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Innovation in Environmental Technology

The Role of Policy in the Promoting Environmental Innovation

Morrigan Hayes

Supervisors

Naoko Tojo

Tareq Emtairah

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Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

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Finally, to Mike, my best friend in the world. Enough said.

Abstract

This thesis investigates the process of innovation in environmental technology and the role that government interventions can play in fostering this innovation, using a cross-sectoral perspective based on three Nordic sectors – mobile phones, pulp and paper, and buildings. Using an analytical framework based on innovation and environmental policy and their interactions with three preconditions for innovation – access to knowledge, access to resources, and market formation – the dynamics of environmental innovation occurring across the three sectors (mobile phones, pulp and paper, and buildings) were examined. Literature and empirical materials were used to establish a picture of the innovation dynamics of the sectors under review and additional information gathered from sector-specific case studies was used to provide insight into how actors within the various sectors innovate and respond to policy interventions. Suggested policy directions are put forward based on issues identified through an analysis of the materials. The research confirms that policy interventions require a sector-specific approach but notes that environmental innovations face similar barriers with regards to a lack of markets across all sectors. This thesis argues that environmental policy can be used in conjunction with innovation policy to put forward the necessary impetus to allow the preconditions for innovation to be fulfilled with respect to environmental technology development. Furthermore, it notes that there is a potential for learning between sectors in some cases to be used as means of helping to overcome innovation barriers. A method that policy makers can use to help select appropriate interventions to foster innovation in environmental technology is proposed. While this thesis provides some preliminary insight into the overall innovation dynamics of the studied sectors and the specific process of environmental innovation, innovation dynamics, environmental issues and policy interventions remain complex fields. Further research at both the sector level and the policy level are needed to gain a deeper understanding of the environmental innovation process.

Executive Summary

This thesis investigates the process of innovation in environmental technology and the role that government interventions can play in fostering this innovation in the Nordic countries. Environmental technology represents an important part of the solution to reduce environmental pressures that are occurring worldwide and innovation in environmental technology presents a unique opportunity to couple the goals of economic and environmental growth. The Nordic Council of Ministers has developed an Environmental Action Plan, with the aim of cementing the Nordic region as a front runner in environmental matters, and has identified environmental technologies as an important element in achieving their strategy. Additional insight into how to promote innovation in environmental technologies through policy interventions could serve as a useful tool in helping to address these goals. In particular, three Nordic sectors are examined in closer detail – mobile phones, pulp and paper, and buildings. These sectors represent important areas of the Nordic economy and have historically and/or presently been on the environmental policy agenda.

Innovation is a complex process that is the result of a series of interactions between a firm and its environment and that is affected by a number of factors, including government policy. Based on previous work done, three necessary preconditions for innovation have been identified – access to knowledge, access to resources, and formation of markets. Environmental innovation is a particular subset of innovation, which has been broadly defined as the use of production equipment, techniques and procedures, and products and product delivery mechanisms that are sustainable. It comprises innovations having environmental benefits that are realised intentionally or as unintended side effects. Based on the public goods nature of environmental innovation, a third element of regulatory pull is considered to be a necessary addition to the traditional technology push and market pull model of innovation. The nature of environmental innovation makes it interesting from two particular policy perspectives – innovation and environmental policy. Based on a review of literature, innovation policy tends to support the first two preconditions of innovation – access to knowledge and access to resources – while environmental policy largely supports the third – formation of markets. As such, these policy areas could be used as complementary tools to help foster environmental innovation.

Using an analytical framework based on innovation and environmental policy and their interactions with the three preconditions for innovation, the dynamics of environmental innovation occurring across the three selected sectors were examined. Literature, interviews, and unpublished project materials were used to gain insight into the innovation dynamics of each sector and case studies within each industry were used in order to gain a more nuanced understanding of how actors within the different sectors innovate.

The materials reviewed confirm that sectors display different characteristics that require specific, customised policy interventions. Conditions and issues surrounding the preconditions of innovations vary between sectors. Familiarity with knowledge generating activities, frames of reference of actors, patenting issues, industry structure, and the role of SMEs can vary between sectors. The case studies have pointed to the importance of multiple knowledge inputs and networking in the innovation process, as well as to the multidisciplinary nature of environmental innovations. Industry resources, access to and attitudes towards public funding, and human resource issues are varied amongst sectors and the importance of the availability and timing of public funding interventions as well as access to private funding are highlighted. Issues surrounding market development have included the nature of the innovation (e.g. customer or supplier-led, core business or otherwise), market distorting

factors, and consumer demand and potential sensitisation of the industry to environmental issues. These factors can affect the types of interventions that may best be suited to a particular innovation trajectory. Several case studies have demonstrated that ability of environmental innovation to arise in the absence of direct environmental policy drivers, while in others environmental policy has played an important role in creating markets and/or stimulating knowledge generation activities. This indicates that environmental policy has the potential to play an important role in facilitating environmental innovations in some instances.

Based on the work conducted, a method to help policy makers gain insight into what measures to take to help foster innovation in environmental technology is put forward. Environmental innovation is a subset of innovation. Consequently, it is affected by the innovation dynamics and characteristics of the sector in question as well as by the nature of the environmental innovation. In order to help establish the most appropriate environmental policy and innovation policy interventions, selection of the sector where improvement is sought after, as well as the desired direction of innovation is a potential first step. An understanding of the sector's innovation dynamics and characteristics, and the nature of the innovation is a subsequent step. A picture of the nature of this innovation in relation to the sector characteristics can then be established in order to provide insight into potential courses of policy action.

While this research has provided some preliminary insight into the nature of environmental innovation in three Nordic sectors, innovation dynamics, environmental improvements and policy remain complex issues that require further research in order to gain a broader understanding of the topic at hand and additional insight into the role of policy in specific sectors.

Table of Contents

List of Figures

List of Tables

1 Introduction

The world is undergoing significant transformations. The human population doubled from 3 billion to 6 billion in the 40 years between 1959 and 1999, and the total population is expected to reach 9 billion by the year 2042 (U.S. Census Bureau, 2007). The majority of this population growth has occurred, and is expected to occur, in the developing countries (The World Bank Group, 2001) The world is becoming increasingly industrialised and, economically, globalisation is occurring at a substantial pace. Developing economies are growing rapidly as industries formerly hosted in developed countries move to regions with relatively lower production costs and large workforces.

In recent years, the European Union (EU) has drawn attention to these issues and to its declining ability to compete on the world economic stage in terms of traditional manufacturing and industrial activities. As a result, at the Lisbon summit in March 2000, the European Council presented its new development plan for the European Union, declaring its strategy to make the EU *"the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion"*.

The social and economic changes described above have come hand in hand with substantial environmental effects. Resource depletion, waste generation, and environmental degradation are occurring at an alarming pace. Consequently, increasing attention is also being paid to the need to simultaneously address environmental concerns. In 2001, following the Lisbon strategy and recognising the need to incorporate environmental issues into the Lisbon agenda, the Göteborg European Council launched the EU strategy for sustainable development (that is, development that meets the needs of the present without compromising those of future generations). The strategy sets objectives for sustainability, calling for a more integrated approach to policy making which will allow economic, social and environmental objectives to be achieved concurrently.

In October of 2003, the European Council recognised the potential of environmental technology to help realise these objectives and to create synergies between environmental protection and economic growth. As a response, the Environmental Technologies Action Plan (ETAP) was created with the aim of "harness[ing] the full potential [of environmental technologies] to reduce pressures on our natural resources, improve the quality of life of European citizens and stimulate economic growth" . The objectives of the Action Plan are:

- to remove the obstacles in order to tap the full potential of environmental technologies to protect the environment while contributing to competitiveness and economic growth;
- to ensure that over the coming years the EU takes a leading role in the development and application of environmental technologies; and
- to mobilise all stakeholders in support of these objectives (European Commission, 2004).

The field of environmental technology represents a unique area in which the European Union can work to bridge the aspirations of the both the Lisbon and Göteborg strategies, helping the goals of sustainable development and knowledge creation to be achieved simultaneously. Through innovation in the field of environmental technology, Europe can continue to strive for its goal of environmental protection, while developing a unique knowledge base which will allow it to position itself as a forerunner in environmental technology development.

Despite this recognition by the European Union of the importance of environmental technology, there is, however, a general perception that these technologies are currently not reaching their full market potential. As such, additional efforts are needed to stimulate innovation in this field. This then raises the question: "*How can governments and policy makers help to foster innovation in the field of environmental technology*"?

The simplicity of this question, however, belies the complexity of the answer. The process of innovation and the inclusion of environmental goals in the marketplace are complex and multi-dimensional issues. Policy makers have used innovation policy and environmental policy to correct market failures in both processes and much effort has been put into understanding innovation dynamics.

This thesis focuses on environmental technology innovation in the Nordic countries. This region has a long tradition of cooperation in the environmental field and has been a leader in this area for years (Nordic Council of Ministers, 2007). The Nordic Council of Ministers has developed an Environmental Action Plan, with the aim of cementing the Nordic region as a front runner in environmental matters, and has identified environmental technologies as an important element in achieving their strategy (Nordic Council of Ministers, 2007). Additional insight into how to promote innovation in environmental technologies through policy interventions could serve as a useful tool in helping to address these goals.

It has been recognised in innovation literature that the rate and type of innovation and the organisation of innovative activities varies across sectors (Malerba, 2005). Sector-specific characteristics can play a role in the innovation process and consequently sectors may have different responses to and needs from environmental and innovation policy interventions. This thesis examines the occurrence of environmental innovation in three sectors in the Nordic economy, through an overview of the sector's innovation dynamics and a review of several environmental innovation case studies in each sector. Examination of the environmental innovation process across a range of sectors and through a number of case studies can provide a unique insight into the differences and similarities which occur across sectors in regards to environmental innovations, with the aim of providing a view into how innovation in environmental technology can better be fostered through government intervention. In particular, this study focuses on environmental technology innovations in three distinct sectors: mobile phones, pulp and paper, and buildings. All three of these sectors play a significant role in the Nordic economies and have, historically and/ or presently, caught the attention of environmental regulators. They represent interesting points of focus because of their diversity, their significance in the Nordic region, and their innovation potential.

1.1 Purpose of the Study

The purposes of this study are *to contribute to an understanding of the types and characteristics of government interventions that can be used to foster innovation in environmental technology in general and, more specifically, in the sectors under review*, and, in addition *to contribute to an understanding of the role that sector characteristics play in shaping the environmental innovation process*.

1.2 Research Questions

In order to fulfil the objective of this study the following research questions are addressed:

- How has knowledge been accessed and used by actors in the innovation process and what, if any, government interventions have played a role in this?

- How have resources been accessed and used by actors in the innovation process and what, if any, government interventions have played a role in this?

- How has the formation of markets influenced the innovation process and what, if any, government interventions have played a role in this?

- What are sector characteristics that affect the environmental innovation process?

1.3 Methodology

1.3.1 Research Background

The work done for this thesis has been carried in conjunction with an ongoing project funded by the Nordic Council of Ministers (*Green Markets and Cleaner Technologies [GMCT] – Leading Nordic Innovation and Technological Potential for Future Markets)* that aims at supporting Nordic activities which enhance the diffusion of environmental technologies. The project partners are the International Institute for Industrial Environmental Economics (IIIEE) at Lund University in Sweden; the Finnish Environment Institute (SYKE); and the Department of Development and Planning at Aalborg University (AAU) in Denmark. Additionally, input with regards to the area of technology evolution and industrial transformation has been provided by Risoe National Laboratory in Denmark. Three sectors – mobile phones, pulp and paper and buildings – each representing an important part of the Nordic economy, were chosen for review as part of the project. Selection of the sectors was completed within the project framework by the project partners and was based on a number of criteria including recommendations of various Nordic government bodies, relevance to the Nordic innovation systems, input from project partners, and availability of data from previous studies. AAU has undertaken responsibility for the mobile phone sector study, SYKE for the pulp and paper sector study, and the IIIEE for the building sector study. Case studies within each sector were conducted by the respective project partners in order to gain a more nuanced understanding of how actors within the different sectors innovate and how they respond to different environmental and innovation policy signals. Work conducted by each project partner has been synthesised into a series of three sector reports. The specific case studies reviewed for each sector were chosen by the project partners based on a number of criteria, which are further outlined in the individual sector reports. The author of this thesis has not been involved in the original selection of the sectors or the case studies used for the project purposes. The selection, research and analysis of the case studies used for the project have been conducted by the respective partners (the IIIEE team, the SYKE team and the AAU team). The case studies presented in this thesis have been synthesised from the project case studies and, in some instances, this work has been supplemented by additional primary and secondary data obtained by the author of this thesis.

This thesis uses the sector and case study materials collected by the various GMCT project partners, furthered by additional literature and empirical materials, to examine policy implications for innovation in environmental technology. For the purpose of this thesis, in the cases of the pulp and paper and the building sectors, only select case studies were reviewed from amongst those completed by the project partners. This was done in order to ensure that a similar number of case studies were reviewed for all sectors and to provide a reasonable scope for the work. Case studies reviewed for the thesis were chosen based on their relation to energy efficiency developments as well as on their ability to provide interesting insight into different aspects of the sectors. Energy efficiency represents a mutual theme of interest across all of the sectors reviewed in this thesis and provides a common basis for discussion across all three sectors. Additionally, there is growing international concern regarding energy-related issues[1], making this an important point of focus in the policy field.

1.3.2 Research Phases

The work for thesis has been performed in three phases:

- Phase 1: Review of background information on environmental technology and the innovation process and literature on innovation policy and environmental policy in relation to innovation;

- Phase II: Review of study materials related to the innovation dynamics and case studies in the relevant sectors and supplementary interviews;

- Phase III: Analysis of the data gathered using the two aforementioned methods.

In phase I, literature regarding the topics of environmental technology, innovation, environmental policy, and innovation policy was reviewed. Previous findings regarding the effects of policy instruments in environmental innovations were examined, as was literature on innovation policy, in order to gain a better understanding of these fields and their interactions.

In phase II, data from material collected within the GMCT project framework (sector reports, background reports, workshop presentations and notes, unpublished memos, and interview notes), from literature, and from interviews were used to establish a picture of the sectoral context in which the three sectors innovate. Case studies for each of three sectors were reviewed. Where necessary and/or available, additional information regarding the innovation dynamics of the sectors and the case studies was gathered via literature and interview sources. Interviews were conducted in a semi-structured manner. Open-ended questions were used to guide the interviews, but the discussion was not limited to these areas in order to help allow relevant ideas and information to surface. Questions and topics were adjusted based on the interviewee. The majority of interviews were conducted via telephone, due to distance constraints, and all interviews were conducted in English. Potential interviewees were selected based on their ability to provide an additional perspective into the material collected during the original case studies and/or on their ability to provide additional insight into the innovation dynamics of a sector. Where the inputs of a particular actor group were not present in the sector-specific and case study materials, attempts to arrange discussions with these groups were made. In total, in addition to the written materials provided for the project, eleven discussions were held (five from the mobile sector, three from the pulp and paper sector, and three from the building sector). Participants included authors of the case studies, industry representatives, and academia. A complete list is provided in the references.

In phase III, analysis of the collected material was completed. Based on the analysis, a discussion of the implications for policy in the promotion of environmental technology

[1] For example, in 2006, the EU adopted a new Directive on Energy End-use Efficiency and Energy Services (2006/32/EC), requiring that member states adopt and aim to achieve an overall national indicative energy savings of 9% for the ninth year of application of the Directive (to be implemented in 2008).

innovation was conducted and suggestions for issues to consider in future policy plans were put forward.

1.3.3 Research Framework

During the initial stages of the GMCT project, a research framework was established by the project partners to be applied to all of the sectoral studies. Within innovation systems discourse, a number of activities that are necessary for innovation to occur have been put forward (see for e.g. (Jacobsson and Bergek, 2004)). Based on discussions amongst the GMCT project team, several of the key activities related to innovation – access to knowledge, access to resources and formation of markets – have been selected to form the basis for the project framework (see Figure 1-1). These activities represent preconditions which must be met in order for innovation to occur.

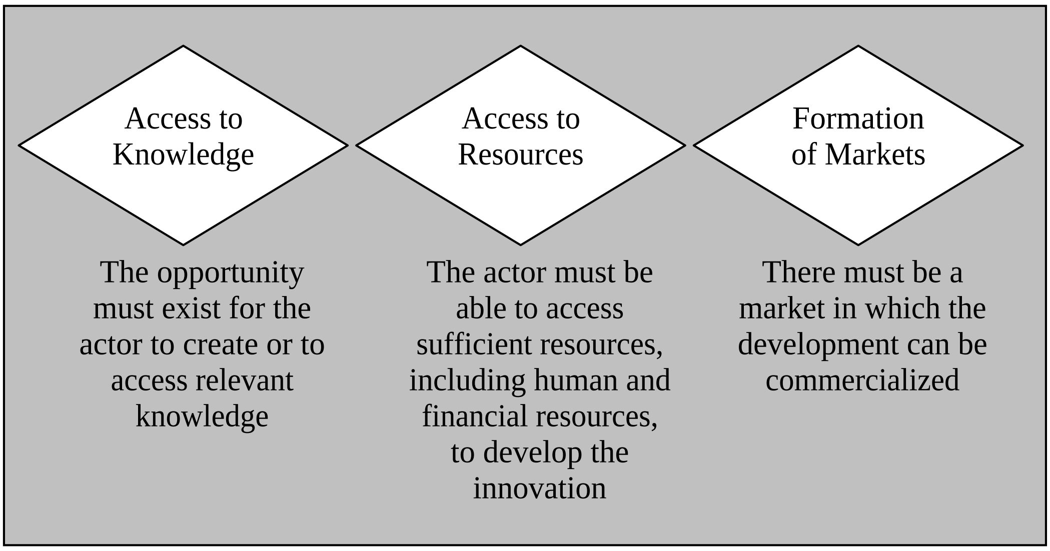

Figure 1-1 Preconditions for Innovation (Adapted from Rozite, 2006a)

Knowledge is a necessary precondition for innovation, including environmental innovation. This process can include the creation of new knowledge, for example through research, the application or modification of an existing idea to a new frame of reference, or the compilation of existing streams of knowledge to form a new solution. The involved actor(s) must have access to the required knowledge, must be able to process this knowledge, and must be able to relate it to an application. As a technological development proceeds, additional knowledge required to overcome barriers must be accessible. Further, the capacity to transfer the knowledge related to the innovation throughout the entire chain from conceptualisation to commercialisation must exist.

In order for an innovation to be realised, the necessary *resources* must be available to the involved actors. These resources include those of both a financial and a human nature. Technology innovations are often coupled with high R&D costs and a need to demonstrate the new technology prior to attempting commercialisation. Furthermore, in order for innovation to be realised, proper human resources must be available. These human resources bring with them the necessary knowledge and capabilities to allow innovation to occur. If the necessary resources are absent at any point along an innovation path, the process can be greatly slowed or halted.

Innovation involves the first commercialisation of a new idea. As such, the existence of a *market* is a necessary precondition to allow innovation to occur. Furthermore, in the case of environmental innovations, a greater benefit will be realised with their diffusion throughout the marketplace, in lieu of less environmentally favourable alternatives. Markets can be created "naturally", as a result of changes to the industry's internal market situation (e.g. a need for new products) or to changes to external markets (e.g. changes in energy markets), or they can be "forced" via regulatory measures.

These innovation preconditions, as outlined in Figure 1-1, form the basis for the analysis performed within this work.

Innovation is a complex process which is affected by many factors, including actors, institutions, and policies (Kemp, Smith et al., 2000). The characteristics of various sectors and of the related sectoral innovation systems can play a role in shaping the innovation process within a given industry (Malerba, 2005). An examination of these characteristics and of the corresponding barriers related to the innovation preconditions in a cross-sectoral perspective can serve to facilitate a better understanding of the environmental innovation process. From a policy perspective, both environmental and innovation policy represent interesting points of focus with regards to environmental innovations. These policy areas have received increasing attention in recent years with regards to their influence on environmental innovation. These policies can assist in the fulfillment of the necessary innovation preconditions by alleviating barriers that exist within the innovation process. Insight into how these policies affect the innovation preconditions within a sector and an identification of the characteristics of supportive policies can help to provide a clearer picture of the policy elements required to foster green innovations. Based on these premises and on the preconditions of innovation discussed above, the following framework (see Figure 1-2) is used within this thesis to guide the analysis of the collected materials.

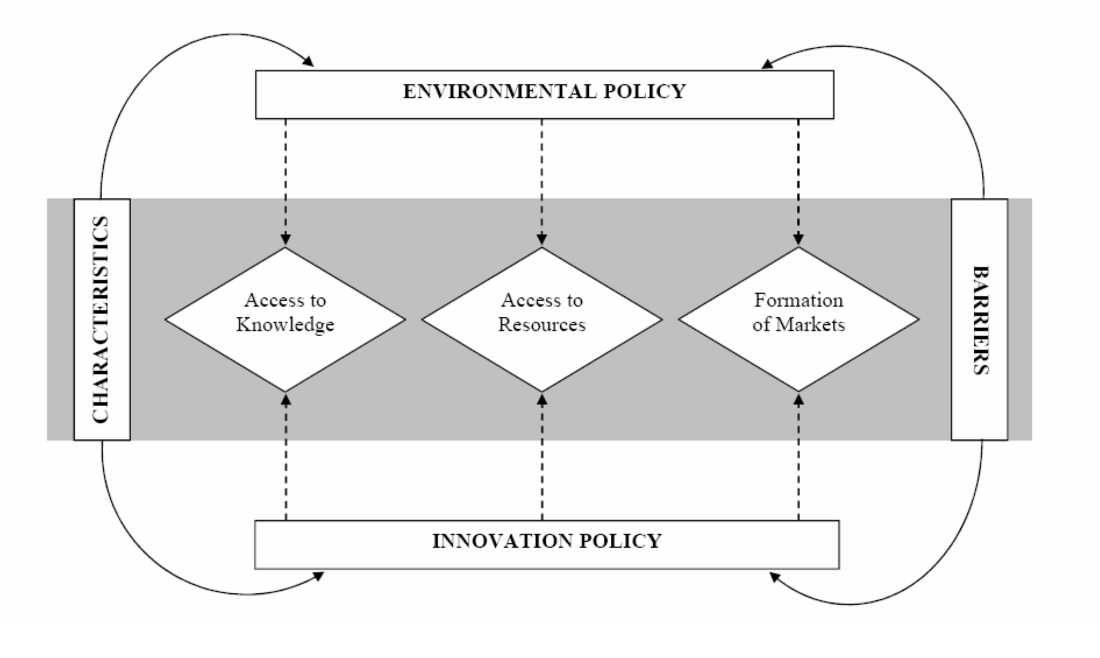

Figure 1-2 Analytical Framework

1.4 Scope and Limitations

This thesis focuses on policies to foster innovation in environmental technology. The geographic scope of this work includes the Nordic countries, with specific emphasis, by nature of the sector characteristics[2] and selected case studies, on Denmark, Sweden, and Finland.

Innovation is an intricate process that is affected by a number of factors including individuals, networks, institutions, and other framework conditions. This thesis, however, focuses primarily on the role of policy intervention in the process. Additionally, innovation is affected by a wide range of policy areas that can help to influence the setting in which it occurs. This thesis focuses specifically on the areas of innovation policy and environmental policy and their role in the innovation process.

While the achievement of sustainability is presumed to require innovation of various types, including social, organisational and technological innovations, this thesis focuses principally on the area of technological innovation. While innovation, as elaborated in Chapter 2, has been used to refer specifically to the first commercialisation of a new technology[3], the diffusion process whereby a "green" innovation permeates the marketplace can help to realise more widespread environmental benefit. Therefore, the thesis also considers the diffusion process as an important effect of government intervention.

Environmental technology encompasses a broad range of technologies such as cleaner materials and more resource and energy efficient products and processes. The environmental innovation cases examined in this thesis relate primarily to energy issues. Consequently, the discussions put forward largely concern energy-related innovations and policies. This being said, however, insights into the overall innovation dynamics of the sectors provided in the work may have a broader relevance to a number of environmentally-related innovations.

In order for sustainability to become an achievable goal, environmental innovations must occur and must be fostered across a broad range of sectors. However, this work is limited to innovations occurring in the pulp and paper, mobile phone and building industries. While a review of these sectors may also help to provide a wider view of the environmental innovation process, specific policy recommendations are limited to these areas.

1.5 Outline

This thesis is organised into a number of chapters.

Chapter 2 introduces the concepts of environmental technology, innovation and policy that are further called upon in this work.

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[2] In the case of the mobile phone industry, the major industry players in the Nordic countries are Swedish and Finnish, with a strong research core in Denmark. In the case of the pulp and paper industry, major Nordic production occurs in Sweden and Finland. In the case of the building sector, while it plays a significant role in all Nordic countries, the case studies focus on Denmark, Sweden and Finland.

[3] According to Schumpeterian tradition, there are three stages in which a new technology permeates the marketplace. The first is *invention*, which is the initial development of a scientifically or technically new product or process. The second stage is *innovation* whereby a new product or process is made available on the market (commercialised). The final stage of technological change is *diffusion*, where a successful innovation comes to be widely available for use in the appropriate marketplace (Jaffe, Newell et al., 2002). This is discussed further in Chapter 2.

Chapter 3 provides a review of literature pertaining to environmental and innovation policy and their effects on the promotion of innovation in environmental technology. A framework for the analysis of collected data based on this review is presented.

Chapter 4 presents the three sectors under discussion in order to provide insight into their innovation dynamics and the innovation setting in which the actors operate. The case studies for each sector are presented in detail. Work in this chapter is based on both literature and empirical data.

In Chapter 5, the collected materials are analysed and discussed. Based on this discussion, a series of potential policy directions are proposed.

Finally, in Chapter 6 major findings and recommendations are put forward.

2 Review of Literature: Introduction to the Concepts of Environmental Technology, Innovation & Policy

Environmental technology, innovation, and policy are key concepts in the discussion of how to foster innovation in environmental technology. The following section provides an introduction to each of these concepts.

2.1 Environmental Technology

Environmental technology has been touted as an important means of securing sustainable development goals, by permitting the decoupling of economic growth from environmental degradation (Stevens, 2000). While the historically narrow view of environmental technology is limited to those technologies developed uniquely for purposes of environmental improvement (one tends to think of emission control devices on smokestacks), the current understanding of the term broadens the perspective.

The definition of environmental technology, as provided in ETAP, includes "all technologies whose use is less environmentally harmful than relevant alternatives[4]" (European Commission, 2004). This broad definition of environmental technology has been further subdivided by Hemmelskamp (1997) into two major categories: **additive (end-of-pipe) technologies** and **integrated technologies**.

Additive technologies are disposal methods and recycling technologies related to actual production and consumption processes. These technologies modify the emissions so that they become less environmentally detrimental and/or transfer them to another medium (for example, in an air stripper, waterborne chemicals will be transferred to an air phase) which is easier to handle or which has been deemed as still being able to tolerate additional inputs. With these types of technologies, minor, if any, changes are required to the original production processes.

Conversely, **integrated technologies** begin at the source of the emissions (i.e. at the process or product itself). This includes, for example, the use of "cleaner" production techniques, which generate less residual waste and/or use less resources (e.g. energy-optimised control systems), the use of materials which are less environmentally harmful (e.g. solvent-free lacquers), and the production of products that have a lower environmental impact (e.g. products that use less energy or produce less waste). Within integrated technologies it is further important to distinguish between **products** and **processes**. Products refer generally to goods or services while processes refers to production methods, including methods of product delivery (OECD, 2005e).

[4] This definition in turn, is based on the definition provided in Chapter 34 of Agenda 21 for environmentally sound technologies: "Environmentally sound technologies protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substitutes. Environmentally sound technologies in the context of pollution are process and product technologies that generate low or no waste, for the prevention of pollution. They also cover end of the pipe technologies for treatment of pollution after it has been generated. Environmentally sound technologies are not just individual technologies, but total systems which include know-how, procedures, goods and services, and equipment as well as organisational and managerial procedures." (European Commission, 2004)

The types of environmental technologies discussed above, relate directly to specific products and processes. Banks and Heaton (1995), however, consider two additional categories of environmental technologies: **new systems** and **new technological fields**.

New systems comprise major changes in basic infrastructure such as energy, transport, and housing that move the system towards environmental sustainability. An example of this is the creation of an advanced public transportation system.

New technological fields include areas that can provide fundamentally different pathways for activities and processes, resulting in less environmental damage being realised. Examples include biotechnology, which could reduce the use of fertilizers and pesticides, and nanotechnology.

2.2 Innovation

The concept of innovation has been interpreted in many different ways throughout academia, government and society and there is no universally accepted definition. In a very general sense, innovation can be described as the introduction of a new idea, method, or device. In the discussion regarding innovations that are necessary to transfer the industrial state to a sustainable one, innovation can be broadly classified into three categories: **organisational**, **social**, and **technological** innovation – although the distinctions among these three may not always be clear (Ashford, 2001). It is also important to note that these classes of innovation are interrelated and can affect one another. Social innovation as defined below, for example, can shape the direction of technological innovation.

Organisational innovation is often used to refer to the larger organisational features of a firm, beyond the organisational features of a specific product line. This type of innovation is concerned with changes in and amongst various organisational aspects of functions of the firm, including research, product development, marketing, environmental and governmental affairs, industrial relations, worker health and safety, and customer and community relations. **Social** innovation has been used to refer to modifications in the preferences of consumers, citizens, and workers regarding the types of products, services, environmental quality, leisure activities, and work, as well as modifications to the processes by which they influence those changes. Social innovation can alter both the demand for and the supply of what the industrial state might offer (Ashford, 2002b).

The third type of innovation – **technological** – is the focus of this thesis. In the context of environmental technology and innovation, the term technological innovation is often presented as an element of the process of technological change. According to Schumpeterian tradition, there are three stages in which a new technology permeates the marketplace. The first is *invention*, which is the initial development of a scientifically or technically new product or process. The second stage is *innovation* whereby a new product or process is made available on the market (commercialised). The final stage of technological change is *diffusion*, where a successful innovation comes to be widely available for use in the appropriate marketplace (Jaffe, Newell et al., 2002). It is important here to note the distinction between invention and innovation. As articulated by Schumpeter: "Innovation is possible without anything we should identify as invention, and invention does not necessarily induce innovation, but produces of itself . . .no economically relevant effect at all," cited in (Ruttan, 1959). In this sense, a firm can innovate without ever inventing by recognising an existing technological idea that was never brought to market and by commercialising this idea (Jaffe, Newell et al., 2002). The distinction between innovation and diffusion often becomes blurry, due to the nature of the innovation process. In many cases it is difficult for the new users to adopt the technology without some additional modification. When modifications are extensive, a further innovation may result (Ashford, 2001).

It is important to note that within the area of environmental technologies, the diffusion of innovations can be highly significant. While the commercialisation of new technologies represents a notable first step, the diffusion of these innovations throughout a sector is essential to bring about significant environmental benefits. For example, if "environmentally-improved" insulation exists but, in application, is used only in a small niche market of homes, a lesser environmental benefit will be realised than if the new technology is widely diffused. As such, while this thesis is concerned with environmental technology innovations, their diffusion is also considered.

Technological innovation can be further divided into four main categories, according to Freeman and Perez (1991): **incremental** innovation, **radical** innovation, changes of **technology systems**, and changes in **techno-economic paradigms**.

Incremental innovation involves the improvement of an existing technology for established markets and generally consists of continuous improvements within an industry or service (Ashford, 2001). An example of incremental innovation is the modification of a certain stage in the production process to improve productivity. This type of innovation often occurs as a result of inventions and suggestions by those directly involved in the production process or from proposals by users themselves, rather than by deliberate R&D (R&D) activity. While the combined effect of a number of incremental innovations is important for growth and productivity, the effects of any single incremental innovation are modest (Freeman and Perez, 1991).

Radical innovation is the introduction of a technology for a new market, implying that the innovation takes place in an environment of uncertainty (Ashford, 2001). These types of innovation are discontinuous events and are usually the result of deliberate R&D attempts. An example of this type of innovation is the appearance of nylon in the fabric industry. Over a long period, radical innovations may have relatively substantial effects however the overall economic impact is usually small and localised. Exceptions to this result when a cluster of radical innovations link together to give rise to new industries and services (Freeman and Perez, 1991). Radical innovation typically renders a considerable part of a company's investment in knowledge and expertise, processes, and infrastructure obsolete (Jänicke, Blazejczak et al., 2000).

Changes of technology systems are the result of a range of social and technological (socio-technical) innovations occurring at both the radical and incremental levels. These types of innovations can give rise to new industrial sectors and induce major changes across several branches of the economy. Examples of these types of innovation include innovations in synthetic materials and innovations in injection moulding (Freeman and Perez, 1991).

Changes in techno-economic paradigms are innovations with the most far reaching effects. These types of innovations involve clusters of both incremental and radical innovations, lead to the materialisation of new products, services, systems and industries, and have a major influence on the behaviour of the entire economy. These types of innovations result in changes to engineering trajectories as well as to changes in the cost structure and production and distribution conditions throughout the system. Once they have exerted dominant influence on engineers, designers and manufacturers, they can result in a "technological regime" that can last several decades. Examples include the emergence of steam power (Freeman and Perez, 1991).

It is important to recognise that the adoption of an innovation is not based solely on its characteristics, but is also influenced by its compatibility with existing systems and structures. New innovations are dependent on a network of relations or systems and changes to existing systems must be made to accommodate these new innovations. The more radical the innovation, the greater the change required and the greater the resistance and inertia faced. Consequently, the process of innovation tends to take place in a particular trajectory with incremental innovations often being favoured over more radical, change-demanding, ones (Murphy and Gouldson, 2000).

2.2.1 Innovation Theories

Theories of innovation can be classified as **linear** or **systems-oriented**. The **linear** model of innovation is based on the concept that science leads to technology and that technology satisfies market needs. In this view, there is a smooth, uni-directional flow from basic scientific research to commercial applications (or vice versa) with no feedback from the latter stages of the innovation process (e.g. product development and marketing) to the initial stage of research (Edquist and Hommen, 1999). The technology push theory is a linear model whereby the scientific or technological advances push a new product into the market. In the market pull model, market needs draw a new product into the market (Galanakis, 2006). These two models are depicted in Figure 2-1.

Basic Research → Producer → Market

Basic Research ← Producer ← Market

Figure 2-1 Technology Push/Market Pull Theories of Innovation (Widén, 2002)

A number of problems with the linear model of innovation have been noted, including a lack of feedback paths not consistent with practice, the realisation that not all scientific research leads to the design of innovations, and the fact that technological innovations, according to their definition, may proceed without ever interacting with science (Edquist and Hommen, 1999).

System-oriented innovation theory began to emerge in the 1980s and 1990s as a response to the growing challenges to the linear models (Galanakis, 2006). The Innovation System (IS) approach is based on the idea that innovation and diffusion of technology is both an individual and collective act (Hekkert, Suurs et al., 2007). Innovation, in this approach, can be seen as a complex series of interactions between a firm and its environment. It is a collective activity, which is distributed across many actors (Kemp, Smith et al., 2000). The innovation system can be defined as all the institutions and economic structures that affect the rate and direction of technological change experienced in society. Determinants of technological change are found within the innovation system as well as in the individual firm (Hekkert, Suurs et al., 2007).

Various types of innovation systems have been identified within the innovation system perspective. Two common distinctions include territorially-based systems (which build on some sort of geographical proximity – local, regional, national, global, etc.) and technologically-based systems (industry sectors, specific technologies). It is important to note that these systems are open and can overlap; a specific firm may, for example, belong to more than one system (Gregersen and Johnson, 1996).

National innovation systems refer to firms, organisations and government agencies which interact with each other in ways that influence the innovation performance of a national economy. The system is influenced by parts of the institutional set-up, knowledge infrastructure, demand structure (i.e. consumer tastes), and government policy (Gregersen and Johnson, 1996).

Regional innovation systems are based on the idea that innovation results are determined by an institutional infrastructure and production system that exists within a certain territory. Innovation is dependent on the stock of knowledge created by the firms and institutions within that territory and on how they interact with one another and their environment (Doloreux, 2002). The rationale for focusing on regional innovation systems is based upon the notion that the factors which are identified in the national innovation systems theory to be important (e.g. R&D activity, innovation activity), can differ significantly across regions (Oughton, Landabaso et al., 2002).

A sector, as defined by Malerba (2005), refers to a "set of activities which are unified by some related product groups for a given or emerging demand and which share some basic knowledge". A **sectoral system** of innovation, consequently, is one which shares a knowledge base, technology, actors and networks, and institutions aimed at innovating and diffusing new products within a given sector (Malerba, 2005). Within the field of innovation studies, it has been widely recognised that the sectoral features of a particular industrial sector play a significant role in influencing the innovation process (Reichstein, Salter et al., 2005).

2.2.2 Environmental Innovation

Environmental innovation is a particular subset of innovation, which has been broadly defined as the use of production equipment, techniques and procedures, and products and product delivery mechanisms that are sustainable (i.e. that conserve resources and energy, minimise environmental impact and protect the natural environment) (Dewick and Miozzo, 2004). While some have argued that environmental innovation refers to those innovations intentionally aimed at reducing the negative environmental impacts caused by products and processes (Hemmelskamp, 1997), others have argued that it is any innovation that serves to improve the environment regardless of original intention (Klemmer, Lehr et al., 1999; Kemp, Smith et al., 2000).

In this thesis, the term "environmental innovation" is used to describe all innovative technologies whose use is less environmentally harmful than relevant alternatives, in correspondence with the concept of environmental technology used in the European Commission's ETAP, regardless of the original motivation for the innovation.

While environmental innovations may vary greatly amongst themselves, there are a few generally accepted basic characteristics of this subset of innovation. Firstly, it is generally agreed upon that environmental innovation is the result of a multidimensional package of factors. Secondly, environmental innovation appears to be characterised by a very long term and supranational perspective. Thirdly, in many cases, the success of environmental technological innovation depends upon the complementary organisational and social innovations. Fourthly, high risk levels can be associated with the uncertainty and lengthy maturation terms of these types of innovations (Lehr and Löbbe, 2000).

Environmental innovations are further characterised by their "public goods" nature. While the costs of the innovation are borne solely by the innovator, society as a whole benefits from the innovation (for example, while a company may pay to develop or adopt a process that produces less harmful emissions, all of society will benefit from the cleaner air). However, there may be no one consumer group that is willing to pay for this public benefit (Beise and Rennings, 2005). As long as markets do not charge for negative environmental impacts (that is, that the costs of environmental damages remain negative externalities), competition between traditional and environmental innovation will be distorted. Therefore, the state plays an important role in fostering environmental innovations through policy measures that serve to address this imbalance. This peculiarity regarding environmental innovation requires a change to the traditional "push-pull" innovation model, which discusses whether innovation is spurred by a push from technology or by a pull from the market. In the case of environmental innovation, a third push/ pull factor, regulatory measures, plays an important role. This altered model of innovation is provided in Figure 2-2.

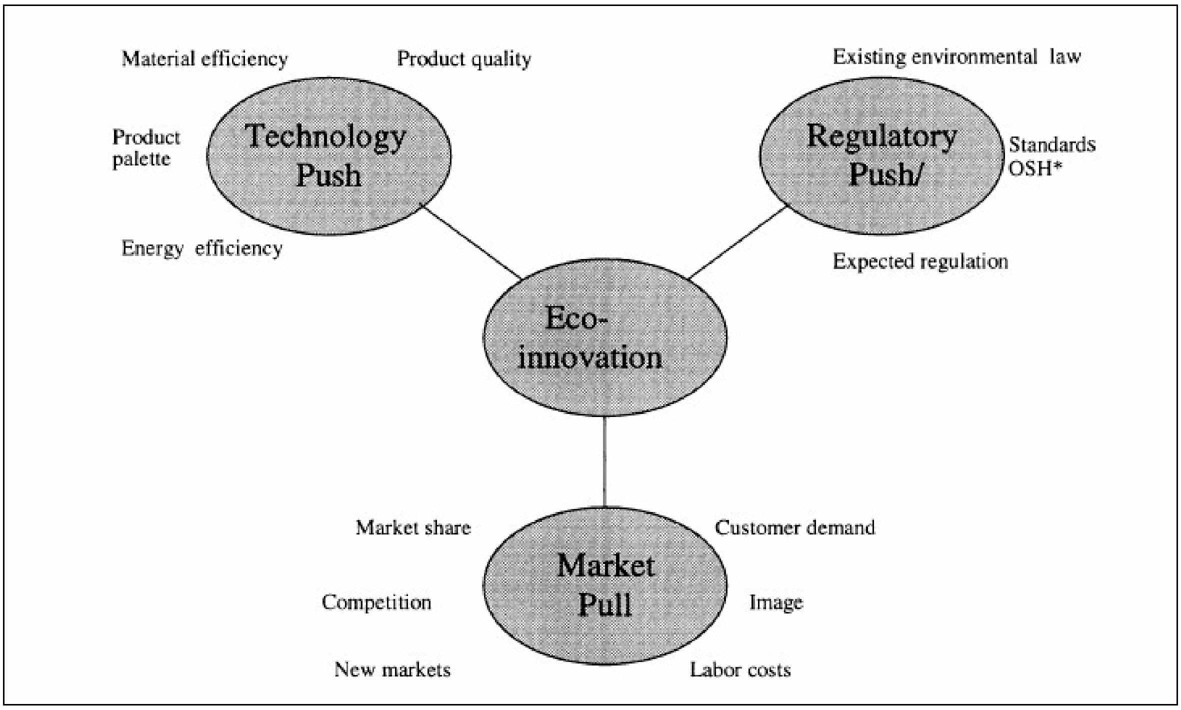

Figure 2-2 Determinants of Eco-innovation (Rennings, 2000)

2.3 Policy

Public policy refers to a course of action chosen by government to address a specific problem. Public policy instruments, in turn, are defined as the set of techniques used by governmental authorities to achieve their specific objectives (Howlett, 1991). Throughout the literature on policy analysis and public administration, numerous classifications of policy instruments have been proposed. For the purposes of this thesis, and based on the typologies provided by Vedung (1998), Gunningham et al. (1998), and the Finnish Ministry of the Environment (2007), the following classification of policy instruments is used:

- Administrative
- Economic
- Informational

Administrative instruments refer to those measures taken by governmental authorities to influence individuals by means of formulated rules and directives by mandating them to act according to these rules (Vedung, 1998). These instruments are commonly referred to as "command and control" or "direct" regulations and tend to focus on enforcements and restrictions. Examples include occupational health and safety standards which regulate working conditions, emission limits, performance standards which mandate a certain performance that must be achieved by a product, and prohibition or mandating of certain activities.

Economic instruments are those measures which involve the allocation or removal of material resources, either in cash or in kind. These types of instruments make it cheaper or more expensive to engage in certain activities and they can be further subdivided into incentives or disincentives (Vedung, 1998). Economic incentives can include such things as the provision of subsidies for certain activities, reduced interest loans, tax exemptions, procurement activities and property rights. Economic disincentives can include such things as taxes, charges, fees, the creation of markets (i.e. through the issue of tradable pollution rights), and liability instruments (e.g. through civil liability).

Informational instruments refer to those instruments that attempt to influence the behaviour of individuals through the transfer of knowledge (Vedung, 1998). Examples include public awareness campaigns, the provision of training programmes, award schemes, public pollutant inventories and product labelling (e.g. to identify for customers the environmental properties of a certain product).

Within each policy instrument class, the policies can range from **mandatory** to **voluntary**. For example, economic instruments such as subsidies have a voluntary nature. That is, the choice of their use is optional and dependent on the user. No sanctions will be imposed if these subsidies are not used. Conversely, taxes which must be paid on a given volume of pollution are mandatory in nature. That is, the polluter is obliged to pay the necessary amount of taxes as calculated and could face sanctions if they do not act as required. In many cases, administrative instruments are mandatory in nature (e.g. fixed emission limits that must not be exceeded by an industry). However, in some cases, industry might choose to "self regulate", resulting in a voluntary administrative instrument. In this particular case, an organised group (e.g. a specific industry) may organise its own rules and standards related to the conduct of the group. A well-documented example of this is the Responsible Care programme which has been implemented by the chemical industry in over 40 countries (Gunningham, Grabosky et al., 1998). In other cases, this voluntary administrative instrument might entail a voluntary agreement made between the government and a particular organisation. Examples of these types of agreements include energy saving programmes whereby certain businesses or industries voluntarily agree to undertake energy efficiency measures. Other examples of voluntary agreements include the adoption and use of environmental management systems (EMS) such as EMAS or ISO 14001 by individual organisations. In the category of informational instruments, voluntary policies may include things such as eco-labelling schemes, where a given company can choose whether or not to participate in labelling their products. Conversely, mandatory informational policies may include such things as emission inventories, whereby a company is mandated to disclose to the public their pollutant emission levels.

Governmental bodies have a wide array of policy portfolios, ranging from health care to foreign affairs. In each of these policy areas, they create policies and employ a variety of instruments to steer society towards specific goals. As this thesis focuses on innovation in environmental technology, two specific policy areas – environmental policy and innovation policy – are given special attention.

2.3.1 Environmental Policy

Environmental policy refers to the body of laws, regulations and other policy mechanisms which the government creates and employs to deal with issues concerning the environment and sustainability. Externalities are costs or benefits arising from an economic transaction that are borne or received by parties who are not directly involved in the transaction. Pollution resulting from various production and consumption activities represents a type of negative externality. The aim of environmental policy is to address this market failure and to correct these negative externalities through the use of standards, taxes and other instruments (Grubb and Ulph, 2002).

Environmental policy gained prominence in the early 1970s, when public environmental concern pushed governments in most developed countries to introduce a number of regulations designed to prohibit or restrict environmentally harmful activities (Gunningham, Grabosky et al., 1998). These early models of environmental policy making were based largely on the approach of “command and control” regulation, such as mandatory emission limits on industries. While “command and control” regulation, such as standards, continue to play an active role in the environmental policy portfolio, in more recent years the domain of environmental policy has seen the increasing employment of voluntary agreements and economic instruments to achieve environmental goals (Jordan, Wurzel et al., 2003). These instruments include agreements between industry and authority to implement specific measures (such as energy efficient equipment) or to achieve specific standards on a voluntary basis, as well as emission taxes and tradable permits schemes.

2.3.2 Innovation Policy

The innovation process itself is also subject to a number of market failures. These include: failure to get the right number of firms to innovate and to choose the right research paths; failure of firms to undertake the correct amount of R&D; and lack of incentives for firms to share their discoveries with rival firms (Grubb and Ulph, 2002). In order to address these failures, intervention in the form of innovation-related policies is frequently undertaken.

In order to understand the concept of innovation policy, it is useful to first have a brief understanding of the policies related to its conception. Government intervention in scientific research largely took place in the post World War II era with the emergence of national science policies in many countries. These types of policies were largely concerned with the generation of scientific knowledge. These policies were followed in the 1970s by technology policies, which focused on the promotion of industrial application of knowledge. In the 1990s, a viewpoint began to emerge throughout the EU that existing technology policies were incapable of addressing the complex process of innovation. The result was a new focus on the creation of innovation policies, aimed at better responding to the complexities of the innovation process (Borrás, 2003).

To provide a clearer understanding of the evolution and distinction of science, technology, and innovation policy, Borrás (2003) has provided a graphical illustration of the evolution of these policies typologies and their major characteristics.

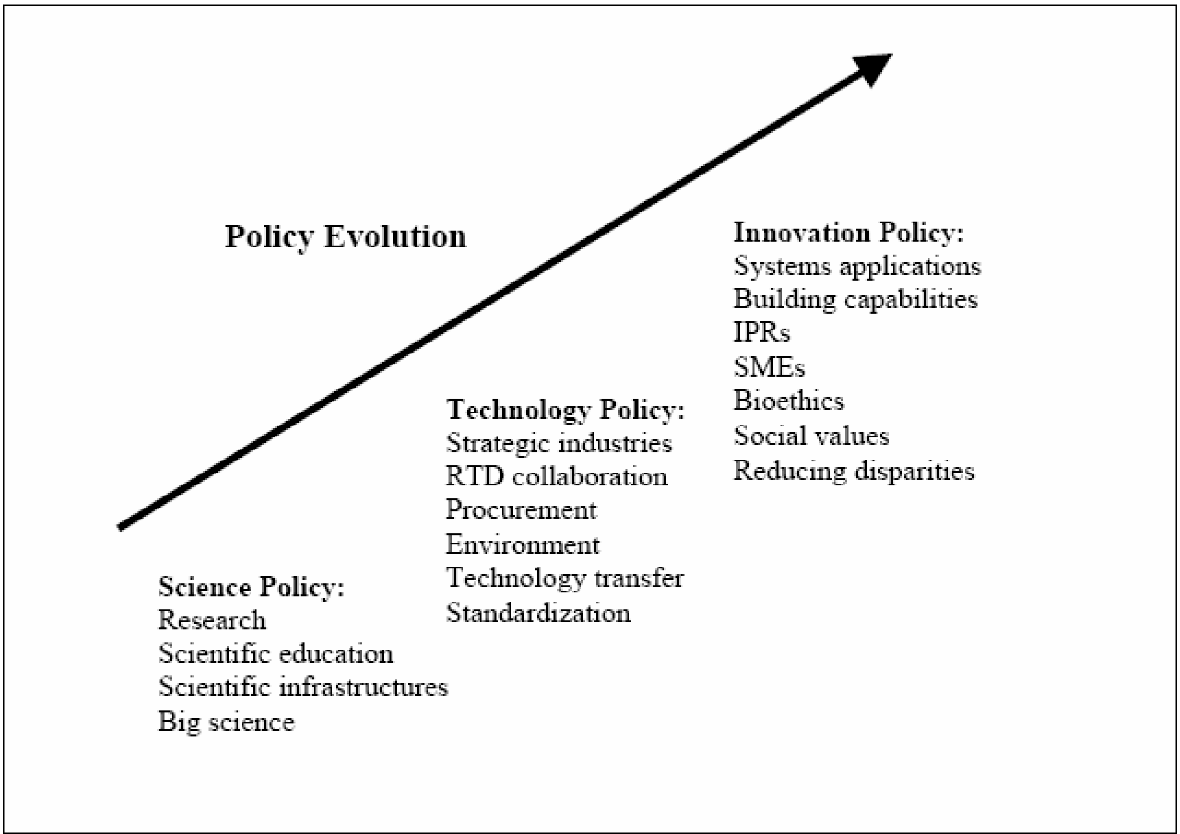

Figure 2-3 Evolution of Science, Technology and Innovation Policy (Borrás, 2003)

There are varying definitions of innovation policy throughout the literature, but one general explanation which has been offered up by Dodgson and Bessant (1996) is as follows: "Innovation is a process which involves flows of technology and information between multiple actors, including firms of all sizes and public and private research institutes. Innovation policy's principal aim is to facilitate this interaction". Another, more detailed, definition to supplement this overview is provided by Georghiou (2006):

> *…Any policy which seeks to help firms, singly or collectively, to improve their capacity to innovate may be seen as innovation policy. This includes the provision of scientific infrastructure in research and education and direct and indirect support for research and technological development. It also includes a wide range of policies which aim to build networks, to make markets more conducive to innovation, to facilitate the transfer of technology, to help firms to acquire relevant capabilities, and to provide a supporting infrastructure in areas such as standards and intellectual property. Many other public policies also affect innovation, though this is not their main objective. This group includes macro-economic policies, education, more generally, public procurement, regulation (pollution or health and safety) and competition policy.*

Despite the increasing focus on innovation policy by academics and governments, there are still differing opinions regarding its contents and boundaries. Two general interpretations of innovation policy co-exist. The first is the "wide agenda", which includes things such as information and advice to innovators, technology foresight programmes, competition policy, education and training, and organisational change above and beyond the typical policy instruments of provision of finance and support for networking. In this wide view, Borrás and Lundvall (1997) in their report entitled, "The Globalising Learning Economy", consider innovation policy as:

> *…elements of science, technology and industrial policy that explicitly aim at promoting the development, spread and efficient use of new products, services and processes in markets or inside private and public organisations. The main focus is on the impact on economic performance and social cohesion…[It] includes policies which aim at organisational change and the marketing of new projects.*

The "narrow agenda" of innovation policy corresponds to the definition provided by Georghiou above and imposes more narrow functional limits on the scope of innovation policy by excluding such areas as education and training, telecom infrastructures, or competition policies. This narrow definition of innovation policy has been adopted by the EU in their innovation efforts (Borrás, 2003). As such, this "narrow" form of innovation policy is the definition used in this thesis work. However, since the boundaries between innovation policy and other related policy areas are highly flexible, these other areas may be called upon where required.

2.3.3 Historic Interactions of Innovation Policy & Environmental Policy

Historically, innovation policy and environmental policy have existed as distinctly separate entities with little interaction. It has been argued that environmental protection imposes additional costs on firms and thus has negative effects on economic growth and welfare. Conversely the aim of innovation policy is to orient private companies toward economic goals. In light of this, it is not difficult to see the apparent discord between innovation and environmental policy. This discord has been confirmed in practice and it has been noted that existing innovation policy is poorly coordinated with other policy areas (particularly environmental policy), and that it is not sufficiently oriented towards environmentally beneficial system innovations (Gross and Foxon, 2003; Ruud and Larsen, 2004; Kemp, 2007).

Despite this previous misalignment, however, interest in a better coupling of environmental policy with innovation policy is beginning to grow. The prices of many goods do not reflect resource use or environmental externalities and the result is "clean" substitutes which tend to be more expensive than conventional technologies. The environmental benefits reaped are more public than private and the result is insufficient industrial investment and inadequate technological innovation. As such, it has been observed that governments have an important role to play in providing a climate for environment-related innovation through future environmental policy designs (Stevens, 2000). Innovation-oriented environment policy is an extremely attractive option for policy makers, as it is expected that innovation can cut costs of environmental measures and overcome existing trade-offs between economic and ecological goals (Rennings, Hemmelskamp et al., 2000).

In addition to this growing interest in coupling environmental policy with innovation goals, more recently attention has also been drawn to the need for better integration of environmental considerations into innovation policy design (Ruud and Larsen, 2004). Governments in developed countries have recognised that environmental technology may represent an increasingly important market segment over the coming years, as the needs and demands for this technology continue to grow. Consequently, innovation in the field of environmental technology represents an important potential source of economic growth that has captured the interest of policymakers.

3 Review of Literature: Policy & Innovation Effects

Interest in the relationship between policy and innovation has grown over the past decade. In relation to the issue of innovation in environmental technology, there are three pertinent streams of literature that merit consideration here.

The first stream of literature takes on an environmental policy perspective. These works focus on environmental policies, as defined in Section 2.3.1 above, and study, in turn, the respective effects of these policies on fostering environmental innovations. This method looks at if and/ or how environmental policies can be used to promote innovative environmental technologies.

The second stream of literature is related to the field of innovation policy. Innovation policy is largely concerned with setting the framework for innovation to occur within a state. These works focus primarily on how innovation policies can be used to foster innovation-conducive systems and to promote innovative activity throughout the economy. As such, there is a relatively more minor focus on the promotion of specific goals within the innovation system (e.g. sustainability, ICT, etc.).

The third stream of literature which is emerging in regards to innovation in environmental technology is related to policy integration. This approach moves beyond individual policy areas, focusing on the interaction between innovation and environmental policy and the integration requirements of these two policy fields. In some cases, it calls upon a new class of "sustainable innovation" policy (Foxon, Pearson et al., 2005).

In the following sections, literature findings from each of the approaches are synthesised and discussed in relation to the innovation pre-conditions outlined in Section 1.3: access to knowledge, access to resources, and market formation. Furthermore, general characteristics regarding environmental innovation-friendly policies are outlined.

3.1 Environmental Policy & Innovation Effects

Interest in the relationship between environmental policy and innovation has grown over the past ten years (Jaffe, Newell et al., 2002). Various theoretical frameworks including traditional environmental economics, innovation research, new growth theory, institutional economics, policy analysis and evolutionary economics have been applied in an attempt to understand environmental innovation (Klemmer, Lehr et al., 1999; Rennings, Hemmelskamp et al., 2000). Despite the usefulness of the theoretical background of these frameworks, however, there has been consensus that a simple analytical framework cannot do justice to the complex and interdependent influence of environmental policy on innovation (Jänicke, Blazejczak et al., 2000).

There is an increasing literature regarding the actual effects of environmental policy on technological innovation and change. That literature which relies on empirical evidence can be grouped into two main categories – 1) case studies and 2) econometric and modelling analyses. Case studies have included those cases conducted under the German "Innovation Impacts of Environmental Policy" (FIU) project framework (Klemmer, Lehr et al., 1999), as well as reviews of renewable energy technologies (Christiansen, 2001; Skjaerseth and Christiansen, 2006), the pulp and paper industry in both Europe and the U.S. (Norberg-Bohm, 1998; Kivimaa, 2007a), the U.S. chemical manufacturing industry (Ashford), and end of life vehicles legislation (Manzatti and Zoboli, 2006), amongst various others. A number of econometric and modelling analyses of the innovation effects of environmental policies have focused on R&D expenditures and patents as an indicator of innovation, (Jaffe and Palmer, 1997; OECD, 2005a), though limitations to both of these methods as an accurate marker of innovation have been noted. Some of these works take a top-down approach, examining the effects of a specific policy measure, some take a bottom-up approach, examining the motivations behind certain environmentally beneficial innovations occurring in industry, and others take a combined approach.

Despite this growing literature it is commonly perceived that the relationship between environmental policy and technological change is still poorly understood (Skjaerseth and Christiansen, 2006). It is also recognised that few environmental policy instruments, thus far, have been designed with the primary intention of promoting innovation[5]. Amongst the exceptions to this are extended producer responsibility legislation (EPR) such as the European Community Directive on Waste Electrical and Electronic Equipment (WEEE), and the EURO norms for vehicles, which specify European engine performance. Consequently, many innovations which have arisen from environmental policies in the past have done so as “side effect” (Kivimaa, 2007a). However, the issue of innovation in the environmental policy field has been receiving increasing interest over the past several years and there is an ongoing trend to include innovation as an environmental policy evaluation criterion.

Policy Discussion

As previously mentioned, within the environmental policy portfolio, the most commonly employed instruments have traditionally been administrative. From a theoretical standpoint, administrative environmental instruments (including bans, product specifications, emission standards, etc.), are typically considered to be rather innovation impeding, since the pollutant emitter is no longer interested in a further reduction of emissions once they have met their target (Hemmelskamp, 1997; OECD, 1999). Despite this claim, however, it is commonly recognised that the actual effects of regulation often differ from theory and a number of empirical studies having been conducted regarding the relationship between administrative instruments and environmental innovation.

Support for the use of administrative instruments in the stimulation of environmental innovation has come from a number of studies. Ashford (2002a) conducted a series of U.S. studies on the effects of health and safety regulation in the 1980s and concluded that properly designed and implemented regulation, complemented – but not replaced – by economic incentives, is of strategic usefulness towards innovation in environmental technology. In studies of the construction industry in both the U.K. and the Netherlands, it has been found that administrative instruments, such as building regulations and performance standards, are a key factor in promoting innovation in the building industry (Dewick and Miozzo, 2002; Vermeulen and Hovens, 2006). In the 1990, the state of California implemented a Zero Emission Vehicle (ZEV) regulation, mandating that 2% of all passenger cars and light trucks sold in the state by every major car manufacturer must be zero emission vehicles, beginning with the 1998 models. This mandate was said to have been a crucial condition for large scale investments in fuel cells, as well as attracting new entrants with innovative technologies to the industry (van den Hoed, 2007). Several studies (based on the Nordic pulp and paper industry

[5] It should be noted that there is ongoing debate regarding the role of environmental policy as an agent of innovation. One school of thought believes that environmental policy should focus on the principle goal of protecting the environment. The other argues that environmental policy can and should also be used as a tool to foster innovation within the environmental field to help realise significant, beneficial changes.

and the German manufacturing sector) have noted the differing effects of administrative instruments on process versus product innovations. These works have concluded that strategic market goals are a significant influence in regards to environmental product innovation, while environmental process innovation is determined to a greater extent by environmental regulation (Rennings and Cleff, 1999; Kivimaa, 2007a).

A comprehensive series of studies conducted as part of a German research project in a variety of industries attempted to shed some insight into the specific outcomes of administrative instruments in terms of environmental innovation encouragement. These studies revealed that the use of regulation alone had only a trivial effect on the creation of new knowledge. Exceptions to this, however, have been noted in the case of drastic regulation, such as the CFC ban which was considered to have made considerable contribution to **knowledge creation** and the development of new solutions in several cases (Klemmer, Lehr et al., 1999). This reinforces the notion that the stringency of regulation can play an important role in determining the degree of innovation (i.e. more stringent regulation, such as a ban, results in more radical innovation) (Kemp, 2000). The studies also revealed that, while mandatory instruments had a limited effect on creation of knowledge, they played a key role in the adaptation and diffusion of technology into the **marketplace** (Klemmer, Lehr et al., 1999). Significant attention has also been paid by Klemmer, Lehr et al. (1999) to the basis for a particular standard or limit and its effects on innovation. According to their study: "…in the vast majority of cases, the Best Available Technology determines the state of the art, and therefore offers little in the way of incentives [for innovative activity]."

One programme which has been designed to help overcome this issue and to promote continual improvement of energy efficiency in certain product groups is the Japanese Top Runner programme. The programme introduces product-specific energy performance requirements, where the basis for adopting the standards is defined as the use-phase energy performance of the best available technology (BAT) on the market at the time of revision of the standard. The programme undergoes recurring revisions based on pre-determined timelines. The programme has generally been considered to be successful by stakeholders though some criticism of too-low target setting (potentially reducing the push for innovation) has been put forward (Nordqvist, 2006).

In addition to effects stemming from the actual implementation of an administrative instrument, there has been significant discussion regarding the effects related to its announcement. It has been noted that there exists a sort of "announcement effect"', whereby the announcement of a pending regulation has a greater effect on innovation then the regulation itself (Klemmer, Lehr et al., 1999). This "announcement effect" has been observed throughout the literature on a variety of other occasions (Kemp, Smith et al., 2000; Hyvättinen and Hildén, 2004; Wettestad, 2004; Kivimaa, 2007a), indicating that the expectation of an impending regulation can play an important role in the innovation process.

By stipulating the requirements for new products or processes, administrative instruments can force the creation of a **market** which entails the adaptation and/ or diffusion of infant technologies. In some cases, where regulation is extreme (such as a ban), these instruments can create a **market** for an entirely new set of products or processes and spur **knowledge** creation.

A number of studies have also considered the impacts of voluntary and informational environmental instruments on innovation. Based on the findings of Klemmer, Lehr et al. (1999), voluntary agreements stimulated creation of knowledge only to a "no regrets" point, which produces results similar to the business-as-usual case. This result was echoed by

Skjaerseth and Christiansen (2006) who, based on studies of the renewable energy sector in several European countries, found that mandatory instruments rather than voluntary ones appear more effective in terms of technological change. Klemmer, Lehr et al. (1999), however, did note that voluntary agreements played a role in assisting **adaptation** and **diffusion** of technologies, by limiting risk and uncertainty throughout the market. Findings regarding the performance of informational instruments such as ecolabels and environmental management systems (EMS) in terms of fostering innovation have also yielded mixed results. In some cases ecolabels have been shown to have had little impact on innovation while, in others (such as the case of energy efficient Danish refrigerator case and U.S. Energy Star), labels have been shown to be an effective component of an innovation-fostering system (often in conjunction with public procurement policies) (Klemmer, Lehr et al., 1999; Rehfeld, Rennings et al., 2007). Studies have shown similar mixed results for the ability of EMS systems to inspire innovative activity. In the case of the Dutch programme on Environmental Management and the British adoption of the European EMAS regulation, the reason that firms chose to participate in the EMS programmes was to improve their capability to respond to increasingly stringent environmental regulation from government and participation in the programmes had little effect on innovation (Norberg-Bohm and de Bruijn, 2005a). Similarly, a study by Kautto (2006) involving companies in the electronics, machinery, and pulp and paper sectors showed only a weak or absent link between EMS and product development. Conversely, an econometric analysis of data from the German manufacturing sector by Rehfeld, Rennings et al. (2007) showed a positive effect of EMS systems in environmental product innovations.

In their book *Industrial Transformation*, Norberg-Bohm and de Bruijn (2005b) have reviewed a series of "innovative" policy instruments which are characterised by a voluntary, collaborative and/ or information-based nature (including the US Energy Star Programme, Cleaner Technology in Denmark, and the Dutch Target Policy Group). According to Norberg-Bohm and de Bruijn, there are three main arguments for the usefulness of these instruments in promoting technological change. The first is their potential to create new relationships between stakeholders. The second is their potential to engage industry in a learning process that creates the capabilities within firms to make significant environmental improvements. The third is their ability to create first movers within an industry. In their review of various voluntary policy initiatives in place in the U.S. and Europe (the Dutch Target Group Policy, the German end-of-life vehicles policy, the U.S. Energy Star, and the U.S. Common Sense Initiative) it was concluded that: "The new approaches are not a panacea for industrial transformation….There will remain a role for direct regulations and market-based approaches as part of an overall strategy – these mechanisms will be needed to create sufficient pressures to push industry along the path towards sustainability." Furthermore, it was noted that linking these voluntary programmes more directly to government policies that provide imperatives or incentives for action (such as subsidies, standards, or threats of standards) results in a greater level of effectiveness. As such, it appears that the encouragement of knowledge creation and networks to facilitate the sharing of this knowledge may not be entirely sufficient without additional efforts to provide either supply side stimulus, such as economic resources, or demand side stimulus for market formation.

In recent years, a move towards the use of economic instruments in the environmental policy field has been seen. These instruments largely fall into the category of economic disincentives, such as pollution charges, taxes and tradable emission permits. A number of theoretical arguments have been put forward regarding the use of these market-based instruments to stimulate environmental innovation. Within traditional environmental economics, market-based instruments have been identified as environmental policy instruments with the highest dynamic efficiency (Rennings and Cleff, 1999). However, in the real world, the information necessary to establish the appropriate environmental tax rate does not exist, meaning that the rate must be fixed according to a trial and error method. In the event that the rate is set too high, capital will be tied up and will no longer be available for R&D activities. In the event that the rate is set too low, existing and economically desirable methods may never become competitive (Hemmelskamp, 1997). In the case of tradable permits, the incentives of the permit towards innovation may be lost in the long term, due to an improvement in performance coupled with a decrease in demand for permits and, hence, their price. Additionally, while a shorter period of validity for issued permits may be of greater benefit for authorities (providing them with greater flexibility), the result for industry of a shorter permit time will likely be innovation that can be quickly adopted – particularly, an end-of-pipe technology. Furthermore, tradable permits have been criticised for making it possible to create barriers to market entry for new and potentially innovative companies (Hemmelskamp, 1997). As such, these permits could potentially serve as a hindrance to the bringing of new resources to the field.

Empirical studies have reported similar mixed results regarding the effects of market instruments on environmental innovation. In terms of tradable permits, some innovation-related studies have been conducted regarding the U.S. SO_2 permit trading scheme (e.g. (Burtraw, 2000)). According to Burtraw, the permit trading scheme resulted in several forms of innovation (primarily changes in production processes, organisational behaviour, and regulation), though the innovation realised was generally not of a patentable nature. In an early German study on an effluent tax, it was concluded that in the area of residual pollution the effluent levy failed to have any dynamic innovative effects (Hemmelskamp, 1997). Contrary to this, a study of the CO_2 taxes applied in the Norwegian petroleum sector revealed that some innovations (including several radical ones) occurred after the implementation of the tax and concluded that less innovation likely would have happened in absence of this instrument. However, it was also noted in this case that there were highly specific circumstances existing which favoured the implementation of many of the most important innovations (Christiansen, 2001). In the studies completed by Klemmer, Lehr et al. (1999), it was noted the effect of economic instruments on the creation of knowledge was limited, but that these instruments played a role in facilitating adaptation and diffusion of technologies. Additionally, economic instruments can be used to create markets, as in the case of the Danish refrigerators (in this case, it was said that the introduction of the Danish energy tax, combined with product labelling played a key role in fostering demand). In general, it appears as though economic incentives may be more suited to stimulate adaptation and diffusion of technologies through **market** formation than to stimulate knowledge creation (Klemmer, Lehr et al., 1999; Kemp, 2000).

Extended producer responsibility legislation represents a relatively more recent form of policy whose ultimate aim is the establishment of economic incentives for improved product design (Mayers, 2007). According to Thomas Lindhqvist, who introduced the principle, EPR is defined as: "a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the entire life cycle of the product, especially to the take-back, recycling and final disposal of the product" (Lindhqvist, 2000). This principle has been introduced in a number of EU Directives including the Directive on Waste Electrical and Electronic Equipment (WEEE) (2002/96/EC), the Directive on Packaging and Packaging Waste (94/62/EC), and the Directive on End-of-Life Vehicles (ELV) (2000/53/EC). The Directives are comprised of a series of policy instruments. In the case of the WEEE, Packaging and ELV Directives, financial responsibility of the producer is combined with mandatory recycling and recovery targets. The Directives are also associated with substance bans/restrictions that prohibit or limit the use of several toxic substances. In the case of the WEEE Directive these substance bans are implemented through the corresponding Directive on the Restriction and the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS). The EPR principle has been studied on a number of occasions, with mixed results regarding its effects on innovation. Studies on the vehicle industry have shown that the ELV has had an impact on “end of pipe” innovations in recycling technologies but discussions regarding the economic effects of the Directive on product design have been mixed (Gerrard and Kandlikar, 2007). While some studies have noted positive design changes for re-use and recycling, others for example, have noted that design for end-of-life design has not been a high priority for manufacturers (van Rossem, Tojo et al., 2006; Gerrard and Kandlikar, 2007). Furthermore, the recycling targets have been said to potentially impede other innovative options on the design side (Gerrard and Kandlikar, 2007). A study of the lighting sector in Europe has shown that the EPR, at least in the short run, was unlikely to drive eco-design, due in part to the fact that the demand for products is relatively inelastic and the regulation affects all the producers equally (Gottberg, Morris et al., 2006). Studies in the pulp and paper and telecommunications industries have shown some positive effects of EPR legislation on product design, though these changes have also been inspired by other factors (Kautto, 2006; van Rossem, Tojo et al., 2006). Regardless of varied findings, there is general agreement that the effects of EPR are highly dependant on the particular characteristics of the policy design and implementation. While the economic instrument effects of EPR have been debated, there has been greater consensus regarding the impact of the material bans that have accompanied this legislation. Studies have shown that these bans have largely resulted in efforts to replace and remove these substances from the products through the design and implementation of alternate materials and methods (Gottberg, Morris et al., 2006; van Rossem, Tojo et al., 2006; Gerrard and Kandlikar, 2007)

A certain number of economic incentives have also been used in the environmental policy field. The use of green public procurement has been shown to have played a role facilitating innovation in environmental technology. In the case of the U.S. Energy Star programme, public procurement of energy efficient office equipment provided a significant boost for the programme, through the creation of a **market** (Paton, 2005). Similarly, in Japan, the national Green Procurement Law has been said to have created positive synergies with the Top Runner Programme in the improvement of use-phase energy efficiency in electronic products (Tojo, 2007). Additionally, R&D and investment subsidies have been used for the explicit promotion of innovation in environmental technologies. While these instruments coincide with the field of innovation policy, they will be discussed briefly here due to their inclusion in the literature on environmental technology development.

According to the literature, the performance of investment subsidies related to encouragement of environmental innovation has been mixed. In a number of Dutch studies where investment subsidies were examined, the effectiveness of these subsidies has been noted be small and has resulted in windfall gains to the subsidy recipients. In a study of investment subsidies for thermal insulation under the National Insulation Programme (NIP) in the Netherlands, econometric analysis revealed only a weak positive relationship between subsidies for thermal home improvements and the diffusion of thermal insulation technologies (Kemp, 1997).

Despite these discouraging results however, a large number of studies have shown the positive potential of investment subsidies. In the case of the development of a wind power industry, Denmark has been considered as being one of the most successful countries (Kamp, Smits et al., 2004; Astrand and Neij, 2006; Buen, 2006). Studies have shown that investment subsidies have played a significant role in the development of the Danish wind industry. During the emergence of the Danish wind industry, subsidies were issued to private individuals and cooperatives for the investment in the installation of wind capacity located within three kilometres of them. The issuance of subsidies to individuals and cooperatives has been said to have increased popular support for wind power in Denmark – a crucial factor in the development of the wind industry. To preserve quality in the technology, subsidies were issued only for those turbines that had passed approval by the national test station. Moreover, in addition to the investment subsidies, a production subsidy was also offered to producers, further encouraging investment in high quality turbines (Buen, 2006). As such, through the use of investment subsidies, the Danish government was able to create **a market** for wind turbines.

R&D subsidies have also played a role in the development of various environmental technologies. In such a way, the government can foster creation of **knowledge**. In a study of the Finnish pulp and paper industry, it was found that technology push, through searches for specific environmental improvements and through public R&D funding, have been important for the emergence of environmentally sounder innovations (Kivimaa, 2007a). The Danish Clean Technology Development Programme has also had positive results. The Danish Environmental Protection Agency (EPA) played an active role in selecting the projects and in "match-making" – i.e. finding the right partner to cooperate with – and the overall conclusion was that the programme was successful in developing cleaner technology options (Kemp, 2000). Again, in this case, however, it was noted that more than half of the projects undertaken as part of the programme were motivated by actual or potential environmental requirements and that economic motivation alone was insufficient to induce companies to undertake the costs and risks of cleaner technology development on their own. This reinforces the notion that mandatory environmental regulation can play important role in creating demand for environmental technologies (Jørgensen, 2005). It is also interesting to note that while R&D subsidies can play a useful supply push role, findings presented in the literature have demonstrated that they alone may not be sufficient to achieve successful results. For example, in the cases of the Norwegian and the Danish wind industries, it was noted that while Norway had significantly more supply side subsidies for wind power development than Denmark, the presence of demand side investment subsidies was a key factor in the greater success of the Danish industry.

In addition to the creation of knowledge through R&D activities, the importance of access to this knowledge has been widely recognised. In the case of the Danish and Californian wind power industries, information compiled during research activities was consolidated into a wind atlas, which was published to allow for more effective siting of wind turbines. In both cases, the publication of the atlas was said to have played an important, non-traditional, demand pull role, by facilitating the **market**-entry process for developers and investors (Loiter and Norberg-Bohm, 1999; Buen, 2006).

The aforementioned renewable energy studies have also shown how the interaction of instruments can play a key role in the innovation process. In the Danish case, a 10-year agreement between the government and power companies in 1985 ensured that power companies would guarantee grid connection, pay 35% of connection costs and purchase excess power from individuals and cooperatives at 85% of consumer costs. The 1992 Wind Turbine Law renewed this fixed price agreement, supplementing the investment subsidies offered by the government and ensuring a continued **market** for wind energy (Buen, 2006). Furthermore, in the case of German renewables, the implementation of the German electricity feed-in law (EFL), which mandated the purchase of renewable electricity by utilities, was said to have been a large factor in the expansion of the wind energy **market,** consequently attracting new entrants and a new supply of resources to the market (Jacobsson and Bergek, 2004). Conversely, however, the case of wind power development in Sweden has been used to demonstrate how administrative instruments have hindered wind power development by conflicting with wind power policy. In this case, difficulties associated with planning and permit granting for wind turbine installation at the local level have been said to have created a degree of uncertainty in the Swedish wind industry, discouraging investment (Astrand and Neij, 2006).

The effects of policy synergies can also be seen in the cases of the Danish system for more energy efficient refrigerators and the Japanese Top Runner programme. The Danish programme was deemed to have had high success levels due to the combined effects of a CO_2 tax, labelling scheme, demand side subsidies and regulatory tightening of energy consumption standards (Jänicke, Blazejczak et al., 2000). The Japanese Top Runner programme has been used in conjunction with a national green procurement law, green automobile tax scheme and voluntary labelling programme amongst others to realise positive improvements in the energy efficiency of various product groups (Tojo, 2007).

Summary

Studies have shown that environmental policy, whether explicitly intended to or not, can have an influence on the innovation and diffusion processes. While the innovative effects of specific environmental policies are highly dependent on their design and implementation, their presence can play a role in stimulating players to action. The use of administrative and economic instruments can promote the development of new technologies or the adaptation/diffusion of infant technologies to address impending requirements or to minimise costs. Green procurement has been considered as a successful tool in promoting knowledge creation and commercialisation processes, through the formation of markets for new products. The provision of information regarding technologies and options (such as the Danish/ California wind energy cases and eco-labelling) has played a useful role, often in conjunction with procurement policies, in creating a demand pull for certain products. The use of voluntary agreements has assisted in the diffusion of new technologies. The use of investment subsidies has assisted in market formation by creating a demand for newly developed technologies (e.g. in the case of the renewable energy systems). A number of cases have shown that R&D subsidies have also played an important role in fostering innovation processes through the creation of knowledge and demonstration opportunities, though the distinction between subsidies as an innovation policy or as an environmental policy tool is not always clear.

By and large, the literature has demonstrated the usefulness of environmental policy towards innovation in terms of its ability to contribute to the **formation of markets** through the provision of incentives (such as procurement) or imperatives (such as emission limits) for action. Through the formation of markets, in turn, environmental policy instruments can create a demand pull in the innovation process, providing incentives for investment in knowledge and attracting new resources to the industry. Furthermore, in cases of extreme regulation, such as the implementation of substance bans, administrative instruments have been shown to contribute to **knowledge** formation during the search for new and alternative solutions.

3.2 Innovation Policy & Innovation Effects

Conversely to environmental policy, the explicit aim of innovation policy is to foster innovative activity throughout the economy. As depicted in Figure 2-3, innovation policy attempts to take a systems approach to innovation, focusing on capacity and network building. The types of instruments employed in innovation policy differ widely from environmental policy, with a major focus on economic incentives including R&D support in lieu of administrative instruments. There exists a large body of literature which has discussed the effects of specific policy instruments in contributing to innovation based on econometric analysis as well as a body of literature which has examined how the specific characteristics (including implementation) of these policies influences their success (e.g.(David, Hall et al., 2000; Hall and Van Reenen, 2000; Jaffe, 2000)). The OECD and the EU have conducted a number of studies regarding specific innovation policy instruments as well as the effectiveness of various national innovation policy systems. The European Innovation Trendchart has been established by the EU in order to monitor, evaluate and compare the national innovation systems in various EU and OECD countries in an attempt to stimulate improved innovation performance throughout Europe.

Policy Discussion

Innovation and innovation policy place a heavy emphasis on the concepts of knowledge and learning. As such, prior to the discussion of specific policy instruments, it is worth a brief introduction to these ideas.

The importance of accumulated knowledge in the innovation process has been recognised and accepted throughout the field of innovation policy. In particular, two types of knowledge have been generally acknowledged by evolutionary-institutional economists: **tacit** and **codified** knowledge. Codified knowledge is knowledge which has been extracted from its generator and converted into a common language that can be exchanged with others (e.g. mathematics, chemical formulas, etc.). Tacit knowledge is knowledge which has not been documented and made explicit by the one who uses it. Consequently, the knowledge rests with its generator (Borrás, 2003). The distinction between tacit and codified knowledge is important as it implies that not all prerequisites in the innovation process can necessarily be transferred via tangible media.

Further to the various forms of knowledge, innovation literature is also concerned with different learning mechanisms. These include learning by doing (involving conscious network experimentation and organisation adaptation); learning by using (learning when products are used, or from potential users during the innovation process); learning through interaction (learning by interacting with various other actors); learning from advances in science and technology (acquiring relevant knowledge from scientific and technological communities); and learning from spillovers (learning from leakages or exchanges of information, such as reverse engineering or patent disclosures) (Rycroft and Kash, 1999).

Literature on the innovation policy portfolio reveals a number of common themes, including R&D in the public sector, R&D in the private sector, public-private partnerships, networks/ support programmes, and intellectual property rights (IPR). There exist a number of linkages between these target areas.

Within the innovation policy field there has been significant recent discussion regarding the changing role of universities and public research organisations (PROs). On one hand, there is a push towards orienting these institutes towards greater degrees of technology transfer and applied, industry-driven research programmes. On the other, it is recognised that the preservation of fundamental research activities is needed to promote long-term advancement of the **knowledge** pool, to preserve the public-goods nature of scientific advances, and to stimulate private sector R&D (Branscomb and Keller, 1998; European Commission, 2003b; OECD, 2006). The effectiveness of public R&D in fostering private R&D and in promoting innovation performance has been said to be dependent on a number of factors including industry-science linkages and the governance of PROs (OECD, 2006). Policy systems which are based on allocation of research grants through a competitive process (e.g. by research councils or other funding organisations) have been noted to have a better response to public policies than systems in which funds are allocated via block grants to research institutes (European Commission, 2003b). A shift towards project-based funding has also been shown to allow for a better targeting of research towards economic and social aims. Furthermore, the concentration of research funds in a more limited number of research centres (in order to create 'critical mass' and encourage multidisciplinary research) has been shown to be an effective policy tool (OECD, 2006). In addition to improving public sector research through funding policies, there are a number of other general policy tools which can be used to enhance public sector research, including the granting of greater autonomy to institutions in establishing hiring, promotion, and collaborative agreement procedures, and encouraging international collaboration between research organisations through the facilitation of human resources mobility (OECD, 2006).

Support for private R&D, through fiscal/ financial measures also plays a key role in the innovation policy portfolio by providing firms with the necessary **resources** to pursue new ideas and create new **knowledge**. Direct support for private R&D can occur in a number of ways including: fiscal measures, such as corporation tax reductions for volume or increment in R&D, reductions in employer's payroll tax and social contributions or personal tax incentives for R&D workers; equity support measures, such as public or mixed venture capital funds, tax incentives for investors in technology development, and loss underwriting and guarantees; and direct support through the provision of funding, prizes, or collaborative grants (Georghiou, 2006). While the ability of these instruments to affect innovation has largely been recognised, there is general consensus that the effectiveness of various instruments is dependent on their specific design and implementation (OECD, 2006). Empirical research has shown that tax incentives for R&D have moderate, positive effects on R&D activity (Hall and Van Reenen, 2000; OECD, 2006). Conversely, however, there is greater controversy regarding the productivity of direct government R&D subsidies for private R&D (Hall, 2002). Literature regarding the question of whether public R&D spending is complementary to private funding or whether it substitutes and reduces incentives for private R&D reveals conflicting answers (David, Hall et al., 2000). This is inline with the findings of some of the environmental policy findings which concluded that subsidies, in some cases, provided windfall gains to recipients. It has generally been found that direct R&D support is more successful in programmes targeted at small firms (OECD, 2006).

In addition to looking at private and public R&D as distinct areas, there is growing interest in the innovation policy field in better collaboration between these two sectors. As stated in the 2005 OECD report, *Innovation Policy and Performance*, "Improving the ability of business to exploit the outputs of universities and PROs is at or near the top of the innovation policy maker's agenda in most OECD countries," (OECD, 2005b). The encouragement of public-private partnerships has been suggested as a means of fostering R&D activity within a country (Branscomb and Keller, 1998; Drejer and Jørgensen, 2005) and increased collaborative efforts between industry and science can provide much needed access to **knowledge** and **resources** (both financial, material, and human). According to current evaluations of innovation systems, however, this is a weak component in many of the European countries. One suggested explanation for the relatively low levels of firm-research institute cooperation is the idea that in such collaborations two very different types of organisations, with two very different frames of reference, confront each other. Consequently, mechanisms such as information channels to inform firms about what they can gain from involvement with public research institutions, guidelines for the organisation of collaborative research efforts, and formal programmes containing supportive structures for structures and public co-funding as a means to drive joint projects forward have been suggested as a means to help parties overcome this barrier (Drejer and Jørgensen, 2005). Other methods to improve collaborative efforts have included the provision of funds for the commercialisation of public-sector technologies (such as the Ideas 2 Innovations, I2I programme, in Canada), the establishment of public-private partnerships such as joint research centres which promote cost, risk and benefit sharing, and the implementation of researcher mobility programmes between research institutes and industry (such as the Danish Industrial PhD Initiative[6]) (European Commission, 2006; OECD, 2006). In addition to facilitating network and knowledge creation, programmes which facilitate the transfer of personnel can assist in the diffusion of tacit knowledge associated with those individuals.

The provision of networks and support programmes are a crucial point of systems-oriented innovation policy. Policies to help stimulate the creation of networks between firms and research institutes, including those described above, as well as stimulating firm-to-firm and inter-PRO communication, through measures such as science parks, sponsored conferences and resource centres, can help to build bridges between actors, allowing for improved access to **resources** (such as equipment and human resources) and access to **knowledge** possessed by other relevant actors. These networks can be especially valuable to small and medium-sized enterprises (SMEs), where resource limitations may otherwise be prohibitive to the development of new ideas (Dodgson and Bessant, 1996). Additionally, the provision of support measures, such as brokering activities and support centres can provide access to the **resources** needed by firms to engage in innovation activities (Dodgson and Bessant, 1996).

It should be noted here that within innovation policy there is significant emphasis on the role of SMEs and new technology-based firms (NTBFs) in the early stage of development of new technologies. Reasons for this include: the attractiveness of SMEs as an external resource of new technologies for large firms; the role of SMEs in maintaining locally-based innovative activities within a country (particularly in countries such as Sweden, where a limited number of SMEs provide the basis for business R&D and fundamental innovation); the ability of SMEs to develop and exploit high technologies more easily then large, established companies; and the potential for SMEs to aid in economic regeneration of disadvantaged regions (OECD, 2005b). Consequently, support for R&D funding and networking measures aimed at SMEs is often high on the policy agenda.

While some may argue whether they actually fall into the innovation policy domain, the topics of intellectual property rights (IPR) and patenting are pervasive throughout innovation policy literature. The argument for the regulation of patents in order to support the innovation process has been substantiated via three main arguments. The first argument is the "incentive to innovate" provided by a patent. In this case, the innovator is granted a temporary monopoly on their innovation, allowing them to capitalise on their work without threat of imitation (Borrás, 2003). In this manner, intellectual property rights can act as an incentive for the creation of **knowledge** and investment of **resources**. The second argument is the

[6] The Industrial PhD programme is a Danish initiative to enhance R&D in the Danish business sector by training researchers to gain insight into the business related aspects of R&D and by building personal networks between companies and research institutes/universities.

establishment of an "innovation market", which results from the buy-sell actions of patents or licence rights. The rights to a patent-protected idea can be sold to interested parties who see an application for the idea, thus allowing the originator of the idea to benefit from their work. As such, IPR can induce the commercialisation of the results of innovative activity that may otherwise have been kept secret by their creator. The third argument regarding the role of IPR in the innovation process is the "disclosure" function of a patent. While the innovator retains rights to their innovation, the public availability of the patent data allows for disclosure of the new innovation (Borrás, 2003). In such a manner, IPR allows access by others to the new **knowledge** of the inventor. Despite these arguments for the importance of patenting and IPR for the innovation process, however, empirical evidence regarding its effects on innovation remains limited. A review by Jaffe (2000) of the previous analysis attempts of economists to measure the impacts of major changes in patent policy and practices in the U.S. over the last two decades revealed few robust conclusions regarding the innovative impacts of IPR and patent policy. Some, such as Branscomb and Keller (1998), have pointed out that the importance of patenting is heavily dependent on the industrial sector (for example, the pharmaceutical industry is more patent dependent than the computer industry).

In addition to the focus on supply side measures of innovation policy, there has been some discussion regarding demand side policy instruments in the innovation portfolio. A recent report published by the Fraunhofer Institute for Systems and Innovation Research (ISI) in Germany (2005) has indicated renewed interest by the European Commission in public procurement as an innovation policy tool and several studies have noted the potential of procurement tools in promoting innovation (OECD, 2005b; OECD, 2006). Despite this discussion, however, Georghiou (2006) has noted that:

> *The range of explicit innovation policies being applied today is very much concerned with the supply side and even more with R&D support of various types, ranging from funding of science in public institutions through to fiscal incentives for firms to increase R&D spending. Much less attention has been paid to policies which could increase either the motivation or the likely success of innovation by acting upon the demand side, that is the specification and purchase of innovative goods and services.*

Summary

Conversely to environmental policy and, as has been pointed out by Georghiou and ISI, innovation policy is largely focused on the supply side of the innovation process. Policies in the innovation portfolio have a significant emphasis on R&D funding to provide resources for the creation of new **knowledge** and on measures to promote networking and actor interaction in the innovation system and to contribute to access to **knowledge** and **resources**.

3.3 Dynamics between Innovation Policy & Environmental Policy

The previous sections have examined the environmental policy and the innovation policy perspectives on innovation. However, there is another form of discussion which has emerged in the environmental innovation literature, concerning the integration of innovation and environmental policy.

The concept of environment policy integration (EPI) emerged from the 1992 United Nations Conference on Environment and Development (UNCED) as a requirement for sustainable development. EPI is defined 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" (Ruud and Larsen, 2004). As such, according to the concept of EPI, environmental priorities need to be made part of the fundamental process for all policy making, through both horizontal and vertical policy integration (HPI/VPI)[7]. Despite the fact that EPI has been widely recognised to be an important principle, however, a number of studies have revealed that there is very little integration or "greening of policies" currently taking place (Lenschow, 2002; Ruud and Larsen, 2004; Kivimaa and Mickwitz, 2006).

At the same time that EPI is being discussed amongst academics and policy makers, there is an ongoing dialogue regarding a new third generation of innovation policy which places policy integration at its core. The first generation of innovation policy was based largely on the idea that innovation was a linear process, beginning with laboratory activities and moving towards commercial applications. Realisation that innovation is, in fact, a complex process involving a network of actors and interactions, resulted in the move towards the second generation of innovation policy (largely employed today) which focuses on strengthening the innovation system. Third generation innovation policy, however, recognises that innovation is deeply interlinked with a number of areas and activities and, as such, calls for the placement of innovation at the heart of every policy area (Lengrand, 2002; OECD, 2005c). A 2002 report prepared for the European Commission regarding the evolution towards a third generation policy has attempted to highlight the interactions between innovation and a variety of related policy areas and has noted that there needs to be a call not only for innovation considerations in environmental policy, but also for environmental considerations in innovation policy (Lengrand, 2002). Foxon, Pearson et al. (2004) have employed the term 'sustainable innovation policy' to address this issue of improved interaction between innovation and environmental policy.

A relatively new stream of literature has recently emerged which discusses the integration of innovation and environmental policy together. The importance of combining environmental and innovation policy elements in order to spur environmental innovations has been noted. While discussion regarding this topic has begun on paper however, those national evaluations which have been done (Norway, Finland, Belgium) have shown that, in reality, integration of these two policy fields has, to this point, been rather limited (Ruud and Larsen, 2004; Van Humbeeck, Dries et al., 2004; Kivimaa and Mickwitz, 2006).

The previous discussions regarding environmental and innovation policy and policy integration lead to some interesting points. From a review of environmental and innovation policies with reference to the preconditions of innovation proposed in Section 1.3, it seems that environmental and innovation policy are not necessarily antagonistic, as may first appear, but are instead potentially complementary in their focus, as shown in Figure 3-1.

[7] Horizontal policy integration (HPI) refers to the process of inter-ministerial policy coordination (i.e. the integration of environment concerns into various policy areas). Vertical policy integration (VPI) refers to the integration of environmental measures throughout the ministry and its respective policies (Ruud and Larsen, 2004).

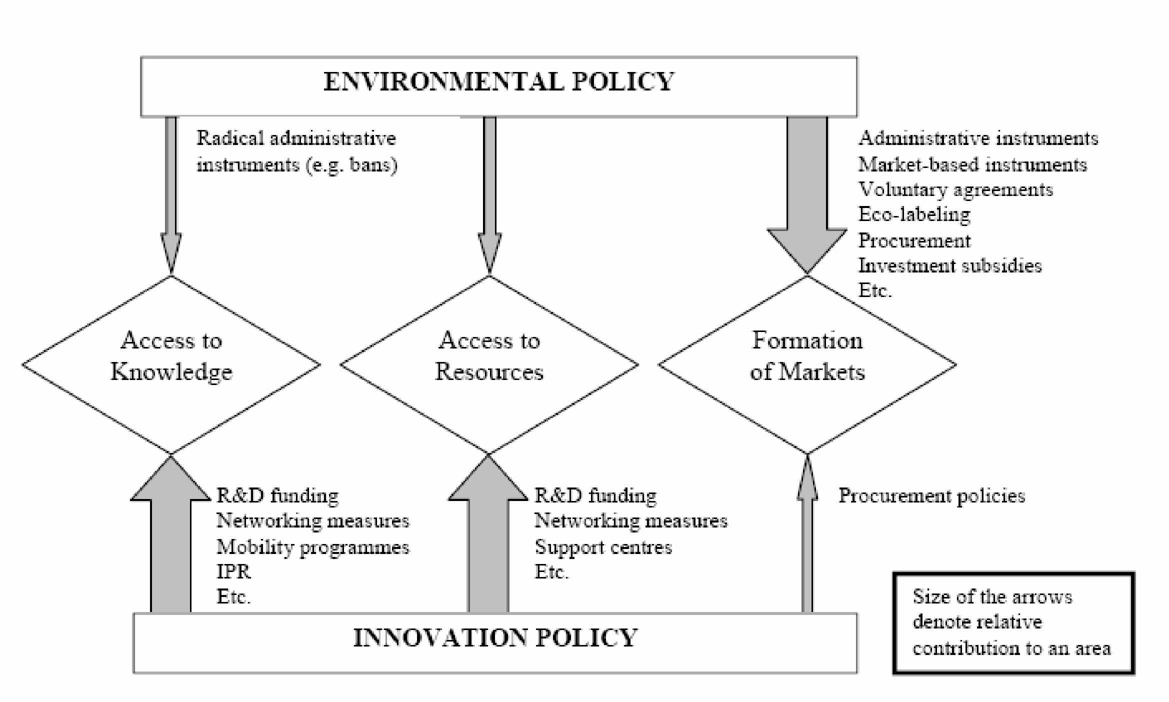

Figure 3-1 Innovation and Environmental Policy Dynamics in the Knowledge, Resources, Markets Framework

On one hand, environmental policy tends to foster a demand side pull in the innovation process, through the formation of markets. On the other, innovation policy has been shown to provide access to knowledge and to resources through its provision of networking and R&D opportunities. As such, a combination of these two policy areas, as suggested above, may provide a valuable means of fulfilling the required preconditions of the innovation process.

3.4 Characteristics of "Green-Innovation Friendly" Policies

While there appears to be disparity in the field regarding the effectiveness of particular policy instruments in fostering environmental innovation, there is general consensus across the board that the impact of policy depends very much upon the local context in which it is applied (Hemmelskamp, 1997; Kemp, Smith et al., 2000; Kivimaa, 2007a). For instance, it has been pointed out by Norberg-Bohm and de Bruijn (2005a) that while collaborative agreements may work well in the Dutch setting with its strong neo-corporatist traits, these have typically not functioned well in the traditional rigid and adversarial environmental policy approach in the United States. Additionally, the Danish wind case illustrates that the socio-political context in which the industry emerged has played a huge role in contributing to its successful development (Buen, 2006).

Furthermore, it has been recognised from environmental innovation studies that innovation is not subject to isolated determinants, but rather a combination of them (the "multi-impulse" theory) (Klemmer, Lehr et al., 1999). According to a series of studies conducted under a German project on environmental technology innovations for example, "ambitious goals for environmental innovations can only be reached with a multi-impulse strategy oriented towards specific barriers and players" (Klemmer, Lehr et al., 1999).

Despite the recognition of the context-specificity of successful policies, however, various studies conducted regarding traditional and innovative environmental policy instruments have also attempted to elucidate those general characteristics of policies which have been found to contribute to the elicitation of a green innovative response by industry. Based on the results of empirical studies, the following factors have been noted to play a role in green innovation:

- Stringency/ Ambition level (Jänicke, Blazejczak et al., 2000; Kemp, 2000). Drastic regulations, such as bans, have been shown, in some cases, to elicit a more radical innovation response.

- Reduction in uncertainty (Norberg-Bohm, 1999; Lehr and Löbbe, 2000; Astrand and Neij, 2006; Kivimaa, 2006c). There must be a degree of predictability for industry, developers and investors, as well as foreseeability regarding future policy directions and timelines.

- Flexibility (Norberg-Bohm, 1999; Lehr and Löbbe, 2000). An innovative policy will allow firms to respond to goals with any technology that meets the environmental goal and will avoid "picking winners".

- Time horizon/ Instrument timing (Lehr and Löbbe, 2000; Norberg-Bohm, 2000; Astrand and Neij, 2006). Adequate time is necessary prior to the enforcement of a regulation to encourage innovation and avoid hasty, short-term solutions. However, this must be traded off against the risk of increased environment, health or safety damage. Furthermore, policy instruments must be timed appropriately so as to provide incentives or imperatives at the appropriate intervals and to maintain support for the appropriate timeframe.

- Elicitation of continuous improvement (Kivimaa, 2006c; Kivimaa, 2007a). (This could perhaps be tied to the ambition level/stringency of policy noted above). Policies which require industries to strive for continuous improvement, through target setting and gradual tightening of requirements, can help to provide continual incentives for innovation.

- Stimulation of industry-generated information (Norberg-Bohm, 1999).

- Provision of economic or political incentives (such as information dissemination programmes that can result in public pressure) (Norberg-Bohm, 1999; Jänicke, Blazejczak et al., 2000).

- Contribution of both supply and demand policies (Norberg-Bohm, 1999; Christiansen, 2002; Buen, 2006). Supply and demand policies should be implemented in parallel in order to stimulate technological development from both a push and a pull perspective.

- Diversification of R&D (Norberg-Bohm, 2000; Jacobsson and Bergek, 2004; Astrand and Neij, 2006). R&D policies should be designed so that options for the pursuit of multiple strategies for a single technology, as well as multiple technologies, remain open and avoid technological lock-in.

4 Three Sector Cases

In order to develop a greater understanding of the environmental innovation process in the Nordic countries, three sectors have been examined in closer detail: the mobile phone industry, the pulp and paper industry, and the building industry. Each of these sectors has played a significant role in the Nordic economy and has been of interest, historically and/ or presently, in terms of environmental performance. They span from low to high technology sectors and represent, respectively, product, process and project-based industries. There are a variety of similarities and differences among them in terms of sector characteristics and innovation dynamics, which have played a role in shaping their development and progress in the field of environmental technology. Within each sector, several case studies pertaining to environmental innovations have been reviewed in order to provide some unique case level insight into the processes of environmental innovation in the various industries. While the sectors and case studies themselves are quite distinct from one another, they all focus on energy and/or energy efficiency related innovations.

This chapter provides an overview of the innovation dynamics of and the significant environmental policies affecting each of the three sectors in the Nordic countries and presents the corresponding sector-specific case studies.

4.1 The Mobile Phone Sector

4.1.1 Overview

The mobile phone industry has a unique history in the Nordic region. These countries have played a significant role in the development of the modern mobile network system and currently they host some of the most significant actors in the mobile phone industry. In 2004, electronic and telecommunication products represented 15.5% of the total export value of Sweden (Swedish Institute, 2007a). Similarly, in 2006, the value of telecommunications exports represented 13.7% of the total value of exports in Finland (Statistics Finland, 2006).

The first commercial cellular networks (1G), based on an analogue system, were launched in Japan in 1979, in Scandinavia in 1981, and in Chicago in 1983 (Dirckinck-Holmfeld, Andersen et al., 2007). The Scandinavian countries chose to adopt a common mobile standard, NMT, for which the specifications were free and open. This open standard allowed for the creation of an international mobile telephone system and the broadening of the mobile phone market across borders. As a result, many companies produced hardware compatible with the NMT standard, driving prices downward, and a rapid increase in mobile telephone usage, particularly in Northern European countries, ensued. The use of an open system resulted in a greater focus of the Nordic countries on international telecommunications strategies in comparison with U.S. and Japanese players who were limited to intra-national competition due to incompatible systems. (Remmen, 2007a)

At the beginning of the 1990s, mobile phone communication was digitalised, resulting in the second generation (2G) of mobile phones. The network capacity was expanded, allowing more users to access the system at once and improving call quality. Inspired by the success of the NMT system, the EU created the GSM standard, with significant involvement of the Nordic countries (Dirckinck-Holmfeld, Andersen et al., 2007). This standard provides international roaming capability, giving consumers seamless connectivity across numerous countries. In line with the historic Nordic prominence in the mobile phone industry, Finland became the first country in the world to offer a GSM service in 1992. GSM is currently the world leading wireless mobile communications standard, having over 2 billion subscribers, although different competing national standards continue to exist in the U.S., Japan, China and elsewhere (GSM World, 2007). Contrary to much of the first and second generation systems, the GSM standard has been established through cooperation of a multitude of companies, where a number of actors hold patents. In lieu of the traditional use of patents to exclude others, in this system the patents are instead used as a method of gaining royalties. (Dirckinck-Holmfeld, Andersen et al., 2007)

The latest cellular phone technology available today is referred to as third generation (3G). This technology followed quickly behind 2G and is based on an International Telecommunication Union (ITU) initiative for a single global wireless standard. This concept has now evolved into a family of five 3G wireless standards. It is commonly stated that 3G is not a "rigid" standard, but rather is a set of requirements that most networks and brandholders must follow regarding minimum bit-rates (2 Mb/s in fixed environments, 384 Kb/s in urban environments, 144 Kb/s in wide area mobile environments, and variable data rates in large geographic area systems) (3G Today, 2007). 3G allows for greater data transmission via the mobile phones (applications such as internet connections and content downloads), resulting in greater network usage. Today, both 2G and 3G mobile phone systems coexist and several of the 3G standards are compatible with the 2G system. Initially the 3G system faced several technical problems including low battery time (due to high power draw) and handover problems between networks. These problems have now been addressed, however the diffusion of 3G has been notably slower in the European market than in the more advanced Asian markets such as South Korea and Japan. (Dirckinck-Holmfeld, Andersen et al., 2007)

Despite the fact that 3G networks are still relatively new, discussion regarding 4G networks has already been initiated. No formal definition has been set for 4G as of yet, but the basic idea is to make data transmission more flexible and independent from any specific access technology. The basic technologies required for 4G are Internet Protocol (IP) technology, therefore making the system compatible with all common network technologies (e.g. Bluetooth, WiFi, etc.), and software which allows the handset to access different frequencies. 4G will allow for greatly increased data transmission, enabling such applications as interactive multimedia, voice and video streaming. (Mobile in a Minute, 2006; Dirckinck-Holmfeld, Andersen et al., 2007)

In line with their historic role in the development of mobile phone systems, several Nordic players continue to have a dominant role in today's mobile phone industry. Nokia (a Finnish based company) and Sony Ericsson (of Swedish origin) are, respectively, the first and fourth largest providers of handsets in the world. Additionally, Ericsson is the largest producer of network equipment worldwide, followed by the newly established joint venture between the network divisions of Nokia and Siemens. (Enter & IDATE, 2007) Significant R&D activities related to mobile communications development have taken and continue to take place within Danish research clusters situated in Northern Jutland and in Copenhagen (Remmen, 2007a).

4.1.2 Sector Characteristics

Sector Classifications

According to the OECD classification system of manufacturing industries (which is based upon an analysis of R&D expenditures and output), the mobile phone sector is considered to be a high technology industry (OECD, 2005d). Furthermore, the sector can be characterised as product-based, referring to the fact that the focus of this industry is on the development of the final product and on its performance, rather than the process by which it arrives.

In comparison to many "traditional" industries such as pulp and paper, the mobile phone industry is relatively new, with the first generation mobile phone systems originating in the late 1970s/ early 1980s as described above. The continual development of new products within the sector is an important activity within the industry and large brandholders spend approximately 10% of their turnover on R&D activities (Dirckinck-Holmfeld, Andersen et al., 2007; Moussette, 2007). It has been mentioned that, in some cases regarding the design of phones, technology development precedes marketing ideas. That is, technology develops first and brandholders then decide what sort of applications could exist for this new technology (Moussette, 2007).

Actors and Interactions

The mobile phone industry plays a significant role in the Nordic countries. In 2006, Nokia had a turnover of 41 billion Euros and employed approximately 70 000 individuals, over 35% of whom worked in Finland (Remmen, 2007a). Similarly, in Sweden, Ericsson and Sony Ericsson represent significant industry presences. In addition to direct employment effects, the mobile phone industry has close relationships with the education and research facilities around it. For example, early engagement of the mobile phone industry in Denmark has resulted in the establishment of two research clusters, related closely to the Danish Technical University and Aalborg University (Remmen, 2007a). The importance of education for the success of the industry has been realised since the beginning stages of the industry. An initial part of Finnish Nokia's efforts towards internationalisation of the company concerned formal education. Nokia's CEO stressed the need for international student exchange programmes and close collaboration between industry and academia. One result of this was the establishment of "Nokia University", an education programme managed by several Finnish universities in collaboration with Nokia, with the aim of increasing the formal competence of all Nokia employees by one level (i.e. those with a Bachelor's degree were encouraged to obtain a Master's degree). (Blomström and Kokko, 2003)

The mobile phone industry is characterised by a wide range of actors who play a role in the innovation dynamics of the sector. Globalisation of the industry has resulted in production, assembly and R&D activities being spread over a wide geographic area. Production of the most advanced components typically takes place in the U.S., South Korea and Taiwan. Production of basic components and assembly generally occurs in lower-labour cost countries. R&D activities typically occur in Western countries, though recently many knowledge-based activities are being off-shored to South-East Asia. (Dirckinck-Holmfeld, Andersen et al., 2007) A general overview of the sector's organisation and its interactions is provided in Figure 4-1.

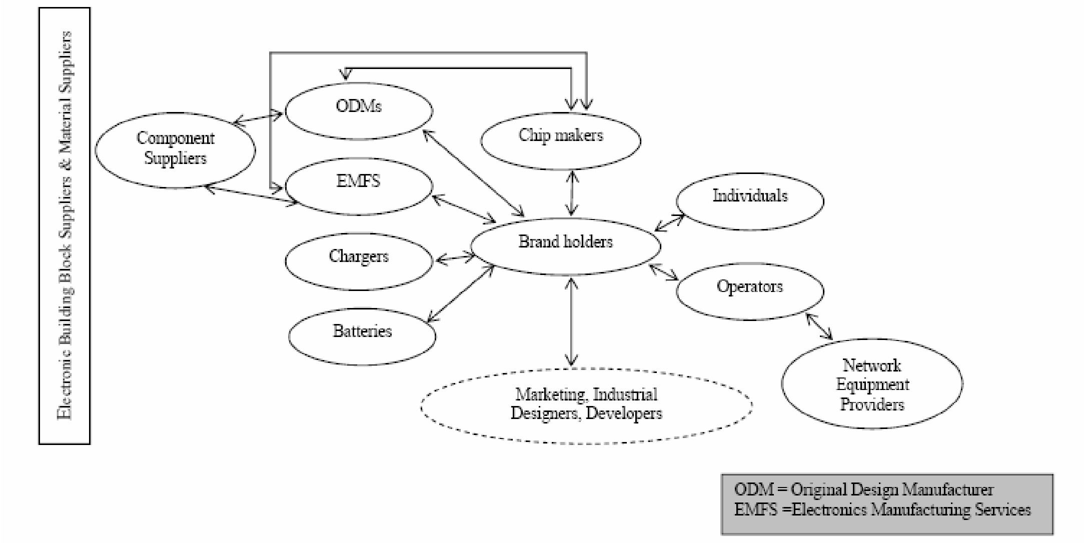

Figure 4-1 Mobile Phone Sector Actor Network (Adapted from Dirckinck-Holmfeld, Andersen et al. 2007)[8]

The intense competition which has existed in the handset market and the economic crisis experienced by many IT sectors at the turn of the century has resulted in a mobile phone market that is currently dominated by a few large global players (Dirckinck-Holmfeld, Andersen et al., 2007). As of 2006, six major brandholders held approximately 85% of the share in the global terminal market (see Figure 4-2). Design of the mobile phones is typically done in conjunction with developers, marketing personnel and industrial designers, based on the technology road map created by the brandholders (Moussette, 2007).

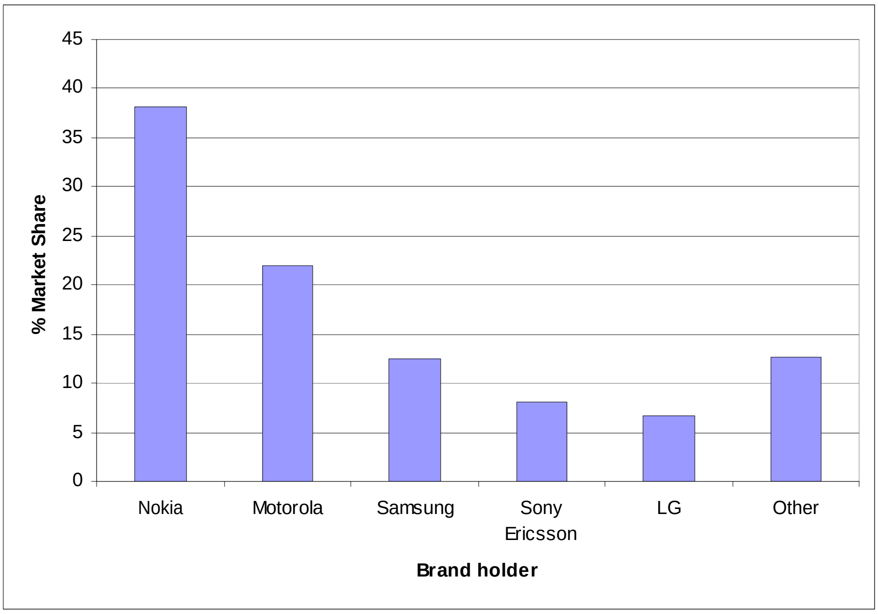

Figure 4-2 Mobile Phone Brandholders Market Share, Q3 2006 (Enter & IDATE, 2007)

[8] Note that this figure is intended to represent the industry actor network and not the innovation network (research institutes, universities, and other relevant innovation actors are not present). The same note applies to the actor network diagrams for the pulp and paper and building sectors.

From the beginning of the 1990's onwards, mobile phone companies have increasingly begun to outsource phone manufacturing as a strategy to decrease production costs. The contract manufacturers, often referred to as Electronics Manufacturing Services (EMFS) in the electronics industry, face fierce competition. As such, they often try to better position themselves by providing production and assembly services to several brandholders at once (allowing them to further capitalise on their equipment investments and desensitise themselves to market fluctuations), and by providing additional value added services, such as the production of critical components. Recently, many large EMFS' have expanded their competences to include supply chain management, logistics planning, testing and customer contact, so that brandholders only need to deal with one supplier. These EMFS' are referred to as turnkey suppliers. Other contract manufacturers provide the service of Original Design Manufacturing (ODM). The main difference between an EMFS and an ODM is that an ODM produces a product based on its own intellectual property rights, while the EMFS produces based on the property rights of its clients. ODM services include the technical and, sometimes, the visual design of its products. In many cases, EMFS' are large global providers whose turnovers and number of employees exceed those of the brandholders themselves. (Dirckinck-Holmfeld, Andersen et al., 2007; Remmen, 2007a)

Central chips and chipsets represent highly important parts of a mobile phone, and chipmakers typically work directly with the brands or with the EMFS or ODM. Components suppliers (e.g. speakers, printed circuit boards, etc.) generally supply to the EMFS or ODM. The electronic building block manufacturers and material suppliers who supply central electronic components and materials to manufacturers represent major industries which are notably larger than the brandholders themselves. The batteries and chargers supplied with the phone are typically specified by brandholders and are supplied as modular units. (Dirckinck-Holmfeld, Andersen et al., 2007; Remmen, 2007a)

Network operators play a major role in the mobile phone industry, representing the largest customers to both the brandholders and the network equipment providers (Lundberg, 2007; Moussette, 2007). The majority of phones are sold through operators and, through advertisements and subsidisation of phones (e.g. payment of phones through monthly instalments), they can have a significant influence over the types of phone sold. Operators are increasingly asking for customisation of phones around their services to support and drive the content and data applications that the operators are investing in (Singhal, 2005b; Moussette, 2007). It has been said that operators are largely interested in promoting phones that increase network usage (i.e. phones with features that encourage increased use of data transmission) in order to increase their revenues (Dirckinck-Holmfeld, Andersen et al., 2007). The result is a corresponding increase in the energy consumption of the phone. In regards to network equipment, the demands of the operator also play a significant role in product development. Concerns from operators in the past have been said to have played an influencing role in cleaner materials and energy efficiency improvements (Tojo, 2001; Lundberg, 2007). The ultimate client for the network operators, in turn, is the individual end user.

Despite high levels of competition that exist between various actors, in regards to environmental issues the mobile phone industry in general is characterised by a relatively high level of cooperation and interaction on environmental matters between major industry players (Singhal, 2007). This can be partly attributed to the requirements for standardisation within the industry (Rice and Shadur, 2000). Additionally, the industry has a history of cooperative interactions with governmental authorities and significant ties to university research institutes within the Nordic countries.

As dictated by its nature, actors in the mobile phone sector involved in R&D activities, generally consist of individuals with a post secondary education and formal training in the electronics field. As such, many actors are familiar with a formalised learning system and, therefore, are more likely to share a similar frame of reference.

Markets & Innovation Trends

Within the mobile phone market, the value added of the product generally comes from the functionality and features of the phones (Singhal, 2005b; Moussette, 2007). Handsets are designed and produced for variety of markets, both domestic and international. The design of the product and its features is largely dependent on the target market and segmentation exists both within a national market and between geographical regions. For example, within the Nordic countries there may be markets for both a relatively sophisticated phone as well as for a simple phone which has only basic call and text message features. Additionally, between the Nordic and Asian markets, there is a substantial difference in market interests (Moussette, 2007).

Despite the variety of target markets in the industry, there is a general perception that the overall market for green mobile phones is limited (Singhal, 2005b). In addition, there is some indication that the level of consumer awareness regarding the environmental impacts of mobile phones may be limited. In a survey initiated by the Danish product panel for electronic products under the Danish EPA approximately one third of respondents answered ‘no’ when asked if environmental problems arise in connection with the production, use or disposal of electronic products. Similarly, only one in five consumers indicated that they believed that the production, use or disposal of mobile phones is associated with environmental problems. (Jensen, Sørensen et al., 2003)

There are a number of ongoing innovation trends within the mobile phone industry. The first is a shift towards the modularisation of components, enabling a core hardware platform to be combined with varying software platforms and modules (i.e. enhancing features, such as cameras). This platform-based hardware development allows brandholders to offer differentiated products to the market, while maintaining efficient production by using the same building blocks (Dirckinck-Holmfeld, Andersen et al., 2007; Moussette, 2007). Additional trends include increased data transmission as can be seen with the evolution of mobile phones from 1G towards the pending 4G system, and the increased integration of other electronic devices (e.g. cameras, music features) into mobile phones (Dirckinck-Holmfeld, Andersen et al., 2007; Moussette, 2007). Accompanying these ongoing increases in data transmission rates and functionality are increases in energy demands on the phone. Past industry efforts to increase the energy efficiency of mobile phones have largely been driven by a need to balance increasing energy demand with a reasonable battery time and small phone size – features demanded by the market (Moussette, 2007).

In recent years, a series of energy efficiency improvements in mobile phone chargers have also been realised. These improvements have been associated with a need to better the charger’s technical performance coupled with an increasing public policy focus on energy consumption issues and with a change in market prices for raw materials (Remmen, 2007a). In the case of network operations, energy expenses typically represent variable costs. As such, efforts to improve the energy efficiency of network equipment are largely driven from an economic perspective (Lundberg, 2007; Singhal, 2007).

Policies

The mobile phone industry is affected by a number of policies, which include Electromagnetic Compatibility Requirements (EMC), product safety requirements, and the requirements and guidelines for the product accessibility of mobile devices in every region (Singhal, 2005b). In recent years, a number of policies aimed towards product-related environmental improvement in the consumer electronics sector have arisen. The global nature of much of the electronics industry, including the mobile phone sector, has resulted in the orientation of much of this policy towards an international (e.g. EU) level. Significant product-related environmental policies which affect the mobile phone industry include:

- The Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC) (*mandatory*). The WEEE directive is based on the concept of extended producer responsibility and aims to prevent the generation of electrical and electronic waste, to maximise the recovery of this waste, and to encourage the producer to take environmental issues into account in the product design phase. Through the directive, producers of electrical and electronic equipment are responsible for their end-of-life products and they can choose to handle their responsibilities individually or via a collective system (involving a producer organisation). The directive itself is a framework directive meaning that implementation is up to individual EU Member States. In regards to its effects on the mobile phone industry, the WEEE directive has received some mixed reviews. While optimism regarding the ability of the directive to influence the collection and design of products has been expressed by some (e.g. (Workshop, 2007d)), criticism regarding its effect on the mobile phone industry has also been expressed. The small size of the products and their inclusion in a combined product category have been cited as potential obstacles to realising more effective collection and design changes in mobile phone products[9] (Dirckinck-Holmfeld, Andersen et al., 2007).

- The Restriction on the use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive (2002/95/EC) (*mandatory*). The RoHS directive is related to the restriction of the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) in electrical and electronic equipment. It essentially serves to ban the use of these substances, with the exception of a series of exemptions. Conversely to the WEEE directive, RoHS is a harmonisation directive, which means that Member States cannot adopt national measures that deviate from its basic level of requirement. Ambiguities concerning interpretation of some of the directive's requirements have been said to have contributed to difficulties in its implementation and issues regarding monitoring and enforcement of compliance (both by companies and authorities) have been noted as a potential problem area (Kautto and Kärnä, 2006; Dirckinck-Holmfeld, Andersen et al., 2007). Despite this, however, the directive has been credited with having a number of benefits including lending credibility to environmental work

[9] Within the WEEE Directive, mobile phones are included under product category 3 – IT and Telecommunications equipment. In addition to mobile phones, this category includes such items as personal computers, laptops, printers, and fax machines. The Directive specifies that member states should ensure that a separate rate of collection of at least four kilograms of WEEE per habitant per year from private households is achieved by member states. Further, it specifies that for WEEE falling within product category 3, the rate of recovery should be a minimum of 75% by an average weight per appliance and rate of the reuse and recycling should be a minimum of 65% by an average weight per appliance. Due to their small size, it has been suggested that collection and re-design efforts for mobile phones could be overlooked in favour of focus on heavier or larger items (Dirckinck-Holmfeld, 2007).

amongst companies; inspiring communication throughout the supply chain; and diffusion of practices such as lead free soldering (Kautto and Kärnä, 2006; Dirckinck-Holmfeld, Andersen et al., 2007).

- Ecolabelling Initiatives (*voluntary*). Ecolabels (Type 1) refer to environmental labels that can be placed on products to indicate overall environmental preferability of a product within a product category based on life cycle considerations[10]. Currently, there are no EU level ecolabels which exist for mobile phones, though criteria have been established by the Swedish Confederation for Professional Employees (TCO) and the German Blue Angel. Currently, no mobile phone companies have chosen to ecolabel their phones, stating as a partial reason, the inapplicability of current label types to the mobile phone industry (i.e. the process of evaluating a product and awarding a label is too lengthy) (Remmen, 2007a; Singhal, 2007).

The aforementioned policies target the mobile phone itself and are largely geared towards materials and waste management issues. In regards to energy and energy efficiency issues, several EU-level policies exist, including:

- The Eco-Design of Energy-Using Products (EuP) Directive (2005/32/EC) (*mandatory)*. Similarly to RoHS, the EuP is a harmonisation directive. It does not introduce directly binding requirements for specific products, but does define conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics. Based on the directive, requirements for specific product groups will be established. Consumer electronics (including mobile phones and accessories) represents a product group that will be addressed in the first stages of implementation measures. Discussions regarding the type of criteria that should be applied to external power supplies (including mobile phone chargers) are currently in progress (Remmen, 2007a).

- The European Code of Conduct (CoC) on Efficiency of External Power Supplies (*voluntary)*. This code of conduct stipulates the maximum acceptable power consumption of external power supplies (including mobile phone chargers). The majority of manufacturers in the mobile phone industry adhere to this code of conduct, which requires a standby power consumption of less than 0.3W, though the standard has been criticised for being easy to meet using today's conventional technologies (Workshop, 2007e).

- The IPP Pilot Project (*voluntary*). The IPP Pilot Project for mobile phones was initiated by the European Commission as part of ongoing efforts to work together with stakeholders to develop Integrated Product Policy (IPP)[11] (Singhal, 2005a). The project is headed by Nokia and the stakeholder group involved in the project includes mobile phone producers, component manufacturers, government organisations, research institutes, telecom operators, recyclers, non-governmental organisations (NGOs), and consumers. The project consists of five stages. In the first stage, the life cycle impacts of mobile phones were evaluated. In the second stage, options to

[10] This is the definition provided by the International Organisation for Standardization (ISO) for a Type I environmental label. Currently, there are three types of environmental labels defined by ISO.

[11] The IPP approach of the European Commission aims to "reduce the environmental impacts from products throughout their life-cycle, harnessing, where possible, a market-driven approach, within which competitiveness concerns are integrated" (Singhal, 2005a).

improve the environmental impact of the phones based on the findings of the stage I report were identified. In stage III, the social and economic impacts of the identified measures were evaluated. In the fourth stage, stakeholders committed to take action to reduce the environmental impact of the phones in the key environmental areas. In the fifth stage (currently ongoing), the stakeholders are responsible for implementing the commitments made during the fourth stage of the project (European Commission, 2007b).

4.1.3 The Cases

The case studies presented in this section have been selected, researched and analysed by the project partner, Aalborg University (AAU) in Denmark. The case descriptions presented below are synthesised from the work conducted by the AAU team. In some instances, material collected by the partner has been supplemented with additional primary and secondary data.

The case studies reviewed for the mobile phone sector are 1) energy efficient chargers; and 2) a potential system configuration for the up and coming 4G network systems. In the Stage I IPP report produced regarding the mobile phone industry, energy consumption associated with the phone has been identified as the most important environmental issue during various life cycle phases (Singhal, 2005a). Mobile phone chargers (and standby power supply units in general) have received increasing attention over the past several years due to the potential energy savings associated with their improvement. There is significant ongoing discussion at the government and industry level regarding the appropriate measures that should be taken to address this issue. In regards to 4G networks, it is hypothesised within the industry that a movement towards this new system will bring about notable additional increases in energy consumption of the mobile phone network. However, consideration of energy efficiency in the area of 4G development has, as of yet, received relatively little public attention, making it an interesting point of focus (Remmen, 2007b).

<u>Mobile Phone Chargers (Mobile-1)</u>

It has been recognised for a number of years that the standby power consumption[12] of electronic devices represents a significant usage in energy when considered as a whole. Standby power consumption in the residential sector in the OECD countries is estimated at approximately 1.5% of total energy consumption. Data in the commercial sector is less prevalent, however estimates have shown that this value may account for 2.2% of OECD electricity use. (Bertoldi, Aebischer et al., 2002)

Chargers can be categorised as linear or switch mode. Linear chargers are generally considered to be quite inefficient, converting less than half of the input energy when charging the phone and, in the worst cases, having a standby power consumption equal to a full load charge. Switch mode chargers, on the other hand, have an average performance level of 75% during charging, and have an average standby power consumption of 0.2-0.3W. Throughout the 1990s and the early 2000s, linear chargers dominated the mobile phone market, with switch mode chargers being sold only with high end phones and as accessories to those wanting a faster charge of their phones. However, from the early 2000s onwards, switch mode

[12] Standby power has been defined as electricity consumed by end-use electronics, such as televisions, cordless phones, office equipment, when switched off or not performing its main function (Bertoldi, Aebischer et al., 2002).

chargers began to represent a growing market and are now supplied with most mid to high end phones. This switch have been attributed to several factors including increased performance demands from consumers (switch mode chargers are smaller and provide faster charging time), increasing plastic and copper prices (these items are used in a greater amount in linear chargers), and an increasing government focus on the issue of standby power consumption. (BioIntelligence Service, 2006; Remmen, 2007a)

While switch mode chargers perform substantially better than linear chargers, the capacity exists today for even better performing devices. In 2000, a PhD thesis at the Danish Technical University (DTU), involving the design of a high efficiency, low standby power consumption power supply for a Bang & Olufsen (B&O) television set, was completed. The project, which was financed by the Danish Energy Agency and completed in collaboration with several companies and another university, resulted in the design of a power supply unit capable of achieving 83% efficiency during the supply of 1W and consumption of less than 0.006W in standby mode. If the design were applied to a mobile phone charger (which typically has a higher energy pull in standby mode), it is anticipated that the standby power consumption would be less than 0.01W. The results of the PhD project were partially implemented in a B&O television set, were presented at various conferences, in academics papers, and to brandholders and ODMs, and are available on the internet. Salcomp, a Finnish company who is one of the world's leading manufacturers of power supplies for handheld devices, has similarly designed a new charger with an in-use efficiency of 63% and a standby power consumption of 0.01W. The development was made by Salcomp in order to establish Best Available Technology (BAT) as part of their pre-operational work related to the EuP directive. (Remmen, 2007a)

Despite the fact that better technologies are currently available, however, they have not yet penetrated the mobile phone market. Academia, brandholders and power supply manufacturers have all cited cost as the main barrier for the implementation of the new technology (Singhal, 2007; Workshop, 2007e). Furthermore, lack of economic incentive on the part of both the brandholder and the consumer has been noted as a drawback to the commercialisation of more efficient chargers. While the brandholder realises the additional cost of the charger, the consumer recognises the savings. Because the overall savings resulting from a more efficient charger are insignificant in the eyes of the consumer, they see no economic incentive to pay more for the more efficient charger. (Remmen, 2007a)

While the best performing chargers are still not on the market, work has been undertaken by several major players on the charger standby power consumption issue and improvements have been seen (see for e.g. (Nokia, 2007)). Nokia, as part of its climate change strategy has stated that they will introduce near-zero no-load chargers with their high end phones and will ensure that average no-load charger consumption will be reduced by 50% by 2010. Furthermore, new models of Nokia phones are equipped with a reminder to unplug the charger when charging is complete, a recommendation which arose as part of the EU IPP pilot project headed by Nokia.(Singhal, 2007)

4G Network (Mobile-2)

As previously mentioned, although 3G mobile phone technology is still in its beginning stages, discussions regarding 4G technology and its potential forms have already begun. While the basic premise of 4G is to make data transmission more flexible and independent from any specific access technology by basing the system on IP technology, there are a number of ideas on how the system should actually materialise in form. While some operators, who currently maintain a favourable position in the industry, would like stability and little change in the new network, others have a different viewpoint. Generally, while Japan and Europe would like to see 4G continue along the same path as an extension of 3G, the United States is favouring a greater change in network structure. (Dirckinck-Holmfeld, 2007)

Historically the shifts from each generation of the mobile technology to the next have entailed an increase in energy consumption in the network. Therefore, regardless of the route taken with 4G, energy efficiency concerns related to increased data transmission are likely to present themselves. Increased energy consumption associated with increased data transmission will require increased energy efficiency of the phone, the battery, or both. A research group at Aalborg University (AAU) in Denmark has been undertaking work on the development of a system that would use ad-hoc clustering and peer-to-peer sharing in order to reduce the energy pull of individual phones. The basic idea is that the phones of individual users 'cooperate' by sharing data between one another. In such a manner, data transmission rates and energy efficiency of the phones can be increased. Aalborg University has a tradition of research within wireless technologies and is currently administrating the EU MAGNET Beyond programme, co-financed by the EU 6th Framework Programme (FP6). Despite this, however, the clustering research has received less attention, and is primarily funded by the university. (Remmen, 2007a)

A software programme allowing for the establishment of a cluster and the reception and retransmission of data has been created by the research team. However, the use of the technology is currently limited to phones with open software and requires a user's active involvement. In order for the system to become viable, the involvement and cooperation of both brandholders and operators is needed. While the project has received some interest from industry, the research group has not yet succeeded in commercialising the technology. Despite the potential energy savings also experienced by the network operator (energy consumption represents a variable cost for network operators and consequently maximising energy efficiency is a core business priority), lack of interest by operators has been theorised to be related to the lack of an appropriate payment structure to allow for peer-to-peer sharing and/ or operators' generally reactive approach to new technologies. Furthermore, the industry is currently in an uncertain position with regards to what 4G will bring. Consequently, there may be a lack of willingness to commit to any given path. (Remmen, 2007a)

4.2 The Pulp & Paper Sector

4.2.1 Overview

Similar to the mobile phone sector, the pulp and paper industry has played a substantial role in the Nordic economies. Worldwide, the pulp and paper sector is currently dominated by North American (Canadian and U.S.), East Asian (e.g. Japan), and northern European (primarily Sweden and Finland) countries (Price Waterhouse Coopers, 2006).

The modern paper-based industry began to develop in the latter part of the 19th century and the Nordic countries began trading pulp, paper, board and sawn timber in Europe at the start of the 20th century. As a result, the forest-based sector became the largest exporter in Finland, Sweden and Norway (pulp and paper production has always been lower in Denmark and Iceland). Today, pulp and paper continues to play a strong role in the Finnish and Swedish economies, representing 23% and 11% of the value of total exports in these countries, respectively. In Norway, however, the relative importance of the pulp and paper industry has declined in recent years (now producing only 2.5% of the total export value of Norway), due in part to the increasing importance of energy production in the country. (Kivimaa, Kautto et al., 2006)

4.2.2 Sector Characteristics

Sector Classifications

According to the OECD classification system of manufacturing industries, (which is based upon an analysis of R&D expenditures and output), the pulp and paper sector is considered to be a low technology industry[13] (OECD, 2005d). Furthermore, the pulp and paper sector can be characterised as process-based, referring to the fact that the focus of this industry has historically been on the development of production processes by which the final product is created.

Despite the fact that the pulp and paper industry is classified as low technology, however, it is considered to be a part of the “forest cluster”, which consists of a wide range of industries that span a variety of technology levels. Within the Finnish forest cluster, for example (see Figure 4-3), these industries include the forest economy, the packaging industry, the chemical industry, the printing industry, industrial engineering, consulting and risk management services, research and education, energy, logistics, machinery and equipment, automation and information technology, as well as wood construction (Invest in Finland, 2007).

[13] There is an ongoing debate however regarding the appropriateness of this classification due to the industry’s increasing level of technological sophistication and its noted adeptness at integrating technological innovations from its equipment suppliers and other cluster members into its operations. This is further discussed in Section 5.1.1.

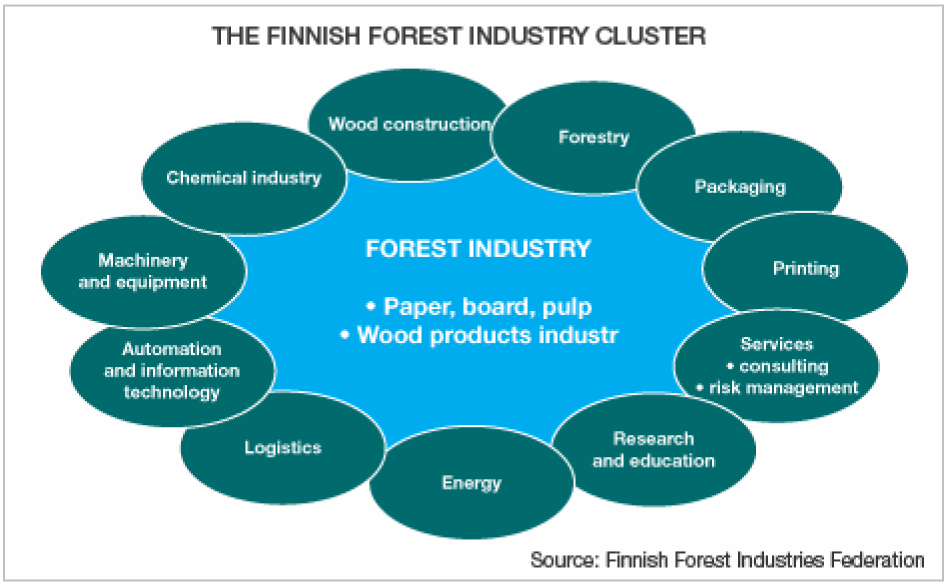

Figure 4-3 Finnish Forest Industry Cluster (Invest in Finland, 2007)

The pulp and paper sector is generally considered to be a mature industry and, as is common with traditional industries, it is often regarded as less innovative than its more high tech counterparts. Typically, Nordic pulp and paper producers spend less than 1% of their turnover on R&D activities (Kivimaa, Kautto et al., 2006). Despite these relatively low R&D inputs by the pulp and paper sector, however, other members of the forest cluster (e.g. the equipment manufacturers) have notably higher levels of R&D activity (Autio, Dietrichs et al., 1997). The Finnish forest cluster as a whole spends an annual amount of approximately 350-400 million Euros on R&D activities with an aim to double this amount by 2030 (Finnish Forestry Industries Federation, 2007). Similarly, in Sweden, the forestry industry in 2005 spent approximately 200 million Euros on R&D activities (Skogsindustrierna, 2007). Finland's Science and Technology Policy Council has called for the establishment of five centres of excellence within the country to promote continued innovation and the forest cluster represents one of the focus areas of these centres. The major companies in the Finnish forest cluster in combination with the Technical Research Centre of Finland, the Finnish Forest Research Institute and four Finnish universities have established the Forest Cluster Ltd. to lead the centre of excellence (Finnish Forestry Industries Federation, 2007).

Actors and Interactions

The forest cluster and the pulp and paper industry are significant employers in both Sweden and Finland. The Finnish forest cluster provides direct and indirect employment for almost 200 000 individuals, with approximately 31% (63 000) of these jobs occurring in the pulp, paper and wood products industries (Finnish Forestry Industries Federation, 2007). Similarly, 26% of all industrial employees in Sweden are employed within forest industry cluster (Skogsindustrierna, 1999). In addition to the direct and indirect employment affects resulting from it, the pulp and paper industry has also served to influence the focus of education around it, particularly in the technical universities of Sweden and Finland (Blomström and Kokko, 2003; Kivimaa, Kautto et al., 2006). The Nordic countries have been largely credited with developing the education side of the pulp and paper industry and a significant number of paper engineers are educated in the Nordic countries (with a particularly high proportion of these being educated in Finland) (Kivimaa, 2007b; Molkentin-Matilainen, 2007).

As previously mentioned, the forestry sector is impacted by a number of players, with the pulp and paper sector representing the largest part of the sector (Kivimaa, 2007b). Pulp and paper manufacturing consists of pulp mills (where usable pulp is produced from wood chips), paper mills (where this pulp is converted to paper), and integrated mills (where both pulping and paper making occur). Similar to the mobile phone industry, the pulp and paper sector has experienced an increasing internationalisation over the past decades. Prior to the 1980s, the Nordic pulp and paper sector consisted of dozens of small companies. In the later 1980s, consolidation of companies began to occur through mergers and acquisitions and internationalisation of the industry began. The process continued throughout the 1990s and, today, the Nordic pulp and paper industry is dominated by a few multinational companies (Kivimaa, Kautto et al., 2006; Finnish Forestry Industries Federation, 2007). The Finnish industry, for example, consists of three large pulp and paper producers and one slightly smaller producer, and ownership of the companies is largely foreign (Kivimaa, 2007b). A similar dominance of the sector by limited number of large companies exists in Sweden (Swedish Institute, 2007b). The industry is largely governed by economies of scale and it has been said that there is limited room for new entrants to the industry (Toivanen, 2007). While the industry is dominated by large companies, however, there also exists within the industry a number of small to medium sized companies who have carved out their operating niches in particular areas (for example, in the field of recycled paper or specialised products (Blomström and Kokko, 2002; Toivanen, 2007).

In addition to the pulp and paper producers themselves, other relevant actors in the industry include pulp and paper technology development firms, responsible for developing equipment used in the manufacturing processes, consulting firms and research institutes, chemical companies and customers (Kivimaa, Kautto et al., 2006; Kivimaa, 2007b). Large customers have been said to play an important role in the network via their demand power (Kivimaa, 2007b; Laurila, 2007). A general overview of the sector's organisation and its interactions is provided in Figure 4-4.

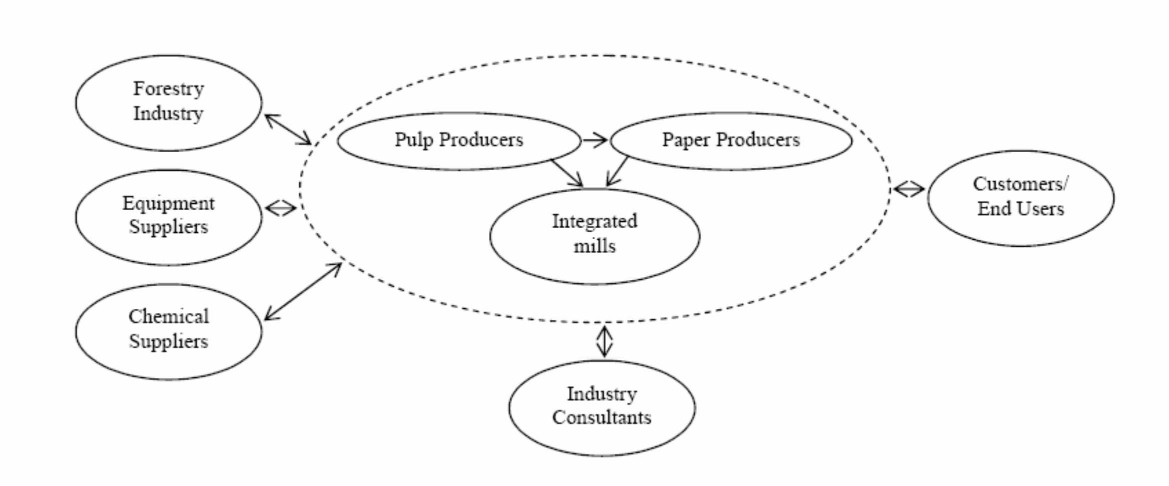

Figure 4-4 Pulp and Paper Sector Actor Network (Adapted from Kivimaa, 2007b; Laurila, 2007)

The Swedish and Finnish forestry industries have been characterised historically by strong ties between the forest industry, land owners and the state (Kivimaa, Kautto et al., 2006). There is a significant amount of cooperation throughout the industry regarding R&D activities. Historically, the industry has cooperated with government and influenced the development of public technology policies and has had close relationships to the state as a result of strong sector regulation (Kivimaa, Kautto et al., 2006; Kivimaa, 2007b). In addition to close cooperation with other members of the industry, the forest cluster and the government, the pulp and paper industries in both Sweden and Finland have developed close links with universities and research institutes (Blomström and Kokko, 2003).

While considered to be a low technology manufacturing industry according to the OECD classification, the pulp and paper sector has undergone increasing automation over the years and their production processes are generally considered to be quite technology-intensive (Swedish Institute, 2007b). The education level of many sector actors is at the post-secondary level (e.g. engineers) (Toivanen, 2007). These actors, therefore, are familiarised with a formal learning process and have the potential to share a common frame of reference amongst one another. The strong knowledge base in the pulp and paper industry has been considered an important feature of the industry. In the Swedish case, one explanation which has been put forward for the relatively high skill and education level present within the sector is the efforts that have been made by the Research Institute of the Swedish Forest Industries (STFI) to transfer skills from academic institutions to industry. By recruiting engineers and researchers as “trainees” during business down-cycles, the institute has assisted in the stabilisation of the demand for skilled labour, allowing the industry to retain a strong knowledge and skills base. Additionally, the institute has provided encouragement to the industry to employ skilled labour, by providing information about various types of education to the industry and by influencing the content of higher education in the direction of the industry’s demands. (Blomström and Kokko, 2003)

Markets & Innovation Trends

Despite its label as a "traditional", low technology industry, the Nordic pulp and paper sector has made significant improvements in environmental performance over the last several decades (Kuik, 2006). Significant environmental changes to the industry have included the employment of various methods to reduce harmful air and water emissions, the change in bleaching technology used in the paper making process to minimise or altogether avoid the use of chlorine, the increasing usage of recycled paper, and various alterations to production processes to minimise energy and water consumption (Kuik, 2006). These improvements in the industry have resulted from a variety of factors including public pressures, regulatory measures and searches for higher process efficiency (Blomström and Kokko, 2002; Kivimaa, Kautto et al., 2006).

The pulp and paper industry has been a point of environmental interest for many years. Public attention towards environmental problems originating from the sector began in the latter half of the 19th century, first focusing on water pollution and then on air emissions from the industry (Kivimaa, Kautto et al., 2006). In such a way, the pulp and paper sector has been a sort of "first under pressure" actor in regards to environmental issues, requiring it to undertake action to preserve its image on the public stage (Kivimaa, 2007b). In some instances regulation has inspired the adoption of new technologies and, in others, such as in the case of chlorine bleaching, customer demand has been noted to have been a significant factor in prompting environmental improvements (Kivimaa, Kautto et al., 2006; Kuik, 2006).

Pulp and paper is considered to be an energy intensive industry and is the fourth largest industrial consumer of energy (6% of total energy use). The industry also produces energy as a by-product of its production processes and generates approximately 50% of its own energy needs from biomass (International Energy Agency, 2006). Energy represents a variable production cost and while overall energy consumption in the industry has continued to grow over time, there have been indications that relative primary energy consumption in the industry has decreased over the last several decades (Farla, Blok et al., 1997).

Due in part to the focus of regulatory requirements and to consumer pressures, as well as to economic efficiency considerations, the majority of environmental innovations which have occurred in the pulp and paper industry in the past have focused on process innovations (Kivimaa, 2007a; Laurila, 2007; Toivanen, 2007). To this point, environmental product innovations have largely focused on the use of recycled fibres in the production process (Kivimaa, Kautto et al., 2006). However, historic stability within the pulp and paper sector has been replaced over the last decade with uncertainty for the future due to the movement of production to lower cost countries and changing market demands (Kivimaa, Kautto et al., 2006; Finnish Forestry Industries Federation, 2007). Consequently, in response to rising competition there is an ongoing trend in the pulp and paper industry towards product innovations and expansion into new market areas in order to maintain a competitive advantage (Kivimaa, Kautto et al., 2006; Finnish Forestry Industries Federation, 2007). Strategies pursued by the Nordic pulp and paper industry to remain competitive on the world-wide stage include a "value-added" strategy which focuses on the provision of more refined products with higher value added to the market. In some cases, companies have developed close connections with customers in order to develop specialised products for niche market demands (Blomström and Kokko, 2002). Despite this move towards product innovations however, the conservative nature of some of the industry's customers has been highlighted as a potential limitation to product innovations within the industry (Laurila, 2007; Toivanen, 2007). Where customers want to maintain a traditional product for market or economic reasons, this can impede the innovation process. Additionally, exports are a significant market for the Finnish and Swedish forestry industry. In Finland, in 2005, 91% of the total production of the paper and paperboard industries were exported (Finnish Forestry Industries Federation, 2007). Similarly, in 2005 Swedish exports totalled 89% of the country's paper production (Skogsindustrierna, 2006). The distance of the Nordic countries from the demand markets has been put forward as a dissuading factor for engagement in the specialisation strategy, which may be better applied by those companies having close market connections (Blomström and Kokko, 2002). This high level of export can also play a role in affecting how product innovations may best be encouraged.

Policies

The nature of the pulp and paper industry has historically made it to be the focus of local and national, as opposed to international, environmental regulation. Within Sweden and Finland, the pulp and paper industry has a lengthy history of environmental regulation largely related to production processes. In the 1970s and 1980s, policy emphasis was on regulatory instruments (such as emission limits), and these were later accompanied by economic instruments such as taxation. Environmental policy instruments affecting the industry have included water and air pollution regulations requiring the obtainment of an operating permit and/ or specifying plant discharge limits and chemical regulations specifying chemical handling and usage requirements. Studies regarding Finland and Sweden have concluded that administrative instruments have likely contributed to the diffusion of environmental technologies and that, in some cases, the anticipation of environmental regulation has led to new process-related developments (Hildén, Lepola et al., 2002; Kivimaa, 2007a).

Energy-related policy instruments affecting the industry have included electricity and CO_2 taxes. An evaluation conducted by Hildén, Lepola et al. (2002) regarding the effects of these economic instruments in the Finnish pulp and paper industry has noted that for many observed firms, the taxes had only marginal cost effects and modest direct environmental effectiveness. However, the study has also noted that the instruments have contributed to the public discussion concerning energy that has provided political signals for companies to undertake energy-related developments. In addition to these mandatory economic instruments, Finland and Sweden have both organised voluntary instruments with the industry to improve energy efficiency. Within Finland, beginning in 1997, the government has initiated a series of voluntary energy conservation agreements with industry, including pulp and paper producers. Between 1998 and 2002, 157 million Euros worth of investments had been carried out according to energy analyses conducted within the programme, resulting in estimated yearly savings of 70 million Euros. Approximately two-thirds of these investments and savings were realised in the pulp and paper industry (Hietaniemi and Ahtila, 2003). Within Sweden, in 2005, the Programme for Improving Energy Efficiency in Energy-Intensive Industries (PfE) came into force. Energy intensive manufacturing industries which meet the criteria are given the opportunity to participate in the programme in an effort to undertake energy efficiency improvement actions that will provide them the opportunity of being granted tax exemptions on their electricity consumption (STEM, 2007).

More recently, several product-related policies have been implemented, which affect the pulp and paper industry. Conversely to the traditionally used instruments that have focused on process regulation, the product policies often occur at an international (e.g. EU) level. These policies include the EU Packaging and Packing Waste Directive (2004/ 12/EC) which contains provisions on the prevention of packaging waste, the reuse of packaging and the recovery and recycling of packaging waste, as well as voluntary ecolabelling measures. The Packaging Directive employs the principle of EPR and is implemented at a national level by EU Member

States. It has been cited in the past as an influencing factor in certain instances in new product development within the paper and packaging industry (Kautto, 2006; Kivimaa, 2007a). In particular, in the case of the German packaging ordinance where the costs are based on the weight of the packaging, pressure from customers (the "filler" of the package is financially responsible for its handling) has been noted in one study to have played a role in accelerating product development (Kautto, 2006).

4.2.3 The Cases

The case studies presented in this section have been selected, researched and analysed by the project partner, the Finnish Environment Institute (SYKE) in Finland. The case descriptions presented below are synthesised from the work conducted by the SYKE team. In some instances, material collected by the partner has been supplemented with additional secondary data.

The case studies reviewed for the pulp and paper sector are 1) the gasification of black liquor for the production of dimethyl ether (DME) transportation fuel; 2) the development of LignoBoost technology for the extraction of lignin from the pulp making process for use in applications such as the production of biofuels; and 3) the development of a bleached, chemi-thermomechanical pulping (BCTMP) process that enables greater process efficiency and lighter and whiter end-products. Pulp and paper represents a highly energy intensive industry and significant interest in energy efficiency improvements of the sector has been shown in recent years. Industry and government have supported the concept of transforming the sector into a supplier of clean energy and of making the industry an important part of a sustainable society. The first two case studies concern innovations that result in the production of energy products that could be supplied to the market. While these innovations affect the process technology used in the industry, they do not impact the actual pulp production process or alter the final paper product that is produced. The third case study involves a technology innovation that results in a cleaner production process with better resource and energy efficiency. Additionally, in this case a new type of paper product is produced as a result of the new process, making it an interesting addition to the first two cases.

<u>Black Liquor Gasification (Pulp-1)</u>

Black liquor is a residue remaining from the pulping process after the cellulose has been removed to be used for paper-making. In a conventional system, the black liquor is burned in a recovery boiler, allowing for the recovery of pulping chemicals and the generation of energy (U.S. Department of Energy, 2006). Interest in black liquor gasification for electricity production began in the 1980s and R&D efforts and public and private investments in the technology were made in both Sweden and Finland throughout the 1980s and 90s. Despite these efforts, however, black liquor gasification technology failed to commercialise. This failure has been attributed to a number of factors including technological uncertainties, low demand, and relatively low electricity prices due to the availability of hydropower and nuclear energy in the Nordic countries. (Kivimaa, 2006b; Kivimaa, Kautto et al., 2006)

Despite the numerous failed efforts, one Swedish company, Chemrec, has continued to pursue black liquor gasification technology steadfastly since the 1980s. The idea for the technology came from an engineer with a background in the pulp and paper industry who thought that the gasification technology used for oil and gas could be used in the case of black liquor due to its resemblance to heavy fuel oil. In conjunction with a friend working in the recovery boiler industry, the engineer applied for a patent for the idea. In order to obtain funding to develop the technology, they contacted several Swedish and foreign companies and in 1987 the rights were sold to a company called Chemrec, which was involved in the development of plasma technology for recycling processes in pulp mills. The initial trials using plasma generators failed and since 1990 Chemrec has changed ownership a number of times, moving between owners in both the pulp and paper and oil and goal gasification industries. The project has faced a number of challenges, including internal conflict (as one owning company also produced recovery boilers, which Chemrec technology was destined to replace), technical issues that have been partially attributed to inefficient knowledge transfer between offices, and material selection difficulties. From 1997, development of the project was supported by the Swedish Energy Agency (STEM) through financial grants and letters of payment guarantee. This support has been stated to have been crucial for the survival of the project as it changed hands. Furthermore, continuation of the project has been largely attributed to individual perseverance and dedication from Chemrec supporters, staff and management. (Kivimaa, 2006b; Kivimaa, Kautto et al., 2006)

Since the beginning of the 21st century, a Swedish research programme (The Black Liquor Gasification research programme) has focused on the development of black liquor gasification technology (Kivimaa, 2006b). The programme has aimed to facilitate commercialisation of the high temperature black liquor gasification technology in the pulp and paper industry and tasks within the programme have included the construction of large scale tests in a gasifier developed by Chemrec, as well as fundamental and applied research on the black liquor gasification process (Arosenius, 2007). The programme is funded by various forest companies, the energy producer Vattenfall, Chemrec, the Swedish Energy Agency, the Swedish Foundation for Strategic Environmental Research (Mistra), and the authority of Norrbotten. The partners in the program are Energitekniskt Centrum (ETC, coordinator), Luleå University of Technology (LTU), Umeå University (UmU), Chalmers University of Technology (CTH), STFI, and Swedish Corrosion Institute (Chemrec AB, 2007b). The pulp and paper industry has been stated to have been the hardest partner to convince to support the project due to their uncertainty concerning the future potential of black liquor gasification technology. No Finnish pulp and paper companies have yet been convinced to invest. In 2005, a demonstration plant for Chemrec's gasification technology was mechanically completed in Piteå, Sweden. The plant is continuing to undergo operational testing and is expected to achieve continuous operation by 2010-2011. Expertise from both the pulp and paper industry and the petrochemicals industry has been considered to be extremely important in the start up and technical refinements required in the test plant. (Kivimaa, 2006b; Kivimaa, Kautto et al., 2006)

In 2003, the European Commission passed the Directive on the Promotion of the use of Biofuels or other Renewable Fuels for Transport (2003/30/EC). Chemrec were the first to notice that black liquor gasification could be used to produce transport biofuels. As a result of this new demand, the technical director of Chemrec invented a method of producing transport fuels using gasification technology. The resulting Black Liquor Gasification with Motor Fuels production (BLGMF) system is an alternative method of processing black liquor and is intended to replace conventional recovery boilers. The technology allows for the production of dimethyl ether (DME) which can be used as a transportation fuel which does not have sulphur or nitrogen emissions. The system has been patented by Chemrec. In addition to the biofuels directive, the rising oil prices and Swedish tax reliefs for renewable fuels have served as economic drivers for the project. Chemrec has very recently created a partnership with Volvo regarding the production of DME fuel. In expectation of more stringent future regulations regarding truck emissions, Volvo has created an engine to run on DME. At the beginning of 2009, the Piteå test plant will begin producing DME and the fuel will be tested on 30 Volvo trucks. (Kivimaa, 2006b; Kivimaa, Kautto et al., 2006) Financial grants have been provided to Volvo for the development of these vehicles by Swedish energy authorities. The support from Volvo has been said to have been a major boost for Chemrec's transport fuels technology (NyTeknik & IAGS, 2007). In January of 2007, Chemrec secured a substantial amount of venture capital funding from AB Volvo Technology Transfer and VantagePoint Venture Partners to help accelerate the commercialisation of the technology and expand company staff (Chemrec AB, 2007a).

The time for reaching full commercial application has been estimated to be 5-10 years away. In Finland, the near term realistic potential of the technology is 2-3 mills, as a result of the competing use of black liquor for heat and electricity production. Worldwide there are 400 recovery boilers that have the potential to be replaced by black liquor gasification technology when their useful life span has ended. (Kivimaa, 2006b)

LignoBoost (Pulp-2)

The Research Institute of the Swedish Forest Industries (STFI) is a private research and consulting company in Sweden related to the forestry industry. During detailed studies of lignin, a compound in wood, they noticed that the substance could be removed from black liquor to produce a solid biofuel. In 1996, development of the LignoBoost process (as previously described) began in STFI, with the vision that the pulp mill could be a major supplier of energy to society. The idea was originally received with some scepticism by the pulp and paper industry, and motivation to participate was limited due to low fossil fuel prices. An additional driving force for STFI however, was the ability of the process to also increase the pulp capacity of the mill. Typically, the recovery boiler serves as the limiting factor in the pulping process. By removing the lignin, the recovery boiler has a higher capacity. Furthermore, the life of the boiler can be extended by 8-10 years, resulting in savings of 50-70% of the cost to build a recovery boiler. (Kivimaa, 2006d)

The LignoBoost technology was developed as a result of R&D work carried out within the framework of the KAM (Ecocyclic Pulp Mill) and FRAM (Future Resource-adapted Pulp Mill) programmes. The KAM programme, which ran from 1996-2002, was aimed at developing a plant which produced top quality pulp and paper products while minimising the use of non-renewable resources and plant emissions (MISTRA, 2007). Another aim has said to have been the education of research scientists (Axegård, 2006). The programme was hosted by STFI and the major financiers of the project were Mistra, the Swedish Energy Agency, and the pulp and paper industry and its suppliers (Berntsson, nd). The programme involved close cooperation between universities and industry (Axegård, 2006). In the FRAM1 & FRAM2 programmes, STFI and its partners have taken the most promising results from the KAM programme towards full scale applications. FRAM1 has received funding from the Swedish Energy Agency, Mistra and industry, and success within the programme has been partially attributed to strong networks formed within the initial KAM programme (STFI, 2005). The currently operational FRAM2 programme aims to further develop the LignoBoost process concepts, to identify the consequences for several mills in the commercial application of the process and to further develop the lignin fuel products. The programme is funded by the Swedish Energy Agency and various industrial stakeholders and its network involves both industry and academia (LignoBoost AB, 2006).

The LignoBoost process has been tested as a mobile unit in Portugal and the U.S. and a demonstration plant (to be used in some of the FRAM2 trials) has been established at the Bäckhammer unbleached kraft pulp mill in Sweden. Regular production at the plant began in January 2007 and in 2007 there will be decisions on full-scale investments in Europe and North America based on the plant's performance. Partial funding for the demonstration plant has come from the Swedish Energy Agency, along with the pre-selling of technology licences. (Kivimaa, 2006d) Future possibilities created by LignoBoost related to the further conversion of a kraft pulp mill to a biorefinery are being discussed, including biomass gasification (Axegård, 2006).

BCTMP (Pulp-3)

The development of the bleached, chemi-thermomechanical pulping (BCTMP) process began when a large pulp and paper company, M-Real, recognised the need to increase the capacity of its mechanical pulp production and to improve the cost efficiency of its processes. Ideas within the company were collected and the project was later combined with the product goal of producing a lighter weight paper that could be used in product groups previously only using chemically produced pulp. Chemical and equipment companies within the forestry cluster, as well as universities, participated in the development. Funding for the project largely came from M-Real, however additional funding was provided by the Finnish Funding Agency for Technology and Innovation (Tekes) due to the cooperation of M-Real with several smaller companies in the development process. (Kivimaa, 2006a) The project was largely driven forward by its ability to improve the cost-efficiency of the production process (less resources in terms of raw materials, water and energy are required than with the traditional process), to produce a new beneficial product (lighter weight paper results in lower transportation costs), and to reduce environmental impact through energy savings, chemical reduction and a near closed waste water loop (Energy & Enviro Finland, 2005; Kivimaa, 2006a).

4.3 The Building Sector

4.3.1 Overview

While not specifically unique to the Nordic countries, the building sector nonetheless plays a significant role in the Nordic national economies. The building and construction industry employs a substantial number of individuals and represents a notable portion of national GNP. Table 4-1 provides an overview of national building and construction industry statistics in the Nordic countries.

	Finland	Sweden	Norway	Denmark	Iceland
GNP (total) (mill Euro)	139 700	312 340	190 091	156 590	8 952
Construction sector	19 240	20 400	19 275	8084	656
B&C/GNP	13.8	6.6	10.1	5.2	7.3
Companies (total)	225 847	842 000	429 910	297 706	8 184
Companies (B&C)	29 588	57 000	39 191	27 224	656
Companies, B&C/Companies, total	13.2	6.7	9.1	9.1	8
No. of employees (total)	2 372 000	4 272 000	2 055 000	2 692 000	156 700
No. of employees (B&C)	148 000*	235 000	136 697	173 000	12 200
No. of employees, B&C/No. of employees, total	6.2	5.5	6.6	6.4	7.8

*In addition, the number of employees in the construction products industry is 70 000.

GNP = gross national product

B&C = Building and construction sector

Table 4-1 Nordic Building and Construction Industry Statistics, 2002 (Ingvaldsen, Lakka et al., 2004)

4.3.2 Sector Characteristics

Sector Classifications

The building industry does not receive a classification according to the OECD system of manufacturing industries, however, it is generally considered to be a low technology sector, with relatively low levels of expenditures on innovation activities (Reichstein, Salter et al., 2005). Similar to the pulp and paper industry, the building sector is considered to be a traditional industry and has been described as being rather conservative in nature (Rozite, 2006b). Despite this categorisation, however, as in the case of the pulp and paper industry there is increasing incorporation of technologically-advanced elements into the building process. The building industry can be considered as a part of the retail and construction cluster that exists within the national economy (Uusikylä, Valovirta et al., 2003). This cluster, as identified by Tekes, consists of the real estate industry, the building industry, the building products industry, and the building services industry (Uusikylä, Valovirta et al., 2003). While the building industry itself may have relatively low R&D investments, the building services sector which feeds the building industry has a relatively higher level of R&D inputs (for example, in Finland, in 2000, the total annual average R&D investment in the cluster was 0.8% whereas the building services industry's R&D investments represented 3.2% of turnover) (Uusikylä, Valovirta et al., 2003). Unlike the forest cluster, however, the construction and real estate cluster has not generally been considered by the actors themselves to be a business ecosystem where cooperation is beneficial to all parties (Uusikylä, Valovirta et al., 2003). In a sense, while the cluster exists in principle, its members have not necessarily established mutual relationships.

Conversely to the mobile phone and pulp and paper sector, the building industry is often considered to be a project-based industry (Gann and Salter, 2000). In such an industry, firms are set up around projects and are involved in the provision of complex services and products for their clients (Blindenbach-Driessen and van den Ende, 2006). The project-based nature of the industry requires that firms practice their technical competencies in association with those of other firms with whom they are cooperating on a given project. It has been argued that these types of project-based operations require a set of skills and resources that differ from those that exist in more stable, or fixed, industries (Gann and Salter, 2000). In recent years, a number of studies have been undertaken to examine the impacts of the project-based nature of an industry on operational and innovation activities (Gann and Salter, 2000; Bresnen, Goussevskaia et al., 2005; Blindenbach-Driessen and van den Ende, 2006). Typical issues which have been identified include lack of a common meeting ground for exchange of ideas, loss of knowledge between projects due to changes of actors, and fragmented networks.

<u>Actors & Interactions</u>

The building industry is a significant employer in the Nordic countries, as can be seen from Table 4-1. The building sector involves a wide range of actors who play a role in the overall construction process. A general overview of the organisation and interactions of these actors is provided in Figure 4-5.

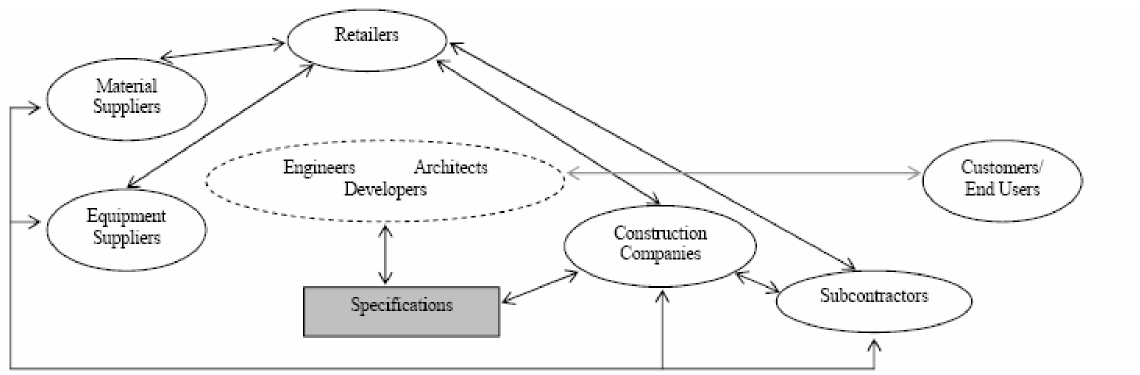

Figure 4-5 Building Sector Actor Network (Adapted from Rozite, 2006a)

The building developer represents the actor in the project with the financial resources. Consequently, they execute the major economic decisions and issue the primary demands regarding the building's construction. The building developer's role can be filled by a number of parties including individuals, private companies, industries, government agencies, or construction companies. In some cases the building is intended for private use. In others, the intention is to rent out or to sell the building for revenues. Investors providing capital to the building developer can potentially be actors capable of providing additional demands regarding the building's characteristics. (Rozite, 2006a)

The physical design of the building is done by engineers and architects. Both actors can influence the environmental performance of a building significantly depending on the designs, materials, and systems selected. Once the specifications have been established, construction of the structure is typically assigned to a construction company which is charged with recruiting the necessary subcontractors and purchasing the necessary materials and system components (e.g. heating, ventilation, and air conditioning systems – HVAC, or automation systems). Purchases may be made directly from material and component suppliers, or through retailers. It has been indicated that retailers can have a significant influence on the types of materials sold due to their selling power and ability to offer discounts, credit insurance, and other similar benefits to construction companies. In some cases, actors take on combined roles in the building process. For example, the construction company may also supply design and engineering services or may serve as a project developer. (Rozite, 2006b; Rozite, 2006a)

Within Sweden, as mentioned above, there are currently three major players in the building construction arena, who display similar prominence in the construction industries of other

Nordic countries. These large contractors are also active as building developers and it has been noted that there seems to be an increasing trend in all Nordic countries that the contractor and the developer are part of the same company or trust (Ingvaldsen, Lakka et al., 2004). A similar domination of the building market by a few large firms has also been noted in Denmark, Norway and Finland (Ingvaldsen, Lakka et al., 2004; Virtual Finland, 2004; Kristiansen, Emmitt et al., 2005; Rozite, 2006a). While these large actors hold a significant portion of the building market share, however, there still remains a number of small and medium-sized companies which compete with the major firms at the local and regional levels (NCC, 2006).

In terms of building material producers, in most cases in Sweden, a few producers of a given material lay claim to 80-100% of the market (Ingvaldsen, Lakka et al., 2004). This concentration of suppliers is indicated in Table 4-2.

Building Material	**Concentration**
Cement	1 has 95%
Aggregate (stone & gravel)	4 have 80%
Ready-made concrete	5 have 80%
Asphalt	2 have 80%
Steel for reinforcement	1 has 80%
Prefabricated concrete elements	2 have 60%
Lightweight	1 has 100%
Concrete pipes	3 have 100%
Plastic pipes	1 has 50%
Gypsum boards	3 have 100%
Mineral wool	2 have 90%
Floor materials	2 have 60%
Windows	2 have 70%
Doors	1 has 50%
Kitchen and wardrobes	4 have 80%
Bath tubs	2 have 100%
Sanitary equipment of porcelain	3 have 90%
Stainless steel sinks	2 have 80%

Table 4-2 Concentration in the Building Material Supply Industry - Sweden (Ingvaldsen, Lakka et al., 2004)

Furthermore, it has been noted that in certain areas within Sweden, including aggregates, prefabricated concrete elements, asphalt, ready made concrete and concrete pipes that many producers are, in turn, owned by the large contracting firms (Ingvaldsen, Lakka et al., 2004). Similarly, within Denmark, some of the largest contractors have purchased installation firms, building material firms and other trade firms, increasing their own size and moving towards control of a larger portion of the value chain (Kristiansen, Emmitt et al., 2005). A general shift towards vertical integration within the construction sector is being observed (Rozite, 2006b). Within both Sweden and Denmark, the construction sector has faced criticism regarding lack of competition (Ingvaldsen, Lakka et al., 2004; Kristiansen, Emmitt et al., 2005).

In the area of building service installation firms (typically subcontractors), who are responsible for the supply and installation of heating, ventilation, water supply and drainage units, the market is more varied. It is characterised in Sweden, and generally throughout the industry, by a few large and many small firms (Ingvaldsen, Lakka et al., 2004; Reichstein, Salter et al., 2005). The renovation and home repair business is, likewise, dominated by many small firms (Brown, Southworth et al., 2005). Conversely to the pulp and paper industry, lack of barrier to entry in the construction sector has been cited as an issue in regards to performance and innovation (Reichstein, Salter et al., 2005).

As can be observed from the previous discussion, the number of actors involved in a given building project is quite large. The finished product is the result of a significant amount of decision making and acceptance from various parties, where the actions of one party ultimately affect the actions of the next (e.g. where better insulation is placed, a better ventilation system is needed). As such, the production of a more energy efficient building is the result of complex and combined efforts from a series of actors. Not only must the building owner be willing to finance the more energy efficient building, but the building and its systems must be properly designed by the architects and engineers and the necessary people with the correct skills must be available to complete the construction. Furthermore, as construction projects are often heavily focused on time to completion, the necessary materials must be available when needed (Rozite, 2006a; Fabiano, 2007). To summarise the words of one project planner in regards to the installation of new solar lighting, 'the customer must be willing to pay the premium for the new technology, the construction team must be able to install the new lighting, and the project schedule must be flexible enough on the developer's end to allow for additional time that may be required to procure the right components' (Fabiano, 2007).

In contrast with the mobile phone and pulp and paper sector, the building industry has historically been characterised by a high level of segmentation amongst its actors. Building material suppliers are often not involved in the design or building process and the design phase is often separated from the construction phase. As such, lessons learned in one system area often do not get passed on to another. Similarly, lessons learned by using (i.e. from final occupants and maintenance staff) often are not reflected back to the beginning of the building chain. (Reichstein, Salter et al., 2005; Rozite, 2006a) Additionally, from literature and empirical materials, the impression exists that there is, in many cases, a certain division between various actors in the building chain, where some actors (for example, suppliers of mechanical equipment) do not see themselves as a part of the building industry. Issues in supply chain management have been noted throughout the industry and customer-supplier relationships have been characterised as being of an arms length-type rather than partnership due to the 'temporary multiple organisation' of the projects.

Within the building chain, actors come from a variety of educational backgrounds. While some are educated at the post secondary level (e.g. architects and engineers), others have more applied training. As such, individuals involved in the chain may have differing frames of reference and may be familiar with different forms of learning and have varied levels of experience with formal education (Rozite, 2006b). It has been mentioned that, due, in part, to its "unglamorous" image, recruitment of students and highly skilled actors in the building and construction field may be difficult (European Monitoring Centre on Change, 2005). Furthermore, it has been noted that university and research institute linkages are weak in many cases, outside of those that typically exist with the largest firms (Bröchner, 2006; Rozite, 2006b).

The knowledge encompassed in a building project is both tacit and codified, with a large amount of knowledge gained during the actual building process. It has been suggested that tacit knowledge may be particularly important in the building sector (Gann and Salter, 2000). This feature of tacit-based knowledge combined with the project-based nature of the industry has been noted as a potential source of weakness in the innovation process. New knowledge that is gained during a building project as a result of various interactions and learning processes may be difficult to capture and/or transfer to future projects. Different constellations of actors may work together on different projects, resulting in difficulties in collecting experiences. Furthermore, as the actors involved come from a variety of backgrounds, their experiences may be largely restrained to their particular sector of specialisation. (Rozite, 2006a)

<u>Markets & Innovation Trends</u>

The focus of construction firms is often a local market or regional market and, to some degree, particularly amongst large firms, there is a national orientation (Reichstein, Salter et al., 2005; Rozite, 2006b). While there is growing internationalisation within the construction industry, international markets generally play a more limited role in the sector (Reichstein, Salter et al., 2005).

The building sector is subject to cyclical periods of growth and recession that are often perceived to be more considerable than in other sectors. Periods of upswings and downswings lasting approximately 5-6 years result in periods of high demand characterised by economic growth and the need for significant employees and resources and periods of low demand characterised by decreased income, layoffs and downsizing (Rozite, 2006a). The market fluctuations in the construction sector have been said to induce a sort of "hyper-flexibility" in the sector, whereby little investment is made in competency building and risky development activities. As a result of these factors, and others, the building sector has largely been criticised for having poor innovation performance. In particular, it has been noted that in many cases, even when new, performance enhancing technologies exist, these are often not incorporated into building projects.

The market structure of the construction industry has frequently been noted to be a barrier to the adoption of energy efficiency measures. In many cases, there is a discrepancy between the actor funding the construction or renovation activities and the user of the building responsible for paying operational costs (e.g. where a building is constructed by a developer and then sold to another party for end use, or where a building is owned by a landlord, but utilities are paid by the tenant). In such an event, there may be little incentive for the financier to implement energy efficiency measures (OECD, 2003). Even in cases where commercial owners will be the occupier of the building themselves, problems have been noted where the department involved in the procurement of new facilities is different from that responsible for maintenance operations and the two departments operate on separate budgets (Linturo, 2007).

Furthermore, it has been indicated by various members of the building and construction industry that the demand side represents a significant challenge for the implementation of energy efficiency measures. Demands in the sector are often mainstream, requesting standardised products. As such, the incentive for innovation is reduced. Furthermore, low capital cost is often one of the most important specification parameters for new buildings, drawing focus away from potentially new, energy-saving options, and may limit the incentive of material and equipment suppliers to invest in innovation activities. In regards to the final building owner, there is often a lack of awareness, interest or ability to calculate energy efficiency savings and to make decisions based on life cycle costs. (Kiss, 2007) As such, the role of the consumer in the innovation process within the building industry has been questioned and innovation within the sector has been characterised as supplier dominated (Reichstein, Salter et al., 2005; Rozite, 2006a). In some cases, where buildings are procured by organisations familiar with the building process, the opportunity may exist to make informed decisions based on life cycle costing or similar methods (Fabiano, 2007). However, in many cases (e.g. in residential housing), the end user and purchaser may not be an experienced buyer (most people buy homes only a few times over the course of a life time) and/ or may not be fully aware of their needs (Naaranojaa and Udenb, 2007). As a result, they may not be in a position to know exactly what building options are available to them, to distinguish between different options, or to express their needs. Furthermore, different consumer structures can play a difference in the feasibility of innovations. For example, in Finland, many single family homes are built individually. This can potentially make the process of implementing certain measures (e.g. centralised automation systems) more difficult than in a situation where a number of homes are built by a single contractor, providing the economy of scale advantage (Kiss, 2007).

To further compound matters, within the building sector, there are often a number of features which are competing for market interest. These include things such as location, design, specific features (e.g. regarding accessibility), and price. As such, energy efficiency concerns may not be a high priority when selecting a building. Additionally, it has been stated that in some cases, affluent consumers may not even be concerned with financial savings resulting from increased energy savings. (Rozite, 2006a; Kiss, 2007)

Often innovations in the building sector are incremental in nature, make use of previously existing ideas or are process or design-related. The result is that innovation patents in the industry are often difficult to acquire, which can potentially act to dissuade a company from developing new products and concepts due to an inability to capitalise on the innovation. Additionally, difficulties in monitoring patents in such a fragmented industry can serve as a potential barrier to the innovation process. (Rozite, 2006b)

In recent years there has been significant attention put on the increasing inefficiency in the building sector. The industry in Sweden, for example, has experienced a rising cost index that is notably higher than the national average (Fritzon, 2007). Partially in response to this, there has been a trend toward industrialisation of the building process and modularisation of building components by a number of major actors in recent years (Fritzon, 2007).

While much focus is often put on the construction of new energy efficiency buildings, the existing building stock also represents an important component of the built environment. It is often said that the most frequent opportunities for the incorporation of energy efficiency innovations occur during the initial construction phase. However, new buildings typically constitute only 2-3% of the existing building stock in any year (Brown, Southworth et al., 2005). The share of renovation construction has been growing for a number of years throughout all of the Nordic countries, and is expected to continue to grow in light of deterioration and functional obsolescence of older buildings (Confederation of Finnish Construction Industries, 2002; Ingvaldsen, Lakka et al., 2004).

<u>Policies</u>

Similar to the pulp and paper industry, the nature of the building industry has historically made it to be the focus of local and national regulation, as opposed to international policy. The building industry in the Nordic region is heavily regulated by a number of policies including building codes, fire codes, zoning and planning legislation, and public housing regulations which dictate things such as rent control.

Attention to environmental issues in the building industry has increased in recent years and these issues have been explicitly addressed via a number of policy instruments. The building code has often been cited as one of the most significant components in influencing energy efficiency improvements in the building sector (Rozite, 2006b; Fabiano, 2007; Workshop, 2007a). Approximately 95% of buildings are constructed according to the building code specifications (Rozite, 2006a). The first concerns regarding energy efficiency appeared in the national Swedish building code in 1960 (Byggnadsstyrelsens anvisingar till byggnadstadgan, BABS 1960) with component specific U-values and requirements for double pane windows. The energy efficiency demands of the code were significantly strengthened following the oil crisis in 1977 and several efforts to further tighten the demands of the code have been made since (Smeds, 2004). Similarly in Denmark, the energy efficiency demands of the code have been progressively tightened over the last several decades. A new code with heightened energy efficiency requirements entered into effect in 2006 and further tightening of the regulations is anticipated for 2010 and for 2015 (Rockwool, 2007). The Finnish building code has likewise incorporated energy efficiency considerations into its design. In some instances, the building code has been criticised for restricting innovation possibilities and for flaws or weaknesses in its efforts to mandate energy efficiency measures (Smeds, 2004; Rozite, 2006a). Regardless of these criticisms, however, based on interviews and reviewed materials there is an apparent agreement among a number of stakeholders that the building code is an important tool in the building industry. Additionally, the literature has shown that in some cases administrative instruments, such as building regulations and performance standards, have been key factors in promoting innovation in the building industry (Dewick and Miozzo, 2002; Vermeulen and Hovens, 2006).

While the building codes discussed above are mandatory in nature, some countries, including Switzerland and Austria, have introduced alternative voluntary standards which stipulate a higher performance with respect to the energy efficiency of buildings (the Minergie® and Passivhaus standards, respectively). In Austria, for example, these voluntary standards have been coupled with several socio-political factors to make the country the leader in passive houses[14] per capita worldwide (Treberspurg and Smutny, 2006).

In 2003, the EU Directive on the Energy Performance of Buildings (EPBD) (2002/91/EC) entered into force, reinforcing the effort to incorporate energy efficiency into building requirements. This framework directive, which necessitated incorporation of its content into the national legislation of Member States by January 2006, requires that a common methodology for calculating the energy performance of buildings be applied throughout the EU, that minimum standards for the energy efficiency be applied to both new buildings and to major refurbishments of existing large buildings, that boilers and air conditioning systems above minimum sizes be regularly inspected, and that a certification system be developed for buildings that will make the energy consumption levels much more readily apparent to all parties (European Commission, 2003a). Countries have begun undertaking the implementation of the Directive to varying degrees. Since 1997, prior to the Directive, Denmark has had a labelling scheme in place for both large and small buildings[15]. Three reviews of these schemes (two for the labelling of large buildings and one for small buildings) have been carried out. In both cases (small and large buildings), issues associated with awareness of the scheme by relevant parties have been noted. In the case of the large buildings

[14] A passive house is a super insulated building that is capable of maintaining a comfortable indoor climate without active heating or cooling systems. Necessary aspects include a super insulated building envelope, an airtight building envelope, passive solar use, and highly efficient heat recovery from exhaust air. A passive house is not a defined construction method or building style, but is rather a building standard, which stipulates a heating load of less than 10 W/m2 per net residential area (Treberspurg and Smutny, 2006).

[15] Under the Danish *Order on Energy Labelling etc. in Buildings*, a large building is defined as a building having a size greater than 1500 m^2. Small buildings are those having less than 1500 m^2, used for residence, by public institutions or for private service and trade. Buildings used for production and buildings with very low energy consumption are excluded (Lausten, 2003).

it was found that a greater degree of buildings registered in the scheme had implemented energy and water saving initiatives compared with those not taking part. This same phenomenon was not observed in the case of small buildings, though it was noted that improvements undertaken in labelled (small) buildings had larger saving potential then those undertaken in non-labelled (small) buildings (which tended to be of a more aesthetic scope). (Laustsen, 2003) Alterations to the existing Danish labelling schemes are being made in order to fulfill the Directive's requirements and to address issues that were noted with the original schemes.

In addition to the building code and the energy performance directive, a number of other policy instruments have been used to help effectuate positive changes in the area of energy efficiency in buildings. In Sweden, Denmark and Finland these measures have included labelling of appliances and windows, energy saving information programmes, mandatory individual metering schemes for energy consumption, advice programmes, energy related taxes, and investment and subsidy schemes[16]. A number of evaluations have been performed regarding various policy instruments aimed at promoting energy efficiency, though these evaluations often focus on effectiveness and efficiency of the adopted measures, rather than their innovation fostering effects. Several studies, which have focused on the innovation aspect of such energy efficiency policies have put forward the argument that existing policies have had very moderate effects on innovation in the construction industry, typically resulting in incremental innovations in existing products and diffusion of existing technology (Kemp, 1997; Beerepoot, 2007).

4.3.3 The Cases

The case studies presented in this section have been selected, researched and analysed by the project partner, the International Institute for Industrial Environmental Economics at Lund University in Sweden. The case descriptions presented below are synthesised from the work conducted by the IIIEE team. In some instances, material collected by the partner has been supplemented with additional primary and secondary data.

The case studies reviewed for the building sector are 1) an energy efficient foundation system; 2) a heating, cooling, and ventilation system; and 3) a building automation system. Energy efficiency in the building industry has received considerable attention in recent years. It has been estimated that the building sector accounts for 40% of the EU's energy requirements (European Commission, 2007a). Energy efficiency improvements in buildings can be achieved through a number of means including entire design concept changes (e.g. passive houses) as well as changes to materials, equipment, systems, and building envelopes. The first two cases reviewed involve the application of a new approach to fundamental building technologies (foundation systems and HVAC). The third case involves the integration of advanced building services technology into the building process. The building services sector represents a unique part of the building cluster that typically has higher levels R&D and technology-based activities than other cluster members, making it an interesting point of focus in addition to the two structural innovations.

[16] See Appendix A for a list of some of the energy-related policy instruments affecting the building, mobile phone and pulp and paper sectors.

Energy Efficient Foundation System (Building-1)

The product under review here is an energy efficient foundation system that has been developed by a Danish company, based upon a similar system existing within Sweden. The system is based on the idea of the prefabrication of a complete foundation system having built-in insulation properties and involves the integration of both the structural and building insulation requirements as a complete solution. (Emtairah, 2007) The product was developed by the company out of a combined desire to retain autonomy by using self-developed products (rather than selling products "owned" by others) and to create a product that could potentially fulfil demands originating from the introduction of new Danish building regulations in 2006 which placed a significant focus on thermal bridges and foundations (Rozite, 2006b).

The product was primarily developed using internal resources and co-operation with in-house actors, partly due to the company's internal policy to be self-reliant. Cooperation between the company and research institutions is generally said to be limited, however cooperation with universities for product testing services and for the development of an energy calculation programme has been undertaken. (Rozite, 2006b)

The company has chosen to legitimise the products through certifications and standards and to market the product through building retailers (Emtairah, 2007). While this selling method does not allow the company to sell directly to the contractors, it has been indicated that it assists them in avoiding a potential "lock-out" situation with retailers, whereby they may exclude a product from their portfolio if by-passed in the selling process (Rozite, 2006b). The company attempts to reach developers through media and advertising and the product is promoted as having a number of positive features, such as being light-weight, saving time, and living up to the new insulation criteria of the Danish building regulations (Emtairah, 2007). Barriers expressed by the company with regards to innovation developments are conflicts with other building regulations, such as the fire code, limitations in market openings for new products, and lack of concern for energy efficiency amongst the industry and consumers. The developed product currently sells well on the market. (Rozite, 2006b)

Termodeck (Building-2)

Termodeck represents a unique heating, cooling and ventilation system that uses the high thermal mass of structural hollow core concrete slabs to warm or cool incoming air in a building. The supply of air, controlled by the building management system, passes slowly through the hollow cores, allowing passive heat exchange between the air and concrete slabs. Success of the innovation requires early integration of the product in the building design and, hence, requires interactions with other actors in the building industry to effectuate the necessary design changes (Tarmac, 2006).

The Termodeck concept was developed in the 1970s by two researchers, one of them the CEO of a ventilation company and the other a researcher at the Royal Institute of Technology (KTH) in Stockholm, Sweden. The invention was essentially related to two knowledge areas – materials (concrete) and ventilation – and was concerned with how to use the temperature retention capacity of cement. (Emtairah, 2007) The idea was presented to a Swedish company, where it was taken in and developed over the course of several years to the commercialisation stage. The company has stated that cooperation with universities has worked well for them and that it has been important that they have been able to return to the research institutes to jointly develop product improvements. (Rozite, 2006b)

Drivers for the commercialisation of the product include the oil crisis, the weak functioning of existing HVAC systems and the low investment costs (Workshop, 2007c). The product provides energy saving potential while simultaneously reducing capital costs associated with building ventilation requirements. For marketing, the product was offered with a 5-year climate and energy guarantee. Furthermore, the company made use of complementary measurement tools and demonstration of energy saving potential to attract clients. (Emtairah, 2007) Barriers to the product's commercialisation include resistance from consultants and ventilation experts, since the product was sold as a system and it was felt by some actors to intrude on their "territory" (Rozite, 2006b). The product received considerable interest in the 1980s but experienced set-backs during the building crisis in the 1990s. Weak interest in energy savings have contributed to low interest despite significant increases in office building construction at the end of the 1990s. (Workshop, 2007c) Overall, the company behind the concept has made limited commercialisation of the product in the Nordic market and internationally, having installed it in over 200 building projects since its inception at the end of the 1970s (Emtairah, 2007).

COBA (Building-3)

COBA (connected open building automation) is a Finnish effort undertaken by companies in the construction, building automation, telecommunications and information technology areas to develop an open software architecture for a building operating system. It is based on the idea of offering a common interface for all facility management systems (heating, cooling, ventilation, lighting consumption metering, alarms, etc.). (COBA Group, nd.) Applications and services can access and control the building's functionality, allowing for increased security and comfort and reduced costs and energy consumption throughout the building's life cycle. Figure 4-6 offers a simplistic example of the COBA system in practice.

> *"In an office building Megahouse there are several separate systems: HVAC-automation systems facility access control, security cameras, burglar alarm systems, fire alarm system, etc. Each of these are operated and maintained by different companies or peer groups. One company – the user of the facility – wishes to reduce costs of the maintenance, so they install a COBA server to the facility. No changes to the subsystems are required. Now maintenance companies can access the systems even remotely, and the maintenance can be carried out by any capable company on the market."*
>
> (COBA Press Release)

Figure 4-6 The COBA System (COBA Group, 2001)

The idea for the system originated from an individual with a background in the microcomputers industry, who recognised the similarity between computer operating systems and building automation systems and whose interest in the building industry was sparked during the construction of his own home (Linturo, 2007).

In 2000, the project COBA was initiated in participation with 15 companies, bringing in expertise from a wide range of areas. Funding for the project came from high tech investors, interested companies who each paid a fee to learn the technology and to be involved if the project was successful and from Tekes, as part of the Building Services Technology (CUBE) programme (Linturo, 2007).

The project is related to two unique research programmes organised by Tekes. Between 1995 and 1999, Tekes ran the Smart and Modular Building Automation (SaMBA) programme. The official aim of the programme was to "bring together the building services industry, building owners and end-users to develop new intelligent interoperable field devices as well the necessary new services for their utilisation" (Uusikylä, Valovirta et al., 2003). The programme used a fixed technology standard (participants were to use LonWorks™, LonTalk™ and LonMark™) and R&D subsidies and loans were provided through the programme to help companies with the generation of products for lon-based building automation systems. Tekes' primary motivation for initiating the programme was a desire to integrate the subsectors of the building services industry (e.g. automation, heating and airconditioning, electricity), who, at the time, did not see themselves as part of the same sector. It was hoped that integration efforts could help to provide better service to users and to spur the growth of the building automation industry in Finland. The Finnish Association of Building Owners and Construction Clients (RAKLI) also had substantial involvement in the preparation of the programme. Their motivation was largely to address the market lock-in situation existing in the building automation industry[17]. The creation of an open standard[18] would facilitate the entry of new SMEs into the market and the development of interoperable building systems that could meet customer needs. Issues surrounding the interoperability of devices were noted during the SaMBA programme and a need for a common definition of openness was seen within the Building Services Technology programme (CUBE) that followed SaMBA (2002-2006). (Hyvättinen, 2006) The COBA development has been funded under this subsequent programme.

The first large scale implementation of COBA was done at the headquarters of Senate Properties, a government owned enterprise responsible for managing, developing and letting the property assets of the Finnish state. The system has been in operation since 2002 (COBA Group, nd.). Two companies have attempted to commercialise COBA-based products. The first company has been involved in software development for COBA. The second company provided the control modules that interface with various sub-systems. The first company managed to commercialise approximately 100 systems before going out of business due to financial reasons. (Emtairah, 2007) The second company has been more successful and the system has been commercialised and has been installed anywhere from dozens to hundreds (small scale) of systems in Scandinavian, Eastern Europe and the United Arab Emirates (UAE), with the greatest success having been seen in the UAE. The system has been mainly implemented in commercial buildings and there has been a limited market for the technology due to costs and logistics (Linturo, 2007).

[17] At the time, the automation market consisted of systems with closed, propriety interfaces. This meant that the supplier of the system was essentially the only party capable of maintenance and supply of new parts for the system.

[18] Here, an open standard/ system refers to a system where the components of different vendors can be combined because the interface used is available to all providers.

5 Analysis & Discussion

In this chapter, the specific issues and policies surrounding the development of environmental innovations within the innovation system of each sector are discussed. In Section 5.1, the collected materials are analysed based upon the proposed framework in Section 1.3.3. Conditions and issues surrounding the innovation process are analysed with respect to the innovation preconditions, based upon the data collected regarding the innovation dynamics of the studied sectors and from the case studies. This is done in an effort to identify factors affecting, aiding and hindering the innovation process, including environmental innovations, in each sector. Policies which played a role in the innovation process are discussed in regards to sector characteristics and to the literature findings. In Section 5.2, potential directions for policy based on the analysis are put forward. Sector specific and general measures are highlighted.

5.1 The Sectors

It has been recognised from the literature, that innovation characteristics vary across sectors and that successful system changes require a variety of different policy instruments that are customised to the specific needs of various sectors and industries (Guy, 2002; Malerba, 2005). This section examines how the various sectors studied in this thesis operate in regards to the necessary preconditions of innovation – access to knowledge, access to resources and formation of markets – and to policy interventions, based on the sector dynamics and case studies, in order to shed further light onto the environmental innovation process.

5.1.1 Knowledge

Access to Knowledge and Frame of Reference

A sector's ability to generate and transfer knowledge can play a significant role in affecting its innovation capacity. The mobile phone sector is an industry focused on codified knowledge, whose business is substantially dependent on the ability to acquire information and to engage in the continuous development of new products in the sector. Accompanying this "knowledge-intensive" industry is a familiarity with the R&D process and a strong network with university and research institutes that facilitates knowledge transfer from the academic to the commercial arena. Key actors in the field often share a similar frame of reference in terms of educational background, which can facilitate transfer of knowledge and ideas throughout the system.

The pulp and paper sector, while classified as a low technology sector in the manufacturing field according to the OECD classifications, finds itself in an interesting position due to its placement in the strategic forest cluster that exists within the Nordic countries. Sophisticated technology suppliers existing within the forest cluster have been shown to play a key role in innovation in the pulp and paper sector and past studies have put forward evidence that the industry has a high ability to use knowledge that is external to the firm (Autio, Dietrichs et al., 1997). The sector, by association, is privy to close ties with the research, university and forestry-related communities that have historically facilitated knowledge transfer and made the industry within the Nordic countries traditionally more R&D-oriented than its North American competitors (Kivimaa, Kautto et al., 2006). Actors within the pulp and paper industry often share a common frame of reference with respect to education, with a particular focus on engineering (Kivimaa, 2007b; Laurila, 2007). Like the mobile phone sector, this common frame of reference can help to facilitate communication and knowledge transfer amongst actors. The case studies from within the pulp and paper sector have reinforced the ability of the industry to participate in and be privy to knowledge-related activities through links within the cluster.

Conversely, the building sector has been a point of interest for environmental researchers over the past years due to the apparent inability of energy efficiency innovations to diffuse throughout the industry. Arguments have been made that the knowledge to perform energy improvements in buildings exists (Fabiano, 2007; Fritzon, 2007; Workshop, 2007a) and the case studies have demonstrated that the capacity to innovate is, at least in some instances, present in the industry. However, numerous barriers affecting the capture and transfer of this knowledge have been identified within the sector. These include "broken learning loops" which exist as a result of the project-based nature of the industry and which mean that knowledge or experiences gained during one project are not transferred to the next, as well as segmentation and trust issues that exist between various actors. This segmentation has explicitly been cited as a barrier to commercialisation in at least one of the building cases (Building-2) and represents a potentially significant obstacle in the innovation process.

Furthermore, the actors in the building process are often from very different backgrounds, which may serve to aggravate this segmentation and act as a further barrier to communication, interaction and the formation of networks. This variation in frame of reference among actors may potentially contribute to the difficulties of actors within the building cluster to recognise and interact with one another. Within the building industry, the networks between academia and the industry have traditionally been known as being rather weak, which can impede the transfer of knowledge and the commercialisation of new ideas. Two of the case studies have involved limited interaction with the academic research community, as a result of the nature of the projects and, in one case, company attitude (Building-1, Building-3). This being said, however, there are instances, where companies have successfully established close ties with research institutes that have facilitated the innovation process (Building-2). In this case, the product idea originated from work that was conducted by two individuals, one of whom was a university researcher, which could perhaps have facilitated the academia-industry interactions. Past work, conducted regarding the Swedish construction industry, has shown that firms that lack employees with a research degree are unlikely to collaborate with universities and research institutes (Bröchner, 2006). Consequently, programmes to enhance the interaction and involvement between academia and industry, perhaps through employment and industrial research opportunities, could be a useful tool to support innovation in the industry.

The ability to generate and to transfer knowledge is an important component of the innovation process. While some sectors may have developed a certain degree of proficiency in these areas, others may be considered to suffer from weaknesses in this field, as has been demonstrated in the reviewed sectors. Identification of these weaknesses can help to allow appropriate measures to be taken to strengthen the necessary innovation base in the sector.

Knowledge Protection

Differences in the usage and applicability of intellectual property rights and patenting have come across in the three sectors under review. In the case of the mobile phone industry, patents play a significant role in the innovation process, serving as a means amongst actors to collect royalty payments. The decision regarding patent shares in a standard, such as in the case of the development of the 4G network (Mobile-2), can play a role in influencing the direction of development of an idea depending on the interests of various parties (Remmen, 2007a). In the pulp and paper industry, intellectual property rights have been noted to have played an important role in technological regime shifts throughout the evolution of the pulp and paper industry and have been used in all of the case studies reviewed herein (Pulp-1, Pulp-2, Pulp-3) (Toivanen, 2004). Conversely, in the building sector, the difficulty in patenting new ideas has frequently arisen as a disincentive towards innovation in the industry (Rozite, 2006b). In some cases, in lieu of attempting to obtain a patent, companies have chosen to rely on the complexity of technology and first mover advantage to capitalise on new innovations (Rozite, 2006b). The ability of a sector to protect its ideas and the manner in which it makes use of property rights can potentially affect its propensity to innovate. Consequently, these differences in patenting opportunities and usages may present challenges in the innovation process that vary between sectors and that influence the types and nature of interventions best suited to an innovation case.

Actor Network

The actor network in the various industries can play a significant role in how knowledge flows within an industry. Throughout the past several decades all three sectors have shown an increasing trend towards centralisation. The pulp and paper, mobile phone and building sectors are all now dominated by several large actors who control a significant portion of the market and who have the opportunity to take a lead in regards to environmental matters. However, while the pulp and paper sector typically maintains a more vertically integrated structure, the mobile phone and building sectors have a high degree of fragmentation throughout the industry. The pulp and paper industry has established tight, turn-key relationships with industry suppliers and industry products are largely based on single materials rather than on multiple input components. This vertical integration may serve to facilitate the networking and the innovation process, allowing for easier collaboration among actors, in addition to providing different opportunities in a policy setting. (For example, in the past, operating permit agreements have been set within the industry on a case by case basis).

In the case of the mobile phone and building industries, there are multiple actors who play a role in the value chain providing materials and/ or services for the final end product. These parts originate from a variety of sources and in order to achieve the complex finished products, the mobile phone and building industries rely on standards and specifications to communicate requirements across a broad range of actors. Companies in the value chain often buy the process or product for its function, not its composition. Furthermore, the products must operate within a framework that is established in conjunction with other actors. (For example, in the mobile phone industry, products must operate on a network that is established and agreed upon by several relevant actors. In the building industry, designs can be constrained by framework settings, such as district heating systems). As such, clear, unambiguous directions (e.g. for example through standards) may be better suited to facilitating changes across the industry in particular innovation cases.

The role of SMEs in a sector's actor network may also represent an interesting point of discussion with regards to knowledge generation activities in the innovation process. On one hand, innovation policy stresses the importance of SMEs in the innovation system for reasons including: their use as an external resource of new technologies for large firms; their role in maintaining locally based innovative activities within a country; and their ability to develop and exploit high technologies more easily than large, established companies (OECD, 2005b). On the other hand, however, SMEs are often considered to be a weak point from an environmental perspective, experiencing difficulties in complying with legislation due to limitations such as lack of time, personnel, experience and financial resources (Ecotec Research & Consulting, 2000). Particularly in more traditional, low technology industries, SMEs are said to have limited resources to invest in new technologies, R&D activities or higher risk endeavours and/or are often lacking capacities to absorb new innovations (Sexton, Barrett et al., 2006). In the building industry, in particular, lack of barrier to entry to new firms has previously been cited as an issue in the industry. This high proliferation rate of small, less sophisticated companies may represent an area of concern with regards to the innovation process – including environmental innovations if a large number of actors in the industry do not have the capacity or mentality to undertake innovative activities that could feed innovation within the sector. Special innovation programmes targeting SMEs therefore may be particularly important in a sector of this nature.

Knowledge Sources

The case studies from the three sectors have demonstrated the diversity of knowledge sources from which an innovation can originate, including individuals, companies and academia, as well as the differing motives for these innovations. In three of the case studies (Mobile-1, Pulp-1, Buildings-1), the idea for the innovation was encouraged by the existence and/or anticipation of specific environmental regulation, indicating that in some cases environmental policy can create inspire knowledge generation. In other cases, however, innovation efforts have emerged in the absence of direct policy "pull" and have been inspired by perceived need, desire for improved process efficiency and/or new products, reinforcing the idea that innovation is often the product of a complex series of interactions. In a number of cases, knowledge that is required for the realisation of the innovation has stemmed from basic research and through research programmes (Building-2, Pulp-1, Pulp-2, Mobile-1, Mobile-2), supporting the notion that funding and assistance in these areas are important elements in aiding the innovation process.

It is interesting to note that the more radical innovations in the pulp and paper and the building sector (Pulp-1, Building-3) have originated from individuals outside of the main industrial sector in question, who were able to relate experiences from one sector to another frame of reference. Additionally, another case (Building-2) brought together two distinct pools of knowledge – materials and ventilation – to arrive at a unique energy efficiency innovation. It has frequently been stated that innovations for sustainability require a multidisciplinary approach that makes use of knowledge and activities across a wide range of sectors. The experiences from the case studies reinforce this idea and illustrate some of the benefits that can arise from the combination of different perspectives and knowledge pools.

The case studies have further demonstrated that the full development of an idea often requires collaboration between a variety of organisations which possess the relevant knowledge. In almost all of the cases reviewed, realisation of the innovation was done through a combined effort of both academia and industry and required the input of a number of parties in order to be successfully developed. Even in the case of Building-1, where relationships with academic institutes were considered by the company to be distant, help from universities has been sought out in order to legitimise products through certification and to develop an energy calculation programme for the company's product. In several cases, the networking process between actors (both inter-industry and industry-academia) has been encouraged through public funding opportunities (e.g. Buildings-3, Pulp-1, Pulp-2, Mobile-1). Consequently, the importance of strong networks in the innovation process between and amongst industry and academia has been reinforced through the case studies.

5.1.2 Resources

Industry Resources

The resources within an industry and the attitude towards these resources and the value of R&D activities can shape the potential for innovation. The mobile phone industry is a high technology sector which is dependent on continual innovation for market growth. The industry spends relatively high amounts on R&D (upwards of 10%) which is indicative of the importance of innovation in the sector that has been stressed throughout literature and discussions with sector actors.

The pulp and paper industry has low R&D expenditures and is considered to be relatively conservative, with many innovations being of an incremental nature. Despite this, however, the industry is located within a cluster with a relatively high level of innovation activity. For example, typical R&D investments of pulp and paper equipment manufacturers range up to 4-6% of sales with fixed amounts being dedicated to development projects with high risk and to basic research (Autio, Dietrichs et al., 1997). The pulp and paper industry, in a sense, is a consumer of a number of high tech innovations originating within the cluster and has shown a capacity to work within the cluster and to absorb and integrate these innovations into its operations (Pulp-1, Pulp-2). While R&D expenditures of the pulp and paper companies themselves have been considered to be variable and relatively low, the sector has also demonstrated its "internal" capacity to innovate where perceived necessary (Pulp-3). The Nordic pulp and paper industry has a long history of supplying goods to the national and international markets, however it is facing increasing pressure as of late due to growing competition with other industries worldwide and with other materials. This competition may help contribute to the industry's interest in the innovation process (Kivimaa, Kautto et al., 2006) and hence to its integration into the forest cluster.

Despite its position within the relatively innovative forest cluster setting, however, the pulp and paper sector remains a capital intensive industry, whose operations are based on high priced and long-life equipment. Changes to existing equipment and processes require significant investment. This situation has frequently been cited as an innovation barrier for all capital intensive industries, contributing to the risk-averse nature of the industry (Toivanen, 2007). In some cases, where risk is high or payoff uncertain, support in the form of financial assistance and/or regulatory signals may be necessary to overcome the initial investment hurdles faced by the industry (Pulp-1, Pulp-2).

Similarly to the pulp and paper industry, the building industry is characterised by relatively low levels of R&D, but is situated within a cluster where other actors undertake relatively higher R&D investments (particularly in the case of the building services sector). Conversely to the pulp and paper sector, however, the building sector has not established the same relationships with its cluster members. This weak relationship may potentially contribute to the difficulties in introducing new innovations (such as those experienced in the case studies) into the building process. Additionally, within the building cluster, focus has frequently been on lowest cost (Rozite, 2006b). Consequently, in combination with the difficulties in obtaining patents, usage of internal resources for R&D by sector actors such as building materials and equipment suppliers may not appear justified. Furthermore, the building industry has been noted to be subject to severe economic cycles of recessions and booms (Rozite, 2006a). These upswings and downswings can potentially have an effect on the industry's access to financial and human resources, acting as a barrier to investment in research activities.

The building sector, like the pulp and paper industry, is traditionally considered to be relatively conservative in nature. A building represents a significant capital investment and building guarantees are relatively short, typically lasting for two years (Rozite, 2006a). The risk of an unsuccessful building attempt because of the use of new components and techniques can be highly discouraging from the perspective of both the builder and the buyer. One of the marketing techniques used within the building case studies to help overcome this and to facilitate commercialisation of the product was a prolonged energy performance guarantee (Building-2). Furthermore, it could be suggested that there is a rather high "knowledge-capital" investment in the current building processes. The alteration of the building process requires significant changes from the point of view of the developers, as well as of the architects, engineers, contractors and subcontractors involved in the actual building process (Fritzon, 2007). As such, while not bound to the same installation capital lock-in as the pulp and paper industry, the building sector may face a knowledge capital lock-in that dissuades it from undertaking significant change. Like the pulp and paper industry, additional efforts in the form of policy interventions may be needed to help overcome this "lock-in" effect.

The availability of and attitude towards industry resources and the perception of the value of innovation can affect the propensity of the industry to innovate. Comprehension of these issues can help to provide a better picture of the direction and nature of interventions best suited to the sector's needs.

Human Resources

The ability of a sector to attract and maintain competent personnel is a key criterion in its ability to innovate. The mobile phone sector has attracted highly skilled human resources to the field who are able to help drive the innovation process forward. A number of education and research programmes are directed towards the electronics and telecommunications industry, helping to attract new individuals into the field and, historically, significant efforts have been made to ensure the existence of a highly skilled staff-base in the Nordic countries through programmes designed to advance education levels in the sector (Blomström and Kokko, 2003). Similarly, the pulp and paper sector in the Nordic countries has made efforts over the years to engage in educational programmes and to attract highly-skilled individuals into the field (Blomström and Kokko, 2002; Molkentin-Matilainen, 2007). Currently, a significant number of pulp and paper engineers are educated in the Nordic region and past efforts have been taken through employment programmes to ensure that the industry retains a competent personnel base (by supporting skilled staff and graduates during economic down cycles) (Blomström and Kokko, 2002; Molkentin-Matilainen, 2007). While a detailed study of education and human resources in the industries has not been completed and continuous efforts are important in all areas to provide a strong personnel base, in general, human resource issues have not arisen in the materials reviewed for these sectors as a major innovation barrier.

Conversely, however, it has been suggested that the building sector has maintained a certain reputation over the years that may not lend itself to the attraction of skilled personnel

(European Monitoring Centre on Change, 2005; Rozite, 2006b). While the case studies have demonstrated that there are a number of innovative and skilled individuals in the industry, the overall picture has indicated that there is room for improvement in this field, perhaps through increased efforts to attract individuals to pursue higher education and research in the sector. Past studies have shown that the presence of academics within the building industry can help to facilitate industry-academia interactions (Bröchner, 2006). Consequently, efforts to renew the industry's image and to strengthen the knowledge level of the human resources base may also serve to improve industry-academia networks. The human resource issue in the sector is further compounded by the cyclical losses of industry personnel during times of recessions (Rozite, 2006b). The loss of skilled industry personnel and researchers during down cycles can result in the discontinuation of research efforts (which must often be pursued on a long-time scale to achieve commercialisable results) and the loss of tacit knowledge embodied in these individuals. Within the building industry, efforts to help maintain a strong human resources base, such as those made in the pulp and paper sector, may be helpful to strengthen the sector's innovation capabilities.

Public Funding

Public funding is a frequently used tool in the innovation portfolio and has played a role in almost all of the studied innovation cases.

In the cases studies reviewed for the mobile phone industry, public and university funding have played a role in the innovation developments (Mobile-1, Mobile-2). In the first case, public funding has been received in collaboration with industry participation. In the second, university funding has constituted the primary source of project funding in the absence of industry partners.

In the case of the two bioenergy related innovations, public funding and research programmes have played an important role in the evolution of the technology from research infancy to commercialisation. In the case of Pulp-2, the innovation was developed and taken further towards commercialisation over the course of two consecutive research projects with the support of the public funding agencies Mistra and the Swedish Energy Agency and in collaboration with other industry actors. The principle contractor of the programmes has stipulated the importance of trying to get all actors, including the technology users, involved from an early phase in the development process and the networks formed during the initial stages of the project and the continuity of the research programmes have been credited with helping with the technology's development (STFI, 2005). In the case of Pulp-1, public funding has played a key role in keeping the technology alive as it changed ownership numerous times and experienced several difficulties (Kivimaa, Kautto et al., 2006). Later on, a research programme has been undertaken with the aim of assisting with the technology's development process. The programme has been noted as playing a role in helping to overcome the "catch-22" which often arises with a new technology, whereby it is difficult to find investors prior to demonstration that the technology is working on a large-scale (MISTRA, 2006). This continuity and correct timing of support may be particularly important in a capital-intensive industry, such as the pulp and paper sector, whereby changes to existing processes entail significant investments. In the third pulp and paper case (Pulp-3), while a large portion of development resources came from within the company itself, some public funding was provided for the project by Tekes, due in part to the cooperation of the large company with several smaller companies (Kivimaa, Kautto et al., 2006).

In the building sector, the development of one innovation (Building-3) was related to a series of unique research programmes initiated by Tekes. The programmes represented an effort to integrate the building automation cluster in order to assist customers by bringing different building automation services to one place, to break the technology lock-in situation experienced within the building services industry due to propriety systems, and to improve the performance of the building services sector (Hyvättinen, 2006; Tekes, 2006). These programmes have attempted to orient the building services industry towards customer demand by calling for integration of these actors (building owners and contractors) in the development process. In an industry frequently described as being characterised by segmentation between actors, and where the contractor and/or developer can have a significant role in shaping the building process, this coordination effort could be considered as highly important. According to actors involved, the programmes have been credited with helping to facilitate technology development in the area of automation systems, helping to achieve system integration, and helping to initiate a break in the market lock-in experienced in the building services industry (Hyvättinen, 2006). There has, however, been some discussion regarding the success of the programmes in terms of assistance with product commercialisation. Comments from participants in the first programme have, in some cases, expressed the idea that following the end of the programme, the developed products were left without sufficient supporting markets (Hyvättinen, 2006). In the subsequent research programme efforts towards the development of the COBA system were undertaken and successful technology development was realised. Similarly to the case of the first programme, however, difficulties in achieving commercial success within the Nordic market were observed. In the case of Building-1, the innovating company chose not to seek out funding assistance during the development of the project, due to an internal policy that development falls within the responsibility of the company itself. While one case cannot be used to draw a sector-wide generalisation, this may potentially reflect on the traditional mentality of the sector, the weak links with research institutions and/or a lack of familiarity with the research and funding process.

The sector cases have confirmed the idea that public funding can play an important role in the innovation process. In particular, the cases have reinforced the notion that the significance of public funding is not just in the amounts spent, but on how the funding is supplied and organised. Collaboration with a network of actors, including research communities and end users, is highly important to help establish relationships to facilitate the technology development and to help secure a market for the technology. Public funding opportunities can facilitate these interactions (Mobile-1, Pulp-1, Pulp-2, Pulp-3, Building-3). The integration of SMEs into the innovation process through cooperative funding (Pulp-3), particularly in the low technology sectors, can serve as an important tool in integrating these operations into the innovation system. Additionally, the timing and the duration of funding can be vital in helping a new technology (particularly one that is capitally intensive and requires large-scale demonstration) to overcome the initial investment reluctance that exists before a technology is proven.

Other funding

While public and industry funding can be important resources for technology development, the case studies reviewed have demonstrated the relevance and importance of other sources of funding for the innovation process. In particular, in the pulp and paper cases (Pulp-1, Pulp-2), resources to assist with the commercialisation of the product have been obtained through alternate means such as the pre-selling of technology licenses (in order to avoid giving up ownership of the technology) and venture capital funding. Access to private funding can be highly important in facilitating the commercialisation of a new technology but the attraction of funding (both public and private) for an innovation project can be a complex and challenging task (Kivimaa, Kautto et al., 2006). In addition to providing financing through public funds, the assistance of public agencies in helping to seek out and negotiate funding (particularly for industries who are less familiar with the process or who may traditionally have a lower profile in investment terms) may potentially serve an important role in the innovation process as has been shown in the pulp and paper sector case. This may be particularly relevant in the case of SMEs, who have less familiarity with the funding process and may be particularly significant in industries such as buildings, where a large number of SMEs operate.

5.1.3 Markets

Customer vs. Supplier-Led Innovation

The sector materials and case studies have shown that the role that the customer and consumer[19] play in the innovation process and the entities which fulfil this role of innovator and customer have the potential to shape the way that a sector engages in innovation.

In the case of the mobile phone and pulp and paper industries, the companies, in a sense, operate in a business to business environment where their products are principally sold to another commercial actor. In the building industry, the picture is not always as clear, with contractors operating on behalf of a wide range of clients. However, in many cases, a similar business to business phenomenon (e.g. construction of buildings to property management and rental firms) is witnessed. In addition, depending on the type of innovation occurring, the role of customer can be fulfilled by differing parties.

In the case of the mobile phone industry, the customer role is often viewed to be filled by the network operators, who are by far the brandholders largest customer. Their demands have been noted to influence the direction of movement of the industry, exerting a significant pull on its progress (Dirckinck-Holmfeld, 2007; Dirckinck-Holmfeld, Andersen et al., 2007; Singhal, 2007). As such, while some of the brandholders' marketing strategies for the mobile phones centre on consumer preferences, they must also incorporate the wants of the operators into their decision-making processes. Currently, there appears to be a trend towards the demand for increased data transmission within the industry, which is coupled with an increase in energy demand of the phones. In the cases examined as part of this work, the innovations did not pertain to the mobile phone itself, as a product, but rather to the accessories (e.g. chargers) and networks related to the product. In the case of the charger (Mobile-1), the mobile industry can serve to fulfil the role of customer, procuring the devices

[19] In this work, the term customer and consumer will be used as two distinct terms. Customer will be used to refer principally to the purchaser of a good or service for further refinement or sale. Consumer will be used to refer to the final, individual consumer of the product (e.g. the individual who purchases the cell phone of home for final use).

from industry suppliers (i.e. having a modular relationship with the charger manufacturers) and supplying them, in turn, to their customers. In this case, the mobile phone industry and operators have the potential to influence the direction of innovation being realised. In the second case concerning network development (Mobile-2), the picture becomes more complicated, as the direction that the system will take is dependent on agreements and interactions between a number of actors. Nonetheless, in this case the operators also play a significant role, representing the customer base for the network providers and having the potential to shape industry developments through their demands (Lundberg, 2007).

Within the pulp and paper industry, the product users represent a significant power group in regards to product innovations[20] (and process innovations which alter products) within the sector. In some cases, the customers of the pulp and paper industry have been identified as a driving force for the adoption of environmental innovations (e.g. chlorine-free bleaching) (Kivimaa, Kautto et al., 2006). In the case of Pulp-3, the pulp and paper industry itself was the effectuator of the innovation and one driving force for the development was their desire to create a new product that responded to customer wishes. In other cases, however, it has been suggested that conservative customers can also hinder the innovation process within the industry. An example of this is where a given company wants to provide the same product to their customers over decades as part of tradition and/or image (Laurila, 2007; Toivanen, 2007). A new process which produces a new product may not be readily accepted by customers. Additionally, while changes to the pulp and paper process require significant capital investments for the industry, the production of new products can also require changes in capital infrastructure of the customer (Workshop, 2007b). For example, where a new type of paper based packaging is offered to replace an existing plastic one to a food industry, changes to the packaging equipment may be required. In these cases, incorporation of customers into the innovation process and customer targeted measures can potentially play a role in facilitating product innovation.

In the case of process innovations which are less drastically linked to product changes (such as in the cases of Pulp-1 and Pulp-2), a slightly different case may present itself. In this case, the industry may represent the effectuator and/or the consumer of the innovation (e.g. as in the case of Pulp-1 and Pulp-2, where the innovation originated from a supplier or consultant to the industry, rather than from the industry itself). Within the pulp and paper industry, energy efficiency and resource maximisation represent core business considerations and, where reasonable investments can be made to improve the system performance, some incentive exists to undertake them (as demonstrated by Pulp-3). In cases where the investments may appear less sure, the industry may be less willing to invest, as has been demonstrated in the biorefinery case studies (Pulp-1, Pulp-2) where the pulp and paper industry proved to be the most difficult actor to convince (Kivimaa, Kautto et al., 2006). In these cases, external impetus may be required to help the innovation to succeed.

Within the building sector, the role of the customer and/or the consumer in the innovation process often appears less clear. The developer funding the project represents the actor with the final decision-making powers (Fabiano, 2007). However, there are several factors influencing the developer/customer demands. In many cases, the developer is not the party who is intended as the final user or "consumer" of the building. The actual "consumer" chooses from what is available to him/her on the market (similarly to the mobile phone situation). As such, the developer designs a building as they see fit. In other cases, regardless

[20] While the scope of this work is to focus on energy efficiency innovations, product innovations are touched upon here due to their interrelationship with process innovations, whereby alterations to the industry processes have an ultimate effect on the end product that is produced.

of whether the building is developed for own use or not, the client may lack the capabilities to make environmental value judgements regarding the performance of the building, to know what is best available technology, or to evaluate life cycle savings. In this case, it is in the hands of the project management team to identify possible routes which the client could take. As such, the client is limited to knowledge put forward by the supplier. The result is an innovation chain within the building industry that has been characterised as supplier-led. This may be an important factor as the case studies and reviewed data have shown that it is often the professionals, not the customers, who are stepping back from potential building innovations (Rozite, 2006b). The same market knowledge issue can also be seen with the renovation industry. Many building owners are not in the position to have the greatest level of awareness of energy efficiency options during the renovation process. Consequently, the power falls largely in the hands of the renovation companies, who tend to be small to medium sized enterprises. This may present an additional point of difficulty as SMEs in this and other low-tech industries have been noted, as discussed above, to face some barriers in regards to the innovation process.

The role of customer, consumer and innovator varies between sectors and from innovation to innovation and these variances have the potential to affect how and if the innovation will be realised. Consequently, a better understanding of these dynamics can help in determining the most appropriate course of action necessary for a particularly innovation direction.

Nature of the Innovation

In addition to demonstrating that the innovation process within sectors can be influenced to differing degrees by different actors, the above discussion also highlights the fact that variations can occur within each sector depending on the type and nature of innovation in question. In some instances, the environmental innovation may represent a "core business" opportunity for the industry in question (e.g. in the case of Pulp-2 and Pulp-3 where the innovation allows the efficiency of mill to be improved in addition to representing an environmental benefit). In these cases, industries may have a certain degree of natural impetus to pursue or facilitate innovations in these areas. In other cases, however, the environmental innovation may not represent a core business concern. For example, in the cases of the building sector, Mobile-1, and Pulp-1, the industry itself may not always benefit (at least in a core-business sense) from the innovations. Consequently, different methods may be required to stimulate interest in innovation in these areas.

The case of Mobile-2 raises another interesting point in this area. While this innovation makes sense from both a product performance and core business perspective for the operators (energy costs are variable), the technology has not yet succeeded in attracting partners for the commercialisation, with potential barriers being cited as conservativeness on the part of the operators, the lack of an adequate payment structure for cooperative networks, and the need for compromise by all of the key players in the industry on how the 4G network will proceed. As such, even when an innovation appears to make sense economically and environmentally resistance to change and the varied interests of actors, in the absence of guidance, can slow the process.

Low-Cost Barriers, Cost Discrepancies and Market Steering

Particular market-related issues have also been noted to have the potential to affect the innovation process. In all three of the sectors, cost of the innovations has come up as a barrier to their adoption. While realisations are growing that a focus on high-quality and innovative products may be an important strategy, in both the pulp and paper and the building industry, focus on lowest price has continued to be the dominating market factor (Rozite, 2006b; Working Group of the Finnish Forest Industry, 2006). Similarly, in the case of the mobile phone industry and the charger, lowest cost has been identified as the principle factor in determining the success, or lack thereof, of innovation (Workshop, 2007e). This focus on lowest cost represents a barrier to the innovation process in general, including environmental innovations.

In the case of energy efficiency innovations, the issue of cost discrepancy has presented itself in both the mobile phone sector and the building sector. In terms of the mobile phone itself, there is an ongoing concern for energy efficiency from a core business perspective (Moussette, 2007). The phone battery must last an acceptable amount of time to the user and overheating must not occur. Similarly, in the case of network equipment, there is a need to improve energy efficiency from a core business perspective, as energy is a variable operating cost (Singhal, 2007). However, in terms of peripheral devices, such as chargers, there is a discrepancy issue. The brandholder must invest in the better performing charger, while the user benefits from the lower energy costs. However, because the savings realised by the consumer are so low in relative terms, there is not necessarily an incentive for the consumer to want this charger or to pay extra for it (Remmen, 2007b). In the case of the building industry, the savings realised from energy efficiency investments are to the benefit of the end user, while the developer puts forward the initial investment. If the market interest in investing in more energy efficient homes is low, as suggested by the reviewed materials, the developer has limited interest in pursuing this strategy.

Market distortions have been noted in both the mobile phone and building sectors, with regards to the ability of large actors in the industry to gain market control through subsidisation of the capital costs of a product or system. In the case of the building sector, in terms of building control systems, the large turn-key suppliers are often able to undercut the capital cost of their system by recuperating revenues through monopoly maintenance contracts over the life of the system (Linturo, 2007). Similarly, in the mobile phone industry, the operators can subsidise the cost of the phones, allowing them to steer the market towards the purchase of specific products (Dirckinck-Holmfeld, Andersen et al., 2007). This market-steering situation represents a potential impediment to the commercialisation of new technologies. This fact was recognised by Tekes in their SaMBA programme, described above, in an attempt to break the market-domination situation present within the building services and automation industry.

Identification of specific market barriers which present themselves amongst sectors may be an important tool in choosing the appropriate interventions for a given sector and innovation path.

Consumer Demand, Public Perceptions and Sensitisation

In all sectors, the level of environmental awareness and/ or demand of consumers has been cited as a barrier to the environmental innovation process. In the mobile phone sector, the awareness of environmental impacts and the demand for environmental products is perceived to be limited (Jensen, Sørensen et al., 2003; Singhal, 2005b). In the pulp and paper sector, the general level of awareness of production and product impacts is has been mentioned to be low (Working Group of the Finnish Forest Industry, 2006; Laurila, 2007). In the building sector, lack of customer demand for better buildings has been cited as a market barrier and partly attributed to lack of knowledge regarding the options for and the impacts of the built environment (Rozite, 2006b; Fritzon, 2007). Consequently, there appears to be an ongoing need for efforts to stimulate the demand for green innovation. This being said, however, the ability to do this, and the role that the consumer will play, can vary between sectors and innovations. For example, the choice between a high-efficiency and low-efficiency mobile phone charger may appear to be a relatively straightforward decision for a consumer, assuming that they are aware and concerned. Conversely, however, system changes such as the decision of a mill to engage in biorefinery practices is less relevant in regards to the issue of consumer demand.

Different levels of public awareness, perceptions, and regulation have historically played a role within the various sectors. The pulp and paper industry has frequently found itself in the public eye with regards to environmental issues (due in part to the significant local impacts of its past activities), and the industry has been relatively heavily regulated in regards to environmental issues (Toivanen, 2007). Conversely, in the mobile phone industry, public awareness regarding environmental impacts has been measured to be relatively low. Many production and disposal actions are carried out in distant locations from the consumer (with regards to the Nordic and other developed countries). The focus of environmental regulation on the sector has been relatively recent. Similarly, in the building industry, public perception of environmental issues (or at least though associated with energy consumption) has come across to be low. While energy performance stipulations concerning buildings are present, for example, in the building code, the sector has only as of late begun to be subject to explicit environmental regulation considerations on a large scale. Speculatively, from the vantage point of the author, these variations may potentially affect the level of sensitisation of an industry to environmental innovation considerations and serve as potential guiding factor for decisions within industry.

Environmental Innovations and the Market Precondition

In regards to the market precondition for environmental innovation, the case studies have demonstrated two things: 1) that markets for innovation are the result of a combination of factors; and 2) that an added element of regulatory pull in the traditional technology push, market pull model of innovation can be important in some cases.

In the cases of Pulp-1 and Building-1, a direct driver for the innovation has been new regulation that has provided a clear market for the technology. In the instance of Pulp-1, the anticipation of more stringent regulation in the vehicles sector has further increased investor interest in the technology and renewable fuel tax signals have provided an additional economic driver. In the case of Pulp-2, the innovation has been driven forward by its ability to increase the capacity of the pulp mill at a relatively low investment cost and has been further advanced by increasing oil prices and the biofuels directive (due to the biomass gasification potential). In the case of Mobile-1, new technology has been developed as a result of anticipation of new regulation. No regulation is yet in place however, and the new technology not yet succeeded in being commercialised.

In the cases of Pulp-3, Building-2, and Building-3, commercialisation of the technologies have proceeded in the absence of direct environmental regulation intervention. In the case of Pulp-3, market drivers have included needs to improve mill efficiency, energy savings, and the desire to produce a new product. In the case of Building-2, drivers have included perceived needs for efficiency improvements, rising oil prices, improved building performance, reduced capital costs for HVAC equipment, and extended product guarantees. In the case of Building-3, drivers have included the desire for new products, improved integration of user needs, and sophisticated building performance. It is interesting to note that while these innovations in the building sector have been successfully commercialised, however, they have faced some difficulty in diffusion into the market.

5.1.4 Policies

Different policy interventions have played a role in the case studies and sectors examined within this work. While it is often difficult to draw causal links between a specific policy and an outcome, some discussion regarding the interventions is put forward and reflections back to the theoretical findings are made.

In the case of the cell phone charger, past improvements from linear to switch mode were the result of a combination of factors, including increasing government attention to the issue, demand for improved technical performance, and, largely, markets economics which made it more cost effective to produce the better chargers. The development of the near zero standby power chargers has been encouraged, in one case, by market interest (in another electronic products sector) and the provision of energy agency funding, and, in the other (Salcomp charger), by the need to establish best-available-technology for the impending EuP directive. The anticipation of incoming regulation, as outlined in the literature, can influence the innovation process, in this case providing incentive for the creation of new knowledge. Despite these technological advancements, however, near zero standby load chargers have yet to be marketed due to economic considerations and stated lack of demand. The adoption of better performing chargers by the industry is currently being implemented, though on a much longer time scale then is technologically feasible. In the area of chargers, the mobile phone industry has performed relatively well in response to the voluntary European Code of Conduct regarding External Power Supplies, with a high percentage of its chargers available on the market today meeting the code (European Commission, 2005). However, there is criticism that little effort is needed to achieve this performance and that this voluntary standard has simply moved players to a “no pain” level of performance as suggested in literature, whereas much more is possible by today’s technological standards. The same criticisms have been made of the IPP pilot programme, where many of the suggested actions to improve the phone’s environmental performance (including the charger) have involved actions to be taken on the user’s side (such as the implementation of a reminder on the phone screen to unplug the charger when the phone is finished charging). While the nature of the industry (dominated by several major players) may lend itself to the use of voluntary agreements, these, as anticipated in literature, may provide little incentive for significant environmental innovation.

The innovations in the pulp and paper sector have all benefited from public funding opportunities. In the first two cases (Pulp-1 and Pulp-2), the developments were made as part of ongoing research programmes in the pulp and paper industry. These programmes have facilitated network collaboration and procurement of funding throughout various stages of the innovation process. This has been noted to have been particularly important during the demonstration phase of the technology due to the capitally-intensive nature of the industry. Commercialisation, and, in one case, (Pulp-1) the actual invention of the technology which had evolved from previous work, was encouraged by policy signals for biofuels. In the case of Pulp-1, the economic driver of tax reliefs for renewable fuels has also been said to have been a driver for development (Kivimaa, Kautto et al., 2006). The commercialisation process for this technology has recently received a major boost, receiving notable venture capital support from two interested parties, of Swedish and American origin. Part of the interest on the Swedish side has come from the belief that more stringent regulations regarding heavy engine emissions will occur in the future (Kivimaa, Kautto et al., 2006). The success of the black liquor gasification process in Sweden is notable in the fact that its remains one of the few efforts worldwide that has so closely approached the brink of commercialisation (Whitty, 2002). In case of Pulp-2, while biofuel policy signals have acted as a driver on one hand, conflicting policy signals originating from the green certificates system have been said to have acted as a barrier to the technology's development on the other (Kivimaa, Kautto et al., 2006). Despite this conflict, however, the technology has, to this point, very closely approached the brink of commercialisation. In these first two cases, innovation and environmental policy have worked in conjunction to facilitate knowledge generation and transfer, access to resources, and market formation for the innovations. In the third case (Pulp-3), part of the funding for technology development has been supplied by the Finnish funding agency, Tekes. No specific environmental policy interventions have been identified in driving forward the commercialisation process, however part of the selling point of the innovation has been the improved resource and energy efficiency of the process and the lighter weight products which reduce transportation load. While these changes represent economic benefits for the supplier and the customer, the growing attention which is being paid to environmental, energy and life-cycle related issues may also contribute to interest in the technology.

In the building sector cases, innovations have been realised with the assistance of environmental and innovation policy. Building-3, the automation system, has been developed as part of a unique research programme designed to break market-lock and to better integrate the building services industry into the building cluster through collaborative development opportunities. The programme has been credited with helping to make a technological breakthrough in the building process, to create a market shift, and to change the attitudes of various actors (a task which may be particularly important in this more conservative, segmented field) (Uusikylä, Valovirta et al., 2003). In the case of Building-1, development has been partially driven forward by new building regulations which put specific emphasis on its product area. Part of the company's marketing strategy has been promoting the technology as being able to satisfy the new building regulation requirements and the technology has experienced successful commercialisation.

For all of the cases reviewed, in order for new products, materials, and systems to be integrated into a building, the appropriate decisions must be made early in the process by the developer and/ or the contractor. In many cases, due to the complexity of the building process, it is contractor/ developer rather than the final end user who has the most knowledge regarding potential energy efficiency options. The building industry (developer, contractors, etc.) is in a sense the client of building material, equipment and service suppliers and is the supplier to the final building owner and end user. As such, they have the possibility to play a crucial role in the achievement of environmental improvements in the industry. It has frequently been noted in the materials reviewed that demand for energy efficiency improvements in buildings is lacking for a number of potential reasons, including lack of interest, lack of knowledge, cost or competing features. However, where the demand has been present, the building industry has shown the ability to acquire and integrate new technologies into the building process. A potentially significant issue then appears to be in creating demand at the level of the developer/ contractor. At the same time, however, these actors may experience a knowledge capital lock-in situation, similar to that capital lock-in experienced by the pulp and paper industry. In this case, changes to the building processes require a significant amount of investment in terms of new procedures and new knowledge that must be acquired. Consequently, like their pulp and paper counterparts, the building industry actors may find themselves in a more reluctant position to demand and integrate new technologies. In these cases, where the developer/ contractor and their consultants may often be in one of the most significant position to influence building decisions, the potential result is a sort of "supplier-dominated" innovation process. In this case, supplier targeted measures may represent one of the most appropriate courses of action. It is interesting to note, however, that in terms of energy efficiency, a large number of policy intervention measures have come in the form of economic instruments and demand side programmes (including the new building labelling programme, subsidies, etc.). As suggested by a number of actors, advancing energy efficiency requirements in the building code itself and in the form of other "supply side" (contractor-oriented) measures may help to achieve the necessary markets for new technologies created within the material, equipment and service industries, as has been shown in the case of Building-1. Facilitating the development and commercialisation process of a new building technology through economic supply side means such as continued funding through the large scale demonstration phase (as in the pulp and paper industry cases) may prove to be a valuable tool. However, these innovations must then continue to diffuse across a wide range of building projects in order to survive, a process which may be difficult to facilitate without clear, industry wide signals.

The case studies reviewed have provided support for several of the characteristics of green innovation friendly policy suggested in literature. The cases have reinforced the notion that environmental policy can play an important market forming role but have also demonstrated in three cases (Pulp-1, Mobile-1, and Buildings-1) the ability of environmental policy to inspire knowledge generation activities by providing signals for future market directions. Stringency and ambition level of new regulations have driven forward innovation in the building sector, and reduction in market uncertainty has helped to spur innovations in the pulp and paper industry forward. The importance of instrument timing and providing support for the appropriate intervals has been demonstrated in the cases of both the pulp and paper and building industry. Positive synergies have been seen in the case of the pulp and paper industry in regards to innovation and environmental policy, supporting the value of supply and demand side measures in some instances. While economic drivers have assisted in facilitating market formation in one case, the interventions which have directly encouraged innovation have largely been of a mandatory administrative nature.

5.2 Policy Directions

The previous section has identified a series of similarities and differences between the examined sectors and has highlighted some of the policy interventions that have played a role in the innovation processes of the industries. The following section serves to put forth some preliminary recommendations for potential policy directions, based on the work conducted.

The idea that innovation policy shapes the inputs of innovation while the regulations shape the markets has been recognised in the literature (Guy, 2002). Accordingly, the use of the proposed model, outlined in Figure 3-1, may provide interesting insight into the identification of key policy interventions required for the furthering of environmental innovations within an industry. Through a review of an industry's ability to fulfil the necessary preconditions for innovation, decisions regarding strategic policy intervention can be made. The need for innovation and environmental policies and combinations thereof can be adjusted according to the goals and aims of the policy makers. With this in mind, the suggested model allows for innovation policy to focus on establishing the appropriate prerequisites for innovation and helping to guide the search for environmentally beneficially advancements, while environmental policy can focus on environmental protection while operating to establish the necessary markets for the commercialisation and diffusion of the new technologies.

Some sectors, such as the high-tech mobile phone industry, are highly familiar with the innovation process and the acquisition and use of knowledge and resources. Innovation policy supporting the direction of these activities into environmentally beneficial directions (e.g. better energy performance) may help to guide the search in a favourable direction. Others sectors however, such as the building industry, have frequently been observed to suffer from a variety of innovation barriers inherent to the industry's structure and tradition (for example, differing frames of references of actors and weak networking). In these cases, additional interventions of innovation policy may prove beneficial in facilitating the innovation process in general, including environmental innovations. Regardless of the innovation capacities of the individual industries, however, the precondition of market formation has presented itself as an issue in all of the sectors studied. Even where the knowledge and resources exist, market barriers related to the economics of the environmental innovations, the inherent risks and uncertainties associated with them, and/or the lack of consumer demand have presented themselves. Consequently, environmental policy can serve as important tool in some instances to create the proper market signals.

Mobile Phones

The mobile phone sector has a high familiarity with knowledge generation activities and the process of transferring basic research to practice. The industry is accustomed to high internal R&D spending, has a degree of familiarity with external funding sources, and has a highly educated workforce in terms of product development. The ability to innovate both in general and in an environmentally forward direction has been demonstrated by the industry. However, difficulties in commercialising these ideas have been shown to exist both from a lack of demand and from differences in the interests of various actors. Voluntary agreements can function well within an industry that is dominated by so few global players, however, the difficulty in pushing the industry above the no pain threshold without additional reward or threat has been witnessed with the Code of Conduct. While the IPP programme has been criticised for shifting responsibility to the consumer, use of the supplier to undertake informational interventions may provide an interesting opportunity. If, for example, messages regarding environmental impacts of the phone during disposal were passed through the brandholder upon sale through labels or notices on the phones this could help increase awareness of the consumer (particularly since these brands have significant marketing power and skills). While this approach may not represent the ultimate solution due to various limitations, facilitating the education and awareness of the end consumer may nonetheless represent a valuable part of the approach to creating green demand that could inspire environmental innovations.

It is important to note that the mobile phone industry operates on a global scale and within the larger context of the electronics sector. Efforts to realise changes may be best made at an international (e.g. EU or at least Nordic level). In some cases, such as network evolution, decisions must be taken as a result of the compromises of interests of a variety of actors. Even when decisions appear potentially beneficial from an economic and environmental perspective, they may not be taken due a conflicting interests and factors. In these cases, while controlling the direction of the innovation through regulatory measures may be difficult, measures targeted at the knowledge and resources side of the innovation process using innovation policy could potentially be used to steer Nordic developments into a more environmentally favourable direction (for example, more research programmes for energy efficient options in the industry). This technique could further be extended towards other areas of product development within the industry. While the industry has demonstrated high innovation ability, additional emphasis on environmental considerations could be valuable.

In the case of the mobile phone itself energy efficiency represents a core business consideration due to operational requirements (e.g. sufficient battery life, usage time, etc.), which may provide additional incentive to brandholders for energy efficiency improvements in that domain. In the case of accessories, such as the chargers, however, the same incentive does not apply. In these cases, a clear, external signal may be required to induce innovation and diffusion, such as a mandatory standard.

Within the industry, the operators have a significant demand power in terms of both mobile phones and networks, and there exists the opportunity for a strong demand side pull by these actors as has been shown in the past. Targeting these actors through policy measures, such as voluntary agreements to endorse and request environmental improvements in products, may represent one way to drive forward green innovations in this field. One suggestion that has been put forward regarding the issue of the short life-span of the phones (while not directly related to the issue of energy efficiency) is the prevention of subsidisation of the phones (Dirckinck-Holmfeld, Andersen et al., 2007). The idea behind this is that by forcing the consumers to recognise the true cost of the device, interest in replacing them so frequently may be reduced.

Pulp and Paper

The pulp and paper industry in the Nordic countries has experienced significant regulation over the past decades and the industry has made significant environmental improvements in its processes, partially as a result of these regulations. Sector interest in environmental improvements related to resource and energy efficiency appear to be relatively well established, due perhaps to a combination of factors including the long standing public pressure and regulatory concern regarding pollution, and desires for economically beneficial mill-level improvements. The sector has established a unique innovation network that allows it benefit from the knowledge generation activities and networks of its cluster members. The capital intensive nature of the industry, however, can serve as a barrier to the innovation process, dissuading the industry from investing in new capital intensive technology. As such, research programmes which promote networking amongst actors and stress the inclusion of the technology users themselves at an early stage are important in order to secure interest and to help facilitate the commercialisation process for these innovations.

In light of the capital-intensive nature of the industry, consideration should be given to the appropriate duration of funding programmes that can help to provide the necessary support where it is often crucially needed at the demonstration phase (as shown, particularly, in cases such as the biorefinery developments, where risk appears relatively high). Venture capital and other private funding can play an important role in the innovation process, particularly in such a capital intensive industry and can provide the necessary catalyst for commercialisation. The establishment of programmes that can assist companies in obtaining funding during critical phases such as development and demonstration could serve a valuable role in the innovation process.

In the case of product innovations (and process innovations that affect products), the customer can play a key role through demand side influences. In these cases, policy measures which target these individuals should be made, including, for example, joint research projects between the pulp and paper industry and its customers to engage in the development of environmentally improved products. Exports represent a significant market for the Nordic pulp and paper industry. Therefore, similarly to the mobile phone industry, policy interventions to realise product change may be best directed at the Nordic or EU level.

Buildings

Within the building sector, human resource issues and difficulty in transferring knowledge from academia to industry have arisen as potential issues. Efforts to enhance research opportunities in the building field could help to attract new individuals to the sector that could assist with the transformation of the industry's image and mentality. Furthermore, efforts to help maintain and make use of this research base during the economic down cycles which have traditionally been associated with loss of personnel and lack of development, could help to ensure continued progress within the industry. This technique has been used in the pulp and paper sector in the past, and the sector has involved into a unique innovation system. Typically, the construction market follows the general economic trend, measured in terms of GDP, but with a time lag of at least one year. The housing market reacts most quickly to the cycles, with other building construction being subject to a greater lag (NCC, 2006). Efforts to achieve stabilisation of the industry's human resource and research base require the provision of programmes prior to the down cycle that are capable of accommodating inflows of graduates, researchers and skilled individuals during down times, perhaps through a funding reservation system supported by industry and/ or government. Firms where staff members have an academic research background have been said to be more likely to engage in collaborative research with universities and institutes (perhaps due to a similar frame of reference). Industry-academia programmes such as the Danish Industrial PhD could be promoted in this field to help create stronger linkages between actors. Collaborative R&D programmes between industry and academia could also serve to assist in this area. Segmentation between actors and the lack of recognition of clustering benefits such as those experienced in the pulp and paper industry represent a potential barrier to successful knowledge transfer and innovation generation in the building sector. Research programmes, such as SaMBA and CUBE, which incorporate a variety of actors in the value chain, including end users, could be promoted to help strengthen and foster relationships within the industry. Particular efforts could be aimed at the inclusion of SMEs in the industry as these represent a potential point of innovation weakness.

As demonstrated by the case studies, the development of product certifications, standards and calculation methods and programmes that can be used to help integrate new innovations into the building process can represent an important tool in helping to facilitate entry of new technology into the market. Building innovations must be accepted and integrated by a number of actors in order to be applied. Tools which facilitate this process and which demonstrate product performance have been shown to be valuable in the commercialisation of material and system (ventilation) innovations within the industry. Research and assistance programmes designed to support innovators in the development of these integration and calculation tools for their products may be valuable tools in facilitating commercialisation of new ideas.

Intellectual property rights and patenting has come up in the building sector as an issue in regards to the innovation process. Difficulties in obtaining patents for new innovations and difficulties in verifying the legitimacy of an innovation due to the recirculation of old ideas in the industry have come up as barriers to the innovation process. Consequently, consideration should be given on how to facilitate the climate for innovation within the building industry with respect to IPR.

A new building project can represent a significant risk, particularly if it incorporates unfamiliar elements. Provision of support through funding or funding assistance (i.e. helping to attract industrial or other private investors) programmes, as suggested in the pulp and paper industry, can provide valuable help in the demonstration phase of a new technology. In the building industry, however, a successfully demonstrated technology must then be diffused through a number of other projects to achieve significant market penetration. Consequently, market-forming measures may represent an important component to assist with the commercialisation process.

Various actors in the building industry have agreed that the building code is a valuable tool, perhaps partially due to its ability to provide a standard to which actors within an otherwise fragmented industry can relate. The building code could potentially be used as a means of improving energy efficiency throughout the sector by mandating better performances and therefore providing an important market opportunity for new innovations. In order to encourage and support the market for continued innovation, rather than only diffusion of existing innovations, gradual tightening of demands could be made through periodic revisions of the code. Furthermore, the code could be used as the “floor” for the industry, and industry players could be motivated to move forward and go beyond the requirements, perhaps through the establishment of a voluntary code that becomes mandatory within a certain time frame. Several countries which have had a relatively high success rate in energy efficient buildings have chosen to adopt a voluntary building code. While success has been the result of the interaction of a variety of factors, a voluntary code may help to facilitate energy efficient improvements by providing a clear standard to which a building developer can build and which a client can easily specify. Public procurement of energy efficient buildings could be used to support this method. While individuals within the industry have questioned the potential of the energy labelling directive, labelling, benchmarking and publication of data may help to gradually raise the level of awareness of consumers, assisting in conjunction with supply side measures. One recommendation which has been put forward during discussions (Fritzon, 2007) concerns the possibility of increased standardisation of the building code across the Nordic countries, in an effort to encourage competition and facilitate transfer of knowledge and ideas across borders.

In the case of the building automation industry, as in the case of the mobile phone industry, subsidisation of products has been identified as a potential issue affecting commercialisation opportunities. Prevention of such product subsidisation measures may help with the alleviation of the market lock-in situation. Additionally, in the case study pertaining to the energy efficient foundation, it has been noted that the retailer has significant power, in a sense, in terms of the products that it chooses to sell or to market, similarly to the phone operators. If this is the case, the retailers may then present an interesting point of focus for policy interventions aimed at promoting the diffusion of energy efficient and/ or environmental materials.

In addition to new construction, the area regarding building renovations should not be neglected. A significant portion of buildings in the Nordic countries are legacy buildings and the share of renovation construction in the Nordic building sector is continuing to grow. Renovations face a similar situation to the new building case, whereby the contractor often represents the actor with the greatest knowledge with regards to building options. It may be difficult for building owners to realise the options available to them, or to select the most appropriate ones. Additionally, the renovation industry tends to be dominated by SMEs, who have been noted to face difficulties in the area of innovation. Efforts to encourage R&D into renovation-applicable energy efficiency measures, particularly aimed at encouraging the participation of SMEs, could be made in order to facilitate the process. Demand side incentives could be provided to encourage home owners to undertake renovations that incorporate new and innovative energy efficient measures. Support programmes to assist companies with the promotion of energy efficiency renovation materials and informational campaigns could help to disseminate information to the necessary clients about energy efficient options. (In the case of wind power development in California, a somewhat similar approach to fostering demand side interest was taken, through the provision of a wind siting atlas that provided users with vital information on windmill siting options. This was credited with being an important demand side measure in the wind case). Similarly to the case of new buildings, the inclusion of renovations into the building code could help to induce suppliers to align their priorities accordingly by providing them clear market signals.

General

All of the cases reviewed here have served to emphasise the importance of multidisciplinary approaches to solving environmental problems. In order to realise more radical innovations, knowledge and experiences from a diversity of fields has been combined, bringing to light new solutions and new system possibilities. The experiences from one field can bring ideas into another area that may result in new innovations, as has been seen from cases in both the building and pulp and paper sectors. Additionally, sectors can learn from one another absorbing concepts and ideas that can improve efficiency and environment. As such, well directed innovation policies, such as inter-industry research programmes, experience centres, and researcher and staff mobility programmes, may be beneficial to the development of environmental innovations. In the cases of both the pulp and paper sector and the building sector in particular, it has been observed that research activities and collaborations often occur within a national context. While this may partially be the result of the traditionally localised nature of the industry, increased cooperation at a Nordic level also represents a unique opportunity to strengthen the innovation potential of these sectors. (For example, in one of the case studies within the building sector, innovation has resulted from the transfer of an idea from one country to another).

The case studies have also reinforced the importance of the notion that the interaction of policy instruments can play a significant role in regards to innovation. Environmental policies or policies from other fields can interact in the innovation process, serving as a barrier or a driver for innovation, as has been noted in the case of the building industry (fire code) and the pulp and paper industry (green certificates). As such, a holistic view of the sector and policy setting is required in order to help avoid conflicts and manage the innovation process.

Lack of consumer demand/ awareness has arisen as an issue in all of the sectors studied. While influencing demand may be a slow process and may not be highly influential in all innovation cases, it nonetheless represents an important component of a sustainable strategy.

6 Conclusions & Recommendations for Further Research

6.1 Main Findings

Innovation in environmental technology has been recognised as an important part of helping the European Union work towards the goal of sustainability. The Nordic countries have been frontrunners in the environmental field for many years and excellence in environmental technology innovation represents a unique opportunity for them to couple economic and environmental goals.

It has been noted in literature that different sectors organise the innovation process differently and that policy measures must be tailored to the specific needs of sectors and industries in order to realise changes. The process of environmental technology innovation has the possibility to be affected by both environmental and innovation policy amongst others. This thesis has examined environmental innovations in three sectors in the Nordic countries – mobile phones, pulp and paper, and buildings – to observe how different sectors have innovated and responded to environmental and innovation policy instruments, to contribute to an understanding of how sectoral characteristics can affect the environmental innovation process, and to help provide a clearer picture of how policy measures can be used to help foster innovation in environmental technology.

Access to knowledge, access to resources, and formation of markets have been recognised as important preconditions of the innovation process. Consequently, the sectors and the case studies have been reviewed with reference to these preconditions in order to identify how actors in the various sectors fulfil them. The policies which have played a role in the case studies and the sector characteristics which have been observed to impact the innovation process have been discussed.

The review of the sectors and cases completed here has confirmed that sectors require different combinations of policy instruments to facilitate the environmental innovation process, dependent on sector characteristics and innovation dynamics, and nature of the innovation at hand. Where innovations have occurred in all three sectors, they have done so for a variety of reasons. In one case from each sector, the idea for the innovation has resulted in response to environmental policy signals (Mobile-1, Pulp-1, and Building-1). In the other cases, the innovations have been driven forward by internal and external market signals – namely perceived needs for improved efficiency and/ or new products in the industry and rising energy prices. Consequently, while these cases have shown that environmental policy instruments are not crucial for environmental innovations to occur, they have demonstrated that these policy signals can provide the necessary stimulus in some instances, as suggested in the literature. The mobile phone sector is a high tech sector that has demonstrated a strong ability in terms of R&D activities. A key activity in this sector may then be to use innovation policy to help steer innovation in the "correct" direction via funding and other programme opportunities. The pulp and paper industry is a low-technology sector by definition but has shown the ability to innovate and to integrate the innovations of its cluster members into its operations. Nonetheless, it is a capital intensive industry that has been shown to be reluctant to invest in unproven technologies. Consequently, support in this area may be important to overcome the demonstration hurdle. The building sector has shown the ability to generate new technologies and to bring them to the market. However, a number of issues affecting the knowledge generation and transfer processes have been noted in the sector, some of which have been confirmed in the case studies. These issues can result in low levels of innovation and/or can impede the entry and diffusion of new technologies in the market. As such efforts to strengthen knowledge generation and transfer abilities within the building sector may represent an important tool to foster innovation in general and, hence, environmental innovation, within the industry.

In all three sector cases, public funding resources have been used to help generate the necessary knowledge for the innovation to be realised and/ or to stimulate important networks. The research programmes involved in the pulp and paper sector demonstrate the importance of the timing of support, particularly in the difficult demonstration phase of a capital intensive technology. The research programmes involved in the building sector automation case reviewed in this thesis demonstrate that measures aimed at overcoming networking barriers in the sector can play an important role in facilitating the innovation process. The availability of and/ or attitudes towards internal resources, funding opportunities, and human resources in a sector can influence the sector's propensity to innovate. Consequently, it appears that attention should be paid to these issues in order to help establish a sectoral innovation base.

The market precondition has arisen as a point of interest in all of the sectors. In the case of the mobile phone industry, market interest in the case technologies has been limited to this point due to cost issues and conflicting interests. In the pulp and paper industry, the two energy product innovations have been aided by environmental policy signals in the direction of biofuels. In the third case, while no one specific environmental policy intervention has been identified as a driver for the successful commercialisation of the technology, the increasing focus on environmental and energy issues may well have helped to serve as an indirect driver for the technology's commercialisation. In the case of the building sector, one technology has been partially inspired by and marketed towards fulfilment of new building regulations. The other cases have been driven forward by factors including rising energy prices and desires for new, improved products. These findings indicate that environmental innovations arise as a result of a combination of factors and that environmental policy interventions can, at least in some instances, play a supporting role in the environmental innovation process.

In all three sectors, the combination of innovation policy, environmental policy, or a combination of both, has affected the innovation process. The types of interventions best suited to facilitate the innovation process appear to vary with the specific characteristics of the sectors and the nature of the innovation. Where environmental policy has been noted to have played an explicit role in the case study innovations, it has largely been of a mandatory, administrative nature. The importance of sending clear signals to industry to reduce uncertainty and facilitate the environmental innovation process is suggested by the case studies.

While the sectors reviewed in this thesis represent very different areas and have very different characteristics, an interesting point which has been observed by taking a broad picture is the potential to transfer learning regarding innovation dynamics from one sector to another. For example, the pulp and paper sector and the building sector, while having very different characteristics in some respects, also share some common elements in regards to innovation. While the building sector has been criticised for remaining somewhat stagnant over the years, the pulp and paper industry has overcome some of the same barriers as a traditional "low technology" industry (for instance, the cyclical loss of personnel), to develop a unique innovation system. Consequently, new insight into the barriers faced in one sector may be gained through examination of another.

6.2 Recommendations to Policy Makers

Selecting appropriate policy measures to achieve desired outcomes is a complex task. Designing policy to foster innovation represents an additional challenge due to the very nature of innovation – an "unpredictable" process. Based on this work, a potential methodology for helping policy makers to evaluate potential courses of action to promote innovation in environmental technology is proposed. This method may help to provide a new perspective into the traditional innovation and environmental-policy making process.

This work has shown that the environmental innovation process can vary depending on the sector in question and the nature of the innovation. Consequently, a first step can be to identify the sector of interest and desired direction of innovation (for example, greater energy efficiency in standby power devices).

Environmental innovation is a subset of innovation. In order for environmental innovation to occur, a sector must have the necessary capacities to innovate in a general sense. While this capability exists in all sectors, the familiarity with and engagement in the innovation process can vary greatly between them. For example, while the ICT industry is considered to be highly innovative and typically spends considerable resources on R&D, the building sector has been traditionally considered to have relatively low innovation performance and to suffer from a number of innovation barriers. The characteristics of the sector and its innovation dynamics influence how the sector engages in the innovation process and what type of policy interventions (both innovation and environmental) may be the most appropriate for it. Consequently, a next step is to establish an understanding of the sector's characteristics and innovation dynamics.

The nature of the desired innovation affects the type and extent of policy intervention required. This work has indicated that factors such as who the beneficiaries of the innovation are; what the costs and benefits are to the various parties; whether there are cost discrepancies or other market distortions; and whether there is a strong customer demand can affect the likelihood of the innovation occurring and the degree and type of policy intervention necessary. A subsequent step is to try to establish a picture of the nature of the innovation in relation to the sector characteristics.

Using this picture, a dialogue between innovation and environmental policy makers can ensue regarding the most appropriate types of interventions for the case at hand. This dual-party dialogue could be beneficial from several vantage points. If the sector where improvements are desired suffers from a number of innovation barriers, efforts on the innovation policy side to help strengthen these areas could represent an important contribution to the innovation, process in general. This may be particularly useful where the sector in question is a traditional, "low technology" industry. While these sectors constitute a significant part of the economy and are often associated with considerable environmental impact, they may not typically receive substantial attention in the innovation policy portfolio (as suggested in the EU PILOT project[21]). Focusing on these areas can help to simultaneously advance the goals of

[21] The Policy and Innovation in Low-Tech (PILOT) project (duration December 2002-November 2005) was funded by the European Commission, as part of the key action "Improving the Socio-Economic Knowledge Base". National research teams in the project conducted a series of case studies on non-research intensive, "low-tech" companies in eleven countries. The project has established that most growth and employment in OECD countries still result from low-tech and medium-low-tech industries, has found that significant innovation might occur in the absence of any activity that

environmental improvement and achieving a knowledge-based society. Furthermore, based on this dialogue appropriate innovation policy programmes could be designed to encourage environmental innovation in the desired direction and be supplemented with the appropriate environmental policy interventions to facilitate the innovation through the commercialisation stage.

6.3 Recommendations for Further Research

Upon commencing this work, it was hoped that a review of sector innovation dynamics and specific environmental innovation case studies could provide some insight into the process of environmental innovation in general, as well as into the role played by sector characteristics in shaping the environmental innovation process. While this research has shed some light onto these issues, further work is required in order to develop a more in-depth understanding of the environmental innovation process and the role that policy plays. While a multi-sector perspective has been used here to generate a more comprehensive picture of environmental innovation, a further in-depth review of each sector is required to gain a better understanding of the sector's innovation dynamics and to provide additional insight into issues that were not captured in this limited work. Insight into how different sectors have responded to similar policy interventions may provide interesting input towards gaining a better understanding of the role that sector specific characteristics play in the innovation process (though this type of comparison may limit, in many instances, the range of cross-sector comparisons possible due to the typical sector-specific application of policy instruments). Additionally, a more in-depth inter-country comparison within a sector (for example, the Danish versus Finnish building industry) could potentially provide interesting insight into variations across a sector and the effects of specific policy tools on innovation.

could be classified as R&D under commonly used definitions, has substantiated that interrelationships of mature LMT sectors and young high-tech sectors are of major importance for the innovativeness of industry in general, and has provided evidence that there is a bias in policy towards science-based innovation and high-tech industries (PILOT, 2007).

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Personal Communication

MP-1 A. Remmen, Project team member, Aalborg University, Denmark (29 June 2007)
MP-2 K.R. Dirinck-Holmfeld, Project team member, Aalborg University, Denmark (1 Aug 2007)
MP-3 P. Singhal, Nokia Corporation, Singapore (formerly Finland) (10 July 2007)
MP-4 C. Moussette, Industrial Designer, Masters Project – Mobile Phones, Umeå University, Sweden (30 June 2007)
MP-5 S. Lundberg, Ericsson, Sweden (27 August 2007)
PP-1 P. Kivimaa, Project team member, Finnish Environment Institute, SYKE, Finland (19 July 2007)
PP-2 H. Toivanen, Ministry of Trade and Industry, Finland (15 Aug 2007)
PP-3 J. Laurila, Helsinki School of Economics, Finland (13 Aug 2007)
BI-1 M. Fritzon, Skanska, Sweden (8 Aug 2007)
BI-2 J. Fabiano, Prism Construction Ltd., Canada (2 Aug 2007)
BI-3 R. Linturo, Lonix, Finland (2 Aug 2007)

Abbreviations

AAU	Aalborg University
BAT	Best available technology
BCTMP	Bleached chemi-thermomechanical pulping
BLGMF	Black liquor gasification for motor fuels
COBA	Connected Open Building Automation
CoC	European Code of Conduct on Efficiency of External Power Supplies
CTH	Chalmers Institute of Technology
CUBE	Building Services Technology Programme (Tekes)
DME	Dimethyl ether
DTU	Danish University of Technology
EFL	German electricity feed-in law
ELV	European Community Directive on End-of-Life Vehicles
EMS	Environmental management system
EMFS	Electronics Manufacturing Services
EPA	Environmental Protection Agency
EPBD	European Commission Directive on the Energy Performance of Buildings
EPI	Environmental policy integration
EPR	Extended producer responsibility
ETAP	Environmental Technologies Action Plan (European)
ETC	Energitekniskt Centrum
EU	European Union
EuP	European Community Directive on Eco-Design of Energy-Using Products
GMCT	Green Markets and Cleaner Technologies Project – Leading Nordic Innovation and Technological Potential for Future Markets
HVAC	Heating, ventilation, and air conditioning system
IP	Internet protocol
IPP	Integrated product policy
IPR	Intellectual property rights
IS	Innovation system
ISO	International Organisation for Standardisation
LTU	Luleå University of Technology
Mistra	Foundation for Strategic Environmental Research (Sweden)
NGO	Non-governmental organization
NIP	National Insulation Programme (Netherlands)
NTBF	New technology based firm
ODM	Original design manufacturer
PfE	Swedish Programme for Improving Energy Efficiency in Energy-Intensive Industries

PRO	Public research organisation
RoHS	European Community Directive on the Restriction and the Use of Certain Hazardous Substances in Electrical and Electronic Equipment
SaMBA	Smart and Modular Building Automation (Tekes)
SME	Small to medium sized enterprise
STEM	Swedish Energy Agency
STFI	Research Institute of the Swedish Forest Industries
TCO	Swedish Confederation for Professional Employees
Tekes	Finnish Funding Agency for Technology and Innovation
UAE	United Arab Emirates
UmU	Umeå University
WEEE	European Community Directive on Waste Electrical and Electronic Equipment
ZEV	Zero emission vehicle

Appendix A

The following table provides a brief overview of some of the energy-related policies affecting the three sectors of study at the EU and national levels)

	EU	Sweden	Finland	Denmark
Mobile	EuP Directive			
	Code of Conduct/Energy Star			
	IPP			
Pulp	Transport Directive for Biofuels	CO_2 tax & Energy related taxes	CO_2 tax & Energy related taxes	N/A
		PfE	Voluntary agreements with industry	N/A
Buildings	EPBD	Building Code	Building Code	Building Code
		Labelling of appliances	Labelling of appliances	Labelling of appliances
		Voluntary labelling for windows	Window rating system	Voluntary labelling for windows and phase-out agreement with industry
		Mandatory individual metering (in force in 2009)	Energy certificates (pending)	Mandatory individual metering
		Energy declaration of buildings (in force January 1, 2009)	Promotion of wood pellet heating in buildings	Energy labelling of large buildings
		Local Energy Advice Programme	Procurement competition for energy efficiency detached houses	Energy labelling of small buildings
		Investment support for energy saving and renewable energy measures in public buildings	Programme for energy conservation in oil heated buildings	Subsidies for conversion to district heating
		Technical procurement	Voluntary Energy Conservation Agreement of Municipal and	Grants for energy saving investments in pensioners dwellings - *Closed

	EU	Sweden	Finland	Denmark
			Non-profit Housing Properties of ASRA	2003
		Tax reduction for certain environmentally enhancing installations in single family houses (1 January 2004)	Energy aid for energy audits and energy efficiency	
		Help to convert from direct electric heating to district or individual heating	"Energy expert" education	