of policy.
- Accompanied by an attempt to aggregate presumed environmental consequences into an overall evaluation of policy, and a commitment to minimise contradictions between environmental and sectoral policies by giving principled priority to the former over the latter.

The term environmental policy integration has been used to refer to policy process (e.g. Lafferty and Hovden, 2003), learning (e.g. Nilsson and Persson, 2003), organisational form (e.g. Sørensen, 2003) and policy output or outcome (e.g. Lenschow, 2002). The perspective chosen determines whether policy integration is perceived as a *process* leading to changes in policy-making and policy outputs or a *substantial result* of changes in political decision-making, behaviour or learning. In fact it is all of that. Environmental policy integration requires changes in the actions of the policy makers as well as the policy interventions that follow.

The policy principle needs to be tied into actual organisational or process change in order for environmental policy integration to generate substantial results—and evaluation is needed to ascertain the degree to which this connection exists. A separation of principles from actual practices may occur, if there is inconsistency between organisational goals and institutional requirements and a low willingness or ability to act, or there are multiple incompatible goals imposed on the organisation by institutional constituents (Oliver, 1991). The separation may be caused by organisational avoidance strategies to "disguise nonconformity behind a façade of acquiescence" (Oliver, 1991) or simply by a lack of know-how to perform the necessary activities.

Evaluations of policy integration can shed light on the extent to which a principle has been followed by action and in which areas further effort is needed. Some methods for assessing environmental policy integration have been developed but only a few empirical assessments demonstrating the current state have been carried out (Hertin and Berkhout, 2003; Jacob and Volkery, 2003; Lafferty and Hovden, 2003).

While the links between the environment and technology have been widely discussed (e.g. Freeman, 1996; OECD, 2000; Weber and Hemmelskamp, 2005), the combined role of environmental and technology policies for innovation has been less studied (e.g. Fukasaku, 2000, 2005; Kemp, 2000; Rennings, 2000). Previously we have found that environmental policies and technology policies frequently interact, affecting the development and emergence of environmentally sounder technological innovations (Kivimaa and Mickwitz, 2004). This interaction can provide synergies in the form of these innovations but the two policy fields may also create cases of goal conflict, deriving from the distinctly different policy aims. Environmental policy inherently aims at reducing the anthropogenic environmental impacts and at conserving natural resources. The fundamental aim of national technology policy, in turn, is to seek competitive advantages for the country in question and to increase productivity growth (Edquist, 1995; Lemola, 2002).

Recent academic discussion calls for a shift from traditional technology policy towards innovation policy that is embedded in a broader socio-economic context (Lundvall et al., 2002; Roberts, 1998; Smits and Kuhlmann, 2004). The wider perspective may create more opportunities for merging environmental issues in innovation and technology policy. Yet it has been argued that innovation policy has long underplayed the issue of environmental sustainability (Heaton, 2000, p. 7) and innovation policy for sustainability is far from being developed (Schienstock, 2005, p. 105). For instance, technologies developed and supported by public funding may have negative environmental impacts, especially if profitability is the sole goal of the funding. Technologies could incorporate environmental improvements more cost-efficiently, if potential environmental effects were assessed and addressed in the early stages of the innovation process.

Environmental policies may provide incentives that affect which new technologies are developed and how they diffuse by requiring or motivating improvements in the environmental performance of organizations (Hemmelskamp, 1997; Jaffe et al., 2005; Nordberg-Bohm, 1999; Porter and van der Linde, 1995). Environmental policy may also act as a barrier to innovation, if the instruments in use impede technological change. Some argue, for instance, that structural biases against new technologies have been found in environmental law (Heaton and Banks, 1997). If environmental policy is not designed to incorporate flexibility that allows testing of newer technologies when they become available, unused technological potential may result.

R&D funding allocated through technology policy may be wasted if a newly developed technology is banned by environmental policy. Conflicts between the policy areas may also arise when allocating limited resources and a choice must be made between supporting, for example, technology providing increased employment opportunities or more eco-efficient technology (Hyvättinen, 2004). Fostering innovation implies the selection of particular areas for development, where the development of some technologies may be a success from the environmental perspective while failing in terms of cost criteria (Roberts, 1998). Any technology supported can become "environmental" when so applied (Fukasaku, 2000; Heaton, 2000).

Jaffe et al. (2005) argue that a portfolio of different policies offers a more complete response to environmental problems, including both regulations targeted specifically at environmental issues and policies to generate technological change. The effect of policies on environmentally focused technological change depends on increasing the supply and demand for innovations, i.e. simultaneously investing resources in R&D activities and creating a stable market for the adoption and diffusion of new more eco-efficient technologies (e.g. Christiansen, 2002; Nordberg-Bohm, 1999). The intentions to stimulate environmental innovations through R&D support are not guaranteed and therefore, for the emergence of such technologies, environmental policy integration should be evaluated.

3. Framework and criteria for evaluating environmental policy integration

In policy analysis and evaluation, the 'policy cycle' is often used as a tool to conceptualise key aspects of policy formation and implementation (e.g. Pollitt and Bouckhaert, 2000). We have earlier developed a conceptual model of the policy cycle that can be used as a basis of evaluating policy integration (Mickwitz and Kivimaa, in press). The model illustrates that policy integration could, in principle, take place at many levels of the policy cycle. Assuming that there is a perception that policies should be integrated, this should be reflected at the level of policy strategies as well as at the level of the instruments by which these are implemented. Since the basic idea of policy integration is not only to change bureaucracies, but also to actually change the real world it is very important, although challenging, to extend the examination to include policy outputs and outcomes. If environmental concerns are integrated into technology policies, projects funded and technologies developed should become environmentally sounder and this should be reflected in the state of the environment.

The criteria used in the evaluation were developed from the definitions of policy integration discussed in the previous section. The first evaluation criteria 'the *inclusion* of environmental aspects' is used to determine to what degree environmental aspects are covered in policy documents, either in general or by highlighting specific environmental challenges.

Underdal (1980) states that in integrated policy "different policy instruments are consistent with each other". Lafferty and Hovden (2003), in turn, emphasise that environmental policy integration should be matched with "a commitment to minimise contradictions". The second evaluation criterion, 'the *consistency* of the environmental aspect in relation to other aspects', is used to assess the role policy documents give to the issue of consistency when they address environmental issues. The criterion is not used to evaluate consistency in the documents, but to assess whether the policies themselves take the issue into account. Some degree of 'inclusion' is thus a prerequisite for the 'consistency' criterion.

It has been argued that, from a normative viewpoint, environmental issues should take priority in situations where contradictions between different policy objectives emerge (see the second part of the Lafferty and Hovden definition). This means acknowledging that vital environmental concerns should be seen as principal in overall policy-making where there is risk of irreversible damage, in the same way as economic concerns are currently prioritised (Lafferty, 2004, p. 203). Without engaging in the debate of the pros and cons of such a prioritisation, we use the third criterion, '*weighting* of the environmental aspect with respect to other aspects', to assess the importance given to environmental issues in policy documents. This criterion also requires some 'inclusion'.

The fourth criterion '*reporting*' is based on the importance of feedback for policy consistency and effectiveness. Regarding policy documents, the fourth criterion addresses the degree to which strategies include specifications ex ante about how their environmental aspects are to be followed up and reported and the degree to which assessments of technology programmes/projects include environmental aspects ex post. The ex ante part of the criterion is not possible without some 'inclusion'.

Finnish technology policies can be categorised in several ways. In Fig. 1 two broad categories, 'policy strategies' and 'policy instruments', are illustrated. Although policy strategies may have direct effects producing some outcomes, they are mainly implemented

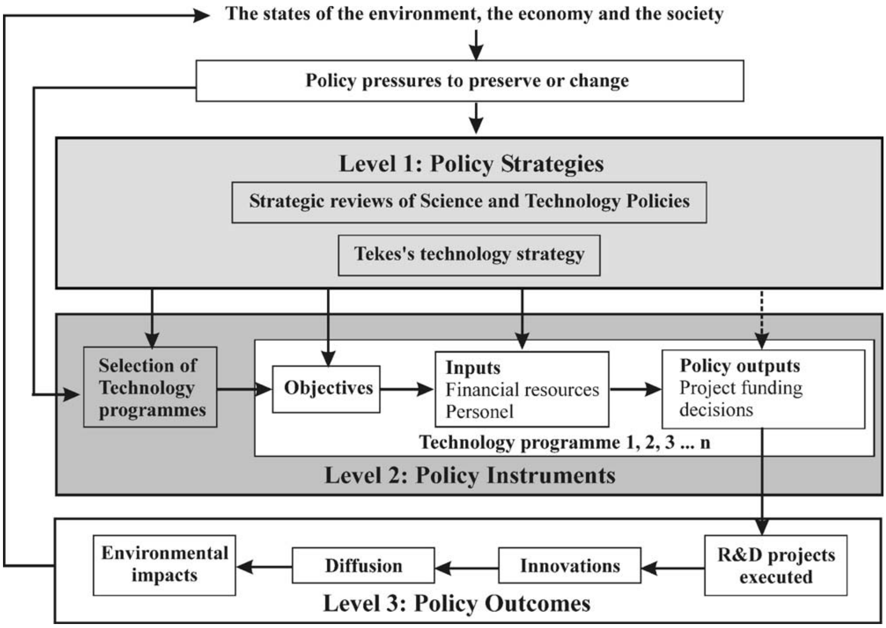

Fig. 1. Levels of Finnish technology policy where environmental policy integration could take place (adapted from Mickwitz and Kivimaa (in press)).

by modifying existing policy instruments or by creating new ones. In the particular case of Finnish technology policy, the subset of policy instruments evaluated is technology R&D programmes. Thus, a new strategic review of the national science and technology policy or a new technology strategy may indicate more resources or new priorities for technology programmes. Alternatively, policy pressures coming from outside the system (general public, environmental organisations, industrial actors, other government institutions) may sometimes directly affect the formation and focus of the technology programmes.

Technology programmes fund and coordinate several different R&D projects, executed by companies and research organisations, that may contribute to the development of technological inventions and innovations. The subsequent use and adoption of the technologies is needed to bring about environmental benefits, but the adoption of technologies is frequently promoted by factors other than the technology programmes. In the case of environmentally sounder technologies, both environmental policies and cost and competitiveness factors have typically played a role (Hyvättinen and Hildén, 2004; Kivimaa and Mickwitz, 2004). Arrows in Fig. 1 therefore indicate influence, but not unconditional causality since many other factors may influence the development.

Environmental policy integration at the strategy level (Level 1, Fig. 1) is evaluated in Section 4 by examining the contents of the strategy documents produced and policy inputs, such as people and financial resources allotted to environmental issues. Six reviews of the Science and Technology Policy Council of Finland (1987, 1990, 1993, 1996, 2000, 2003) and the technology strategy of the National Technology Agency, Tekes, are evaluated. The strategy documents are evaluated using the criteria above. Environmental policy integration at the policy instrument level (Level 2, Fig. 1) is evaluated in Sections 5 and 6. Section 5 focuses on the objectives of different technology programmes and on the allocation of financial resources to different types of programmes. In Section 6 the policy outputs of the technology programmes, i.e. project funding decisions, are evaluated.

The empirical material used to evaluate environmental policy integration comprises 7 strategy level documents and 19 technology programme-related documents including final reports, programme yearbooks, evaluations and other documentation. In addition, three thematic interviews were made among the actors in Finnish technology policy to provide background information on how the system works. Tekes's web-site information on project applications and funding criteria and email survey responses of participants in two technology programmes were used in evaluating policy outputs.

4. Policy strategies—integration of environmental aims in the Finnish strategies for technology policy

Technology policy in Finland emerged in the early 1980s and, through the establishment of the Science and Technology Policy Council (1987), 'the innovation system' outlook was adopted. The Council, an advisory body chaired by the Prime Minister, coordinates Finnish technology policy and issues strategic reviews every third year. Since the 1990s, the reviews have emphasised environmental technologies, sectoral research by different administrative sectors and cooperation between the sectors, for example environmental and technology policies (Science and Technology Policy Council, 1990, 1993, 1996, 2000).

The 1990 review states that sufficient resources should be reserved for technology development in sectoral ministries, including the Ministry of the Environment, and that these activities will also be supported through national technology programmes and funding for businesses' related product development ventures. It also states that "environment related aspects must also be taken into account in other sectors' research". (Science and Technology Policy Council, 1990, pp. 24–25). In 1993, the review brings out the importance of cooperation between administrative sectors and requires assessments of those research areas that extend to several administrative sectors, including 'environment, energy and natural resources' as one of the four identified areas (Science and Technology Policy Council, 1993, pp. 54, 90). The reviews of 1996 and 2000 address policy integration more explicitly by viewing the development of cooperation between environmental policy and technology and innovation policy an important challenge (Science and Technology Policy Council, 1996, p. 51, 2000, p. 6). Moreover, in 2000, sustainable development is described as an inherent part of developing the national innovation system and, by 'determined participation' in the development, the public sector is viewed to help to reduce unanticipated consequences, such as unexpected environmental effects (Science and Technology Policy Council, 2000, p. 7). In the latest review the main development challenges have moved on to internationalisation with few comments on environmental policies. The 2003 review merely states that Finland has succeeded in combining knowledge production and its economic exploitation with sustainable development aims (Science and Technology Policy Council, 2003, p. 8).

The Science and Technology Policy Council can be viewed as an instrument of policy integration. The composition of the Council means that scientific processes and technological development are viewed from the perspectives of different economic actors and the long-standing existence of this institution can be seen as crucial in integrating and overcoming 'territorial thinking' among ministries (Schienstock and Hämäläinen, 2001, p. 44).[1] The environmental administration, or environmental expertise, has not always been represented in the Council, but during the two latest 3-year terms the membership has included the Minister of the Environment and the Director General of the Finnish Environment Institute (SYKE).[2] Despite the representation, the emphasis on environmental issues diminished in the latest review.

The National Technology Agency, Tekes, is the main public financing and expert organisation for technological R&D in Finland. One of the eight thematic areas in Tekes's technology strategy is 'sustainable development', including environmental technologies and life cycle solutions (Tekes, 2004a). When the sustainable development theme is compared with other themes in financial terms in 2003, the former received only 10% of the total funding, which is below the mean and median for all themes.[3]

The strategy also states that all themes complement each other and overlap, so sustainable development is incorporated into the strategy as a whole. According to Tekes (2004a), this means that the direct effects on social, environmental and welfare aspects are included in the criteria for selecting and funding research projects. The degree to which this criterion is actually applied is assessed in Section 6. Environmental issues are also indirectly included in other themes, such as welfare and materials technology. For instance, in the thematic area of materials technology, sustainable development is described to set new requirements to materials development, including durability, recyclability and the use of renewable natural resources (Tekes, 2004a). Table 1 summarises the environmental policy integration at the strategy level based on the criteria presented in Section 3.

[1] The Science and Technology Policy Council consists of 7 ministers and 10 other members representing science and technology policy, industry, research centres, universities and the employers' and employees' organisations.

[2] In the present 3-year term, from March 2005 onwards the Head of the Department for Environmental Health at the National Public Health Institute has replaced the Director General of SYKE in the Council.

[3] In 2003 the funding for sustainable development solutions was € 61 million out of a total € 591 million for all themes (Tekes, 2004a).

Table 1
Environmental policy integration in Finnish technology policy strategies

Criteria	Result
Inclusion	Environmental aspects have been included in the strategies of the Science and Technology Policy Council (1990, pp. 19, 24–25, 48, 1993, pp. 8, 12, 44, 89, 1996, pp. 51, 59–60, 2000, pp. 2, 6–7, 11, 14, 39, 2003, pp. 4, 14) and of Tekes (2004a)
Consistency	The consistency of, or the potential conflicts between, the different objectives have not been discussed in the strategy documents of the Science and Technology Policy Council. Tekes's technology strategy points out the overlap between its different thematic areas
Weighting	The importance of environmental aspects has been implicitly emphasised in the strategies (Science and Technology Policy Council, 1990, p. 48, 1993, p. 12, 1996, p. 51, 2000, pp. 2, 6). However, no ranking between the environmental and other objectives has been provided for cases where prioritisation must be made. Environmental issues were less emphazized in the 2003 review of the Science and Technology Policy Council than in the previous reviews. In Tekes's strategy, the financial resources allocated to the sustainable development theme are below average but sustainable development is also integrated in other themes
Reporting	The strategies have not in general included specifications about how their environmental aims are to be followed up and reported. The requirement for cross-sectoral assessment of the research area of "environment, energy and natural resources" in the 1996 review of the Science and Technology Policy Council is an exception

5. Policy instruments—environmental objectives in the public technology programmes

The instruments used by Tekes to implement its strategy comprise technology programmes, selective project funding, commercialisation of research results, support for the creation of new companies and business operations, and the internationalisation and networking of actors (Tekes, 2004a). Technology programmes, first initiated in the early 1980s, are a major technology policy instrument and a means to allocate public R&D funding. Tekes views them as a proactive instrument to make strategic choices and set priorities, to direct attention to specific nationally important issues, and to increase interaction between projects (Tekes, 2004b; Interviews I[4] and II[5]). In 2003, 48% of Tekes's R&D finance was channelled through technology programmes, in total around € 180 million (Tekes, 2004b).

By the late 1980s, environmental aims were part of some technology programmes while they were not systematically part of Tekes's operation. Some of the programmes were decidedly focused on specific environmental issues such as pollution from pulp production—due to immense public pressure to act on issues such as chlorine bleaching. There have been clear industry and programme specific differences. For example, the first generation pulp and paper industry programmes were largely environmentally focused, but later the focus shifted to quality concerns (Interview III[6]). This emphasis has been replaced in some other areas; e.g. two extensive research programmes related to climate change were initiated in 2003 and 2004.

Eleven technology programmes carried out during the period 1988–2002 were selected to examine environmental policy integration into the programme objectives and their results (Table 2). All the programmes chosen included research affecting the pulp and paper industry. Some of them were focused exclusively on this industrial sector while others covered wider areas incorporating some pulp and paper sector related research. This selection was made to complement our previous research on the factors affecting pulp and paper sector innovations (e.g. Hildén et al., 2002; Kivimaa and Mickwitz, 2004). The programmes studied represent 9% of the total number of technology programmes and 8% of the total budget of the programmes initiated during the period 1987–2000. The selected sample is expected to be the best-case example with respect to considering environmental issues in technology programmes, representing 30% of the environment-related programmes.

SIHTI (1990–1992) was the first programme specifically targeted at environmental issues, i.e. the development of less polluting energy technology. The preceding programmes, such as LIEKKI (1988–1992), had resulted in some environmental improvements but had focused

[4] Interview I: Jari Romanainen, National Technology Agency Tekes, 31 March 2004.

[5] Interview II: Tarmo Lemola, Advansis Ltd., 30 March 2004.

[6] Interview III: Christine Hagström-Näsi, National Technology Agency Tekes, 22 March 2004.

Table 2
Public technology programmes examined

Technology programme	Duration	Topic	Total expenditure
LIEKKI[a]	1988–1992	Combustion technology	€ 24 million
KUITU[b]	1988–1992	Energy-efficient mechanical pulping	€ 7 million
RAINA[c]	1988–1992	Energy-efficient paper production	€ 10 million
SIHTI[d]	1990–1992	Energy and environmental technology	€ 4 million
LIEKKI 2[e]	1993–1998	Combustion and gasification technology	€ 38 million
SIHTI 2[f]	1993–1998	Energy and environmental technology	€ 17 million
Sustainable Paper[g]	1993–1998	Energy in paper and board production	€ 20 million
CACTUS[h]	1996–2000	Low-water-consumption paper production	€ 26 million
Pigments[i]	1998–2001	Pigments as raw materials of paper	€ 4 million
Wood Wisdom[j]	1998–2001	Integrating forestry with other parts of the production chain	€ 33 million
CODE[k]	1999–2002	Modelling of combustion processes	€ 13 million

[a] Hupa (1994).
[b] Sundholm (1993).
[c] Paulapuro and Komppa (1994).
[d] Pietilä (1991).
[e] Hupa and Matinlinna (1996).
[f] Thun and Korhonen (1999).
[g] Lähepelto (1998).
[h] Komppa and Neimo (2000).
[i] Tekes (2002).
[j] Paavilainen (2002) and Seth et al. (2002).
[k] Partanen (2003).

on a few selected technologies, thereby excluding other types of solutions to the issues tackled. This was generally the case in the first technology programmes that were "either clearly technology specific or industry specific" (Interview I (see Footnote 4)). This reduced their potential for achieving the most effective alternative from an environmental viewpoint and provided fewer opportunities for radical change. Nevertheless, the significance of the programmes such as LIEKKI should not be underestimated, because they have provided a consistent and continuous framework for generating the necessary knowledge base for innovation and created competitive know-how for Finnish companies on the world markets (Kivimaa and Mickwitz, 2004).

Through SIHTI the opportunities for different environmental innovations increased but its budget was small in comparison to the preceding programmes. SIHTI was followed by SIHTI 2 (1993–1998), with a larger budget, and other research programmes with more focus on environmental issues than before. For example, LIEKKI 2 (1993–1998) had "a special focus on research serving the development of new, more efficient, environmentally friendlier technologies" and made it possible to meet the tightening NO_x emission requirements (Hupa and Matinlinna, 1996). Nevertheless the programmes were still limited in terms of narrow scope regarding environmental issues. For example, Sustainable Paper (1993–1998) focused on energy but excluded the use of wood for energy and environmental issues related to energy generation (Lähepelto, 1998). However, one might argue that neutral and undirected consideration of issues and technologies is not possible, or even desirable, in technology programmes. When the programmes are a means for focusing on issues perceived as nationally important, the role of independent public funding is then to create possibilities for projects falling outside the scope of any particular programme.

In the late 1990s a more holistic perspective on environmental issues was adopted in some sectorally focused programmes. The CACTUS programme (1996–2000) aimed principally at reducing water consumption in paper-making but also included general environmental aims such as "reducing environmental impacts on water, air and land" (Komppa and Neimo, 2000, p. 3). Unfortunately the programme's environmental aims did not in all cases extend to the level of the funded projects. The programme was initiated by collecting ongoing projects on the topic without a proper unifying idea, so not all individual project objectives were in line with the programme objectives; yet, CACTUS produced knowledge and practical methods for cutting down emissions through reduced water consumption (Komppa and Neimo, 2000). For example, the "Paper Machine Compact Wet End" project did not include any environmental targets, albeit resulting in significant water and energy savings (Kivimaa and Mickwitz, 2004).

Table 3
Environmental policy integration in Finnish technology programmes

Criteria	Result
Inclusion	Environmental objectives have been included in 9 of the 11 studied pulp and paper sector related technology programmes; 4 of these programmes comprised only energy-related environmental aims. Sector specific differences have been noted to exist and environmental aspects are rarely considered in programmes without clear environmental objectives, e.g. Pigments (1998–2001)
Consistency	Within programme objectives no direct conflicts can be observed. However, the environmental objectives have rarely been all inclusive and have focused mostly on energy efficiency or emissions. Consistencies between the different programmes and between the objectives and all environmental impacts have not been assessed in the documents
Weighting	In selected technology programmes some environmental issues have been emphasised and some programmes have been specifically designed for environmental technologies. Their importance, however, has diminished in recent years when the focus has shifted to quality concerns. No ranking between the environmental and other objects has usually been provided
Reporting	Positive environmental impacts generated by the programmes have been brought up in the final reports and assessments of only those programmes containing environmental objectives. Some thematic assessments of groups of programmes have also been carried out by Tekes, but so far they have only covered climate change-related environmental impacts

More recent programmes have tended to focus less on environmental technologies but may include some environmentally relevant aims. For example, CODE (1999–2002) included minimising combustion emissions and increasing the efficiency of fuels used in its research focus (Partanen, 2003). However, if the research focus does not include environmental aims, the environmental aspects of the programme may go completely unmentioned. For example, the final report of the Pigments Programme (1998–2001) provides no information on the environmental aspects of the research area (Tekes, 2002). This may partly be explained by the horizontal application of environmental objectives in Tekes's operation, yet this should not imply that the activities have no impacts, negative or positive, on the environment.

At present Tekes assesses the ex post outcomes of technology programmes, not programme specifically, but thematically starting from the outcomes and benefits and then looking at how a group of programmes has affected their emergence (Interview I (see Footnote 4)). For example, recent ex post assessments have looked at the significance of selected technology programmes for achieving climate change targets (Hjelt et al., 2003), innovation process changes (Valtakari et al., 2004) and internationalisation (Halme et al., 2004). The achievement of societal welfare targets, however, is difficult to measure and these targets, especially those related to climate change, are marked by uncertainty when the outcomes are realised in the long-term future (Hjelt et al., 2003). Often the scopes of ex post assessment have included only a selection of programmes and have thus excluded the indirect outcomes of many other programmes and technology policy measures on the aspects studied.

Table 3 summarises our evaluation of environmental policy integration in the technology programmes listed in Table 2.

6. Policy outputs—environmental aims reflected in project funding decisions

It is clear that environmental policy integration cannot be assessed simply by examining the aims and objectives of the policy strategies and instruments as they only reveal the intentions of the policies and could be primarily symbolic. For example, Lenschow (2002, p. 7) has stated that "the integration process currently faces the challenge of ensuring that substance follows from procedure". Integration may result in cases where environmental aspects are implicit in policies and in new concepts. The implicitness may be an indication of bona fide integration but it complicates assessments regarding the environmental credentials of policies and policy instruments.

When Tekes selects projects to be funded, environmental impacts are intended to be assessed as one criterion among many others, such as business potential, employment and regional development. In practice the criterion is only used for those projects that have obvious environmental connections (Interviews I and II (see Footnotes 4 and 5, respectively)). Tekes's (2004a) application forms for project funding do not include a section for environmental impacts although this is one of the funding criteria. The company funding application for research and product development includes Section 12 "summary of other effects—indirect effects in other companies and societal effects" with no specific comment on environmental impacts in the application form guidelines. The public research funding application, in turn, has Section 9 "benefits and effects", which refers, for example, to societal and indirect effects. Tekes has, however, included on its Internet site the conditions for funding which state that "positive effect of the project on the realisation of generally accepted societal goals influences the finance decision favourably" including climate change prevention and other positive environmental impacts (Tekes, 2004a).

In general discussions several representatives of the agencies in charge of technology policy have expressed the view that positive environmental impacts are indeed counted as a plus in deciding on finance applications.[7] However, no systematic procedure exists for assessing the overall environmental impacts of the proposed projects, both the positive and the negative impacts.

The actual funding applications and the decisions on them are confidential, so we found it difficult to access the details and conduct comprehensive evaluation of environmental policy integration regarding project funding decisions. We acquired this information directly from the participants of two technology programmes – CACTUS (1996–2000) and Pigments (1998–2001) – with fairly low response rates. The answers received through this survey indicate that the environmental impacts of the projects were not widely assessed ex ante by those applying the funding, even in the case of the environmentally focused technology programme, CACTUS. We could only evaluate the environmental benefits of the projects on the basis of their stated objectives and aims. It must be noted that in the mid-1990s when the programmes studied were initiated, the application forms did not include any section for other effects but only a section on "utilisation targets in industry"[8] despite the fact that environmental considerations have been stated in Tekes's annual reports to be among the criteria for decisions on allocating finance since the early 1990s.

Evaluation of environmental policy integration in project funding is summarised in Table 4.

[7] Participant observation by the authors at the numerous events organised by the ProACT Research Programme—funded by the Ministry of Trade and Industry and Tekes.

[8] Comment by one of the respondents to the questionnaire. This is supported by the type of responses obtained from other questionnaire replies.

Table 4
Environmental policy integration in project funding

Criteria	Result
Inclusion	In principle, environmental impacts are among the criteria for selecting projects. In practice, however, the funding application forms do not itemise a section for environmental impacts. Based on a limited sample of two technology programmes, no list or assessment of potential environmental impacts appears in funding applications or project descriptions
Consistency	The project objectives tend to be very specific and technically detailed. Consistency is difficult to evaluate without expertise in the technological field and in the absence of specific environmental objectives
Weighting	Environmental aspects are not considered as relevant as, e.g. the technological or business potential (or in some cases they may be implicit in technical project objectives)
Reporting	The ex post assessments of project outcomes are, again, very technically detailed and do not mention the environmental impacts of the projects

7. Policy outcomes—contribution of technology programmes to environmental innovations

Concrete technological innovations would be an ideal way to assess whether policy integration has resulted in such policy outcomes that can generate positive environmental impacts. Innovations, however, result from a variety of driving forces, of which technology policy measures are only one. Even when focusing solely on public R&D efforts, an innovation may result from several consecutive technology programmes and is often based on several funding decisions, since new technologies take years or even decades to develop. Yet some ex post assessments of programme outcomes can be found, made by the participating parties (see e.g. sources in Table 2). Due to the complexity of factors affecting innovations, this section does not present any causal analysis, merely indications that the technology programmes studied have been among the factors influencing technological development.

According to four pulp and paper companies, the feasibility studies made during the CACTUS programme increased the ability to assess problems and conditions encountered with more closed water loops, such as complications of the processes, increased use of energy, mastering of dynamics and increased risks of spills (Forest Industry, 2001). For the technology company Metso, the profound understanding of the phenomena created the basis for developing separate machinery and subprocesses, as well as the integration of the machines into the entire process (Pekkarinen, 2001). The freshwater consumption of Metso paper machines declined from 7.5 m^3/tonne of paper to 2.5 m^3 during the 1990s, partly because of the research carried out on the CACTUS Programme (Haavanlammi, 2001). In addition, POM technology – described as one of the most significant pulp and paper innovations of the 1990s and resulting in improved energy efficiency and reduced water consumption – was part of the programme in its later development stages (Kivimaa and Mickwitz, 2004).

Some other environmentally beneficial technological outcomes have emerged from other technology programmes examined. Of the early 1990s programmes, SIHTI and RAINA appeared to have achieved only modest improvements in reducing energy consumption, but they provided a basis for the further development of energy-efficient technologies. LIEKKI had a substantial role in developing new, more environmentally sound combustion technology and, for example, Ahlström's combustion boiler (PCFB) was tested during the programme. During SIHTI, Selective Catalytic Reduction for marine diesel NO_x emissions by Wärtsilä and NO_x scrubber for power plants by Tampella were some of the technologies tested (MTI, 1993; Pietilä, 1991).

The following technology programmes, during 1993–1998, had more ground to build on from the earlier programmes and several technologies emerged partly from that development. The LIEKKI 2 results provided valuable information for the design of energy producing power and recovery boilers, and already in the early stages of the programme, for example, the technology developer Ahlström's Pyroflow Compact multi-fuel boiler and Tampella's Cymic boilers were installed in Finnish power plants (Hupa and Matinlinna, 1996). SIHTI 2 had a more holistic approach to the environment and produced a life cycle databank, new emission measurement techniques and developments towards closed water cycles in the pulp and paper industry (Thun and Korhonen, 1999). The considerable developments in the Sustainable Paper Programme included methods allowing a reduction of 5–15% in the energy consumption of the mechanical pulping processes, a few new methods for pilot trials and making a previously developed technology, the Condebelt drier, commercially available (Lähepelto, 1998).

The programmes after CACTUS have had less environmental focus and the identification of technologies improving the environment was difficult. This might indicate that without environmental policy integration in the programme aims the programmes fail to improve the environment. Alternatively, it may illustrate the shortcomings of technological innovations as indicators of environmental policy integration. Some kind of ex ante and ex post environmental impact assessment procedures would be needed to systematically evaluate environmental policy integration in policy outcomes.

8. Discussion

8.1. The extent of environmental policy integration in Finnish technology policies

Environmental considerations have been included in the technology policy strategies of Finland and selectively in the public technology programmes, but generally they have had no priority over other issues. Lafferty and Hovden (2003) stated in their normative ideal case that the principled priority of environmental policies is one of the determinants of environmental policy integration. Liberatore (1997, p. 119), in turn, argued that integration should include components of similar importance and weight – not necessarily priority – but, if one of the components is much weaker, it is likely to be diluted. Our analysis indicates that the specific emphasis on environmental issues has diminished in recent years, while it has been made more implicit in technology policy strategies. If this trend continues and the specific existence of environmental considerations among the other policy objectives is not guaranteed, there is a danger that the environmental aspect will be diluted.

The Science and Technology Policy Council of Finland involves many different actors, including representatives of the environmental administration. Therefore, the Council should have some preconditions for creating strategies that are consistent and coordinated with other policy fields. It is more difficult, however, to say how consistency is achieved in the work of Tekes. The inclusion of environmental objectives at the policy strategy level has been translated into criteria for project funding and for the design of technology programmes at the policy instrument level. A problem appears in the implementation of the objectives, in that environmental aspects are in practice only considered with respect to those operations intended to have clear positive effects on the state of the environment.

No systematic assessments of the positive and negative environmental impacts of the funded projects are carried out, and there is no pre-screening of the overall environmental impacts of the activities promoted by the technology policies. This may be caused by a lack of ability, for example in terms of know-how or budget limitations, to implement systematic environmental assessments. The time periods of technological development and diffusion are long, and it can take decades to observe the long-term effects of the use of new technologies on the environment. Since environmental policies are largely reactive, the consistency between the policies will not become apparent until time has elapsed. This is especially the case because of the lack of pre-screening.

The extent of environmental policy integration in technology programmes has been issue- or sector-specific. This means that environmental policy integration has been selectively pursued at the policy instrument level. In the environmental technology programmes priority for environmental issues could be observed, yet this should be self-evident. The diminished weighting of environmental issues at the strategy level is also reflected on the instrument level. For example, in the pulp and paper sector programmes the focus has shifted in recent years from environmental issues to quality concerns. Yet, this emphasis has been replaced in some other areas, such as climate change. An implementation problem at this level can also occasionally be detected: the objectives of funded projects have not always corresponded to programme objectives. This may result if the goals imposed by the funding agency are incompatible with the goals of the organisation(s) carrying out the project or the other institutional goals imposed on the project (see Oliver, 1991).

Our results concerning the selected technology programmes indicate that, although some new technologies providing improved environmental impacts have been created as part of the programmes, systematic environmental policy integration in the policy outputs and outcomes is fairly weak. The lack of environmental considerations in the objectives and assessments of the executed projects is partly explained by the lack of requirements to consider the environmental impacts in the funding application forms. If the environmental criterion for funding is not adequately reflected in the application forms and, therefore, in the funding decisions the absence of environmental considerations in the projects funded is not surprising. The limitation of the application forms is a logical consequence of the general perception that environmental issues are handled by separate programmes focused on environmental technologies, and for these programmes the positive environmental impacts would be reflected in the main goals. A more comprehensive assessment of the environmental impacts would not only require collecting information, but increased environmental know-how would also be needed. For example, integrating environmental aims in the World Bank depended on a significant change in organisation, practices, partnerships and competences (Picciotto, 2002).

Another apparent shortcoming is the lack of reporting and assessment procedures for documenting the achievement of the environmental objectives or of environmental policy integration at all levels. The lack of environmental policy integration based on the reporting criterion could be caused simply by the lack of priority given to the environment.

The empirical focus of this study was largely confined to analysing the Finnish technological R&D support from the forest industry perspective. This must be acknowledged, because sector specific differences can be observed in the execution of the technology programmes. The forest industry in Finland is much emphasised in economic and environmental terms. Since the 1930s the forest sector agreement has meant safeguarding the growth preconditions (raw material, capital, labour, technology, infrastructure) and the competitiveness of the forest industry by many economic policy and socio-political solutions, often at the expense of other objectives (Donner-Amnell, 1995, pp. 193–194). Since the 1980s the sector has been a target of many environmental protection pressures from the NGOs, customers and public administration—more so than many other industrial sectors. These factors have clearly shaped the formation of Finnish technology policies affecting this industrial sector. One would therefore expect environmental objectives to have been more, rather than less, integrated into programmes affecting this sector compared to other programmes. Further examination of other sectoral programmes would be needed to obtain more comprehensible results.

8.2. Environmental policy integration—from strategies to projects

A systematic inclusion and/or assessment of environmental considerations in the goals and activities of a sectoral policy can be carried out independently of national strategies, and can also be called environmental policy integration. The question is not so much how to define environmental policy integration; rather what kind of policy integration is preferable and efficient.

Our results partly indicate that overarching national strategies, although desirable, are not prerequisites for environmental policy integration to occur in programme design and projects actually funded. For instance, the programme specific variation in incorporating environmental considerations in Finnish technology policy programmes indicates that the actions taken depend on the interests and know-how of the people directly involved. Kuhlmann (2001) has described innovation policy being, not just about implementing policies based on top-down decision-making, but a process of networking between heterogeneous actors. Thus, a uniform principle, such as environmental policy integration, may lead to different interpretations while applied.

Stressing that overarching national strategies are not a prerequisite does not deny the importance of strategies, it merely points out that environmental policy integration may also occur independently of the strategies. National strategies, however, are important in achieving coordination between different policy sectors, in highlighting issues that are perceived important to society and policy-making, and in gaining support for environmental policy integration from actors involved in the innovation systems. Conversely, environmental policy integration included in innovation strategies cannot result in new policy outputs or outcomes without the actions of the actors.

There is a difference between formal strategic goals and the informal goals in all organisations (Mulders, 1999). The difference between the goals may easily increase if the strategic goals change, for instance when requirements to integrate environmental aims are adopted, and the organisation, partnerships and competences are not changed accordingly. Incomplete integration is a natural consequence when informal goals are more important for the actual practices than formal goals. While the reasons for incomplete environmental policy integration are important, a more detailed analysis of these would be beyond the scope of this paper.

8.3. Challenges in carrying out evaluations of environmental policy integration

Some initiatives have been taken to create criteria for assessing environmental policy integration (e.g. Hertin and Berkhout, 2003; Lafferty and Hovden, 2003; OECD, 2002), but they have mainly focused on analysing the process, often on national or EU level, rather than on the outputs or outcomes of sectoral policies. Policy integration is assumed and expected to occur at so many different levels (national strategies, sectoral strategies, policy instruments) and has so many different dimensions (e.g. documentation, communication, co-operation) that creating overarching and comprehensive evaluation criteria for all purposes seems impossible. Instead case-specific criteria, for instance, for national strategy evaluation or for sectoral policy evaluation, could be further developed and tested in practice.

It is clear that it is far easier to evaluate processes and procedures than it is to evaluate policy outcomes due to long timeframes and complex causal relationships. The same, however, is not the case for policy outputs. In principle it is straightforward to evaluate whether environmental issues are integrated into a decision to fund a research project, the policy output of a technology programme. In practice, however, it is often easier to evaluate integration at the strategy level than at the lower levels of the implementation chain. This is partly due to the extent of the documentation material; while there are only a few essential strategic processes and documents, the number of processes and instruments through which they are implemented is often much larger. For example, in the case of Finnish technology policies the seven strategy documents examined represent, if not all, then most of the relevant strategies, while at the level of the technology programmes the 11 programmes studied, comprising hundreds of funded projects, represent just a small sample of all the programmes and the material is still several times larger. In addition to the limited amount of material, the public policy strategies are often more accessible and transparent than the policy instruments through which they are implemented.

The challenges of evaluating environmental policy integration in policy outputs depend largely on the nature of the policies and the policy instruments. It is clear that the situation is different in the case of transport policies implemented in public plans for constructing new roads compared with technology policies implemented through funding for research and development projects. The details of private and commercial R&D projects must be kept secret from existing and potential competitors, which in turn makes independent outside evaluations of environmental policy integration very difficult.

Improved access to information would improve the transparency of policies and facilitate their evaluation. Many of the respondents to our questionnaire, those representing research institutes rather than companies, stated that their funding applications contain no confidential or secret elements. It appears, therefore, that confidentiality is a general status given to all applications and decisions by Tekes regardless of the stand taken by the applicants. The evaluation of the decisions could at least be improved by allowing external access to those applications that the applicant does not require to be kept confidential.

9. Conclusions

The focus is shifting from research and technology policy towards a broader innovation policy. This is widening the scope to integrate societal concerns, such as environmental issues. Policy integration may be effective for improving policy coordination, but declarations of intentions to integrate environmental concerns may also be merely symbolic. There is a need to evaluate the efforts to integrate policies.

The Science and Technology Policy Council of Finland and the National Technology Agency Tekes have stressed environmental objectives in their strategies. The detailed evaluation of environmental policy integration in Finnish technology policy, focusing on R&D funding, using four main criteria – inclusion, consistency, weighting and reporting – showed elements of environmental policy integration. However, the integration did not occur as extensively in the technology programmes and funded projects as it did in the strategies, and, based on the reporting, consistency and weighting criteria there was an evident lack of integration. Environmental objectives were not systematically incorporated and assessed in designing technology programmes and deciding on project funding. Some cases showed incoherence between the objectives of the funded projects and of the programmes providing the funding. In addition reporting on environmental impacts was usually lacking.

Achieving substantial results through environmental policy integration requires a coupling between the principle adopted at the strategy level and the actual practice of decision-making. National level strategies for environmental policy integration are not a prerequisite for this to happen. Environmental policy integration can occur independently in technology programmes and in the funded projects, when supported by the actions of the actors implementing the programmes and those applying and using the resources. In contrast, actions by the innovation policy organisations are necessary to implement national strategies.

The above findings highlight some potential shortcomings in incorporating environmental considerations into technology or innovation policy in general. The decision procedures implementing innovation policies should include a systematic ex ante assessment of the most essential positive and negative environmental impacts of all proposals. In addition, the ex post assessments of technology programmes and projects should incorporate environmental impacts.

Present concerns for global competitiveness and global environmental challenges jointly reinforce the importance of energy- and material-efficiency of all new technologies. This makes comprehensive integration of environmental aims especially important. The aim of environmental policy integration, included, for example, in the Treaty of Amsterdam, is to mainstream environmental considerations in all policy implementation. There is, however, an obvious risk that the environmental objectives will actually be overlooked unless they are matched with resources, capabilities and declared reporting and assessment requirements.

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Article III

The Determinants of Environmental Innovation: the Impacts of Environmental Policies on the Nordic Pulp, Paper and Packaging Industries

Paula Kivimaa

Finnish Environment Institute (SYKE) and Helsinki School of Economics, Finland

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ABSTRACT

Innovations may have positive societal effects such as improved environmental performance, and they are often portrayed as solutions to environmental problems. However, the mechanisms through which innovations develop and the ways in which public incentives support improved environmental performance of innovations are complex. This paper uses empirical cases to examine how environmental policies, market factors and technological push affect process and product innovations in the Nordic pulp, paper and packaging industries. The results show that environmental improvements in technologies and products are simultaneously driven by all three of these factors. Environmental innovations are often developed in anticipation of future policy or as side-effects of existing policies. However, while environmental policy directly influences process innovations, its connection to product innovations is less clear. The study points towards the importance of gradually tightening and predictable environmental policies that are flexible enough to allow the exploration of new technological developments.

INTRODUCTION

While environmental policy on its own is rarely powerful enough to anticipate and force technological innovation, it has contributed significantly to reducing the air and water emissions of industrial installations through technological change (Ashford, 2005; Gunningham et al., 2003; Hildén et al., 2002). This has occurred, for example, through emission limits being imposed on individual production plants through permits and regulations. In some countries, such as Finland, this has been accompanied by public R&D support.

Despite numerous technological achievements, environmental problems are far from solved, and many problems require new types of response from public and private actors. This is particularly true for those environmental problems of a more complex and dispersed nature, such as climate change and chemicals dispersed through consumer products. To solve these problems, traditional regulatory approaches may not be efficient or effective. It has been argued that the traditional command-and-control focused environmental policy is moving towards a 'modern' push-and-pull oriented policy mix with a broader spectrum of actors involved in political decision making (Scheer, 2006, p. 61).

The mechanisms through which innovations develop and the ways in which diverse policy interventions promote innovations that deliver improved environmental performance are complex. Empirical studies have illustrated that the effectiveness of various policy instruments is heavily dependent on the context in which they have been used (e.g. Hemmelskamp, 1997; Kemp, 2000; Mickwitz et al., 2007). Therefore, the discussion on the suitability of specific environmental policy instruments for promoting innovation is outdated. Rather, one should move on to discuss the features of the mix of policy approaches and instruments that can be in place in different contexts. It is also important to recognize the significance of the historical, socio-technical and market conditions that shape the impact of environmental policies in different contexts.

This paper explores the extent to which innovations that deliver improved environmental performance derive from the influence of environmental policy, based on a comparison of process and product examples from the Nordic forest sector. Furthermore, it aims to identify the broader features of environmental policy that are important for innovation, and to consider the influence of market and technology related factors and the significance of the context within which these factors interact. The focus is on technological and product innovations, although social and service innovations may be equally important in achieving environmental improvements. The following section describes some of the literature and conceptions regarding the links between environmental policy and innovation. The next section summarizes the methods used. The fourth section presents the findings from the empirical material regarding the drivers of technological innovations with environmental improvements. The findings are then discussed and an intervention model for environmentally sounder innovations is developed in the fifth section. The sixth section presents the conclusions.

ENVIRONMENTAL POLICY AND TECHNOLOGICAL INNOVATIONS

Innovations can be defined as 'the introduction of a new product, process, method or system into the economy' (Freeman, 1987). An invention is transformed into an innovation when a product or a technology used in producing a product is marketized. Diffusion and the use of a new technology or a product are needed to reap the benefits, such as improved efficiencies or reduced environmental impacts.

The term environmental innovation has been given different meanings in the literature. It has been used to describe all innovations having beneficial environmental effects (see, e.g., Kemp, 1997), or only those innovations intended to have positive environmental effects (see, e.g., Hemmelskamp, 1997). To avoid confusion, the term 'environmentally sounder innovation' has been used here to describe any innovative product or technology that has less harmful environmental effects than the available alternatives. This corresponds to the environmental technology concept used by the European Commission (2004) in its Environmental Technologies Action Plan (ETAP). Reduced environmental effects of innovations can be manifold. For example, a product (i) may be more efficient during manufacture, distribution and use in terms of size, weight, or resource and energy use, (ii) may contain or release less harmful substances or (iii) may be more durable or recyclable after use. In sum, the environmental impact of a product depends on the amount of natural resources used throughout its life-cycle (the quantitative aspect) and on the nature of the intrusions and material flows caused by these activities (the qualitative aspect) (Heiskanen et al., 1995). For example, the paper and packaging cases explored have had impacts related to resource-efficiency and recyclability. By contrast, they have not improved durability.

The traditional models of technological innovation have been based on simple linear chains of activities. In the technology push model, basic scientific R&D is followed by an invention, its development, commercialization (i.e. innovation) and diffusion. Alternatively, the market pull model departs from market needs that are met by technology development, its commercialization and wider adoption. In effect, technological development is likely to experience both push and pull from different directions. For example, Arnold and Bell (2001) in their modern ‘coupling’ model of innovation have shown that in the innovation process effects between the components occur in both directions, and that the different stages are also affected by the needs of society in addition to the market place and the underlying stock of existing knowledge. Societal needs may lead to innovations with positive societal effects, such as environmental improvements, but it is not obvious that this is the case.

Rennings (2000) and Cleff and Rennings (1999) have taken regulatory push and pull into account as a significant determinant of environmentally sounder innovation in addition to technology push and market pull. They argue that new environmentally sounder technologies can be subsumed under technology push factors, such as attempts to improve material and energy efficiency and product quality, while preferences for environmentally sounder products or image can be subsumed under market pull factors, including customer demand and new markets for environmentally sounder innovations. Since the factors of technology push and market pull alone are not strong enough, environmentally sounder innovations need specific regulatory support, described to include existing environmental law, occupational safety and health standards, and expected regulation.

The effects of environmental policies on companies have been widely studied, and one of the focal points has been the effects on innovations and technological change (see, e.g., Hemmelskamp, 1997; Jaffe et al., 2002, 2003, 2005; Kemp, 1997, 2000; Norberg-Bohm, 1999; Porter and van der Linde, 1995). Cases have been identified where environmental policies provide incentives for new technologies by requiring or motivating improvements in the environmental performance of organizations (Jaffe et al., 2005; Hemmelskamp, 1997, Norberg-Bohm, 1999; Porter and van der Linde, 1995). The studies show that a specific environmental policy can affect (i) the development and emergence of a new technology, (ii) its diffusion or (iii) both. Alternatively, environmental policies may impede innovation by being inflexible with respect to the testing of new technologies, by setting too lax limits to follow or by limiting one selected environmental impact so that integrated solutions become impossible.

RESEARCH METHODS AND THE EMPIRICAL CASES

A top-down approach is often used for evaluating the effects of selected policy interventions (see, e.g., Vedung, 2000). It can provide some indications of how the policy under evaluation affects innovation. An examination of the effects of different policies during technology or product development, however, can be obtained through a bottom-up approach identifying the role of different factors affecting the innovation process. The bottom-up approach was used in this study.

In 2003, four process technologies from the pulp and paper industry were examined (Table 1; Kivimaa and Mickwitz, 2004). The empirical material collected in 2005 focused on two product innovation cases (Table 2) and product development in three paper and packaging companies using wood fibre as a raw material: Tetra Pak, Stora Enso and SCA. At company level, R&D and product development have been described as institutionalized and predictable sources of innovations (see, e.g., Pavitt, 2005). The model of the determinants of environmentally sounder innovations (Cleff and Rennings, 1999; Rennings, 2000) presented in the previous section is used to compare process and product innovation in the wood fibre-based industry.

Thematic interviews, focus group discussions and documents were used as data in the case studies. The paper refers to 12 interviews (including 16 interviewees) representing the views of three forest sector consultants, three technology developers, three product developers, three company environmental managers, two company R&D managers and two scientists. Emails from two paper mill managers were also used.

Table 1: Cases of process technology innovations in the pulp and paper industry

Process technology cases	Description	Environmental impacts
Black liquor dry content increase over 80%	Black liquor (BL) is a by-product of cooking pulp, used for generating heat to other processes in a recovery boiler. Increasing the dry solids content was first used to obtain more economic thermo-technical solutions in the combustion of BL and later to reduce air emissions. BL and other industrial liquors account for 40% of Finland's renewable energy consumption.	Reduced air emissions, especially sulphur, and more efficient energy supply
Black liquor gasification	BL can be gasified to produce energy as opposed to firing in a recovery boiler. This is a potential alternative to the conventional recovery boiler or a complement to overloaded recovery boilers, and may be more flexible and environmentally sounder.	Reduced air emissions, more efficient energy generation than from BL combustion
POM-technology	Compact wet-end system for paper machine with an air-removing centrifugal pump as the main component. Simpler and less space consuming than the conventional system, achieves faster/shorter water recirculation and reduces pulp grade change times. Regarded as one of the most significant pulp and paper innovations of the 1990s.	Improved energy-efficiency, reduced water consumption, effluent discharge and waste
Conox-process	Combustion system for process water effluents based on thermal oxidation. Designed to reduce water pollution (namely COD) from bleaching plant effluents, later applied to BL from non-wood pulping.	Reduced water discharges, development towards closed water cycles, small improvement in energy-efficiency.

The pulp and paper cases have been described in detail in Kivimaa and Mickwitz, 2004.

Table 2: Cases for product innovations in the paper and packaging industry

Product invention / innovation case	Description	Environmental Impacts
Ecological paper	VTT Technical Research Centre of Finland has developed natural materials from raw starch enabling the making of high-quality paper that is fully recyclable. With the help of this technology and without changes in paper machinery, starch can replace the mineral rock-based filling and adhesive materials typically used in papermaking. The technology is ready for commercial trials.	Contrary to the recycling of traditional paper, the waste sludge remaining at the end of recycling ecological paper, can be fully converted to bioenergy. Moreover, 20-30% reduced paper weight can reduce transportation costs and, indirectly, emissions from transport. Even partly replacing mineral with starch in paper improves the surface strength and, through requiring less printing ink, the environmental effects of printing are reduced.
Tetra Recart – Retortable carton package	Tetra Pak has developed a carton material that is moisture-resistant and heat-resistant. This means that the package can go through a heating process after it has been filled with food to enable a long shelf-life. It provides an alternative to tin cans and glass jars for storing food.	The lighter weight of the packaging decreases costs and environmental impacts by reducing the space needed for transportation and the weight of the shipments. Potential environmental benefits also derive from the use of wood fibres and recyclability instead of tin cans.

DRIVING FORCES FOR ENVIRONMENTAL PROCESS AND PRODUCT INNOVATIONS IN THE NORDIC FOREST SECTOR

Technology Push – Research Motivations and Technological Development

It has been typical of the cases studied that universities, research institutes and companies have engaged in R&D to improve different technical qualities such as material efficiency, energy efficiency or quality of current processes and products. Often R&D has been conducted collaboratively by different organizations. Some process innovations have had a specific origin in basic scientific research (e.g. black liquor technologies) and many innovations have been based on the developers' interest in finding improvements (e.g. POM and 'ecological paper').

As an example from the process innovation side, Ahström's evaporation technology increasing the dry solids content of black liquor originated from basic research on lignin not related to energy efficiency or emissions (Kettunen, 2002, p. 88). The quests for environmental gains followed the initial invention.

> *In the 1970s, it was noticed that when the dry solids content of black liquor is increased . . . the sulphur emissions disappear* (consultant).

> *It was not expected that sulphur emissions would reduce close to zero . . . emissions remained clearly under the current environmental limits* (scientist).

Regarding products, the development of 'ecological paper' provides an example. The research of the VTT Technical Research Centre of Finland started at the turn of the millennium as an idea to reduce the weight of paper and produce printing paper with as little fibre as possible – aiming at improved resource efficiency. Both the environmental aspect and improving the paper technical aspects regarding paper recyclability and the surface strength of paper affected the researchers' interests to develop the idea further. The companies M-real, Stora Enso, Metso Paper and Ciba Specialty Chemicals co-financed the research together with the Finnish Funding Agency for Technology and Innovation, Tekes.

The majority of the cases studied received public R&D funding at some point in the development. Black liquor technologies were developed during consecutive research funding programmes during the 1980s and 1990s, and it has been argued that technological change would have progressed more slowly without public subsidies, which have lowered the risks to investors (Kivimaa and Mickwitz, 2004). The developments of POM, Conox and 'ecological paper' also received funding from Tekes. In sum, technology push, through searches for specific technical improvements and through public R&D funding, has been important for the emergence of environmentally sounder innovations.

Market Pull – Opportunities to Compete and to Achieve Cost Reductions

After the initial invention of utilizing black liquor, a by-product of pulp production, to produce energy, the processes of combusting or gasifying it were developed further. The further developments were carried out, first, to achieve more economic thermo-technical solutions and, later, to preserve the market share of the Finnish paper producers in response to demands from the Central European paper buyers.

> *Market forces, mostly for preserving reputation, were a powerful factor, and the Finnish forest industry has been ready to invest in environmental issues* (consultant).

> *The reduction of sulphur emissions became a sales argument to a large extent* (scientist).

The development and adoption of a more efficient and compact paper machine wet end, POM, was also strongly driven by cost factors. The initial invention arose from a need to simplify the papermaking process in order to reduce costs and increase flexibility.

> . . . *changes to paper machine processes were the largest cost factor [in paper mills] because of the large volumes and complicated processes* . . . (technology developer).

> *One of the paper machines did not have mechanical air removal before POM. The air was removed chemically and the consumption of chemicals was high. . . . Other solutions [than POM] were not considered, because mechanical air removers are clearly more expensive* (manager at a paper mill).

By contrast, Conox was affected rather by the anticipation of a market created by new environmental regulations than by cost factors.

> . . . *the thermo-economic benefit was not significant* . . . (scientist).

On the product side, the development of Tetra Recart consisted not only of the packaging itself but also of the system sold to food producers for packaging the food and heating it for longer preservation. Improvements in the logistics of packaged food, cost reductions and the need to develop something innovative were behind the invention.

> *They [the company] wanted to have something new, they wanted to compete with a package that is 200 years old . . . and of course you had the economy into it: can we produce a package that is cheaper than the tin can?* (product developers).

> *Two driving forces were operating simultaneously in the development of Tetra Recart: On the one hand, a big potential market was anticipated for the product due to cost savings in the packaging logistics chain. On the other hand, the logistics improvements also benefited the environment through savings in materials, energy and non-renewable resources* (consultant).

The demands of the market have strongly driven the environmental activities of the forest sector (Tetra Pak et al., 2002). The extent to which environmental improvements in products are developed depend heavily on signals from the market. According to the interviews in Tetra Pak, Stora Enso and SCA, much of product development in the paper and packaging companies is customer driven.

> *The main driving force is consumer need and consumer demands* (environmental manager).

> *The customer is a key player* (environmental manager).

> *It's good for our reputation if we have a recycling system* (environmental manager).

Market pull, in the early stages, was more important for environmentally improved products than for process innovations. Only a small percentage of ideas are generally developed into new products, and the role of new anticipated markets or strong existing customer demand is crucial. In the process innovation cases, potential markets might have been somewhat anticipated and some customers had participated in the testing of new technology, but market pull per se did not initiate the development of these technologies.

Regulatory Push and Pull – Environmental Policy Impacts on Innovations

Five of the case studies reveal different types of effects related to environmental policy. These include anticipation of future policies and direct effects of specific policies on either the innovation development or diffusion. The sixth case is a case of 'no effect'.

The original idea behind Conox was spurred on by the anticipation of increased regulatory measures for closing the bleaching processes, because the issue was high on the agenda of the Central European paper buyers. Regulation created market pull was expected among technology developers. Policy anticipation also affected the development of black liquor innovations. Much R&D was accomplished and some pilot installations were built in Finland prior to the 1987 Council of State Decisions setting guidelines for sulphur emissions, while the need to reduce the emissions had already been discussed in the 1970s. In the late 1980s, tightening air pollution policy affected the further development.

> *Certainly environmental regulations have had a large impact, because they have brought forward air pollution issues to pulp and paper producers . . . Then the producers have known to require solutions from technology manufacturers and to get enthusiastic about them . . .* (scientist).

> *Authorities and mills have discussed local issues in advance of environmental permit renewals and have tried to find a solution that satisfies both parties* (consultant).

The diffusion of process technologies, such as black liquor and POM, was in some cases directly affected by plant-specific environmental permit limits for air or water emissions. For instance, POM was acquired by a Spanish paper mill, because it enabled the mill to meet short term maximum limits in the water permit (Clariana, 2003).

The recyclability of packaging has been important in new product development of Tetra Pak, following both the increased demands from customers and the EU Directive on packaging and packaging waste (94/62/EC).

> *The demands [for recycling] came from the government . . . packaging ordinance we call it in Sweden, but it is also the EU Directive on recycling of packaging* (environmental manager).

The Nordic packaging companies Tetra Pak and Stora Enso have set up systems of collecting and handling the packaging waste for recycling in cooperation with food manufacturers and retailers. While newspapers and magazines have been collected from households in Sweden for more than half a century, the introduction of producer responsibility for packaging really started the collection of corrugated board from households (Tetra Pak et al., 2002).

> *The directive has led to all countries having to, in different ways, recover more recycled paper and packaging . . . and product development from recycled paper has improved a lot* (consultant).

According to the interviews and focus groups, the EU packaging and packaging waste directive has been effective in increasing the use of recycled fibre in new products, but some consider it too limited and narrow for the development of future packaging.

> *The packaging directive has been focused on packaging as waste, but if you take an Integrated Product Policy view on packaging, then they will not only look at how much material you have, they will also look at the efficiency of the packaging, its ability to protect the product, and taking care of it in the end* (consultant).

In some cases the impact of environmental policies has been less straightforward than in the above examples. Companies have acted ahead of policies partly in response to market demands and partly to influence future policymaking. For instance, the instruments within the remits of EU Integrated Product Policy (e.g. environmental management, requirements to take back and recycle products, life cycle considerations) have existed throughout the 1990s in some Nordic paper and packaging companies. In Sweden, Tetra Pak and Stora Enso together with the Swedish Forest Industries Federation published a report in 2002 where they identified IPP relevant measures in the companies and showed how IPP has already been used in the product chains ahead of the recent policy initiatives (Tetra Pak et al., 2002).

For 'ecological paper', no specific environmental policies were identified as having affected the research, despite its potential environmental benefits related to the logistics, printing and recycling processes. Environmental policy trends, especially those related to recycling, have in general terms had some influence.

Regulatory push and pull have had more direct effects in the case of process innovations. Specific policies affecting technology diffusion could be identified in each case. Anticipation of new regulation has been important for process technologies because of the long timescales involved in renewing production machinery. By contrast, the effects of environmental policies on the development of new products have been more indirect, with the exception of the EU packaging and packaging waste directive.

Internal Dynamics within Companies

Environmental policies, markets and demands from shareholders shape the operational context of companies.
For example, environmental policies create demands for company environmental management,
who modify internal operations within the confines of the overall context and company culture.
Customer demands are often communicated via marketing departments.
Interviewees at the case companies identified environmental considerations affecting product development
but did not directly connect these to any pressures external to the company. For example, lifecycle inventories and more general corporate rules were referred to by environmental managers and R&D personnel.

Life-cycle inventories are kind of driving product development (environmental manager).

> *There are environmental questions in each step when you go ahead with the development of a product and there can be demands for life-cycle inventory data . .* (environmental manager).

> *The environmental criteria are coming from the overall corporate environmental and product safety policy and then it goes down to the business groups* (R&D manager).

> *Environmental reasons were considered right from the beginning . . . because we have to have that* . . . (product developers).

The measures used by companies are sometimes directly linked to environmental improvements by including environmental baseline criteria in product development, while in other cases the basis of lifecycle inventories lies in cost or competitive benefits.

According to the focus groups and interviews, LCAs have been used in packaging for 30 years and were, for example, originally driven by aims to develop new competitive packaging materials.

Determining direct causality is rendered difficult by the distance between public environmental policy and company product development. Environmental managers were aware of external signals to the company but did not have detailed knowledge of the product development process or its drivers. People working in R&D identified environment-related demands in the product development process but linked them only to corporate rules. Some tentative connections, however, can be made. The packaging and packaging waste directive has been important for the companies, who have also set up systems for recycling. The recyclability of products has improved, thus it may be assumed that the directive has affected the product development processes.

DISCUSSION

Varying Drivers of Product and Process Innovations

The findings support Cleff and Rennings (1999) in that environmentally sounder product innovation is significantly driven by the strategic market behaviour of firms (market pull effect), while environmental process innovation is more driven by regulation (regulatory push/pull effect). The innovation cases, however, show that market and cost factors also play a role in process innovations. According to Hildén et al. (2002), market demands particularly drove the emergence of different non-chlorine bleaching techniques for pulp.

The study shows that more than one determinant is crucial for environmentally sounder technological innovations. Technology push is supported by either market pull or regulatory push and pull, and some cases have been affected by all three. Moreover, regulatory push/pull and technology push can create subsequent market pull when the expectations of the market are raised by information flow and policies have created a new baseline for performance. In other cases, requirements from the market may precede public policies. In addition, an anticipation of environmental policies may dictate what kind of technology push is pursued. While all three types of drivers have been important for environmentally sounder innovation, the relative significance of the different factors varies.

Environmental policy may affect both process and product innovations but specific policies influencing product development in the industry studied were difficult to identify. The target of regulation and the differing conceptions of the actors involved offer some explanations. In the Nordic countries, environmental impacts from industrial processes are often regulated through permits and regulations that impose emission limits on individual production plants. Thus, the effects, for example, of a new emission limit can directly cause the development or purchase of new technology reducing air emissions. By contrast, while certain health and safety standards on products exist, the environmental impacts of paper and packaging products have usually been regulated through their production processes. Causality is difficult to prove because a variety of external signals are transformed in companies into different rules and practices (see, e.g., March and Sutton, 1997) that may or may not be followed in the R&D units. In other sectors where products have been directly targeted by regulation, innovations have followed. For instance, emission limits for cars have aided the diffusion of catalytic converters and standards for fuel efficiency have prompted diesel technology innovations (Beise and Rennings, 2005).

Often self-regulatory and informational policy measures complement more traditional regulation. They are promoted by the idea of extended producer responsibility (EPR), meaning that private organizations assume responsibility for functions that fulfil part of the governance for public interest through such measures as negotiated agreements, product labels and company take-back schemes (see, e.g., Maynz, 2006; Tojo et al., 2006). In this study, these measures were not distinguishable from other company-level operations. For example, when product developers described the innovation processes, they did not make a distinction between the EPR measures and other corporate rules and principles for R&D projects.

Different actors have differing conceptions of the innovation process and of the significance of contributing factors. The differing views on events are a standard notion in the social construction literature (e.g. Garud and Karnøe, 2003; Orlikowski, 2000). The developers often highlighted both the technical and the market motivations behind innovations. People working in the companies also mentioned internal factors. Consultants and scientists were more likely to link environmental policies to certain scientific and technical advances. Those purchasing process innovations described both cost and regulatory drivers behind the new installations. By contrast, purchasers of consumer products are often characterized by lacking sufficient knowledge of the origins and consequences of environmental problems (see, e.g., Reinhard, 2006). While customers are the main focus of new product development, lack of environmental policy targeted at customers means that environmental policy signals for innovation from this direction are rare.

Key Elements of Environmental Policy from the Innovation Perspective

An important finding of the study is that the effects of environmental policies on innovations are not limited to the way in which the traditional 'policy cycle' is depicted (see, e.g., Pollitt and Bouckhaert, 2000). Instead of new technology following directly from new environmental policy, the development of an innovation may precede a policy or even exert influence over the policymaking process. Policies targeting one environmental problem (e.g. the amount of waste through demanding improved recyclability of products) may also cause others (e.g. increased energy use through the recycling processes). In other cases, technologies solving an environmental problem in response to a policy (e.g. emissions from pulp production) may also solve other problems not targeted by specific policies (e.g. improve energy efficiency). Innovations themselves may be either intended or merely side-effects of public policies.

In those cases where environmental policies supported environmentally sounder innovations or their diffusion, they were often flexible and predictable. This supports the two characteristics of environmental policy identified by Norberg-Bohm (1999) presented above. Anticipation of future policy has contributed to the creation of two production-side innovations: the dry solids content increase of black liquor and Conox. Policy anticipation has also emerged as a crucial factor in the technological innovations of other sectors, such as marine engines (Hyvättinen and Hildén, 2004). Some policies cater for foreseeable development. The EU packaging and packaging waste directive in

1994 allowed an implementation period of 1.5 years for member states to set up their own return, collection and recovery systems and another five years to reach the targets set. This has left time and some flexibility for industrial actors to respond, for instance, through product development and to contribute to the development of national systems. However, it has been argued that the model for extended producer responsibility introduced by the directive has only increased recycling and has not led to significant reduction in wastes (EEA, 2005; Melanen et al., 2002). Similar opinions were presented by two Swedish experts interviewed. The limited choice of responses may also hamper innovation.

Traditional policy instruments in Finland have provided flexibility, for instance, through case-specific water permits enabling relaxed conditions during try-outs of new technologies, and permits for air pollution control based on general norms and guidelines not specifying technologies to be used (Hilden et al., 2002; Mickwitz et al., 2007). These have played a role for the testing and adoption of black liquor technologies in Finland for example. Similarly, water permits based on emission limits rather than on specific technology have enabled the installation of POM in a Spanish mill.

Another characteristic of environmental policy listed by Norberg-Bohm, 'providing economic or political incentives', does not explicitly emerge in the interviews. Economic incentives, however, were realized through efficiency improvements gained from installing new technologies in response to regulation, e.g. in the case of black liquor technologies. Political incentives included gaining first-mover competitive advantage when technology was developed ahead of policy.

A characteristic not presented by Norberg-Bohm, but previously mentioned in the literature (e.g. Gunningham et al., 2003), is an element of continuous improvement. For instance, the amended packaging and packaging waste directive (94/62/EC) includes stricter requirements for the level of recovered packaging by 2008. Expectations of stricter regulation for organic pollution prompted the creation of Conox and new permit limits have promoted the diffusion of black liquor technologies (Kivimaa and Mickwitz, 2004). To still be flexible, the continuous improvement target should not excessively burden individual manufacturing plants over too short intervals.

By combining the three important characteristics of environmental policy supporting innovation derived from this study with Rennings' (2000) model of the determinants of environmentally sounder innovation, an intervention model for environmentally sounder innovation can be developed (Figure 1). In evaluation research, the concept of intervention theory/model refers to the presuppositions regarding what the intervention is designed to achieve and how (Vedung, 2000). The intervention model for environmentally sounder innovation presents how, in principle, environmental policy could be directed to support innovation. Environmental policies requiring continuous improvements in a direction that can be anticipated and offering several options for response can (i) directly provide incentives to companies to innovate, (ii) signal or inform research and development or the markets about potential inefficiencies or room for improvement or (iii) create new markets for innovations. Technology and markets, in turn, offer feedback for environmental policymaking on the prevailing problems and available solutions and develop dynamically over time.

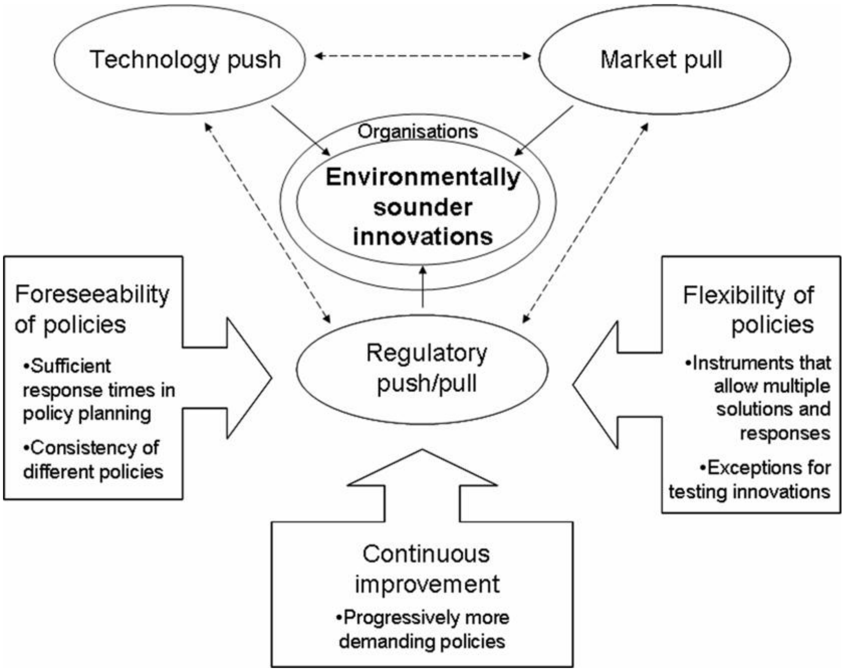

Figure 1. Intervention model for environmentally sounder innovation, expanded from Rennings' model of the determinants of eco-innovation

Technological and product innovations often emerge rather as side-effects of environmental policies than with this specific intention. Therefore, environmental policy sometimes also fails to support innovation – because it has not been its specific intention. Erroneous assumptions behind policies are frequently one of the reasons for their failure (Hoogerwerf, 1990). Provided that innovations are advocated as solutions to environmental problems, environmental policies should be reframed according to those assumptions that have been found to support innovation.

CONCLUSIONS

The mechanisms through which innovations develop and the ways in which public incentives support improved environmental performance of innovations are complex. The effect of environmental policies on innovation is context dependent and influenced by market and technology factors and the heterogeneity of companies. Thus, policies do not always function as expected. Instead of new technology following directly from new environmental policy, the development of an innovation may precede a policy or even exert influence over the policymaking process. Policies targeting a specific environmental problem can increase others, for instance the use of fossil fuels as a result of recycling requirements. In other cases, technologies addressing one issue may also resolve others. It is important to take into account the anticipatory role of environmental policies as well as their unintended side-effects.

Often innovative technologies and products with environmental improvements emerge rather as side-effects of environmental policies than as an intention of those policies.

For the same reason – as policies are not primarily intended to promote innovation – many policies also fail to encourage it. Provided the political aspiration is to promote environmentally sounder innovations to solve environmental problems, and to do so partly through environmental policies, then policies should be reframed accordingly.

Since many empirical studies have illustrated the context specificity of environmental policies, the discussion on the suitability of specific environmental policy instruments for promoting innovation is outdated. Rather, we should move on to discuss the features and elements of policies supporting innovation that are common across different – old and new – policy approaches and instruments. The cases studied show the importance of continuously improving, foreseeable and flexible environmental policy. Policies should progress towards goals and in directions that can be anticipated by non-policymakers while flexibility in choosing multiple responses would provide companies with the opportunities to generate alternative solutions to a problem and to test new unexpected technologies in practice.

In the Nordic paper and packaging industry, the effects of environmental policies on process innovations have been explicit and direct. By contrast, environmental policies have largely affected product development indirectly by setting general trends and by creating a baseline for environmental performance that is often surpassed by customers' requirements. When regulation is targeted at production processes, environmental process innovation is more likely. When policies are also focused on products, as in the car industry, product innovations may emerge.

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Article IV

INTEGRATING ENVIRONMENT FOR INNOVATION

Experiences From Product Development in Paper and Packaging

PAULA KIVIMAA
Finnish Environment Institute (SYKE) and Helsinki School of Economics

Environmental innovations have been emphasized for effectively solving environmental problems. In the innovation literature, organizational factors have been listed among the determinants of innovations, and firm-level research and development (R&D) has been perceived crucial. This indicates that environmental considerations should be integrated into all organizations, especially in R&D, to promote environmental innovation. A typology of six forms of "environmental integration" in product development is created based on organizational integration and product development literatures, and the occurrence of the different integration forms in the product development of four Nordic paper and packaging companies is studied. The results show that although environmental considerations in research and product development are standard practice on some level, the practice still varies a great deal between companies. Furthermore, different combinations of the environmental integration forms used in organizations have implications on the source from which environmental information for innovation originates.

Keywords: *environmental innovation; corporate environmental practice; organizational integration; R&D; product development; paper and packaging industry*

1. INTRODUCTION

The need for environmental innovations has been increasingly emphasized by policy makers and academics alike to effectively solve environmental problems. For instance, the European Commission (2004) published the Environmental Technologies Action Plan to promote environmental innovation. To date, many technological innovations in the Nordic pulp and paper industry have resulted in significantly reduced emissions and increased shares of nonfossil fuels in energy production. Nevertheless, several environmental challenges persist related to climate change, biodiversity, and chemicals dispersed through consumer products. The question therefore arises as to how we can best achieve environmental innovations to better respond to unsolved environmental problems.

Organizational factors have been listed among the determinants in complex innovation processes, and a so-called industrial research and development (R&D) laboratory has been described as a major source of innovation (Edquist, 2005; Pavitt, 2005). On firm level, R&D is a key element of the innovation process, and for instance, Pavitt (2005) has argued that "specialized R&D and related activities have

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become institutionalized and predictable sources of discoveries, inventions, innovations, and improvements" (p. 100). It has also been argued that although strategic control and financial commitment are essential to an innovative company, organizational integration determines the innovative capability that the company actually possesses—although there is no single successful type of organizational integration from the point of view of innovation (Lazonick, 2005). Integrating environmental considerations into company R&D is a potential way to generate environmental innovations.

Processes generating innovations having positive and/or negative environmental impacts are affected by a variety of factors, such as company activities, market dynamics, and institutional conditions (Edquist, 2005; Malerba, 2005). Despite the importance of firm-level activities, much academic literature on environmental innovations has focused merely on company external drivers (e.g., Williander, 2006). The literature on corporate environmental management has discussed the role of organizational cultures (Howard-Grenville, 2006), organizational learning (Halme, 2002), and functional coordination in organizations (Fryxell & Vryxa, 1999) but has focused little on the links between R&D practices and environmental innovation. Following a lack of theoretical discussion of environmental integration in organizations from an innovation perspective, this article discusses it in relation to product development and as a potential contributor to environmental innovations.

The article creates a typology of environmental integration in the context of product development and assesses it based on empirical material from four Nordic paper and packaging companies that use wood-fiber as their main raw material. Rather than pursuing a general model on how environmental innovations are created in companies, the study presents the diversity of ways in which environmental considerations can be acknowledged in contributing to the innovation process. Theory on organizational coupling/decoupling is used to attain a better understanding of the sources of environmental integration in the context of innovation.

Section 2 creates a typology of environmental integration, and Section 3 links this to organizational coupling. In Section 4, the research method is presented. Section 5 looks at the existence of different environmental integration forms in four case companies, and in Section 6, different approaches to environmental integration are depicted as a conceptual map. Section 7 discusses the results from the viewpoint of innovation. Section 8 concludes the article.

2. DEFINING ENVIRONMENTAL INTEGRATION IN COMPANY PRODUCT DEVELOPMENT

"Environmental policy integration" has been highlighted in public governance for implementing the principles of sustainable development horizontally across governmental sectors and vertically within sectoral policy organizations (Lafferty, 2004; Lafferty & Hovden, 2003). Similarly, at firm level, managing environmental considerations should not be limited solely to corporate governance and environmental management units but included in every practice. The integration of environmental considerations into the units and activities of a company can be defined as "environmental integration," taking many forms and being linked to the organization in different ways. A vertical integration could imply the implementation of corporate environmental policies and principles into practices and outputs, whereas a horizontal integration could mean improved cooperation between the environmental management and other company departments.

Lenox and Ehrenfeld (1997) have emphasized the importance of integrating environmental considerations into operations management and product development, because diverse constituents increasingly make demands on companies' environmental performance and environmental integration can be a significant source of competitive advantage. Earlier studies have examined the integration of environmental considerations into multiple functions of organizations (Fryxell & Vryxa, 1999) and operations management (Angell & Klassen, 1999). Some other studies have not focused on integration per se but have explored the connections between environmental management systems and the Design for Environment (Ammenberg & Sundin, 2005), the determinants for new environmental product development (Berchicci & Bodewes, 2005), and how environmental questions affect R&D work in manufacturing (Blomquist & Sandström, 2004). For example, Fryxell and Vryxa (1999) examined the integration of environmental considerations into multiple functions of major U.S. companies in the mid-1990s, showing that integration with product development was the function where corporate environmental departments had the greatest aspirations and where improvement was most sought. Blomquist and Sandström (2004), after briefly exploring the integration of environmental considerations into the R&D activities of two large Swedish manufacturing companies, argue that the ultimate test of visible "greening" is making environmental considerations evident in the R&D work.

Despite the fact that environmental considerations have received some attention in product development studies (e.g., Ammenberg & Sundin, 2005; Baumann, Boons, & Bragd, 2002; Berchicci & Bodewes, 2005; Lenox & Ehrenfeld, 1997), the concept of environmental integration has not been discussed in this literature. Even in the more mainstream literature, the concept of organizational integration has remained vague (e.g., Lazonick, 2005). "Integration" has been used, for instance, to mean the quality of the state of collaboration and the process of achieving unity of effort among organizational subsystems in the accomplishment of the organization's task (Fryxell & Vryxa, 1999; Lawrence & Lorch, 1967).

With the aim to discuss environmental integration in company product development and its contribution to environmental product innovations, different forms of and approaches to environmental integration are identified and discussed in this article.[1] A typology of environmental integration in product development (see Table 1) is developed based on concepts from organization, product development, and environmental management literatures.

2.1 Top-Down Implementation of Corporate Environmental Policies and Practices

Centralized decision making and formal planning combined with written policies, rules, and practices have been described as conventional mechanisms in coordinating organizational activities (e.g., Fryxell & Vryxa, 1999; Lawrence & Lorch, 1967). Corporate environmental management, for example, has been based on integrated systems and procedures to ensure that environmental performance is improved over time (Welford, 1995). Formalized environmental decision making has also been found to promote the adoption of such environmental initiatives that are not based on direct financial benefits for the companies (Berkhout & Rowlands, 2007). Vertical and codified implementation of organizational strategies promotes decisions based on similar premises throughout the organization. Top-down corporate visions, however, have sometimes been claimed to be a

Table 1: Six Forms of Environmental Integration in Company Product Development

		An Application to Product Development	*Characteristics*	*Links To Previous Literature*
Forms of procedure-based environmental integration				
1	Top-down implementation of corporate environmental policies and practices	Corporate-wide environmental criteria and practices in product development	Top-down, vertical integration from strategies to projects, based on rational plan and codified knowledge	Organization theory, environmental management
2	Use of environmental information systems and databases	The use of life-cycle assessments	Either top-down or local, based on rational plan and codified knowledge	Product development, design for environment
Forms of people-based environmental integration				
3	Cross-functional integration between departments	Integration between environmental management and product development departments	Vertical/horizontal integration (depending on the nature of environmental department), based on communication web and tacit knowledge	Organization theory, operations management
4	Cross-functional integration within departments	Environmental experts as members of product development teams	Local integration, based on communication and tacit knowledge	Product development
5	Training in environmental issues	Environmental training of the personnel involved in product development	Top-down, based on both codified and tacit knowledge	Environmental management
Forms of problem-solving-oriented environmental integration				
6	Task forces and ad hoc groups for new environmental issues	The intentional development of environmental product innovations	Top level or bottom-up initiations	Organization theory, product development

poor guide to innovation strategies because of the uncertainties involved in the innovation process (e.g., Pavitt, 2005).

The idea of top-down environmental integration can be linked to the rational plan perspective of product development, defined by Brown and Eisenhardt (1995) to aim at success via superior product that is achieved through senior management support. It relies on the creation and diffusion of codified knowledge. In product development, this form of integration refers to corporate-wide environmental criteria and practices for product development projects.

2.2 Use of Environmental Information Systems and Databases

Information management systems have been associated with nonconventional, process-based mechanisms for coordinating organizational activities (e.g., Fryxell & Vryxa, 1999; Lawrence & Lorch, 1967). Different knowledge sources, in turn, have been found to be crucial to the capability of firms to address environmental concerns in product development (e.g., Lenox & Ehrenfeld, 1997). Thus, information systems and databases processing environmental information, such as life-cycle assessments (LCAs)[2] and inventories, are one way to integrate environmental knowledge into product development processes. Following the idea of rational plan in product development (Brown & Eisenhardt, 1995) and codified knowledge, the use of systems can be imposed top-down for the whole organization or used locally in some of its parts. Environmental design tools, however, have been found to receive too much emphasis in the literature, considering they often fail to consider the context in which they are used (Lenox & Ehrenfeld, 1997).

2.3 Cross-Functional Integration Between Departments

Cross-departmental relations have also been included among the nonconventional means of coordinating organizational activities and have, simultaneously, been considered as one of the most important ways to achieve unity of effort in organizations (e.g., Fryxell & Vryxa, 1999; Lawrence & Lorch, 1967). When an organization becomes larger, the tasks of different departments become more functionally separated with the risk of slowly diffusing information within the organization. Because different organizational tasks require different kinds of activities, the tasks may also create different subcultures around them (e.g., Howard-Grenville, 2006). Thus, there is a risk of functional disintegration (e.g., Fryxell & Vryxa, 1999) between organizational departments formed around tasks.

Case studies of environmental technologies have shown two potentially important organizational tasks from the perspective of environmental innovation, corporate environmental management, and R&D/product development (e.g., Kivimaa, 2007). Interaction between company departments relates to Brown and Eisenhardt's (1995) communication web perspective in product development and is important for tacit knowledge transfer. Whether the integration between environmental management and product development departments is vertical or horizontal depends on the nature of environmental management (corporate level vs. decentralized) in the company.

2.4. Cross-Functional Integration Within Departments

Cross-functional project teams including members from more than one functional area (e.g., engineering, manufacturing, and marketing) have been argued to be among the key elements in product development (Brown & Eisenhardt, 1995), albeit with the risk of making interpersonal communication in teams more difficult (Berchicci & Bodewes, 2005). Cross-functional integration within product development could mean that environmental experts are included as members of product development teams. This can be seen as a form of local integration, based on Brown and Eisenhardt's (1995) communication web and tacit knowledge, but with potential for supporting integration with environmental management.

Environmental experts in product development teams have also been found as crucial in establishing communication linkages between product development team members and environmental knowledge resources of the organization (Lenox & Ehrenfeld, 1997). They may function as gatekeepers or integrators facilitating cross-departmental integration between product developers and environmental personnel in the organization. Individuals as integrators (e.g., Fryxell & Vryxa, 1999) and gatekeepers in product development teams (e.g., Brown & Eisenhardt, 1995; Lenox & Ehrenfeld, 1997) have in effect been found as important coordination means in successful organizational tasks. Interpretive structures through which environmental information is understood by product development team members (e.g., Lenox & Ehrenfeld, 1997) could be supported by integrator-gatekeepers, provided they master both environmental and product development terminology.

2.5 Training in Environmental Issues

Environmental training has not been mentioned in Fryxell and Vryxa's (1999) coordination mechanisms, but Lenox and Ehrenfeld (1997) have mentioned it as an important way to facilitate interpretative structures and communication, supporting the capacity of companies to address environmental concerns in product development. Environmental training of personnel can be seen as a top-down integration effort. It is based on transferring tacit and codified knowledge to organizational members. Environmental training of product development personnel can be seen to relate to both rational plan and communication web approaches of product development (see Brown & Eisenhardt, 1995).

2.6 Task Forces and Ad Hoc Groups for New Environmental Products

Task forces and ad hoc group mechanisms are a part of more unconventional organizational coordination mechanisms (Fryxell & Vryxa, 1999). They can emerge either from top-management commitment or from bottom-up initiation. Task forces and ad hoc groups can be used to intentionally develop new environmental product innovations in cases in which new ideas emerge that need or benefit from specific responses. This more case-specific approach to environmental integration somewhat relates to Brown and Eisenhardt's (1995) disciplined problem-solving approach to product development. Thus, intentional development of environmental products may involve cross-functional project teams, high internal communication, and high involvement with company external actors with relevant expertise.

3. LINKING DIFFERENT FORMS OF ENVIRONMENTAL INTEGRATION TO ORGANIZATIONAL COUPLING/DECOUPLING

Environmental integration involves different types and sources of environmental knowledge—both external (e.g., public policy, customers, suppliers) and internal (e.g., corporate level, environmental department, marketing department, R&D department). The mere existence of knowledge is not enough, and knowledge diffusion within organizations is important from the environmental innovation viewpoint. For example, as public policies have been found to have a potential impact on environmental innovations (e.g., Kemp, 1997) and as environmental policies are usually followed up by environmental departments (e.g., Kivimaa, 2007), internal mechanisms are needed for public policy signals to diffuse to organizational innovation processes. Yet especially in large organizations, the implementation and diffusion of new knowledge arriving from external sources may face considerable barriers (e.g., Brunsson, 1993).

A discrepancy between organizational goals and institutional requirements, posed by external constituents on organizations, may lead to situations where the publicly stated principles of the organization do not match the activities carried out (Brunsson, 1993; Meyer & Rowan, 1983; Oliver, 1991; Westphal & Zajac, 2001). A decoupling of corporate policies and practice can sometimes be viewed as a viable response to institutional pressures (Westphal & Zajac, 2001). Organizational policies adopted in response to institutional requirements may also differ from practice, intentionally or unintentionally, when organizations face multiple conflicting pressures from their stakeholders (e.g., Oliver, 1991) or lack the capacity (e.g., knowledge, time, financial or human resources) to conform.

The intentional differentiation between the publicly stated principles and actual practice has been defined as avoidance strategies by which nonconformity is concealed behind "a façade of acquiescence" (Oliver, 1991, p. 154) and as hypocrisy in reference to situations where the official truth presented in public statements deviates from the private truth (Brunsson, 1993). This could, for instance, refer to corporate environmental strategies and policies that do not have practical implications (Bowen, 2000). Brunsson (1993) has argued that sometimes hypocrisy may provide the only chance of achieving some action without the risk of losing general support for the organization. Profound differences between organizational policies as formally adopted and actual organizational practices have been observed (March & Sutton, 1997; Westphal & Zajac, 2001).

The forms of environmental integration identified earlier have differing abilities to support coupling between corporate environmental principles and practice. Those involving vertical and horizontal integration throughout the organization, such as top-down implementation of corporate environmental policies through corporate-wide environmental criteria and cross-functional integration between environmental management and product development departments, best support coupling. Use of information systems and training can also support coupling to some extent, but the end result is more unclear. In differentiated organizational subcultures, multiple interpretations of an issue are simultaneously held, and multiple solutions may be tailored to the different problems (Howard-Grenville, 2006). For example, Rex (2006) has found considerable differences in the interpretations of the life cycle concept among the environmental managers and representatives of different business operations, and Cooper (1996) has found that a mere existence of a formal product development process has no effect on performance. Thus, the existence of codified practices does not imply a similar understanding throughout the organization.

Tacit knowledge and the degree of collaboration/feedback between product development and other corporate functions have been found to be among the most important factors promoting innovation (Lazonick, 2005; Pavitt, 2005). Functionally integrated product development teams, in which the environmental expert acts as an integrator-gatekeeper, can facilitate coupling through mastering different terminologies. Yet it has been argued that strategies based on decentralization of environmental decision making, rather than coupling corporate practices to uniform standards, may create an environment more advantageous to experimenting and new ideas (e.g., Hales, 1999).

Table 2: Key Data for the Case Companies

Company	*Stora Enso*	*SCA*	*M-real*	*Tetra Pak*
Sector	Pulp, paper, packaging	Packaging, hygiene products, paper	Pulp, paper, packaging	Food packaging
Turnover (2005)	13,188 m €	10,420 m €	5,241 m €	8,107 m €
Production (2005)	17,429 kilotons	9,893 kilotons	8,902 kilotons	120,830 packages
R&D expenditure (2005)	0.7% of turnover	0.6% of turnover	0.4% of turnover (whole group)	0.3% of turnover (whole group)
Number of employees (2005)	46,166	50,916	15,154	20,261
Size within sector (world / Nordic countries)	Fourth largest / largest	Sixth largest / second largest	Tenth largest / fourth largest (whole group)	
Headquarters	Finland / Sweden	Sweden	Finland	Sweden
Studied reports (2005)	*Company Report, Sustainability Report*	*Annual Report, Environmental and Social Report*	*Annual Review, Corporate Responsibility Report*	*Environmental and Social Report, Product Environment Profile, Tetra Laval Report*

4. RESEARCH METHODS

The article examines the forms of environmental integration in the product development of four large Nordic paper and packaging companies (see Table 2). The Nordic paper and packaging sector was chosen for its past environmental improvements in production processes, although it has not been characterized as very innovative on the product side. The industry is dominated by a few large players. Four companies among the largest forest-based ones in the world were chosen to represent those with greatest investment opportunities for innovation and the complexity of large organizations.[3] Choosing multiple cases enabled taking into account the differing organizational contexts and forms of environmental integration.

Research activities in companies relate to production processes, to products and services, or to improving the value chain in which the companies operate. Product development is construed as contributing to the innovation process by taking the inventions for possible new products toward commercialization, while acknowledging that not all company product development is aimed at "innovating." Furthermore, product development is merely one part of company operations, and this examination does not relate to the overall environmental performance of the companies studied. Activities related to raw materials acquisition, production, and distribution also play a significant role in environmental terms.

The research methods included in-depth thematic interviews, trade journal and document analyses, and facilitated workshop discussions. Eight interviews involving 11 interviewees representing the environmental management (5 interviewees) and R&D and product development (6 interviewees) of the case companies (Tetra Pak, Stora Enso, SCA, and M-real) provide the main empirical material for this article. To account for potentially differing views, the interviews covered both environmental and R&D personnel who were interviewed separately. Those representing environmental management were mostly leading persons in corporate environmental management. Those representing R&D and product development varied from corporate-level directors to people working in research units. Four interviews in the consulting sector provided background information for the study.

Most of the interviews were carried out in spring 2005, whereas three additional interviews were conducted in autumn 2006. The additional interviews were undertaken to strengthen the empirical base and to test the conceptual map developed on the basis of the initial findings. For this purpose, M-real was added as the fourth case company in 2006. The references to interviews in Section 5 were checked by the interviewees to ensure the accuracy of the data presented. The interview data regarding the case companies were supplemented with a content analysis of company reports from 2005.[4]

The main trade journal Web site for the pulp and paper industry (www.pponline.com) was initially searched for selected words in articles. The search included news and commentary from *Pulp and Paper* and *Pulp and Paper International* during the period from 2000 to 2005. Twenty-five combinations of words relating to product development and environmental questions were searched; many of the combinations did not appear at all, and the journals did not present articles related to environmental integration in product development. This indicated that environmental integration into product development deserved further exploration.

Deriving from the typology of environmental integration developed based on literature (see Table 1), six potential indicators of integrating environmental considerations into product development were used for the analysis:

1. corporate-wide environmental criteria and practices in product development,
2. the use of LCAs,
3. cooperation between environmental management and product development departments,
4. environmental experts as members of product development teams,
5. environmental training of the personnel involved in product development, and
6. the intentional development of environmental product innovations.

Transcribed interviews and company reports were coded based on the six indicators in the NVivo software program and analyzed accordingly.

5. ENVIRONMENTAL PRODUCT DEVELOPMENT IN THE STUDIED PAPER AND PACKAGING COMPANIES

5.1. Stora Enso

Stora Enso is the largest of the case companies in turnover and production and invests most on R&D (see Table 2). Stora Enso's environmental policy is supported by sets of principles covering the whole value chain (Stora Enso, 2005, p. 6). Yet partly because of its size, it has adopted a context or case-specific approach to creating new products. The program or system applied in new product development depends on the nature of the project (Interview I), and the company does not have standardized environmental criteria that apply in each case. Rather, environmental questions are taken into account by considering supply chain and customer needs and the characteristics of each case (Interviews I and II). For instance, in developing new packaging, an environmental assessment of the different chemicals and materials is already made at the beginning, and packages with unsustainable solutions are abandoned (Interview I). In Stora Enso, customers are the key players who are often also involved in product development (Interviews I and II). According to Stora Enso's (2005, p. 30) *Sustainability Report* and the interviews, key environmental considerations in products include recyclability, renewability of raw materials, and product safety.

Stora Enso has carried out LCAs since the early 1990s (Rex & Baumann, 2004), and LCAs have a clear role in product development. The company does not have formal routines for LCA practice at the corporate level, but since 2002, a coordination team pooling knowledge on LCA has existed within the organization (Rex & Baumann, 2004). The research center of Imatra, in Finland, includes activities for calculating LCAs for projects (Interview I). LCAs are used to drive product development and guide decisions, because environmental impacts often depend on country- or site-specific factors (Interview II).

Stora Enso has environmental experts involved in LCAs, but the actual product development is generally carried out by research and manufacturing staff (Interviews I and II). Thus, cross-functional integration between research and environmental management is only partial. Because of the context-specific approach to including environmental considerations in product development, some projects have involved environmental experts more profoundly than others. Environmental experts, for instance, were involved in developing the High Barrier coating that has replaced aluminum laminates in products such as yogurt packaging in the 1990s (Kautto, Heiskanen, & Melanen, 2002).

Environmental training was not mentioned in the interviews. According to Stora Enso's (2005, p. 6) *Sustainability Report*, sustainability is integrated into all corporate training programs. The ways in which it is specifically realized among product developers remained unclear.

The company has created environmental product innovations in the form of fiber-based solutions that replace other product materials. These include, for example, CD/DVD cases from cardboard and High Barrier coating replacing aluminum laminates in yoghurt packaging. The new products have often resulted from searches for new markets, while at other times products have intentionally been developed to address customers' environmental concerns.

5.2. SCA

SCA is the second largest of the case companies, its turnover exceeding 10 billion. Although environmental issues have not been identified in relation to product development, SCA (2005, p. 5; Interview III) explicitly states that corporate policies have been translated into procedures and guidelines specifying how they are to be implemented in practice.

The company has a specific procedure for product and process development with checkpoints for each of the four phases. Environmental questions are included in one of the checkpoints in the research, the early development, and the product and process development phases, while they are not part of the last phase, product and process launch, because of everything being fixed at that point (Interview III).

In the mid-1990s, SCA designed LCA tools to allow product developers themselves to carry out LCAs early in the process (Rex & Baumann, 2004). LCAs are used in the hygiene products division, which has an environmental competence centre conducting LCA work, but not so much in the packaging or printing divisions (Interview IV).

SCA has an Environmental Committee responsible for establishing and reviewing the company's environmental policies and management standards. The main link between the committee and product development occurs through the LCAs used in the hygiene products division (Interview IV). Thus, akin to Stora Enso, functional integration between research and environmental management departments remains partial.

In SCA, individuals have much power in product development projects, in which a sponsor carries the responsibility and the power to stop the project (Interview III). The interviews did not reveal any examples of environmental experts being a part of product development teams. Information on environmental training in general or in relation to product development teams was neither revealed in the interviews or the company reports. Moreover, based on the studied information, SCA is not engaged in intentional development of environmental product innovations.

5.3. M-real

In M-real (2005; Interview V), similar to SCA, corporate policies have been translated into procedures and guidelines dictating how to implement them in practice. M-real has an official manual for research and product development, but its application in practice depends on the nature of the project. The different stages presented in the manual include environment-, health-, and safety-related questions aiming at the unsustainable choices (e.g., regarding chemicals), being abandoned at the beginning of the projects (Interview VI).

The views of the two interviewees from M-real differed slightly on how and what kind of LCAs are used for product development. LCAs were not identified as a main tool for product development projects (Interview VI) but could be used where necessary (Interview V). General LCA databanks exist in M-real for different purposes (Interviews V and VI).

Similarly to the other case companies, in M-real, the corporate environmental management is not actively involved in product development (Interviews V and VI). Rather, its mandate includes risk management, environmental communication, following environmental policy development, and participating in new investment projects (Interview V). Thus, the units tend to be functionally nonintegrated—at least in formal activities. In product development, environmental know-how is usually obtained from qualified personnel (environmental experts) at the technology center (Interview VI). However, an interviewee acknowledged that the technology center could benefit from an occasional strategic discussion with environmental management (Interview VI). Previously, when the company was smaller, unofficial interaction alone was fruitful enough (Interview VI).

Environmental training in the company is organized case specifically. The corporate environmental management has, for instance, organized training related to the new EU chemicals legislation (Interview V). Specific training organized for product development was not mentioned by the interviewees.

In many cases, environmental considerations have been important in product development projects because of customer demands (Interview V). In the last 15 years, product innovation has focused on reducing the weight of products while maintaining the same functional qualities, thereby improving resource efficiency (Interviews V and VI). In addition, M-real has participated in R&D projects improving the recyclability of paper products (Kivimaa, 2007).

5.4. Tetra Pak

Although the other case companies produce several different paper and packaging products, Tetra Pak has concentrated on food packaging. Akin to SCA and M-real, Tetra Pak (2005, p. 10) explicitly states in its report that corporate policies have been followed by procedures and guidelines specifying policy implementation. Based on the interviews, the implementation of corporate-wide environmental policies is highlighted well in Tetra Pak's product development. Environmental questions are included in each phase of the process, and there may also be demands for life cycle inventory data or a more full LCA during these phases (Interviews VII and VIII). According to the product developers, environmental criteria are among the key issues, and elaborate checkpoints and checklists exist at different development phases. Even at the idea stage, a brief environmental evaluation has to be carried out to determine whether the new product is likely to be better or worse than the previous products, and the depth of environmental analysis increases later in the process (Interview VIII). In addition, Tetra Pak has developed Design for Environment guidelines to systematically include environmental criteria in the product development process (Interview VII; Tetra Pak, 2005, p. 38).

Tetra Pak started using LCAs already in 1975 driven by aims to develop new ideas for packaging milk and to compare them with other types of packaging (Interview VII). Its development projects sometimes involve several LCAs. In the development of Tetra Recart, a small LCA was done within the first years of development to roughly assess the total environmental impact of the system, and at a later stage, it was done more thoroughly (Interview VIII). An LCA expert group is located in Lund, Sweden, pooling knowledge for the whole organization (Interview VII).

Tetra Pak has a central team of environmental experts, in areas such as recycling, food contact legislation, and LCA, that each development project can use (Interview VIII). Thus, environmental issues are fairly well functionally integrated with product development. Yet an environmental manager took the view that sometimes the central group could be involved even earlier. In addition to cooperation between environmental management and product development units, a specific member of a research team is responsible for the environmental angle. Thus, environmental experts are a part of product development teams. As an example, 1 out of 10 people involved in the development of Tetra Recart was an environmental expert working closely with the group, for example, testing the different materials explored (Interview VIII). Environmental training of product development personnel was not mentioned.

Tetra Pak has intentionally developed products that are recyclable. In the past 10 years, recyclability of the product has been one of the first environmental questions in product development because of policy and consumer demands (Interview II). Thus, Tetra Pak has created fiber-based solutions to replace other product materials, such as tin cans for storing food. The use of resources, use and emissions of harmful substances, and waste management options are the key aspects of new products, in addition to the functionality of the package (Tetra Pak, 2005, p. 38).

Table 3: The Occurrence of Different Environmental Integration Forms in the Product Development of Four Case Companies

	Stora Enso	*SCA*	*M-real*	*Tetra Pak*
Corporate-wide environmental criteria and practices in product development	–	+	+	+
The use of life-cycle assessments	+	+/–	+/–	+
Integration between environmental management and product development units	+/–	+/–	(+)/–	+
Environmental experts as members of product development teams	+/–	–	+	+
Environmental training of the personnel involved in product development	+/–	–	+/–	–
The intentional development of environmental product innovations	+/–	–	+	+

5.5. Summary of Environmental Integration in the Product Development of Case Companies

The four case companies had varying approaches to integrating environmental issues into product development. Tetra Pak provided an example of a company supporting most environmental integration forms (apart from training). By contrast, the information regarding SCA showed a lack of environmental integration apart from formal environmental criteria in product development and the selective use of LCAs and LCA experts. Stora Enso had a case-specific approach on environmental integration, where the form of integration varied in different contexts, apart from LCA that was constantly used. M-real supported the use of standard environmental criteria, LCAs, and environmental training but was formally functionally disintegrated from corporate environmental management. This was compensated by integrating environmental experts within research centres.

Table 3 shows that most case companies had adopted corporate-wide environmental criteria in product development, typically as part of a stepwise system, in which different phases of the process have certain criteria and demands to be met before proceeding to the next phase. In contrast to the others, Stora Enso had adopted a more context-specific approach to environmental criteria in product development because of the widely varying nature of different projects.

LCAs were also commonly used by the Nordic paper and packaging companies. They do not indicate how much companies value environmental considerations; they merely show that the various impacts are systematically assessed. LCAs were used to ascertain the potential environmental impacts of new products at various development stages. They were often used as tools in connection with the environmental criteria, and LCA-related expertise was most commonly the link between development projects and environmental management. Their role, however, was not only related to product development but more generally to the assessment of company operations. In one company, LCA was selectively used, and in another company, a member of the research unit viewed the use of LCA differently from a member of corporate environmental management.

Cross-functional integration between corporate environmental management and product development was realized to a limited extent in three of the case companies. Mostly, the contacts between the two departments occurred through central LCA experts or informal communication. Tetra Pak had more intensive integration between the two departments through recycling and Environmental Health and Safety legislation expertise issued to product developers. In the other case companies, corporate environmental management mainly coordinated environmental issues and followed up legislation, while its link to product development was fairly distant. While environmental directors were aware of external environmental drivers, they knew little about product development.

Apart from SCA, environmental experts were usually a part of product development teams. In Stora Enso, the inclusion of environmental experts depended on the development case concerned and was not a standard practice.

General environmental training given to all product development team members was not a typical form of environmental integration used. In Stora Enso and M-real, environmental training of personnel in general was, however, highlighted.

Environmental considerations have become increasingly implicit in the creation of new products. The company cases show that in recent years they have not appeared as main driving forces for product innovations, whereas specific questions in the interviews revealed that environmental considerations are standard in new product development. Customer demand as the main driver has resulted in some environmental product innovations in three case companies, addressing the recyclability of products and material efficiency.

In sum, environmental criteria in product development, the use of LCAs, and environmental members of product development teams are the most common forms of environmental integration in the case companies. Training, on the other hand, is the least common. Despite these similarities, the differing combinations of the environmental integration forms used in the companies show variation between organizational practices regarding environmental integration.

6. A CONCEPTUAL MODEL FOR INTEGRATING ENVIRONMENT INTO R&D PROJECTS

The findings illustrate that environmental integration in product development can arrive from top-down implementation of corporate environmental policies and principles, such as in the Tetra Pak case. Alternatively, environmental integration can mean a case-specific and selective consideration of environmental issues, such as in the Stora Enso case. The cases show also that environmental integration can refer to interaction between other parts of the organization either through formal corporate environmental principles, through tools (such as LCA), or through interdepartmental links. Alternative environmental integration can occur merely locally in product development units and teams, through environmental experts as team members, or through the more local use of tools, such as LCA, aiding environmental product development. Based on the case companies, training is a rare form of environmental integration in product development. The intentional development of environmental product innovations, in turn, incorporates elements from the other integration forms.

Based on the findings regarding the first four forms of integration (excluding training and intentional development of environmental innovation because of their special characteristics), a two-dimensional conceptual map was developed illustrating four different approaches to integrating environment into R&D, where

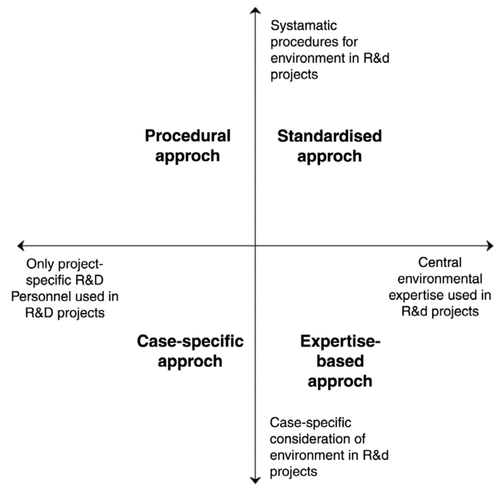

FIGURE 1: A Conceptual Map of Different Approaches to Integrating Environmental Considerations Into Company R&D

the Y- and X-axes are continuums (see Figure 1). The Y-axis shows that product development can follow centrally developed environmental criteria and practices or be based on case-specific consideration of environmental issues. The X-axis shows that environmental experts involved in product development can be located to the corporate level and other departments, or they can be members of product development teams. According to the empirical findings, the companies could tentatively be positioned in Figure 1.

A “standardized approach” is used in organizations that have both standardized procedures for R&D, including environmental criteria defined by corporate management, and a central team of in-house environmental experts for the use of R&D projects (e.g., Tetra Pak). The involvement of the central team may vary from an intense involvement (participation of particular individuals throughout project duration) to a more distant involvement (consultation by project members when needed or environmental training given to R&D personnel).

By contrast, when only project-specific R&D personnel is involved and no standardized corporate procedures for environmental criteria exist, a “case-specific approach” tends to develop. The lack of standardized procedures refers to a consideration of environmental impacts and LCA use case specifically, depending on the commitment of the unit-level people for the environment. In an ideal case, the project-specific team also includes environmental know-how. Stora Enso portrays mostly elements of the case-specific approach. However, the use of LCAs involves also central pools of environmental expertise, partly linking it to an “expertise-based approach,” in which the case-specific consideration of environmental impacts is complemented by a central pool of environmental expertise. By contrast, in a “procedural approach,” project-specific R&D personnel are bound by standardized corporate procedures. SCA portrays elements of the procedural approach. M-real can be seen to situate in between the procedural and case-specific approaches, because it has adopted environmental criteria in product development, but the LCAs are used case specifically.

7. ENVIRONMENTAL INTEGRATION AND INNOVATION

The conceptual map depicting different approaches to environmental integration in R&D shows that integration of ideas and principles may occur through people and procedures, giving most support to the first four environmental integration forms (see Table 1). In combination, the cases illustrated that all companies adopt some elements of both procedure- and people-based environmental integration. In those companies that used LCAs case specifically (e.g., Stora Enso, SCA, and M-real) or involved mostly project-specific environmental experts (e.g., M-real and SCA), the environmental integration did not fully arrive top-down from the corporate level. A vertical "from strategies to projects" application of either people or procedures is not, however, necessary to achieve environmental integration at the innovation-output level. Kivimaa and Mickwitz (2006) have shown in public technology policy that overarching strategies, although useful, are not a prerequisite for environmental integration at project funding level. Environmental integration, thus, may occur throughout the organization or merely in some parts. From an environmental innovation viewpoint, integration toward the end of the process is crucial, while a coupling with environmental strategies can promote a wider diffusion of environmental considerations and affect the focus of R&D.

Following Cooper (1996), the findings indicate that mere codified procedures are not enough to promote environmental innovations. Although SCA, positioned near the procedural approach on environmental integration, has environmental criteria in its product development projects, it is not portrayed as highly innovative in environmental terms. The other company cases show that the people dimension is crucial, as environmental expertise is needed in environmental innovation projects.

Yet product development in the case companies was rarely fully functionally integrated with corporate environmental management. Environmental signals were fed into product development mainly through customer contacts, and environmental expertise was integrated within product development units or teams. Corporate environmental management, in turn, guided manufacture and participated in process development. Thus, the environmental element of product innovation was often separated from corporate environmental management. Project-specific and corporate-level environmental experts have often different types of environmental knowledge, and the former may not be as equipped to follow public policy developments. Therefore, functional disintegration is likely to reduce the impact from public environmental policies on company product development.

The observed functional disintegration may result from the special status the R&D subcultures often enjoy in companies. R&D activities are deemed crucial for the future success and innovativeness of companies (Edquist, 2005; Pavitt, 2005), and a subculture that is crucial and irreplaceable may have its strategies overtaking others when it comes to taking action (Howard-Grenville, 2006). Thus, the findings tentatively indicate that a more comprehensive approach to environmental integration, using more than one form of environmental integration, is needed to promote environmental innovation in action.

In principle, "concealment tactics" (Oliver, 1991) or "hypocrisy" (Brunsson, 1993), hiding a decoupling between corporate principles and practice, are least likely to appear where a standardized approach to environmental integration is applied. The procedures in place transmit codified knowledge, and central people implement corporate principles more or less as intended. The representatives from environmental management and R&D highlighted similar issues in Tetra

Pak, while in M-real the views differed. This means that by adopting a number of environmental integration forms, the choices made regarding the pursuit of environmental improvements arrive systematically from the corporate level, and all development projects follow a similar strategy.

The procedural approach may suffer from a lack of central expertise that would consistently implement product development procedures. By contrast, the expertise-based approach enables the transfer of tacit knowledge but is heavily dependent on central in-house experts for integrating corporate principles because of the lack of explicit procedures (possible human error). In smaller organizations, such as M-real in earlier times, information may flow without formal systems in place.

The case-specific approach to environmental integration, however, may allow more flexible conditions for radical innovation. In disintegrated or fragmented subcultures, the ever-changing lenses might lead to highly effective and flexible responses to environmental questions (Howard-Grenville, 2006). Moreover, following Brunsson's argument that hypocrisy may sometimes provide the only chance for achieving action, some decoupling between official environmental principles and actual practice may be necessary to test the more radical ideas that may well exceed public policy demands.

As innovation processes are complex and affected by many determinants (e.g., Edquist, 2005; Malerba, 2005; Pavitt, 2005), the appropriate strategy for integrating environmental considerations into R&D is dependent on the nature of the organization and the diversity of institutional requirements it faces. Also, the geographical and industrial scope of the company matters. A more centrally controlled approach is useful if the organization is not too large and allows for the bottom-up flow of ideas. Standard environmental criteria acknowledge environmental impacts from the start. If a company has a wide variety of environmental questions to deal with because of different product areas or environmental contexts, a more case-specific approach may be useful. The lack of standard environmental criteria does not necessarily produce products that are worse for the environment, rather that the outcome of projects is varied in its overall environmental impacts.

The approach taken on environmental integration does not determine how different environmental questions are addressed in the innovation process. If the criteria set only acknowledge one or a few selected environmental features, this is no more efficient than a case-specific approach where many cases take a broader outlook. Strong concentration on a single environmental aspect may produce negative impacts on other environmental aspects. A standardized approach to environmental integration has, however, the benefit of enabling a diffusion of criteria that generate products performing better as a whole (in all environmental dimensions) than the available alternatives. This is dependent on the kind of criteria entailed in the standardized approach.

8. CONCLUSION

In a qualitative study of four Nordic paper and packaging companies, the integration of environmental considerations into firm-level product development was examined. Environmental integration was considered as a potential tool to generate environmentally improved innovations. The use of environmental criteria and LCAs, environmental expertise, environmental training, and intentional development of environmental innovations were used as indicators of environmental integration, arriving from a typology of environmental integration created based on previous literature. Systematic procedures in product development, incorporating environmental criteria, and environmental expertise emerge from the findings as the main means for environmental integration. LCAs are considered applicable to many company activities, whereas environmental training and the intentional development of environmental innovations were more seldom mentioned.

A variety of approaches can be used for integrating environmental questions into product development. The conceptual map developed shows how the approaches can extend from standardized to case specific with much variety in between. A standardized approach may provide a better means for coupling corporate environmental principles with R&D practice, which means that public environmental policy signals are more likely to influence product innovation processes. With more case-specific approaches, there is a risk of decoupling complemented with a slow diffusion of tacit and codified knowledge important for innovation. A case-specific approach, however, may be more innovative and free from the boundaries that corporate procedures impose on more radical innovation—in the best case enabling innovation far exceeding public policy demands.

INTERVIEWS

Interview I: Risto Vesanto, Stora Enso InnoCentre, October 2, 2006, Imatra, Finland.

Interview II: Jim Weinbauer, Thomas Otto, Stora Enso, April 27, 2005, Stockholm, Sweden.

Interview III: Ulf Carlsson, SCA, April 26, 2005, Stockholm, Sweden.

Interview IV: Patrik Isaksson, SCA, April 5, 2005, Stockholm, Sweden.

Interview V: Kristiina Honkanen, M-real, October 9, 2006, Espoo, Finland.

Interview VI: Markku Leskelä, M-real, November 2, 2006, Kirkniemi, Finland.

Interview VII: Agneta Melin, Tetra Pak Sverige, March 22, 2005, Stockholm, Sweden.

Interview VIII: Tom Kjelgaard, Katarina Magnusson, and Charlotta Walse, Tetra Recart, May 25, 2005, Lund, Sweden.

NOTES

1. This article distinguishes between forms and approaches of environmental integration, in that an approach can involve one or several of the more specific forms.

2. An LCA can be defined as a tool for calculating the environmental impact of a product throughout its lifetime or a procedure for carrying out such studies that can be used in several business areas (Rex, 2006).

3. A larger number of companies were contacted, but some declined the interview request.

4. M-real Year 2005 *Annual Review*; M-real Year 2005 *Corporate Responsibility Report*; SCA *Annual Report* 2005; SCA *Environmental and Social Report* 2005; Stora Enso Company 2005—*Strategy, Divisions, Summary Financials, Dividend*; Stora Enso *Sustainability* 2005—*Economic, Environmental, Social Responsibility*; Tetra Pak *Environment*

and Social Report 2005; Tetra Pak *Product Environment Profile*; and *Exploring Future Trends > Tetra Laval* 2005/2006.

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Paula Kivimaa works as a researcher at the Finnish Environment Institute. She is also a doctoral candidate in organizations and management at Helsinki School of Economics. Her research interests include innovation and technology studies and their links to public environmental policy and technology policy. She has published scientific articles in Research Policy, Evaluation, Journal of Cleaner Production and European Environment.

Article V

Green Markets and Cleaner Technologies (GMCT)

What drives environmental innovations in the Nordic Pulp and Paper industry?

Paula Kivimaa, Petrus Kautto, Michael Hildén & Juha Oksa

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Helsinki, 12 October 2007

Paula Kivimaa, Petrus Kautto, Mikael Hildén & Juha Oksa
Finnish Environment Institute

Summary

Policy initiatives such as the Lisbon Strategy have highlighted the importance of environmental innovations as a key solution to many environmental problems and looked into different ways to promote them. Based on empirical cases in the Nordic pulp and paper industry, this report explores specific environmentally sounder technological innovations and their relation to societal and economic drivers, especially public policy. The report also discusses the activities of the Environmental Technologies Action Plan (ETAP) from the perspective of the pulp and paper sector. It is based on document analyses, interviews, workshop discussions and comments from the representatives of the Nordic forest cluster. The cases studied include the use of production by-products for energy, new products in the core business areas and new product value chains.

The cases of inventions and innovations examined in the report portray some key drivers and barriers for environmental innovations. The key drivers have included markets supporting more environmentally oriented innovations, often spurred by policy or customer pressure; access to a variety of relevant knowledge; environmentally oriented public and private funding; and new networks of actors. The main barriers that have slowed down the development of environmental innovations have included market inertia, policy support for traditional solutions, strong links between existing solutions and the whole production system, lack of risk capital, market failures with respect to environmental costs of energy and other raw materials, a narrow perspective and resistance to change of some actors, and lack or inefficient transfer of knowledge. The cases demonstrate the importance of different drivers and barriers, but for example the development of bioenergy-related technologies in the Nordic pulp and paper industry also shows that the ratio or the relationship between drivers and barriers can matter greatly.

Public policies, although not important in each individual case, can create a framework supporting environmental innovation and help to identify potential inefficiencies. Public policy has directly influenced environmental innovation in the pulp and paper industry through providing public R&D support, funding development projects and encouraging cooperation between different public and private actors, facilitating the crucial stage of demonstration with investment support and assisting in finding corporate funding, and creating or enforcing markets for environmental innovations through policies that encourage competition between different innovative options that have environmental benefits.

Although the formation of markets for innovation is increasingly dependent on international developments and environmental policies are greatly influenced by the EU, the basis for environmental innovations in the Nordic pulp and paper sector has been strongly linked with national innovation

systems (NIS). The Nordic educational policy which has created large pools of technical know-how has been instrumental in creating a foundation for the more direct ways of supporting innovations.

For the development of environmental policies and ETAP, the potential for the creation or enforcement of greener markets is important. The success of policy-created markets in supporting innovation is, however, crucially dependent on other simultaneous or subsequent market changes, for example, concerning prices of raw material or energy that push the development towards improved environmental performance. Environmental policies alone are seldom sufficient drivers for innovations.

The report has been prepared at the Finnish Environment Institute and it is part of a research project Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) carried out in cooperation with the IIIEE group at Lund University and the University of Aalborg. The project was financed by the working group for Integrated Product Policy of the Nordic Council of Ministers.

1. Introduction

1.1 Background and contents of the report

Environmental innovation is a key solution to many environmental problems. Thus, recent policy discussions on national as well as EU level have highlighted the importance of environmental innovations and looked into different ways to promote them. On a more general level, the political emphasis on competitiveness, in particular through the EU's Lisbon Strategy, has underlined the need to find win-win solutions to environmental problems through innovations.

The European Commission has focused on the technological side of the issue especially through its Environmental Technologies Action Plan ETAP (CEC, 2004) (ec.europa.eu/environment/etap) and the Communication on Integrated Product Policy (CEC, 2003) (ec.europa.eu/environment/ipp). Similarly sectoral efforts, such as the EU level Forest-Based Sector Technology Platform (2006) (www.forestplatform.org) and the national strategic forest-based research agendas of the Nordic countries, address innovation with potential for generating environmental benefits.

Apart from forest sector activities, also recent strong developments in the bioenergy sector have implications on innovation in the forest sector. The EU Biofuels Technology Platform (www.biofuelstp.eu) and the Biofuels Advisory Council consisting of a multitude of stakeholders, including the forest industry, are important initiatives in this field. Recent changes in both the forest sector research agenda and in policy for environmental innovation form an interesting viewpoint for examining the driving forces and barriers for environmental innovation in the Nordic pulp and paper (P&P) industry.

This report documents results from the study Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) based on empirical cases in the Nordic P&P industry. Overall, the report aims:

1) To identify policy interventions that have contributed significantly to the development and marketing of environmental technologies within the Nordic P&P industry.
2) To add to the understanding of key Nordic competencies in the innovation processes leading to cleaner technology and green market development that can further be enhanced by policy interventions.
3) To provide information on the P&P industry that can be used in developing the Nordic implementation of ETAP and other efforts to achieve sustainable production and consumption.

In addition, the report contributes to the overarching aims of the GMCT project ”to add to the understanding of the dynamics, characteristics and influencing factors in Nordic innovations systems enabling/constraining the successful development, application and diffusion of environmental technologies” and to assess the feasibility of further supportive actions to enhance innovation competencies in different sectors

This study explores specific environmentally sounder technological innovations and their relation to societal and economic drivers based on document analyses, interviews, workshop discussions and comments from the representatives of the Nordic forest cluster. Particular focus is placed on the role of public policies in the promotion of environmental innovations. During the work Nordic experts on the P&P industry were contacted through e-mail to invite them to a workshop where the initial results were discussed and to offer them a possibility to comment on the draft report. The discussions of the workshop, which included six experts from the P&P sector, and comments on the first report draft from three other experts have been incorporated in this report. The authors, however, are solely responsible for the content of the report and the interpretation of the results.

The report is organized as follows. Chapter 1 shortly describes the P&P sector, followed by an overview of recent policy initiatives potentially influencing environmental innovation in the sector. Chapter 2 focuses on innovation by describing the innovation characteristics in the P&P industry and by reviewing previous studies on environmental innovation in the sector. Chapter 3 presents the methods used in the study and the new empirical findings in an analytical framework focused on the knowledge, resource and market elements in the innovation processes. Chapter 4 relates the findings of the literature review and the empirical cases to policy development, with particular reference to the Environmental Technologies Action Plan. The overall conclusions are presented in Chapter 5.

1.2 The pulp and paper industry in the Nordic countries

The pulp and paper industry is strongly tied to the history of the Nordic countries, and it has provided significant export revenues, especially for the economies of Finland and Sweden, throughout the 20th century. For these economies the forest-based sector is still a significant branch, pulp and paper contributing to 23 % and 11 %, respectively, of the value of total export in these countries (Table 1.1). In Norway the sector has divested its prominent status and plays now only a minor role, producing 2.5 % of the total value of export. In Denmark the role of the P&P industry is even smaller and for Iceland no production figures could be found. Through globalization of the industry, of its markets and the move of production facilities to places where the factors of production are inexpensive, the historically stable position of the Nordic P&P industry has during the last decade been replaced with uncertainty for the future. This has influenced the economic behavior of the companies, and has contributed to, for example, increasing international investments.

Table 1.1. Pulp and paper statistics for the Nordic countries in 2003

Source: Finnish Statistical Yearbook of Forestry (Finnish Forest Research Institute, 2005)

	Finland	Sweden	Norway	Denmark
GDP per capita (USD in 2004) [1]	30 594	30 361	38 765	31 932
R&D expenditures, economy total (% of GDP) [2]	3.51	3.74	1.75	2.63
Pulp production (1 000 tn)	11 948	11 737	2 389	0
Paper production (1 000 tn)	13 058	11 062	2 186	388
Pulp export (1 000 tn)	2 385	3 426	641	1
Paper export (1 000 tn)	11 734	9 080	1 871	230
Value of export in forest products (USD million)	12 032	10 923	1 655	373
Proport. of total export (%)	23.0	10.9	2.5	0.6
Forest available for wood supply (1 000 ha)	20 675	21 236	6 609	440
Share of forests in private ownership (%)	63	51	78	45
Collection of recycled paper (1 000 tn)	709	1 466	526	730
Use of recycled paper (1 000 tn)	688	1 926	456	400

Following an intensive period of consolidation during the latter half of the 20th century, international corporations dominate the market. The Swedish-Finnish Stora Enso, Swedish SCA and Finnish UPM-Kymmene are among the largest producers of pulp and paper in the world. The Norwegian Norske Skog and the Finnish Metsäliitto belong to the largest paper producers in Europe. In Denmark, two paper companies, Dalum and Hartmann, export globally but are relatively small actors. The P&P companies in the Nordic countries operate as part of a wider forest cluster that involves a variety of actors in research, production and supply processes. In addition to the pulp and paper producing companies, small and large consultancies (e.g. Pöyry and ÅF Consulting) and trade organizations are central actors. The production side involves equipment manufacturers, chemical producers, energy producers and forest owners. Innovation and market demand depend on public and private research organizations, and customers in existing markets (paper, packaging) and in new and anticipated markets (packaging, fuels, logistics, media). Due to the lowering price of paper and stagnating paper demand, the latter are becoming increasingly important.

The over 100-year history of the Nordic P&P industry is characterized by rapidly increasing production levels and improvements in the efficiency of production and utilization of natural resources. Initially the increasing production also resulted in increased environmental load. As a result the environmental impacts of the Nordic P&P industry have received much attention from the public over the second half of the 20th century. First, deteriorating water quality was addressed and, later, air quality.

The significant environmental impact areas of the sector have included water and air emissions, the use of natural resources, waste, and energy use. Despite rapid increases in production levels, the absolute water emissions

[1] www.oecd.org

[2] http://epp.eurostat.ec.europa.eu

have been significantly reduced due to a decoupling between production and water emissions in the 1970s. During the last two and a half decades, the relative use of raw wood has also been reduced by a quarter per tonne of paper produced. Both the waste resulting during production and the waste related to end products are now efficiently utilized. Energy consumption remains one of the largest challenges, as the P&P industry is a significant energy user in Finland and Sweden.

1.3 Recent policy and sectoral initiatives potentially influencing environmental innovation in the Nordic pulp and paper industry

The Environmental Technologies Action Plan (ETAP) of the European Union is a framework for developing ideas presented in the Lisbon Strategy, namely environmentally sounder technological progress that would also benefit the EU economy. It aims to "stimulate eco-innovation and the take-up of environmental technologies on a broad scale." (CEC, 2007: 3). Its overarching elements include the Communication issued by the European Council and the European Parliament in 2004 and the ETAP Policy Agenda which both list a variety of measures and activities to support the implementation of ETAP (CEC, 2004, 2007). ETAP includes the following actions in support of environmental technology (CEC, 2004):

1. Increasing and focusing research, demonstration and dissemination
2. Technology platforms
3. Environmental technology verification
4. Performance targets
5. Mobilization of financing (grants and loans)
6. Market instruments
7. Green public procurement
8. Awareness raising and training

The technology platforms, such as the Forest-Based Sector Technology Platform (FTP) and the Biofuels Technology Platform, are partnerships between public and private actors on a specific research topic. According to ETAP the idea of the platforms is for different stakeholders to jointly build a long-term vision for technology promotion and problem solving in particular areas. The FTP was initiated in 2003, and in 2006 it launched its Strategic Research Agenda that highlights areas with potential for environmental improvement, such as sustainable forest management, energy-efficiency and bioenergy, resource-efficiency, and greener chemicals improvement (Forest-Based Sector Technology Platform, 2006). The EU level action has been followed by the implementation of national forest sector research agendas in eight European countries, including Finland and Sweden. One of the key areas is the development of leading markets.

The Biofuels TP was launched in 2006 and it relates to several EU policy initiatives, including the Biofuels Directive (2003/30/EC), the EU Biomass Action Plan (2005) and the EU Strategy for Biofuels (2006). The Biofuels Vision for 2030 recognizes the importance of industry residuals in the production of biofuels, lists integrated technologies in the pulp and paper sector in second-generation biofuels and aims at close links with the FTP (Biofuels Research Advisory Council, 2006). Both the FTP and the Biofuels TP tie into the idea of a European knowledge-based bioeconomy (CEC, 2006).

More concrete research projects have been carried out as part of the EU Framework Programmes and the ERA-Nets. FP6 has funded large projects, such as EFORWOOD, ECOTARGET and SUSTAINPACK in which several partners from many different countries cooperate. The ERA-Nets, which are networks of organizations funding research, have included, for example, ERA Wood Wisdom Net and ERA-Net Bioenergy.

Integrated product policy (IPP) is another extensive process that has been developed at the European level since the 1990s (see e.g. Rubik, 2006). IPP aims ”to reduce the environmental impacts from products throughout their life-cycle” (CEC, 2003: 6), i.e., from raw materials extraction to disposal of products. So far, the implementation of IPP can be characterized as twofold: at policy level the Commission published a green paper on IPP in 2001 (CEC, 2001) and a communication in 2003 (CEC, 2003). Since then, it has commissioned several studies in order to identify and stimulate action on products with the greatest potential for environmental improvement[3]. On the more instrumental level, the products of the electrical and electronics industry have been a target of special attention of product-oriented environmental legislation (see also Box 2, page 36). So far, the P&P sector has received much less attention within IPP. The main exception is a directive on packaging and packaging waste that has been implemented based on extended producer responsibility in most European countries. Besides, innovations outside the core business areas are more likely to fall within the scope of product-oriented legislation.

Also other recent policy initiatives may influence the sector significantly. In the coming years, the regulation on chemicals and their safe use, REACH[4], will affect both production processes and products. The developments in energy and climate policies, especially through emissions trading, are also of significance to future environmental innovation in the sector.

[3] The products in the areas of food and drink, private transport and housing were identified as having the greatest impact (Tukker et al. 2006).

[4] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

2. Innovation dynamics and environmental innovation

2.1 Innovation characteristics in the Nordic pulp and paper industry

The innovation system surrounding the innovation activities of the Nordic pulp and paper industry is based on both the national innovation systems of the Nordic countries and the sectoral innovation system related to the industrial sector. Table 2.1. depicts relevant actors that form the innovation system of this sector. The national-level actors are generalized based on the operating conditions of the Finnish and Swedish pulp and paper sectors, and slight differences between the countries are likely. Public or other non-profit actors mainly form the national innovation system, whereas the other actors are, rather, related to sector-specific innovation systems that consist of both national and international-level actors. The distribution and existence of public and private actors is sector-specific as, for example, the role of education and research carried out in universities varies for innovation in different business sectors.

Table 2.1. The innovation system for Nordic pulp & paper sector innovations from an actor perspective

	National	International/EU
Public	• Science, technology, innovation policy councils • Ministries (innovation, trade, environment) • Governmental research institutes • Governmental innovation agencies (e.g. Vinnova, Tekes) • Governmental energy agencies (e.g. Swedish Energy Agency) and advisory bodies (e.g. Finnish Motiva and Swedish Swentec) • Universities (mostly public) • R&D funding foundations (e.g. Mistra, Sitra) • Venture capital (government owned)	• The EU - DG Enterprise - DG Research - DG Environment - DG Energy and Transport - Joint Research Centre - European Science Foundation
Public-private partnerships	• Development finance companies (e.g. Finnfund) • Forest Cluster Ltd	• Forest-based Sector Technology Platform • Biofuels Technology Platform • Biofuels Advisory Council
Private	• National industrial federations (SFIF, FFIF) • Sectoral research companies (STFI, KCL) • Small equipment developers/manufacturers (e.g. Chemrec, POM) • Energy producers (mostly national) • Customer companies (e.g. food producers, printing houses) • Venture capital (privately owned) • Private research foundations	• CEPI • Pulp and paper producers • Large equipment developers/manufacturers • International consultancies (ÅF, Pöyry) • Chemical companies • New cooperators in automotive and electronics • Customer companies (e.g. food producers, printing houses) • Energy companies • Venture capital (privately owned)

According to the OECD classification system for manufacturing industries, the P&P sector is a low-technology industry (OECD, 2005). The R&D investments of pulp and paper producers tend to be clearly less than one percent of turnover, and much of the innovation has occurred in production processes, less in products. In process-based innovation P&P companies have cooperated with medium and high technology sectors, including equipment manufacturing, chemicals and information technology. Therefore the Forest Cluster, which the P&P sector is a part of, cannot be strictly characterized as low technology (Autio et al., 1997). Moreover, it has been argued that 'low-R&D industries are not necessarily low-innovation industries' as the Nordic pulp and paper sector shows (ibid.).

Much of the innovation activities in the Nordic P&P industry have taken place in Finland and Sweden. Finnish and Swedish paper companies have over the last two decades invested in R&D and cooperated with different actors through public research programs funding pulp and paper related R&D. For example, during the 1980s and 1990s the Nordic technology companies manufacturing equipment for the P&P industry were able to create competitive advantage through intensive cooperation. In Finland, cooperation between two technology manufacturers in the same public R&D programs, despite the existence of competition, increased the level of know-how and improved their competitive advantage in the world markets (Kivimaa and Mickwitz, 2004).

Compared to another important P&P producer, Canada, which for long has had a role of staple supplier to US markets, the Finnish and Swedish actors have relatively speaking been characterized by a greater emphasis on research and development (Lehtinen et al., 2004). The Norwegian P&P companies have largely been risk averse towards investments and have considered R&D merely as a cost. This has restricted the development of capabilities in the mills and excluded the exploitation of potential resources generated by the national innovation system, hampering Norske Skog in catching up technologically. (Moen and Lilja, 2001) The Danish paper industry, while always being small when compared with other paper producing nations, has been considerably reduced over the last 20 years, and is lacking public infrastructure that would support specific R&D in the paper sector (Andersen, 1999).

Overall, the R&D programs funded on both national and EU levels form a key part of the innovation system for the Nordic P&P industry. The Finnish Funding Agency for Technology and Innovation (Tekes) and the Swedish Governmental Agency for Innovation System (Vinnova) are significant actors in this field, although other funding agencies also exist. In Sweden, the Swedish Energy Agency, the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas) and the Foundation for Strategic Environmental Research (Mistra) are also relevant funders of research related to environmental innovations in the P&P industry. In Finland, other relevant public financiers include the Academy of Finland, the Ministry for Trade and Industry (MTI), the Ministry of Agriculture and Forestry, and the Finnish National Fund for Research and Development (SITRA). A number of R&D programs directly related to the P&P sector have been coordinated by Tekes and Vinnova, while the sector has also participated in more general technology programs (see Table 2.2 for examples). The funding agencies, Tekes and Vinnova, have recently cooperated in carrying out the Wood Material Science Programme during 2003-2006. Research cooperation is further carried out by actors such as STFI and KCL, for example in EU-funded research and development projects.

Table 2.2. Examples of recent R&D programmes influencing the Finnish and Swedish pulp and paper sectors

R&D Programme	Duration	Funding Agencies	Country
Wood Wisdom - Finnish Forest Cluster Research Programme	1998-2001	Tekes, Academy of Finland, MAF, MTI	Finland
WDAT - Wood Design & Technology	2000-2006	Vinnova	Sweden
Wood Material Science Research & Engineering	2003-2006	Academy of Finland, Tekes, MAF, Formas, Vinnova	Finland & Sweden
Green Materials from Renewable Resources	2003-2007	Vinnova	Sweden
ClimBus - new business opportunities from climate change	2004-2008	Tekes	Finland
Serve - innovative service concepts	2006-2010	Tekes	Finland
Sectoral R&D Programme of the Forest Based Industry	2006-2012	Vinnova	Sweden
Biorefine - new biomass products	2007-2012	Tekes	Finland

2.2 Environmental innovation in the Nordic pulp and paper industry

Environmental improvements in the P&P industry can be linked to innovations in manufacturing processes, in products and in the development of emissions treatment. Innovation in these different categories is partly interlinked, because some new products require also renewed production processes and improved production processes may facilitate emission treatment. In the future the role of environmental system innovations relating to sustainable and efficient logistic and transport systems, product value chains and the biomass society may increase. Environmental innovation in processes and products can be further divided into sub-categories based on type of environmental improvement:

- Processes in pulp and paper plants
  - Reductions in air or water emissions
  - Improved resource-efficiency (chemicals, raw materials)
  - Improved energy-efficiency
  - Reduced water consumption
  - Switching fossil fuels to bioenergy

- Products from wood fiber
  - o Improved durability
  - o Improved recyclability
  - o Reduced raw materials per unit
  - o Selection of environmentally less harmful raw materials
  - o Removal of hazardous substances

Innovations in the P&P industry can involve a single environmental improvement, such as a reduction in water emissions, or combine multiple improvements, such as improved energy efficiency and reduced water consumption. The magnitude of the environmental innovation can vary and an environmental innovation can also have negative environmental side effects (Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Kivimaa, 2007a). For example, the Reference Document on Best Available Techniques in the Pulp and Paper Industry shows that there are many potential trade-offs in the use of different technologies (EC, 2001). This complicates the evaluation of which technologies can be considered to be environmentally friendly. While positive environmental effects partly define environmental technology, the point of comparison is ambiguous when assessing whether a certain technological solution is more environmentally beneficial than another. Even tools such as life cycle analysis examine environmental impacts separately, and the weighting of the different impacts is based on opinions, values and practices. (Kivimaa, 2007b)

Previous studies by the Finnish Environment Institute have dealt with process innovations that have reduced emissions, improved energy efficiency, and reduced water consumption (Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Mickwitz et al., 2008) and product innovations that have made products lighter and more durable, improved recyclability and selected less harmful raw materials (Kautto et al., 2002; Kivimaa, 2007a). Other studies in the Nordic countries, based on a literature review, are rare and have mainly dealt with environmental regulation and improvement regarding water pollution (Laestadius, 1998; Sæther, 2000; Harrison, 2002).[5] Reductions in water pollution and improvements in resource efficiency have been the major environmental improvements in the sector, the former often driven by environmental policy and the latter mostly by market factors (Foster et al., 2006).

Environmental innovation in the Nordic P&P industry has mostly focused on production processes rather than products. This is partly because environmental regulation and customer pressures have been targeting mainly at production, not products (Kivimaa, 2007a). On the product side environmental developments have largely focused on the use of recycled fibers, although paper and packaging companies have for decades also aimed to develop lighter and more durable products (Kautto et al., 2002). At the same time product innovation in general has received increasing attention. However,

[5] The literature review covered English language sources, including Science Direct, Inderscience and Google Scholar.

so far, the main emphasis in the P&P sector has been on the environmental impacts of production (cf. e.g., electronics), while the focus of the work on environmental improvements has been on processes.

For the legislator the regulation of environmental impacts through products is demanding for economic and environmental reasons, especially in dynamic business areas. Products and product development are in the core of business and often complex product-related information needs to be obtained from several companies that are part of the product chain. In addition, even the same product can be manufactured, distributed and used in different ways, resulting in dissimilar environmental impacts. The information on the environmental impacts in turn is even more important for product policies than for policies regulating production, especially with end-of-pipe technologies, because the impacts are difficult to detect through use. (Kautto, forthcoming)

So far, environmental product innovations in the sector have mainly reduced the use of wood through improved resource efficiency and the use of recycled fibers. For example, through simultaneous development of paper and coating technologies it is now possible to produce approximately 80% more juice cartons from wood than in 1970 (Vesanto, 2007). In the future the large environmental potential of wood–fiber-based products lies in replacing products made of other raw materials than wood fiber, reducing the use of fossil fuel-based materials and also the environmental impacts of transport by offering lighter alternatives. Other environmental potentials lie in products communicating environmental information to users, decreasing product loss through safe and durable packaging and contributing to tracking systems developed in response to extended producer responsibility.

The role of environmental policies has clearly emerged in previous studies as the most discussed issue regarding environmental innovation in the Nordic P&P industry (Sæther, 2000; Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Kivimaa, 2007a). It has not, however, been identified to affect all of the examined environmental innovations. Efficiency gains and customer demands have also been important drivers (Table 2.3).

Environmental policies have been effective in promoting innovation when they have been foreseeable in advance by companies, flexible in allowing testing of different technologies and gradually tightening (Hildén et al., 2002; Kivimaa and Mickwitz, 2004; Kivimaa, 2007). Sometimes inventions have been developed earlier but interest from companies has increased later when societal pressures regarding the environment have emerged (Sonnenfeld, 1998).

The possibility to react in advance of regulation has given leeway for the proactive companies to respond to political and market situations (Kivimaa and Mickwitz, 2004). For instance, the development of recycled corrugated board before any policy requirements aided a Danish paper company in influencing the European LCA standard (Andersen, 1999). Economic instruments and permit limits can both be flexible in allowing different types of technological solutions, but economic instruments must impose sufficiently high costs for inertia to make innovation attractive (Hildén et al., 2002; Mickwitz et al., 2008). Regulatory systems can create markets for innovation even when an individual limit does not appear to provide incentives due to an expected tightening of the system in the future (Hildén et al., 2002). Permit processes as such can reshape networks of actors and expose operators to new information (Hildén et al., 2002). The success of environmental policy is also dependent on common understandings between government officials and companies and on the importance of the industrial sector being regulated at large (Sæther, 2000).

The importance of other factors than environmental policies was rarely mentioned in these studies. Kivimaa and Mickwitz (2004) have noted the importance of combined impacts of technology and environmental policies, globalization and cooperative networks of actors. Collaboration has also been highlighted by Andersen (1999) who has looked at interfirm learning with respect to innovation. Laestadius (1998) has examined R&D expenditure in the innovation process. Sonnenfeld (1998, 1999) has contributed part of the fast-track development in moving away from chlorine bleaching to a strong institutional role of environmentalists in the Nordic countries, while social movements in advanced and newly industrializing countries have helped gain funding for the technology development processes.

Table 2.3. Environmental innovation cases from literature

Empirical cases from literature	Demonstrated and potential environmental benefits	Economic, market & environmental policy drivers	Time	Sources
End-of-pipe technology				
Conox – process water effluent concentrate combustion system	Reduced water discharges (COD), somewhat improved energy efficiency	Anticipated regulation for closing the bleaching processes.	1990s–2000s	Kivimaa & Mickwitz, 2004.
Activated sludge treatment for waste water	Reduced water discharges	Environmental standards for organic loads (case-by-case permits)	1980s	Hildén et al., 2002
Filters for air emissions	Reduced air emissions	Air permits with emission limits and technology requirements	1980s	Hildén et al. 2002
Core process technology				
POM – air removing, compact pump system for paper machine	Improved energy efficiency; reduced water consumption, effluent discharge and waste compared to the conventional process.	Improved efficiency + in one case water permit affected installation decision	1990s–2000s	Kivimaa & Mickwitz, 2004.
From sulphite to sulphate process	Reduced water (BOD) discharges	Improved resource efficiency	1960s–1970s	Hildén et al. 2002
Non-chlorine bleaching of pulp	Reduced water discharges	Customer demand, strong environmental activism, regulation	1980s–1990s	Harrison, 2002; Hildén et al. 2002; Sonnenfeld, 1998
Closed water cycles	Reduced water use and discharges	Water emission limits, collaboration with chemicals manufacturers	1990s	Andersen, 1999
Process renewal	Reduced water discharges	Environmental regulation, customer pressure since the mid 1990s	1970s–1990s	Sæther, 2000
Other process technology				
Increased dry-solids content of black liquor (BL) recovery boilers	Reduced air emissions and improved energy efficiency	Improved efficiency, air emission limits for sulphur and nitrogen, cooperation between the government and industry	1980s–1990s	Kivimaa & Mickwitz, 2004
Oxygen delignification technology	Reduced water discharges (BOD, AOX)	Case-by-case water permits	1970s–1980s	Harrison, 2002
Products				
Recycled paper	Improved resource efficiency	Attempt to create a green niche market due to intense competition in paper markets	1990s	Andersen, 1999
Use of Chemo-Thermo Mechanical Pulp in three-layer board	Improved energy efficiency in transportation due to lower weight of packaging board	Pressures for improving cost efficiency, extended producer responsibility system especially in Germany	1990s	Kautto et al. 2002
Recycled corrugated board	Improved resource-efficiency	Improved cost efficiency	1950s	Andersen, 1999
Food packaging from wood-fibre	Replacement of tin cans, reduced environmental impacts from transport due to lower weight and improved use of space	Improvements in the logistics of packaged food, cost reductions, and the EU Directive on packaging and packaging waste.	1990s	Kivimaa, 2007

3. Cases of environmental innovation in the Nordic pulp and paper industry – methods, results and synthesis

3.1 Identification of cases

Based on a literature review of past innovation studies in the Nordic pulp and paper industry (see Chapter 2), the focus of the study was defined. Significant advances had already been made regarding traditional air and water emissions in the 1980s and 1990s, often encouraged by regulation (Ashford, 2005; Hildén et al., 2002; Gunningham et al., 2003). The focus of this study is on more recent developments and primarily on innovations/inventions improving resource efficiency and reducing the use of fossil fuels. Technological innovations however, may also simultaneously have other environmental benefits, such as reduced chemicals use. Improvements in resource efficiency and reductions in fossil fuel-based energy are important from the point of view of global energy and climate change issues. The increasing price of electricity creates pressure for more energy-efficient processes, while the intensifying competition for wood resources with bioenergy production further highlights resource efficiency in production processes and products. The efficiency improvements also benefit the environment.

The process of selecting the innovation cases for the study started with a review of trade journal articles from Pulp and Paper International and Paper and Timber published in 2000-2006. Because the information gained from the trade journal review was not sufficient, an e-mail questionnaire was sent to eleven P&P experts in Finland, Sweden, Norway and Denmark to solicit their views on what they consider successful Nordic P&P innovations in the 21st century. Based on five replies and information gathered from written sources, seven cases representing three commercialized innovations and four technologies in demonstration were selected for the study to examine the key drivers and barriers in innovation processes (Table 3.1).

Table 3.1. Short descriptions of the cases studied

Technology cases	Description	Potential environmental benefits	Economic / market drivers	Current status	Sources
Use of production by-products for energy					
Black liquor gasification for electricity (many developers in Finland and Sweden)	Producing electricity from a by-product of pulp making through a gasification technique	A CO2 neutral way to produce electricity, increases the yield of electricity compared to available technologies	1980s: low power to heat ratio of existing technologies 2000s: high oil price, EU emissions trading scheme	Failed to reach commercialization so far. Still ongoing R&D	Interviews: M. Hupa, Åbo Akademi, 14.11.2003; P. McKeough, VTT, 13.10.2006; P. Axegård, STFI, 31.10.2006 Literature: Kivimaa & Mickwitz, 2004.
Black liquor gasification for transport fuels (Chemrec, Sweden)	Producing demethyl ether (DME), a clean burning transport fuel, from a by-product of pulp making through a gasification technique	Reductions in CO2 emissions by replacing fossil fuel use in vehicles, has a higher efficiency than other options for producing transport biofuels	2000s: high oil price, EU created market for transport biofuels	At demonstration stage, expected start of commercial operation 2010-2011	Interviews: J. Rudberg, Chemrec AB, 30.10.2006; P. McKeough, VTT 13.10.2006; P. Axegård, STFI , 31.10.2006 Literature: Croon, 2005. Newspapers: Expressen 4.4.2005; Aftonbladet 24.8.2005; Nyteknik 30.8.2006. Other data: presentation by A. Röj, Volvo, 14.3.2007
Biomass gasification for transport fuels (VTT, Finland)	Producing transport biofuels by feeding additional biomass residues to a gasification process installed in integrated P&P mills	Reductions in CO2 emissions through replacing fossil fuel use in vehicles, has usually a higher efficiency than agriculture-based solutions for producing transport biofuels	2000s: high oil price, EU created market for transport biofuels, low global market prices for paper products (thus a need for new business options for the Finnish P&P industry)	At development stage, expected start of full-scale demonstration 2010	Interviews: P. McKeough, VTT, 13.10.2006 Newspapers: Tekniikka & Talous 20.9.2006, 21.9.2006; Turun Sanomat 12.10.2006; Helsingin Sanomat 1.11.2006, Helsingin Sanomat 17.3.2007 Literature: Finnish Forest Industries Federation, 2006.
LignoBoost (STFI, Sweden)	Extracting lignin, a chemical compound of wood, from the pulp making process e.g. for producing biofuels	Reducing CO2 emissions through replacing mineral oil	2000s: high oil price, increasing capacity of pulp production and extending the age of recovery boilers	At demonstration stage, expected start of commercial operation 2008	Interviews: P. Axegård, STFI, 31.10.2006 Newspapers: Nyteknik 7.6.2006
New production / products in the core business area					
Bleached Chemi-Thermo-Mechanical Pulp (BCTMP) mill (M-real, Finland)	A new type of mechanical pulp producing process that has higher efficiency and enables a higher level of whiteness in end products	Uses only half the amount of chemicals and less energy than the sulphate pulp process (when excluding the heat & power generated from suphate pulping process). Reduced wastewater load due to an almost closed water cycle. Indirectly energy savings in transport due to reduced weight of products	1990s: improved efficiency and resource use of pulp production, economies of scale, new markets for products based on mechanically produced pulp	Started commercial operation in 2001, M-real has now three BCTMP plants in operation	Interviews: M. Leskelä, M-real, 2.11.2006 Newspapers: Pulp & Paper International, April 2002; Tekniikka & Talous 19.5.2005
Recycled packaging (Hartmann, Denmark)	Recyclable and biodegradable moulded fibre packaging made from recycled paper	Reduced material and energy use, reduced amount of waste	1990s: extended producer responsibility for packaging, packaging taxes for plastic packaging in some European countries, high oil price in 2000s	Products sold for decades, environmental arguments were first used in the 1990s, market is expected to grow worldwide	Interviews: T. S. Winther, Hartmann, 12.12.2006 Other data: www.hartman.dk
New product value chains					
RFID (many developers in Nordic countries)	Method for automatic identification, in which so called RFID tags or transponders are utilized for storing and remotely obtaining stored data. Tags can be attached to products, animals or persons	Reduced transportation due to improved logistics, reduced loss of products (e.g. timber), more efficient waste management and recycling, decreased amount of waste	2000s: increasing need for improving logistics due to longer supply chains and outsourcing, extended producer responsibility-based Directives for electronics and end-of-life vehicles	Market has expanded rapidly since the end of 1990s and is expected to grow significantly as tag prices decrease and technology improves	Interviews: T. Varpula, VTT, 26.10.2006; S. Strömberg, UPM Raflatac, 19.10.2006; M. Osswald, SCA, 25.10.2006; Li-Rong Z., KTH, 20.11.2006; several shorther discussions with a variety of people Newspapers: Tekniikka&Talous 28.9.2006 Other data: http://en.wikipedia.org/wiki/RFID
(UPM Raflatac, Finland)	RFID tags and inlays	See above	See above	Lots of potential and expectations, remarkable pilot projects with e.g. METRO Group	Interviews: S. Strömberg, UPM Raflatac, 19.10.2006 Communications at http://www.upmraflatac.com/europe/eng

3.2 Framework

The P&P cases are based on a combination of written and interview sources. The written information sources include previous research, trade journal and newspaper articles, web publications and sites, and annual reports. Interviews were conducted for each technology case. With the aid of literature on innovation systems and previous knowledge gained from conducting innovation studies at the Finnish Environment Institute, a case study framework was developed to be used in forming the interview questions and analyzing the findings (Appendix I). A common analytical frame examining the role of knowledge, markets and resources for environmental innovation was used in all the sectoral case studies of the GMCT project (see Figure 3.1). In this report the analysis of policy drivers has been incorporated into the market perspective in the form of policy-created markets.

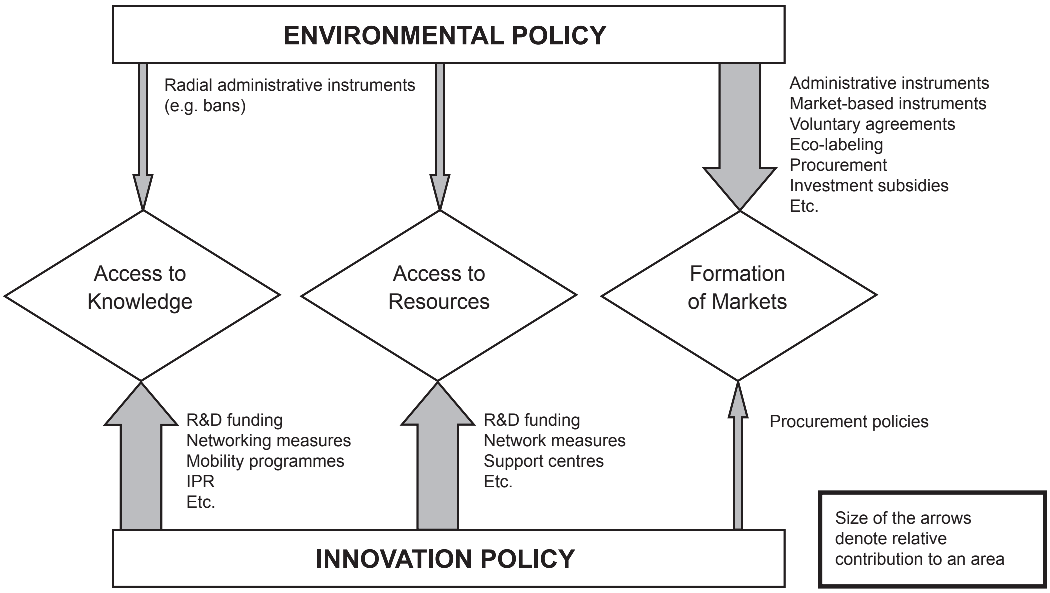

Figure 3.1. Analytical frame used in the GMCT project (Source: IIIEE, Lund University)

3.3 Markets – existing, new and policy-created

There have been three different types of market changes that have affected the emergence, development or commercialization of the studied environmental inventions: 1) Changes in the existing markets for P&P products have made producer companies aware of the need to improve the cost efficiency of production and economies of scale, to create new products for existing markets or to create products for new markets and product values chains; 2) EU-level environmental policies have created new or improved existing markets for bioenergy, CO2 trading, RFID tags and inlays, and recyclable or recycled products; 3) Changes in other markets, such as in energy or electronics, have affected the search for efficiency improvements and for new product markets. The three types of markets changes have played a role in all or some of the studied innovation cases. Also, the review of literature on environmental innovation in the P&P sector indicates a similar conclusion (Table 3.2)

3.3.1 Energy markets and resource-efficiency

The development of the Bleached Chemi-Thermo-Mechanical Pulp (BCTMP) mill began from a need within M-real to increase the capacity of mechanical pulp production and improve its cost efficiency and achieve economies of scale. The cost per tonne of pulp would be reduced and new environmental improvements would also be achieved. Energy saving was a clear need from the beginning because energy prices were expected to increase in the future. Later customer needs and M-real's long-term goal to produce lighter-weight paper that maintains the functional qualities of a heavier paper were intertwined with the project because the BCTMP process enabled the production of pulp used for the lighter-weight paper. One of the driving forces of the development was that BCTMP pulp can be used in product groups that have previously used only chemically produced pulp, the new product being competitive because it weighs less because of the nature of the mechanically separated fiber. Paper with reduced weight offers cost benefits for the customers due to e.g. lower transportation costs.

Searches for mill-level efficiency improvements as well as for improvements in energy efficiency underlie also the so-called biorefinery cases (black liquor gasification, biomass gasification and LignoBoost). They are based on an idea that by producing also other products than the main P&P products, the cost efficiency of the mill as a whole could be improved. The price of and demand for energy products, however, need to be high enough to attract investments into the new energy technology. While the oil and electricity prices are currently high, the ideas behind the three cases of biorefinery-related technologies originated at a time when energy prices were low. The technology developers saw that the efficiency of the existing technologies could be improved and that a pulp mill could be a major supplier of energy.

Table 3.2. Influence of markets for environmental innovation in selected cases

Technological change	Time period	Changes in existing p&p markets	New markets created by environmental policy	Changes in other markets
Changes in the early 21st century				
Biorefinery innovations				
E.g. black liquor & biomass gasification, LignoBoost	2000 -	Pressures for improving cost efficiency and creating business in new product value chains	EU requirements for transport biofuels, national & EU support for RES, EU CO2 emissions trading	Increasing oil price, transforming electricity markets, new vehicle types
RFID innovations	2000 -	Pressures for creating business in new product value chains	EU policies for extended producer responsibility for electronics and end-of-life vehicles	Need for more efficient logistics, longer and more complicated supply chains, improved RFID technology
Changes during the 1990s				
Development of CTMP and BCTMP pulp to replace conventional mechanical pulp	1990s -	Pressures for improving cost efficiency and provide more competitive products	Extended producer responsibility system especially in Germany	Anticipated increased electricity price in the Nordic power market
Packaging from recycled materials	1990s -	Increasing price of wood –fiber in Denmark	Extended producer responsibility for packaging, packaging taxes	Increased (oil and) plastic packaging prices
POM – paper machine wet-end	1990s -	Improved efficiency, expansion of production to China and other new countries	(water emission limits in Spain)	
Conox – effluent concentrate combustion	1990s -	Expansion of production to China and other new countries	Expected national regulation for water emissions	”Discovery” of paper industries with higher organic contents in effluents than in modern wood-based paper industries
Changes during the 1980s				
Energy from black liquor through combustion or gasification	1980s -	Improved thermomechanical efficiency	SO2 and NOx emission limits in Finland	Low electricity price and regulated markets (hindrance)
Activated sludge	1980s -		Water emissions regulation in Finland	
Filters for air emissions	1980s -		National limits for air pollution	

A strong driving force for STFI to develop LignoBoost was that by removing lignin from black liquor, the pulp capacity of the mill can be increased with low investment costs. The system can also extend the age of existing recovery boilers up to 8-10 years, simultaneously saving 50-70% of the investment costs required to rebuild a recovery boiler. STFI has also parallel activities where it examines how lignin could be used to produce different products in the pulp mill biorefinery. The current high price of oil has increased investors' interest in LignoBoost, and two energy companies have been actively involved. Based on a market study, two applications of the technology have a potential of 100 process installations in the world. Pre-purchased licenses also show the growing interest of the market in this technology.

Gasification has long been viewed by its developers as a more efficient solution than recovery boilers to produce energy from black liquor. It needs less space, can increase the yield of electricity and also produce transport fuels. In the 1990s, however, technical uncertainties and a lack of benefits as perceived by the P&P industry hindered further developments. The estimated investment costs required to run a pulp mill with the gasification technology were significantly larger than for a mill using the conventional Tomlinson recovery cycle. The price of electricity was low in the Nordic Power Market and a fairly efficient existing alternative, the recovery boiler, offered a competitive alternative.

Despite the lack of interest from the P&P industry Chemrec continued the development of black liquor gasification for the production of electricity throughout the 1990s. Wider interest in the P&P industry did not arise until the early 2000s, when a directive for the promotion of biofuels for transport (2003/30/EC) was being prepared by the EU. The Directive requires that the Member States achieve a minimum proportion of 2 % of biofuels in the energy content of transport fuels by 31 December 2005 and 5.75 % by 31 December 2010. Thus the directive has created a market for new technology, while the increased price of oil has enhanced the competitiveness of biofuels at the same time. Initially two engineers at Chemrec were looking at other applications for black liquor gasification. Following the new demand for transport biofuels Ingvar Landälv, technical director of Chemrec, came up with the invention to combine syngas and pulp production to produce dimethyl ether (DME) for a transport fuel. Another economic driver have been the energy tax reliefs for renewable fuels in Sweden that make the net payback time quicker. DME costs as much as diesel to produce but environmental charges and taxes do not have to be included in its selling price.

Following the Directive, Chemrec has established cooperation with Volvo, which has developed a truck engine using DME as fuel. Volvo is interested in the cooperation because it anticipates a future with stringent requirements for emissions from heavy-duty diesel engines. Climate change, projected availability of energy sources and energy security act as key drivers for future market developments in transport fuels. Volvo is planning to start the commercial production of DME engines in 2011 and wants to have a large-scale demonstration project from Chemrec for having the fuel commercially available. The demand from Volvo has been very important for Chemrec, and since 2007 Volvo Technology Transfer has also been a co-owner of Chemrec. Worldwide, Chemrec sees a potential market of replacing around 400 recovery boilers with black liquor gasification when the recovery boilers reach their end of life in Sweden, Finland, the US and Canada. The technology is applicable to non-integrated pulp mills as well as integrated P&P mills.

Box 1. Summary of the drivers and barriers for bioenergy related technologies in the P&P sector

The Nordic P&P industry has been and still is an important actor in Finnish and Swedish energy policy for several reasons. First, it has been a significant user of electricity (30% of all consumption in Finland) and, second it has shaped the power generation structure by becoming a significant producer of bioenergy. More than forty percent of the consumption of renewable energy in Finland (including large-scale hydro) is based on black liquor and other concentrated liquors that are mainly by-products of the pulp and paper production processes (Statistics Finland, 2004). This has involved innovations from the 1970s to the 1990s in the recovery boiler technology used to combust black liquor, the by-product of pulp manufacture, to produce heat and electricity. More recent R&D developments in the sector, however, are increasingly focused on both other technologies (e.g. black liquor gasification, Ligno-Boost) converting black liquor into energy and on other end products resulting from the conversion (transport biofuels).

The context for bioenergy-related innovations has changed over time and, interestingly, one can identify a variety of drivers and barriers affecting the developments in bioenergy technologies applied in the P&P industry during 1980s - present. The developments show that significant progress has required strong drivers that have helped to overcome the barriers for innovation.

In the 1980s, much public and private R&D was carried out on both combusting and gasifying black liquor for electricity. A multitude of drivers supported the commercialization of new combustion technology, while the development of gasification technology was hindered by technological uncertainty and the risks it entailed for potential investors. Cost factors, i.e. low efficiencies in utilizing black liquor, and the anticipation of new air pollution control policies following a public concern for industrial air emissions directly influenced the development and commercialization of a new technology increasing the dry solids content of black liquor. Other contributing factors to the success of the innovation process included intensive R&D cooperation and public R&D funding on black liquor, the oil crises of the 1970s followed by an emphasis on wood fuels in energy policy, and discussions on nuclear energy (Kivimaa and Mickwitz, 2004).

In the 1990s, the operating framework changed: the number of drivers was somewhat reduced as R&D activities decreased, and simultaneously the number of barriers increased. The diffusion of the new combustion technologies from the 1980s continued following permit conditions based on new air emission standards for sulphur dioxide. The opening up of Nordic electricity markets and scientific and political debate on climate change also supported the diffusion to some extent. The opening of markets created an incentive for some pulp and paper companies to produce electricity exceeding their own needs and to thus employ more efficient boiler technology. (Kivimaa and Mickwitz, 2004) Climate change further emphasized the importance of bioenergy in national energy policies. At the same time, continued technological uncertainty regarding gasification technology, despite continued R&D efforts by Chemrec, and a low oil price made pulp and paper companies uninterested to invest or participate in the demonstration of new, uncommercialized technologies. Therefore, little innovation was achieved on a Nordic scale during this decade.

At the beginning of the 21st century, new market and policy developments created a window of opportunity for black liquor and biomass gasification technologies (as well as other technologies such as LignoBoost) developed in previous decades. An EU directive for transport biofuels launched in 2003 created a new market for these technologies as the demand for biofuels increased due to legislative requirements. This combined with an increased oil price and the pulp and paper producers' need to seek new business opportunities (due to tightening competition in world paper markets) has made the producers more interested to invest and test the new biofuel-producing technologies. Increased concern for climate change, EU emissions trading supporting renewable energy and the expected opening up of EU energy markets have also created potential for gasification technologies applied to electricity production. Yet the end result of these developments is still unclear, because there are also several potential barriers. The drivers are of general nature offering also opportunities for bioenergy produced by other means. Thus other technological options for producing biofuels act as a barrier together with possible price support for competing renewable energy sources, e.g. through agricultural policies. Availability of wood resources will also influence the success of these ventures. The next few years will show what happens.

The EU Biofuels Directive together with security of supply concerns and increasing price of oil also drive technological development for producing transport fuels from biomass gasification. Biomass gasification has long been researched in Finland, and thus suitable technology is near commercialization to respond to the current EU requirements. The low price for oil has, however, kept many research results unutilized until recently. The interest of the forest industry has been low until lately and Finland has only recently brought the requirements of the EU directive into force. UPM has taken the first move among the forest companies and stated that it will start the production of DME through gasification in connection with its pulp mills in Finland and in other European countries. Stora Enso has also announced a co-operative venture with Neste Oil to start the production of biodiesel.

The globally decreasing price for paper products, stagnating paper demand and an increased price of fossil fuels have only recently increased the interest of P&P producers towards biorefineries. Finland has not focused on black liquor gasification like Sweden, partly because the Finnish pulp mills use much of the black liquor for producing electricity and heat from fairly new recovery boilers. Thus, they perceive biomass gasification as a more viable option in the near future. It is slightly more expensive than black liquor gasification, but the technology can also be applied outside the P&P mills – i.e. with export potential for larger markets. On the other hand, biomass gasification in connection with pulp production always requires an integrated P&P mill. What has served as a driver for Neste Oil is that although biomass gasification has higher manufacturing costs there are no extra infrastructure costs on top of the existing distribution system.

3.3.2 Product tracking and packaging

For several reasons, but especially due to increasing outsourcing of manufacturing, the need to improve supply chain management in many industrial sectors has been stressed in recent years. One way to support the supply chain management is RFID technology. In recent years, RFID technology has become less expensive and more usable as electronics and integrated circuits have developed rapidly. In connection to its labelstock business area, UPM Raflatac and its predecessors have for years developed RFID tags and inlays in order to create new business in this rapidly changing environment. Finally, the EU directives on extended producer responsibility (EPR) for electronics[6] and end-of-life vehicles[7], have created significant pressures to enhance waste management and recycling in these industries and thus created new markets for RFID Technology-based solutions, too.

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[6] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE).

[7] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles.

EPR-based systems for packaging and packaging waste have also created new markets for recyclable and biodegradable molded fiber packaging, which, for example, the Danish Hartmann company has produced for decades. This development has taken place despite less ambitious goals set in the directive for the recycling of plastic than for fiber packaging. In addition, a tax on packaging has favored fiber packaging over plastic in some EU countries. Finally, higher oil prices have also increased the price of plastic and thus supported the growth of the molded fiber packaging market.

3.3.3 Summary of market drivers

The case studies show that the classical drivers of innovation, i.e. the needs to improve the cost efficiency of production and economies of scale, to create new products for existing markets, or to create products for new markets and product value chains have been significant also regarding environmental innovations in the P&P sector. Parts of the new or improved existing markets have clearly emerged as a consequence of policies as shown by bioenergy, CO2 trading, RFID tags and inlays, and recyclable or recycled products. Furthermore, changes in other markets, such as in energy or electronics, have had spillover effects that have contributed to the search for efficiency improvements and new product markets also in the P&P sector.

The findings of the cases suggest that interacting changes in markets (paper & packaging, policy-created, other) are often needed to spur the commercialization of environmental innovations. Markets created or enforced by environmental policies may be crucial for those innovations that provide significant benefits for environmental protection but that at least initially appear to be technologically uncertain or significantly different from the current production and consumption systems (e.g. biofuels, packaging in some sectors). Another observation is that a single strong market driver can affect innovation in different spheres. The increasing oil price has affected different technological developments by directing attention to 1) the weight of products that affect transport fuel needs; 2) the creation of alternative transport fuels reducing dependence on oil; and 3) new packaging materials offering alternatives to fossil-based packaging.

3.4 Knowledge – pools, access and different types of knowledge

Both codified and tacit knowledge is used in the innovation process, within companies and through inter-organizational cooperation. Based on the empirical cases, the nature of knowledge used and its importance has varied in different parts of the innovation process, and in most of the cases a combination of knowledge sources has been used. The cases also show that the original idea or the invention behind a new technology can originate from different sources of knowledge. The following looks at three different types of knowledge sources as initiators of environmental innovation processes and provides concrete examples of cases where these have occurred:

1) knowledge generated through publicly funded research (including long-term investments in R&D, initiatives for cooperation and incorporation of environmental objectives);
2) knowledge generated by market and competitiveness concerns (involves pooling company internal knowledge e.g. due to process inefficiencies or market changes);
3) knowledge spurred by combining information from different business sectors.

Knowledge generated through publicly funded research can function as a start for the development of new process technologies. This corresponds to the traditional view of a technology push-based innovation process. Biomass gasification in Finland is a case where the knowledge generated and diffused through public R&D programmes has played an important role. The Technical Research Centre of Finland (VTT) and the Helsinki University of Technology (HUT) have studied biomass gasification since the 1970s, and the Finnish Funding Agency for Technology and Innovation (Tekes) has funded gasification projects in its technology programs since the 1980s. Later, a consortium of researchers and companies has formed to jointly develop biomass gasification in integrated P&P mills. Researchers from VTT and HUT have worked together with two technology-developing companies. Potential users of technology have also been involved, including three large energy companies and the forest industry in Finland. In addition to knowledge diffused through public R&D funding, public mechanisms have given signals of the need of bioenergy technologies through various renewable energy policies at national and EU levels.

In the market pull model an idea behind an innovation can start from pooling company internal knowledge to solve problems or respond to new market needs. The process of developing BCTMP started from awareness within M-real, a Finnish P&P manufacturer, that the company's existing pulp mills were getting older and producing too little pulp too inefficiently. The research director of M-real pooled knowledge from different parts of the company to generate ideas for renewing pulp production and, through the process, the internal efficiency needs were combined with M-real's market strategy to produce lighter-weight products without reducing their functionality. Later, technical universities, the technology company Metso and the chemicals manufacturer Kemira also took part in the project. M-real obtained funding from Tekes partly because the company was cooperating with some smaller companies as well.

Technology push and market pull often operate simultaneously. In the development of the LignoBoost process at STFI, a private research and consulting company, knowledge generated through research and potential new markets influenced the invention phase. In 1996, research at STFI was based on a vision that a pulp mill could be a major supplier of energy to the society. At the time many people in the P&P industry viewed this as unrealistic, partly because the price of oil was low. Research at STFI was based on the idea that lignin could be removed from black liquor to produce fuel that could, for example, replace mineral oil. LignoBoost was developed further in cooperation with companies, universities and the Foundation for Strategic Environmental Research (MISTRA) and with support from the Swedish Energy Agency. The increasing oil prices have made the P&P industry perceive energy products as a potential business, but the Swedish green certificates scheme somewhat disencourages investments in LignoBoost due to the profitability of producing electricity from excess steam in pulp mills through existing processes.

The technology push may not only arise through formal R&D. A new idea can also emerge through combining experiences from companies operating in different industrial sectors. The pooling of tacit knowledge from different areas may lead to innovations. Chemrec's process of developing black liquor gasification began in the late 1980s when an engineer, with a background in the P&P industry, inferred that gasification technology used in the oil and gas company where he was working could be applied to black liquor due to its resemblance to heavy crude oil. He developed the idea further with a friend working in P&P equipment manufacturing. The ownership of Chemrec, the company established to develop the technology, changed several times in the course of 20 years between companies having either expertise in P&P equipment or oil and gas gasification, while many technical problems remained unsolved – in one case due to an inefficient knowledge transfer between Kvaerner's regional offices. Finally, the problem of finding materials that could withstand corrosive chemicals was solved with the help of a US national laboratory specialized in materials for space shuttles. Chemrec also sought help from a consulting company, ÅF, and worked together with Swedish universities and STFI. The Swedish Energy Agency has funded the development since 1997 and helped Chemrec to negotiate corporate finance. At later development stages, when the technology has been closer to demonstration, potential companies to invest in the technology from the forest industry and the potential end users of the products in the energy sector have become involved through funding and expertise sharing. Part of the interest has been fuelled by signals from EU policy for supporting transport biofuels. Inter-organizational cooperation and public knowledge pools have been important for black liquor gasification.

In addition to overlapping technology push and market pull, the development of RFID technology in P&P industry arises through the combining of technologies from different industrial sectors. RFID technology itself has its origin already in the 1940s, but only the rapid development of electronics and integrated circuits in the past decades has enabled the emergence of new types of RFID appliances. Besides the more common trend and use of RFID to rationalize logistics in the sector, UPM Raflatac and its predecessors have developed RFID tags and inlays for nearly ten years. The development work has been carried out in cooperation with a variety of public research institutions and private partners, e.g., large retailer companies. Gradual advances in technology have enabled the production of label-like and printed tags, which have numerous uses in different applications.

In sum, the knowledge initiating an idea or an invention is based on many different sources and types of knowledge: basic research and research networks, pooling company internal knowledge, entrepreneurial thinking, combining experiences with different business sectors, or combinations of technology push and market pull. Thus, access to and interest to seek a variety of knowledge pools is important. The challenge is how to integrate environmental considerations as standard parts of these processes (cf. Kärnä 1999). The public sector can clearly influence the diffusion of environmental objectives into the knowledge creation process through criteria for research funding, development of educational curricula and, as noted in Section 3.3, by creating or enhancing markets that can attract information from different business sectors.

3.5 Financial and human resources

3.5.1 Financing innovations

Financial resources for developing innovations have been found within the companies doing the main development work, from other sources of private funding and through public support. Public support has been used in all the studied cases, although in the case of molded fiber packaging, public funding has only been used in recent years in order to develop the replacement of plastics by bio-based materials. Public funding for innovation in the Nordic pulp and paper industry has usually been obtained from national funding organizations in Finland or Sweden. It has been supplemented with private and corporate funding. The form of private funding has differed between cases, including ownership in the technology-developing company, loans, and pre-purchase of licenses.

In the later development stages, consortiums of companies and research organizations have been common, where funding is usually obtained from the participating companies and a public funding agency. Getting the pulp and paper companies to participate and invest in a development project has in some cases been difficult. The development of molded fiber packaging by Hartmann and RFID tags and inlays by UPM Raflatac have mainly been done by corporate funding and within consortiums of private actors. In the more general development of RFID technology development at VTT and KHT, the role of public funding has been crucial.

Over the years, the Nordic P&P companies have had little interest to invest in the development of black liquor gasification, partly because the investment costs have been high and the technology yet uncertain. The potential benefits of black liquor gasification have been perceived too low to attract pulp mill owners to invest in demonstration plants. Thus, in the early 1990s many efforts were stopped due to lack of funds. For ten years, since the late 1980s, the development of black liquor gasification in Chemrec was mainly financed by its large owner companies, including Kvaerner Pulping and Babcock Borsig Power GmbH. During the late 1990s, when the large owner companies experienced financial problems and divested their ownership in Chemrec, public funding from the Swedish Energy Agency was crucial to keep the company afloat, to guarantee payment of components and to persuade companies to invest. During the 21st century, when the technology has been closer to commercialization, other companies have been convinced to fund the development, while the P&P industry has been the hardest to persuade. Part of the funding from the P&P companies has been in the form of man hours, i.e. competence. Despite negotiations, no Finnish pulp and paper companies had participated in these efforts by the end of 2006.

The development of LignoBoost has been partly funded by pre-selling licenses of the new technology before it has been ready for commercial use, because the company developing the technology has not wanted to sell its ownership. Pre-purchased licenses are less costly for the companies that buy them but entail uncertainties of unfinished technology. In the development of BCTMP obtaining funding has not been an issue, because as a large company M-real has been able to self-invest in the project. Still, public funding from Tekes has also played a role in developing the technology.

On the monetary resource side, largely the same logic and preconditions apply for environmental innovations as for innovations in general. The public sector has provided additional funding sources for innovative ventures. For example, in Sweden the Foundation for Strategic Environmental Research (Mistra) has been a potential source of funding for environmental technology development. In Finland, R&D programs such as CACTUS have included environmental objectives and directed the development of technologies into that direction (Kivimaa and Mickwitz, 2006). Environmental venture capital is also important, especially for commencing SMEs that often cannot find corporate finance or public funding. Public actions can also influence the perceived ratio between risk and expected benefit. Consistent long-term public policies can reduce the non-technical risks and increase the expected benefit of environmental innovations creating or contributing to developing markets.

3.5.2 Human resources

Underlying the Nordic innovation cases is educational competence that can be perceived as a part of both national and sectoral innovation systems. The high level of education in the Nordic countries and a specific focus on technological higher education in fields that are relevant for the P&P industry have supported innovation in the sector.

Networks of actors have been crucial for all the innovation cases. Competence has usually been pooled from different organizations, as the competence needs vary in different parts of the innovation process. Public intervention has in some of the innovation cases created conditions for new networks of actors to emerge and function. Besides the basic maintenance of universities and research institutes, where basic research is carried out supporting the more applied research done by companies, public research programs have encouraged cooperation between different public and private actors. For instance, in the case of BCTMP pulping, Tekes allocated funding to M-real because of its cooperation with smaller and medium-sized companies. The nature of public funding made Chemrec seek active cooperation with universities in developing black liquor gasification for transport and it also received support from the Swedish Energy Agency for finding suitable corporate partners to fund the development project. Environmental policies have also motivated new types of networks. The EU Directive on transport biofuels has intensified and created new cooperation between the P&P sector and the energy and transport sectors. In the development of RFID, public funding created cooperation in the early stages but the later networks between commercial actors have mainly been induced by market developments.

While the participation of different organizations is important, entrepreneurial individuals are also crucial for the emergence and development of innovations. This is highlighted in an example of the development of black liquor gasification at Chemrec. The fact that Chemrec has reached the near commercialization status of black liquor gasification is largely the result of the work of many devoted individuals. In the starting phase, an engineer and his friend were instrumental for the original technical solution and its patent. Later, in 1993, when Kvaerner was the main owner of Chemrec, the project came to a standstill when a major sponsor of the project died. Since 1997, when Kvaerner made an executive agreement with Nykomb whereby experts in oil and coal gasification started running the project, the chairman of Nykomb has been a dedicated supporter of Chemrec and perceived black liquor gasification as the technology of the future. The people at Chemrec have worked very hard for the project, sometimes even without pay, and a person at the Swedish Energy Agency has helped them to negotiate funding.

The public sector cannot on its own "produce" entrepreneurial individuals. It can support them through an educational system that provides a basis for creative and independent thinking, and by contributing to risk funding, in particular in the early phases of company development.

4. Key factors affecting the innovation process

4.1 Drivers of innovation

The cases of inventions and innovations examined in this study enable the identification of some key drivers and barriers for environmental innovations. Chapters 2 and 3 showed that the key drivers include markets that support more environmentally oriented innovations, often spurred by policy or customer pressure; access to a variety of relevant knowledge; environmentally oriented public and private funding; and new networks of actors. The development of bioenergy-related technologies in the Nordic pulp and paper industry shows, however, that in addition to the type of drivers also the ratio or the relationship between drivers and barriers matters (see Box 1). Public policies, although not important in each individual case, can create a framework that supports environmental innovation and help to identify potential inefficiencies.

Public policy has directly influenced environmental innovation in the P&P industry in three different ways: (1) in the form of public R&D support, funding development projects and encouraging cooperation between different public and private actors; (2) easing the crucial stage of demonstration by investment support and assisting in finding corporate funding; and (3) creating or enforcing markets for environmental innovations through policies that encourage competition between different innovative options that include environmental benefits. In addition, the Nordic educational policy that has created large pools of technical know-how has been instrumental for the more direct ways of supporting innovations.

Based on the findings, environmental policies can have a crucial role in shaping or creating markets for innovations that tackle the challenges related to climate change and other environmental problems. EU level policies have a greater capacity than national policies to create demand for environmental technologies and products, but there are also examples of how relatively local regulations can provide key incentives for innovation (Hyvättinen and Hildén 2005). It is therefore important that environmental policies have flexibility to accept different kinds of innovations meeting the demand rather than supporting pre-selected options (cf. Kivimaa, forthcoming). This includes both flexible regulation and economic instruments that impose high enough costs for inaction.

In some cases, inventions offering potential solutions to environmental problems may be dependent on markets created with the help of public policies in order to become environmental innovations. The bioenergy development is a case in point. New markets are crucial for motivating the companies to invest in new technologies and products. One of the studied cases showed that continued support for existing environmental technologies, such as renewable energy, can also slow down innovation by making the existing technologies too profitable to be improved, even when a better solution from an environmental point of view already exists.

Environmental policies have affected all technological changes described in this report either directly by creating new markets for innovations or indirectly through environmental requirements in the waste management of other sectors. A difference in the environmental policy-created markets can be observed in that, while previously the markets were often created by national-level environmental policies, the new environmental policy-created markets are based on EU-level policies. Therefore, the way in which environmental policies are designed (to be supportive or non-supportive of a wider range of innovations) has more extensive implications on technological development in Europe.

Environmental policies in the Nordic countries and the EU have also indirect impacts on global technological development because many P&P technologies developed in the Nordic countries diffuse to worldwide markets, such as China and South-East Asia (e.g. Sonnenfeld, 1998; Kivimaa and Mickwitz, 2004). The EU legislation may also have a global impact: in the electronics sector subcontractors outside Europe have changed their ways of operating in order to conform to EU legislation and EU has acted as a model for legislation in e.g. China (Kautto and Kärnä, 2006). However, due to differences between the pulp and paper and electronics industries, the focus of environmental policies for these sectors will probably be different also in the future (see Box 2).

Box 2: Product oriented policies for pulp and paper industries: What can we learn from the electronics?

Products of the electrical and electronics industry have in recent years been a target of special attention in EU product-oriented environmental legislation. Three new directives (RoHS, WEEE and EuP) have been approved in 2003-2005 aiming to reduce the negative environmental impacts of electrical and electronic equipment and energy-using products. The requirements of the directives apply to the design, manufacture and waste management of these products.

Based on the experiences gained on these directives so far, the following lessons can, for example, be drawn:

- The use of companies as ”regulatory surrogates”, i.e. making them responsible for their contract manufacturers and subcontractors (cf. Gunningham & Sinclair 2002; Vedung 1997, 153) creates possibilities for environmental product policies in a situation where production is increasingly shifting outside the EU region. In the electronics sector, however, the supply chain management does not go without problems: the availability of information varies and the task of compiling information and assessing its reliability requires a great amount of resources (Kautto & Kärnä 2006). The pulp and paper companies have already been made liable for sustainable forest management, acting as an example of environmental product -based management.
- The need for product-oriented environmental policies in the pulp and paper sector requires careful assessments. The differences between the pulp and paper and electronics industries are evident: while the bulk of environmental impacts in the P&P sector has taken place during the extraction of raw materials and the production, the use phase is essential in the electronics sector. As long as fiber-based products are produced in the EU, the environmental impacts are probably easier to control directly through production. When production moves increasingly to other parts of the

world, the functioning of the current systems, e.g. on recycling, might require product-based standards.

- A division of costs in a way that is generally accepted as fair is a problem within the collective producer organizations created for the management of extended producer responsibility. This can also weaken the link to product development if the greatest costs are not directed to those producers whose products ultimately account for the greatest costs in the waste management systems. The problems are similar within the EPR systems for packaging, but solutions will differ as the value of discarded products is different.
- The flexibility and predictability of legislative measures are often in conflict: e.g. directives that allow the Member States to take local conditions flexibly into account create also remarkable variation in the national systems, and thus more (administrative) work for the industry.
- Generally, environmental pressures from customers, environmental NGOs and policies will in the future focus more on the life-cycle impacts of products. This will highlight the better management of the product material content data as a way of avoiding business risks.

4.2 Barriers to innovation

In several cases there has been a very long time lag between the invention and its development into an innovation with a market. The main barriers that have been observed in the studied cases as slowing down environmental innovations include:

- market inertia;
- policy support, including regulatory systems, for traditional solutions;
- strong links between existing solutions and the whole production system;
- the lack of risk capital;
- market failures with respect to the environmental costs of energy and other raw materials;
- narrow perspective of actors and resistance to change; and
- lack or inefficient transfer of knowledge.

Existing technologies or processes create barriers for new alternative solutions through their dominant market share or because some existing policies that are in force ensure their profitability. This means that new, somewhat uncertain, technology is less appealing to investors and companies renewing their production process. The strong market share of existing products and the related production equipment acts as a barrier, for instance, for the diffusion of wood-fiber-based CD and DVD cases and black liquor gasification. Whole existing systems can also hinder more radical innovation, because incrementally improved technologies often fit better into existing systems than the alternatives. Cooperation demonstrating the applicability of a new technology along the whole product value chain, such as in the Chemrec-Volvo cooperation, could break these barriers.

Profitability that is maintained by adopted policies is "artificial" in that it gives existing technology an unfair advantage. For instance, price support for existing fossil fuel-based and low-efficiency renewable energy technologies might prevent the emergence of more efficient alternatives. Agricultural support, in turn, could reduce the profitability of biofuels technology connected to the P&P industry by artificially lowering the cost of biofuels produced in agriculture.

4.3 Reducing barriers of innovation

Policies may create markets, as in the case of biofuels for transport, and can potentially break system lock-ins. Policies may also be able to correct market failures that show up as low prices of factors of production (such as energy). It is, however, important to ensure that competition is fair with respect to the desired properties of the technology. Moreover, policies should strive to avoid future lock-in situations. With this in mind, coordinated environmental, energy, industrial, transport and agricultural policies are important with respect to the different uses of biomass resources. If coordination fails, public policies may create or maintain technological dead ends.

Each environmental innovation case has been unique in how knowledge has been obtained and how it has contributed to the innovation, but there are also some common features. Cooperation between universities and different companies has been important in most cases. The companies involved are rarely limited to those producing P&P and may include the energy sector, technology manufacturers, electronics and the chemicals industry. In the future, cooperation could extend to many other sectors as well. In the development of bioenergy technologies, the P&P industry has often been the least interested and involved, which has slowed down the innovation process.

Although companies operate on international markets, some elements of the innovation processes have been clearly dependent on the national context. The cases show that the consortiums of actors involved in an innovation process have often been national endeavours despite efforts in some cases to attract partners from other countries. Public, national-level, R&D funding has been crucial in each case, as much of the funding for the P&P sector comes from Tekes in Finland and Mistra and the Swedish Energy Agency in Sweden.

Negotiating funding for an innovation project requires not only a technically good idea but connections and competence on the financial side. The potential difficulties in negotiating funding in some of the studied cases show the importance of public support on this level. The form and source of private funding has varied among the cases including options such as:

- Self-investments from the development company in the project
- Selling the ownership of the development company to different investors
- Acquiring investing companies to participate in the project
- Pre-selling licenses to technology-purchasing companies
- Lending money from banks and other sources

The cases demonstrate that there is no panacea for reducing barriers to innovation, and it takes both private and public actions to support environmental innovations.

4.4 Implications for Environmental Technologies Action Plan (ETAP)

The EU's Environmental Technologies Action Plan (ETAP) has led to several initiatives in its nine action areas (Section 1.3). It is clear that different businesses and product sectors have varying innovation dynamics, and therefore some actions are more relevant for selected sectors than others. Based on the study, we have commented below on the relevance and challenges of the ETAP actions from the point of view of the Nordic P&P sector. These findings may have similar implications on other low and medium technology (LMT) industries. The titles of the sub-sections are taken from the nine action areas of ETAP.

4.4.1 Increase and Focus R&D

First of all it is obvious from the cases that a sufficient educational infrastructure is a necessary precondition for successful long-term research. This has been evident in the Finnish and Swedish P&P sectors. Only then can R&D be increased and focused in a meaningful way in the sector.

R&D programs with environmental aims have been important sources of funding for environmental innovation in the P&P sector, especially as the companies have been characterized by low investments in R&D. The focusing of R&D on environmental technologies is important at all levels from national to the EU.

R&D programs have sometimes, for example in the CACTUS Programme funded by Tekes, directed a development initiated for other reasons to create also positive environmental impacts (Kivimaa and Mickwitz, 2006). Thus, an increasing emphasis on environmental technology research is likely to be useful, provided that environmental technology is rather loosely defined as in ETAP, allowing opportunities for alternative technological paths to be explored.

Increasing emphasis on private sector R&D is important for creating commercial applications from public research. As an example, Finland's Science and Technology Policy Council has called for the establishment of five centers of excellence in the following areas: energy and the environment, metal products and mechanical engineering, the forest cluster, health and well-being, and information and communication industry and services. Following from this and the Forest-Based Sector Technology Platform, a new innovation company, Forest Cluster Ltd, was established in 2007 to initiate research and innovation programs and to channel research funds to selected focus areas (www.forestindustries.fi). The innovation company strengthens public-private networks in forest sector innovation, the owners comprising nine forest sector companies (pulp and paper, equipment, chemicals), four universities, the Technical Research Centre of Finland VTT and the Finnish

Forest Research Insitute (Metla). Funding for the company is provided by the owner companies, Tekes and the Academy of Finland.

Although our study has provided support for the notion that increased and focused R&D plays a key role in generating environmental innovations, the bioenergy cases illustrate that R&D funding is not as such a sufficient condition for successful innovations if markets do not exist or they are underdeveloped.

4.4.2 Technology Platforms

The Forest-Based Sector Technology Platform is not listed among the platforms described by ETAP as relevant for environmental technologies (ec.europa.eu/environment/etap), although the FTP research agenda lists several areas relevant from an environmental point of view. Its role as an environmental technology driver is expected to increase with the development of bioenergy and the possibilities to develop biorefineries. The FTP is likely to be central for future environmental innovation as accumulated experiences show the importance of research cooperation. The FTP has already been followed up by national-level actions, but it could be more efficiently linked to national ETAP initiatives and other technology platforms.

4.4.3 Environmental Technology Verification

There are difficulties in defining ‘environmental technology’ because a specific technology tends to have a variety of negative and positive environmental impacts (Kivimaa, 2007b). We found that environmental technology verification can be relevant in three different contexts: business to business, business to policy, and business to customers. In the business to business dimension, Paper Profile, an environmental product declaration scheme for professional paper buyers, is a voluntary system developed and provided by leading paper producers presenting figures on essential environmental parameters in an uniformed way for specific products (www.paperprofile.com). This means that buyers have access to environmental information, but there is no external verifier who would provide ranking of different products. Yet standard rules exist on how to collect, calculate and present different pieces of information.

In the business to policy dimension, the Reference Document on Best Available Techniques acts as a kind verification of environmental process technologies in the pulp and paper sector. In business to consumers, the only environmental verification of products is based on eco-labels, such as the EU Flower and the Nordic Swan. There is potentially scope for additional standardized information to consumers, such as energy information for appliances. For example environmental loads such as CO2 emissions could also be reported to consumers in a standardized way. This could provide information extending across different sectors, e.g. fiber-based, plastic-based and other packaging, allowing comparisons of the environmental performance of products serving the same purpose.

Verification in some format is definitely useful to promote the development of environmentally sounder technologies and products, but the format and application should be carefully considered. The danger of verification is that certain technological paths will be favored as different types of environmental impacts (e.g. emission vs. biodiversity) cannot be objectively compared. Environmental technology verification needs internationally accepted standards, yet the same technology may have different environmental impacts in different localities, e.g. depending on what technologies it will replace and in which conditions. The verifications also need to be revised on a regular basis, otherwise they might constitute a barrier for innovation. This is, however, easier in more stable industries such as pulp and paper than in very dynamic sectors such as electronics.

4.4.4 Performance targets

Performance targets and performance-based regulation have been found to influence environmental innovation in the P&P sector. Non-binding targets may provide indication of future policies and therefore promote inventions in and the development of new technologies, often at least partly resulting from anticipating future environmental policies. Binding targets better aid the commercialization and diffusion of innovations. For example, both recovery boilers reducing air emissions and more energy-efficient paper manufacture were researched in Finnish technology programs in the 1980s and early 1990s. The diffusion of new recovery boilers, and subsequently the reduction of air emissions in the P&P sector, has been extensive, following binding limits for reduced air emissions in individual mills (Kivimaa and Mickwitz, 2004). At the same time, improvements in actual energy efficiency have been fairly modest and they have mainly been promoted by voluntary agreements.

In connection with targets, it is important to notice that too speedy introduction of binding targets may hamper innovation if more advanced technologies are not yet ready for commercialization and companies must adopt existing solutions. Therefore, the timing of, first, non-binding and, later, binding targets, and their gradual tightening is crucial. In addition environmental policy targets should always be combined with public R&D actions to strengthen the policy signals sent to companies, as it has been found that environmental policies and technology policies have combined effects on environmental innovations in the P&P sector (e..g. Kivimaa and Mickwitz, 2004) and technologies need years of development before they are ready for commercial applications. The biogasification technologies of the P&P sector are a case in point. Without decades of development work, the technologies would not be ready to respond to the EU biofuels directive. Other challenges related to target setting include agreeing on targets that are ambitious enough to promote innovation over existing technologies and flexible for the testing of new solutions. For instance, a target for the reduction of CO2 emissions from transport would offer more flexibility of different types of technological solutions combating climate change than targets for the share of biofuels in transport, even if the biofuels target has been successful in supporting certain types of environmental innovation.

4.4.5 Mobilization of financing

Public and private funding and loans have been crucial in the research, development and demonstration phases of P&P-sector environmental innovations. A variety of funding mechanisms and easy access to them is important. Public actors can also act as guarantee providers to facilitate speedy demonstration of new technologies (see example in 3.4). Private organizations need motivation to invest in environmental innovation, e.g. through consistent, long-term policies. Globalization has increased the P&P sector's access to international private funding, and therefore national-level public funding would better support small start-up companies and their innovation ventures.

4.4.6 Market-based instruments

Market-based instruments, such as environmental tax incentives, have not been directly relevant for many of the environmental innovations of the P&P sector, while environmental regulations have played a significant role. This may be explained by low financial incentives given by the instruments (e.g. Finnish energy tax) or their too recent introduction (e.g. CO2 trading). The challenge of the market-based instruments is to reach a decision by which the instruments provide strong enough incentives that promote environmental innovation and reduce environmental externalities.

4.4.7 Green public procurement

Green public procurement has had low impact on the environmental innovations studied in this report. There is potential for green public procurement in this sector, especially in relation to the development of specific products with environmental labels. For biofuels, public transport can offer possibilities to test and develop new fuel infrastructure. The recent report of the ETAP (CEC, 2007: 10) states that ”systematic and coordinated activity on demand-side is needed” and for example Edler and Georgiou (2007) have recently argued that public procurement has had more positive effects on innovation than R&D public subsidies.

Potential problems regarding the innovation support created by green public procurement arise from a certain rigidity of public systems to change (as innovation could require a rapid renewal of contracts), lack of available expertise on the total environmental impacts of product chains, and value judgments regarding the comparison of different environmental impacts (see verification of environmental technologies). Nevertheless, at the moment, there are plenty of expectations of positive effects from public procurement in different policy areas. This can lead to complicated and costly administrative processes, as all these aspects have to be taken into account and the decisions made have to be reasoned publicly. This means that public decision making is often more complicated and thus less efficient than private (Wilson 1989, 315ff).

4.4.8 Awareness raising and training

New opportunities for environmental innovation lie in inter-sectoral cooperation, e.g. between the P&P industry and the automotive and electronics industries. Raising awareness among the individual actors of the P&P sector about opportunities from crossing sectoral boundaries could be extremely useful for environmental innovation. Moreover, know-how and knowledge generated from a variety of sources and access to knowledge is crucial for environmental innovation processes (Section 3.2). A thorough integration of environmental issues into different knowledge processes (public & company R&D and their evaluation systems) would benefit environmental innovation. In addition, the maintenance and focus of national education systems (as noted in 4.2.1) is relevant.

4.4.9 Supporting eco-technologies in developing countries

In some cases, especially for environmental technologies created by SMEs, the first markets have been found in the developing countries (Kivimaa, forthcoming). P&P production has rapidly expanded in the developing countries allowing for more flexibility to test new technologies, but the availability of funds may restrict the renewal of technology. Support for environmental technologies in developing countries can significantly support environmental innovation and technological change also on a global level. It also reduces the market risks for those investing in innovation by supporting the expansion of the market for new environmentally friendly technologies.

4.4.10 Further development of the ETAP

The discussions and conclusion of the sector workshop organized in Oslo in March 2007 supported many of the activities that form the core of the ETAP. In addition, a number of possible actions that do not exactly coincide with any of the present specific ETAP activities were identified. These include:

1) Novel form of financial support such as support to the users of innovation to

reduce the initial additional costs that arise when new products do not fit into the existing system and support for systems transformation to remove lock-in situations;

2) Greater focus on system innovation by looking at product/service chains and the impacts along their life cycles;
3) Stronger emphasis on the consistency of policies, e.g. regarding energy and environment in order to contribute to systemic rather than piecemeal changes.
4) International cross-sectoral sensing, i.e. identifying large areas for test markets (some of this could be realized through technology platforms);
5) Making lobbying transparent in order to ensure a "politically level playing field" for different technological solutions;

Further development of ETAP should fully recognize that knowledge originates from different public and private sources. As the diffusion of environmental knowledge and environmental policy signals is crucial, ETAP can, by having a clear focus, provide stronger incentives for environmental innovations than the more general, horizontal innovation policies. The discussion on horizontal innovation policy relates to policies embedded in a broader socio-economic context (cf. Lundvall et al., 2002; Pelkonen, 2006).

While ETAP has proposed a variety of actions in support of environmental innovation, attention should also be focused on the evaluation of the measures and in particular on the identification and reduction of innovation barriers in different countries and sectors and in the EU as a whole. For instance, the existing packaging and packaging waste directive sets completely different recycling requirements for plastic and fiber packaging. The problems caused by existing regulatory systems are not fully addressed by ETAP. There are also a number of areas in which the measures included in the ETAP may contribute to the present inertia rather than serve to overcome it (Table 4.1, potential problems indicated in italics). For example, the strong links between existing solutions and the whole production system can be reinforced by performance targets that have been developed for present production systems. In a similar way processes for environmental technology verification can prove to be a barrier for innovative solutions, if the adopted criteria for verification do not match those of a radical new invention.

Future development of the ETAP should recognize the possibility of unintended negative side effects of the measures that at first sight appear to be purely beneficial. To reduce the risks of such unwanted side effects the measures should take a broad view and pay particular attention to system effects and innovations. In addition, the policies and measures should be subjected to in-depth evaluations that can contribute to social learning processes and, thereby, also identify innovative policy opportunities. Initially, much of the focus was on the technological side (for example Galleja et al., 2004) coupled with rather superficial analyses of how policies and policy instruments affect the actors and their innovative capabilities. The most recent report recognizes the policy aspect and the need for demand-side approaches at the level of policy.[8] There is, however, still a need to systematically analyze the barriers to innovation as well as the

[8] CEC (2007) states "Evidence shows that well designed legislation does act as a driver for innovation and environmental technologies, which in turn can help companies in significantly reducing costs" and "Systematic and coordinated activity on the demand-side is needed."

possibilities to introduce innovation drivers in existing regulatory systems.

Table 4.1 The links between the ETAP Actions and the identified barriers: possible advantages and risks

ETAP Action	Market inertia;	Policy support, including regulatory systems, for traditional solutions	Strong links between existing solutions and the whole production system;	The lack of risk capital	Market failures with respect to the environmental costs of energy and other raw materials	Narrow perspective of actors and resistance to change	Lack or inefficient transfer of knowledge
Increase and focus R&D		Need for analyses of policy implications of novel technological solutions	Can highlight problems		Can highlight problems	New perspectives	Improving knowledge transfer through designed networking
Technology platforms		New insights and feedback to policy development; *some risks for corporatism*	May offer forums for debate of transformations *but may also cement traditional thinking and solutions*	Can attract risk capital		May offer forums for debate of transformations *but may also cement traditional thinking and solutions*	Improving knowledge transfer through institutionalised networking
Environmental technology verification	New reference information can lower market barriers	*May strengthen role of traditional solutions and thus hinder removal of barriers*		Can reduce investment risks and thereby attract capital		New reference information can overcome part of resistance *but may also increase resistance to change*	Systematised information is easier to transfer
Performance targets	Prepares grounds for developing markets	May contribute to reassessments, *but can also be conservative, favouring incremental rather than radical change*	May contribute to reassessments, *but can also be conservative, favouring incremental rather than radical change*	Can reduce risks by indicating developing markets	Can highligh solutions	Can overcome some resistance by fostering debate	
Mobilisation of financing (grants and loans)			Can offer opportunities for change, *but rigid criteria may favour existing solutions*	Direct reduction of problem	Can correct for certain market failures	May contribute to rethinking	
Market-based instruments	May also support development of technological market	Can reduce link between specific solutions and policy	May contribute to rethinking		Can correct for certain market failures		
Green public procurement	May create or develop specific markets	May support new solutions, *but too rigid and slowly changing procurement criteria may also become a barrier*		Can reduce risks by indicating developing markets		May support new solutions, *but too rigid and slowly changing procurement criteria may also become a barrier*	Facilitates information transfer
Awareness raising and training	Prepares grounds for developing markets	May contribute to reassessments	May contribute to rethinking	Can reduce risks by indicating developing markets	Can initiate considerations of market failures	Can overcome some resistance by fostering debate	Facilitates information transfer
Supporting eco-technologies in developing countries and promoting foreign investment	May support specific markets	May contribute to regulatory development by demonstrating possibilities to combat pollution	May support system transformation, *but may also maintain existing solutions*	Can reduce risks by developing markets	Can correct for certain market failures		Can greatly enhance knowledge transfer, *risk lack of context sensitivity*

National Innovation Systems still often support the networks through which innovations are created in the P&P sector, but the formation of innovation markets is increasingly dependent on international developments (see also Kivimaa and Kautto, 2007). EU policies, e.g. the biofuels directive, have increasingly created the final impetus for some environmental innovations. While EU policies may create a larger market for potential innovations, the slowness and rigidity of the larger political system may also slow down innovation compared to more local or national-level policies. Thus certain activities supporting environmental innovation can and should be maintained at all levels from local/regional to national and EU. These include focusing R&D on environmental technologies, setting environmental performance targets, mobilization of financing, green public procurement and awareness raising and training.

Although the EU can create more incentives for larger companies to innovate through larger market and funding potential, local initiatives are more flexible for the change needed to spur innovation and more accessible for smaller actors. Our findings on environmental innovation in the P&P industry illustrate the importance of both national and EU standards. Other studies in the marine engine sector have shown that even local market-based instruments can promote innovation that spreads globally (Hyvättinen and Hildén, 2004).

5. Conclusions

Supporting environmental innovations requires consistent efforts that combine and coordinate innovation and environmental policies. ETAP is a good starting point for creating a policy mix for environmental innovation. Innovation support requires drivers that create the base for innovations, factors such as education and basic and applied research, and overall environmental targets that the improvements are aimed at. After the basis is created, more binding requirements are needed to promote the adoption and use of the generated innovations. In addition, public-private partnerships, such as the Forest-Based Sector Technology Platform and the Forest Cluster Ltd, are important in creating visions and action for future innovation.

Innovations are still strongly linked with national innovation systems (NIS) at least in the P&P sector. An extensive NIS, including public higher education and research, can create necessary preconditions for innovation even in low-R&D investment sectors, such as the P&P sector. Yet building up a sectorally oriented NIS, with significant investments in the education and research related to a specific sector takes decades, and is thus not suitable for supporting innovation in every sector and in every location. Still the NIS overall creates some prerequisites for market-based pull for innovations. As many of the technologies take years to develop, knowledge and near-commercialization inventions need to be available to respond to new market demands, whether they are caused by increasing electricity price or new regulatory requirements. The market pull is, by contrast, increasingly dependent on international development in commodity markets or EU policies. Therefore, ETAP actions need to consider the continuum from national to international as well as various forms of public-private partnerships and participatory processes.

The Strategic Research Agenda of the EU's Forest-Based Sector Technology Platform (2006) is an important document highlighting future innovation activities in the European P&P industry. The forest industries in Finland and Sweden have both published their national forest-based research agendas following the technology platform, highlighting fairly similar issues for innovation (Finnish Forest Industries Federation 2006; NRA 2006). Thus the FTP is a tool that combines national and EU efforts in supporting innovation in the forest sector.

The Forest-Based Sector Technology Platform emphasizes environmental issues and aims to turn the threats and challenges facing the forest sector, including the climate change issues, into opportunities. While many environmental improvements have been made in the past to reduce water and air emissions from the forest industry, innovations in the forest sector still have the potential to provide environmental improvements in the form of replacing less harmful chemicals, increasing renewable energy in transport and electricity production, saving energy, providing recyclable products for new product markets, and contributing to waste management along product value chains in other sectors. ETAP should not forget the less likely sources of environmental innovation emerging out of inter-sectoral cooperation.

In addition to highlighting the connection between NIS, internationalizing markets and EU policy-created markets, the study has identified needs for future research. There appears to be clear differences in the innovation dynamics and policy influence between low and high technology sectors, such as pulp and paper and electronics. A more thorough comparison of environmental innovation in low, medium and high technology sectors could tell us more about what kind of policies are needed. Product-related policies have had relatively little influence on the P&P sector, and the future potential of Integrated Product Policy to influence environmental innovation in this sector is still an open question. Furthermore, the links between IPP and ETAP could be subjected to further analysis.

The particular role of public policies and policy intervention needs to be considered and developed further. Apart from the maintenance of general environmentally conscious high-quality education with a high degree of environmental awareness, we have identified the following public roles to be particularly significant:

- Markets created or enforced by environmental policies through regulations or market-based instruments have been crucial for those innovations that provide significant benefits for environmental protection but that at least initially appear to be technologically uncertain or significantly different from the current production and consumption systems.

- The public sector can clearly influence the diffusion of environmental objectives into the knowledge creation processes through criteria for research funding, development of specific educational curricula, supporting networks and by creating or enhancing markets that can attract information from different business sectors.

- Consistent long-term public policies can reduce the non-technical risks and increase the expected benefit of environmental innovations by creating or contributing to developing markets.

- Public funding has contributed to risk funding, in particular in the early phases of company development.

By focusing on these areas and by developing specific measures within these areas the public sector is likely to significantly contribute to environmental innovations also in the future. The measures may also develop awareness in the sector itself that it needs to increase significantly its R&D activities in order to make significant contributions to novel solutions in the spirit of the Lisbon Strategy.

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Sammandrag

Politiska initiativ såsom Lissabonstrategin har betonat miljöinnovationers centrala betydelse då det gäller att lösa miljöproblem och de har strävat till att främja miljöinnovationer på olika sätt. Denna rapport analyserar ett urval miljöbefrämjande teknologiska innovationer och deras förhållande till samhälleliga och ekonomiska drivkrafter, i synnerhet offentlig politik. Studien bygger på empiriskt material hämtat ur den nordiska massa- och pappersindustrin. Rapporten diskuterar också åtgärderna i EU:s miljöhandlingsplan ETAP ur massa- och pappersindustrins synvinkel.

Studien bygger på dokumentanalys, intervjuer, diskussioner vid arbetsmöten samt kommentarer av representanter för den nordisk skogssektorn. De enskilda fallstudierna omfattar användningen av biprodukter för energiproduktion, nya produkter i nyckelaffärsområden och nya värdekedjor.

Uppfinningarna och innovationerna som analyserats i studien pekar på några centrala drivkrafter och hinder för miljöinnovationer. Viktiga drivkrafter innefattar utvecklingen av en marknad för miljöorienterade innovationer – ofta stödd av miljöpolitik och konsumenttryck - tillgång till ett brett fält av relavant kunskap, miljöorienterad offentlig och privat finansiering samt nya nätverk av aktörer. Tröghet på marknaderna, politikbaserat stöd för traditionella lösningar, starka bindningar mellan traditionella lösningar och hela produktionssystemet, brist på riskkapital, marknadsfel i fråga miljökostnader för energin och andra råvaror, vissa aktörers snäva perspektiv och motstånd mot förändringar samt ineffektiv överföring av kunskap har varit betydande hinder som bromsat upp utvecklingen av miljöinnovationer. De olika exemplen visar att olika hinder och drivkrafter kan spela in, men till exempel utvecklingen av bioenergiteknologin visar att inte bara den absoluta styrkan utan också förhållandet mellan pådrivande krafter och hinder är av stor betydelse.

Offentlig politik har inte varit avgörande i varje enskilt fall men kan skapa ett ramverk som stöder miljöinnovationer och samtidigt hjälpa till att identifiera bristande miljöeffektivitet. Den offentliga politiken har påverkat miljöinnovationer inom massa- och pappersindustrin genom allmänt stöd till forskning och utveckling, delfinansiering av utvecklingsprojekt samt genom att skapa förutsättningar för samarbete mellan offentliga och privata aktörer. Investeringsstöd för demonstrationsprojekt och stöd för utveckling av företagsfinansiering har även påverkat innovationerna. Därtill har den offentliga politiken skapat eller stärkt marknader för miljöinnovationer som kunnat konkurrera i fråga om positiva miljöeffekter.

Även om innovationsmarknaderna i allt högre grad är beroende av internationell utveckling och miljöpolitiken påverkas starkt av EU ligger grunden för miljöinnovationerna inom den nordiska massa- och pappersindustrin i de

nationella innovationssystemen. Den nordiska utbildningspolitiken som har skapat ett starkt tekniskt kunnande har varit avgörande då det gällt att utveckla den bas som behövs för att ett mer direkt stöd till innovationer skall kunna fungera.

För miljöpolitiken och ETAP är möjligheterna att skapa eller stärka ”gröna” marknader med hjälp av offentlig politik viktiga. Framgången för marknader som skapats av politik är emellertid i avgörande grad beroende av andra parallella eller påföljande marknadsförändringar såsom priset på råvaror eller energi, vilka stärker utvecklingen mot bättre miljöeffektivitet. Miljöpolitiken klarar sällan ensam av att tvinga fram innovationer.

Studien har genomförts vid Finlands miljöcentral och är en del av forskningsprojektet Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) som genomförts i samarbete forskare från IIIEE vid Lunds universitet och universitetet i Ålborg. Projektet finansierades av arbetsgruppen för integrerad produktpolitik under Nordiska Ministerrådet.

Yhteenveto

Politiikka-aloitteet, kuten Lissabonin strategia, ovat painottaneet ympäristöinnovaatioiden tärkeyttä monien ympäristöongelmien keskeisenä ratkaisuna ja pyrkineet monin tavoin niiden edistämiseen. Tässä raportissa analysoidaan pohjoismaisesta massa- ja paperiteollisuusteollisuudesta kootun empiirisen aineiston perusteella ympäristöinnovaatioita ja niiden suhdetta erilaisiin yhteiskunnallisiin ja taloudellisiin tekijöihin, erityisesti julkisiin toimintapolitiikkoihin. Lisäksi raportissa pohditaan EY:n komission Ympäristöteknologian toimintaohjelman (ETAP) ehdotuksia massa- ja paperiteollisuuden näkökulmasta. Tutkimus perustuu dokumenttianalyyseille, haastatteluille, keskusteluille hankkeen työpajoissa sekä pohjoismaisen metsäsektorin edustajien kommenteille. Tutkitut tapaukset liittyvät tuotannon sivutuotteiden energiahyödyntämiseen, uusiin tuotteisiin ydintoimialueella ja uusiin arvoketjuihin.

Raportissa analysoitujen keksintöjen ja innovaatioiden perusteella voidaan tunnistaa ympäristöinnovaatioiden syntyä keskeisesti edistäviä ja estäviä tekijöitä. Keskeisiä innovaatioiden syntyä edistäviä tekijöitä ovat muun muassa politiikan luomat tai asiakaspaineista syntyneet innovaatioita tukevat markkinat, saatavilla oleva monipuolinen tieto, ympäristöperusteinen julkinen ja yksityinen rahoitus sekä toimijoiden väliset uudet verkostot. Keskeisinä ympäristöinnovaatioiden syntyä estävinä seikkoina tulivat esiin markkinoiden inertia, politiikan tuki vallitseville ratkaisuille, valitsevien ratkaisujen kytkeytyminen koko tuotantojärjestelmään, riskipääoman puute, markkinahäiriöt energian ja raaka-aineiden käytön ympäristövaikutusten näkymisessä hinnoissa, joidenkin toimijoiden kapea näkökulma ja muutosvastaisuus sekä huono tiedonkulku. Tapaukset ilmentävät eri kannusteiden ja esteiden tärkeyttä, mutta esimerkiksi bioenergiaan pohjoismaisessa massa- ja paperiteollisuudessa liittyvät tapaukset osoittavat myös näiden kannusteiden ja esteiden keskinäisten suhteiden suuren merkityksen.

Vaikka politiikkatoimenpiteet eivät olekaan kaikissa tutkituissa tapauksissa olleet tärkeitä, voivat ne tukea ympäristöinnovaatiota ja auttaa tehottomuuksien löytämisessä. Julkiset toimintapolitiikat ovat vaikuttaneet massa- ja paperiteollisuuden ympäristöinnovaatioihin suoraan julkisena T&K-tukena, kehityshankkeiden rahoituksena, yksityisten ja julkisten toimijoiden väliseen yhteistyöhön kannustamisena, investointitukena ja apuna sen löytämisessä demonstraatiohankkeille, sekä luomalla tai vahvistamalla markkinoita ympäristöinnovaatioille ja kannustamalla näiden väliseen kilpailuun.

Vaikka markkinoiden muodostuminen innovaatioille onkin enenevässä määrin kytköksissä kansainväliseen kehitykseen ja ympäristöpolitiikan muotoilu tapahtuu pääosin EU-tasolla, ympäristöinnovaatioilla on Pohjoismaisessa massa- ja paperiteollisuudessa selkeä yhteys kansallisiin innovaatiojärjestelmiin (national innovation systems, NIS). Suuria teknisen tietämyksen kokonaisuuksia luonut pohjoismainen koulutuspolitiikka on monessa suhteessa ollut perustana suoremmalle innovaatiotuelle.

Ympäristöpolitiikkojen ja ETAP:n kehityksen kannalta vihreiden markkinoiden luominen ja vahvistaminen ovat oleellisia. Toimintapolitiikkojen luomien markkinoiden onnistuminen on kuitenkin pitkälti riippuvainen samanaikaisista tai sitä seuraavista muutoksista esimerkiksi energian ja raaka-aineiden hinnoissa, joilla on samansuuntainen vaikutus ympäristöasioiden huomioon ottamiseen. Ympäristöpolitiikka on vain harvoin yksin riittävä kannuste innovaatioille.

Raportti on laadittu Suomen ympäristökeskuksessa (SYKE) ja se on osa SYKEn yhdessä Lundin yliopiston IIEEE–instituutin ja Aalborgin ylipiston kanssa toteuttamaa Green Markets and Cleaner Technologies - Leading Nordic Innovation and Technological Potential for Future (GMCT, 2006-2007) –tutkimushanketta. Hankkeen rahoittajana oli Pohjoismaisen ministerineuvoston Yhdennetyn tuotepolitiikan ryhmä.

Appendix I: Case-study framework

QUESTIONS FOR INNOVATION CASES		
Can you describe how the technology has been developed? Why did the process start? What were the main driving forces to take this further? Who where the main participants? With whom did you worked with? Which were the key milestones?		
Research questions for case studies	**Sub-questions**	**CHECKLIST FOR InterviewS**
Knowledge - pools, access, roles of different types of knowledge?	Generation and diffusion of knowledge through public mechanisms?	Participation in public R&D programmes?
		Basic knowledge from publicly funded R&D as contributing to the innovation?
		Co-operation with universities and public research institutes?
		Signals from public policy (e.g., environmental or technology policy) affecting the development?
	Generation and diffusion of knowledge within the company?	Co-operation between departments (e.g., product development and environmental management)?
		Investment in creating new ideas and innovations (e.g. innovation centers, own R&D)?
		Environmental training of people involved in R&D issues?
	Generation and diffusion of knowledge through inter-organisational cooperation?	Different actors involved in idea generation, R&D, pilot testing and diffusion of the innovation?
		Closeness of cooperation with other organizations?
		Role of inter-company R&D forums?
Standards, criteria and institutional rules?	Role of public policies as drivers for innovation or its diffusion?	Technical standards?
		Environmental policies (e.g. emissions limits, recycling requirements)?
		Health policies?
		Aims to modify the rules of the game (e.g. influence the public policy?) If yes, as a company or through an association?
	Role of intra-organizational standards and rules?	Environmental standards in intra-organizational rules and procedures for R&D?
	Role of national and international inter-organisational standards and standard setting?	Market standards (e.g., product and electricity markets)?
		Technical standards?
		Environmental standards (e.g., ecolabels, forest certification)?
		Participation in the standardization work?
Funding and financial resources?	Public funding?	Subsidies? R&D funding? Tax exemptions? Public risk capital? Public venture capital?
	Corporate funding?	Innovation centers? Own R&D project funding? Establishing a subsidiary company around the innovation?
	Other private funding?	Venture capital? Bank loans? Stock markets? Collaboration with other companies?
Actors & Networks	Public actors	Policy makers? Universities? Research institutes? Public-owned funding institutions?
	Intraorganizational	Environmental unit? R&D unit? Product development unit? Marketing unit?
	Private actors	Customers? Competitors?

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Kirjakauppa
Runeberginkatu 14-16
00100 Helsinki
Puh. (09) 4313 8310, fax (09) 495 617
Sähköposti: kykirja@ky.hse.fi

Helsingin kauppakorkeakoulu
Julkaisutoimittaja
PL 1210
00101 Helsinki
Puh. (09) 4313 8579, fax (09) 4313 8305
Sähköposti: julkaisu@hse.fi

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