# The Greening of Innovation Systems for Eco-innovation - Towards an Evolutionary Climate Mitigation Policy

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# THE GREENING OF INNOVATION SYSTEMS FOR ECO-INNOVATION - TOWARDS AN EVOLUTIONARY CLIMATE MITIGATION POLICY

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Policies for mitigating climate change have never received as much attention worldwide as now. At the same time another upcoming policy trend is the increasing synthesis between innovation- and environmental policy, a synthesis that is captured by the eco-innovation concept. However, the climate and innovation policy areas are currently little aligned and have in fact been considered opposites until very recently.
The paper seeks to identify how evolutionary economic theory, hitherto very little applied to the environmental area, may guide the development of climate policies and eco-innovation policies in important ways. The paper argues that the evolutionary economic perspective entails a new policy rationale which not only puts more emphasis on greening of markets as a means towards reaching climate goals but also shifts the representation of the economy towards a more dynamic one. The policy implications of this shift are considerable and have hitherto gained little attention.
A deeper understanding of eco-innovation dynamics is strongly needed for informing both climate and innovation policies. The paper argues that the fact that environmental problems have largely been neglected by evolutionary economic research illustrates a lack of genuine systems thinking within this line of thought, despite the prominence of systems ideas. The paper proposes a strong paradigmatic explanation of eco-innovation based on a combination of innovation systems thinking and an evolutionary capabilities approach.

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# The Greening of Innovation Systems for Eco-innovation - Towards an Evolutionary Climate Mitigation Policy

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***Abstract***

Policies for mitigating climate change have never received as much attention worldwide as now. At the same time another upcoming policy trend is the increasing synthesis between innovation- and environmental policy, a synthesis that is captured by the "eco-innovation" concept. However, the climate and innovation policy areas are currently little aligned and have in fact been considered "opposites" until very recently.

The paper seeks to identify how evolutionary economic theory, hitherto very little applied to the environmental area, may guide the development of climate policies and eco-innovation policies in important ways. The paper argues that the evolutionary economic perspective entails a new policy rationale which not only puts more emphasis on greening of markets as a means towards reaching climate goals but also shifts the representation of the economy towards a more dynamic one. The policy implications of this shift are considerable and have hitherto gained little attention.

A deeper understanding of eco-innovation dynamics is strongly needed for informing both climate and innovation policies. The paper argues that the fact that environmental problems have largely been neglected by evolutionary economic research illustrates a lack of genuine systems thinking within this line of thought, despite the prominence of systems ideas. The paper proposes a strong paradigmatic explanation of eco-innovation based on a combination of innovation systems thinking and an evolutionary capabilities approach.

Based on this frame the paper provides policy recommendations arguing that the innovation system concept may form a needed analytical frame for translating overall carbon reduction goals into innovation targets. The paper suggests a long run policy for creating a high innovative capacity for eco-innovation among sectoral, national and regional innovation systems.

*Keywords: Eco-innovation, climate mitigation policy, innovation policy, evolutionary economic theory, innovation systems, paradigm change, industrial dynamics*

## 1. Introduction

In December this year (2009), world leaders will meet in Copenhagen to agree on a new global deal to address climate change, the COP15 meeting. The overall goal of the COP 15 meeting is, following up on the Kyoto Protocol of 1997, to set up new global carbon reduction targets, the expectation being that these will be quite severe. This meeting, and the overall global climate change agenda is currently one of the hottest international policy issues. While the warnings on the rate that human-induced climate change is happening and the likely adverse impacts have strengthened (IPCC, 2008), this seems only part of the reason for the rising climate interest. Rather the alignment of environmental issues with energy supply targets and security policies has created a very powerful political agenda which is gaining widespread acceptance internationally as well as across policy domains. Accordingly, the environmental policy area is gaining a much larger and more central position than ever before. This change in policy orientation is likely to have major effects on the global economy. The purposes of this paper are (1) to inform climate policy debates with insights from innovation systems theory, based on evolutionary economic thinking, and (2) to encourage and develop the further application of innovation systems theory to understanding eco-innovation for climate change mitigation.

The dramatic rise of the climate agenda has had a significant effect on the innovation policy area. Green growth is suddenly a mainstream global policy target. There is a new global race to become leaders in what leading politicians term the “New green deal” (Obama, 2009; Brown, 2009) or “the green industrial revolution” (Milliband, 2007; Barroso, 2007). A range of policy measures and institutional changes have been debated and begun to be put in place, including innovation policy measures.

These developments represent a marked changed from earlier innovation policy practice. In fact innovation policy making has dealt very little with the environmental area until quite recently. The environment has largely been seen as a cost to business and therefore as something innovation policy should seek to restrict or avoid (Kemp and Andersen, 2004, Andersen, 2008a). Preceeding the recent climate era, there has, however, been a slow rise of the “eco-innovation agenda” starting around the turn of the millennium. Analytically, the eco-innovation concept puts emphasis on the competitiveness effects of eco-innovation; in relation to policy, it seeks to forward greater synergy between environmental and innovation policy (see e.g. Fussler and James 1996, Andersen, 1999, 2004b, 2006, 2008a 2008, Fukasako 1999, WBCSD 2000, Rennings 2000, 2003, Markusson, 2001, OECD 2005, Foxon 2005, van den Bergh et al., 2006, 2007; Reid and Miedzinski, 2008). The eco-innovation policy area represents a very immature policy area in need of further clarification but it is gaining rapid momentum these last 1-3 years, none the least at the level of important international institutions such as EU, OECD and UN (EUROPEAN COMMISSION 2003, Kemp and Andersen, 2004; COM 2006, UNESCAP, 2007, OECD (2009).

However, this development of eco-innovation policy is largely taking place in parallel to climate change mitigation policy, with relatively little interactions. The reason for this is that they are rooted in different policy domains respectively the environmental and the innovation/industrial policy domain. Climate and environmental policy is largely based on neoclassical economic thinking, while innovation policy is based on evolutionary economic theory. These differences in underlying rationales are, however, little recognized, but they have major policy implications.

An important factor in the climate debate is that there is not only a call for innovation but also for radical innovations. Arguably, the central challenge of climate change mitigation is how to achieve a radical transition to low-carbon systems of production and consumption in such a way that social and economic costs of the transition are minimised and social and economic benefits are maximised. Though this transition will not be achieved without significant government action, this will largely take the form of creating the right incentive structures for business and entrepreneurs to invest in innovation and deployment of low-carbon technologies, processes and systems. However, current climate policy debates tend to focus on the short-term costs that will be faced by current high-carbon industries, rather than on the economic benefits to nations that become leaders in new low-carbon industrial sectors.

This paper aims to provide conceptual clarifications as to how evolutionary economic theory could usefully inform these debates within climate change mitigation policy, and promote the application of eco-innovation thinking to climate policy. The focus is on clarifying the theoretical interpretation of eco-innovation dynamics and using this as a basis for constructive policy suggestions. We restrict the theoretical discussion in this paper to the evolutionary economic literature, which has so far been very limited in application to the environmental area. The main argument of the paper is that evolutionary economic theory may in important ways reframe how we understand climate mitigation issues and its relationship to the innovation process and economic performance. We argue that a deeper understanding of eco-innovation dynamics, including formation and evolution of innovation systems, are needed to guide policy making in the area; insights which may in important ways inform both climate policy making and innovation policy. We propose here a strong paradigmatic explanation of eco-innovation which draws on a combination of innovation systems thinking and the evolutionary capabilities approach, the latter hardly been applied to the environmental area so far (see Andersen, 1992, 2002). We argue finally that the national innovation system frame may form an important framework for understanding the uptake and global diffusion of a green techno-economic paradigm.

The innovation system frame could be an important analytical frame for translating overall carbon reduction goals into innovation targets. The paper suggests a long run policy for creating a high innovative capacity for eco-innovation among national, sectoral and regional innovation systems. We particularly focus on the co-evolutionary development of technologies and service innovations, organisational structures, institutions and user practices, appropriate to a world in which higher value is attributed to significantly lower carbon emissions and reduced environmental impacts more generally. We refer to this as ‘the greening of the innovation cycle’.

The paper is structured as follows. Section 2 examines recent policy developments under the climate change mitigation agenda, and examines what we claim is wrong with the framing of this agenda from an innovation perspective. Section 3 briefly reviews innovation systems thinking, and identifies key concepts which are relevant for climate policy. Section 4 examines the recent focus on eco-innovation and proposes how this could be extended to the greening of innovation systems. Section 5 examines the implications of these ideas for a long run climate policy focus on wiring up the innovation system for eco-innovation. Section 6 concludes and identifies areas where further research is needed, particularly from the innovation research community.

## 2. Climate change mitigation agenda

### 2.1. Recent climate policy developments

The economic debate on climate change was significantly taken forward by the publication in late 2007 of the Stern Review on the economics of climate change (Stern, 2008). Sir Nicholas Stern, former Chief Economist at the World Bank, and his team argued that climate change represents the "greatest market failure the world has ever seen", but that the costs of mitigation (an annual cost of 1-2% of global GDP by 2050) are much lower than the likely social and economic costs of climate change impacts (equivalent to an annual cost of 5-20% of global GDP by 2050). The estimated costs of climate change mitigation have reduced, as global macro-economic models have incorporated economically-induced technological change (Kohler et al., 2007; Strachan et al., 2008).

In order to reduce the risks of major climate change, it is estimated that atmospheric concentrations of greenhouse gases (GHG) will need to stabilise below 500 ppm $CO_2$equiv. This implies global emissions reductions of 50% by 2050, and 80% reductions by industrialised countries, assuming equitable sharing between countries (Climate Change Committee, 2008). To achieve emissions reductions of these orders of magnitude will require dramatic transformation of systems of production and consumption, particularly in relation to power generation, transport and overall energy use. As we shall argue, this will require insights from innovation systems theory on industrial dynamics.

While climate policies have a strong focus on reduction targets in carbon emissions, there is a recent increasing interest into technological innovation as a core issue. As Stern (2007, Ch.16) argued, "accelerating technological innovation" is thus a key component of policies to deliver timely, effective and economically efficient climate change mitigation.
Stern identified three key policy areas for accelerating innovation:

- **carbon pricing**, through taxes or tradable permit schemes;
- increasing support for **R&D, demonstration projects and early stage commercialisation** of clean technologies;
- measures to overcome **institutional and other non-market barriers** to deployment.

These priorities are beginning to be reflected in policies of the European Union member states. These are seen as forming part of a "new, green industrial revolution" (Milliband, 2007; Barroso, 2007). Such calls have recently been echoed by the new US Secretary of Energy (Chu, 2009). In December 2008, the European Council of Ministers agreed on an Energy and Climate Policy package, both for domestic action and as a basis for negotiation at the Copenhagen meeting. This package aims to address environmental targets, whilst, at the same time, contributing to ensuring security of energy supply for EU countries. The main aims of this package are to achieve by 2020:

- a 20% reduction in carbon emissions, with a promise of a 30% reduction in carbon emissions by 2020, if there is an international agreement at the COP15 meeting in Copenhagen;
- 20% of final energy from renewables;
- a 20% improvement in energy efficiency.

The main policy instruments to achieve these targets are the extension of the European Emissions Trading Scheme (ETS), a carbon market covering around 50% of emissions, including power generation and energy-intensive industries, and R&D and price-support measures for deployment of new renewable and other low-carbon energy technologies. As well as stimulating the deployment of existing low-carbon technologies and processes, these measures are intended to promote innovation and rapid take-up of low-carbon alternatives, such as wind power, solar photovoltaics, nuclear power, and carbon capture and storage (CCS), which are currently more expensive than the dominant alternatives of using coal and gas for electricity generation. Complementary measures to improve the building stock, in order to reduce the heat demand by homes and businesses, have received more attention in some countries, such as Germany, than others, such as the UK.

**2.2. What's wrong with the framing of the climate agenda?**

Hence there is increasing focus on innovation as a core means to achieve environmental goals, a focus that is becoming much more mainstream both across policy domains and different regions and among business. Still, the climate agenda is so far only limitedly linked to innovation policy more generally. Even more importantly, innovation research has so far only played a limited role in climate policy thinking.

The alignment of environmental issues and energy supply and security targets has created a very powerful and more horizontal political agenda, than has previously been the case with other environmental issues. However, most of the focus has so far been on agreeing global and national $CO_2$ targets, and using carbon trading and support for R&D and early commercialisation of low-carbon technologies to achieve these. This approach has so far met with only limited success. Problems with the over-supply of emissions permits in the first phase of the European ETS led to a collapse in the trading price, reducing the incentive for emissions reductions, and the economic recession is now leading to a further drop in the carbon trading price in phase two of the ETS. Incentives for the deployment of renewable energy technologies, such as feed-in tariffs in Germany and Spain, and the Renewables Obligation in the UK, have only led to relatively modest increases in the take-up of these technologies (Stenzel and Frenzel, 2007).

So, despite lots of activity and significant institutional change, such as the introduction of the European ETS, the high-level rhetoric of a new green industrial revolution being a focus for green growth and international competitiveness has not been matched by measures to promote the radical, disruptive innovation that will be needed to meet challenging long-term emissions reduction targets. There has also been little positive vision or public discussion of what a low-carbon society might look like, and much emphasis on negative reduction targets.

We argue that this is at least partially the result of the framing of the climate issue, which is still dominated by neo-classical economic and linear innovation thinking. This focuses on short run allocation issues, using models based largely on rational actors with perfect foresight. As such, they form an inadequate basis for addressing long-term environmental problems, in which actors need to make decisions in the face of high levels of risk and uncertainty, both in relation to outcomes of current actions and the potential for the development of alternatives. Table 1 outlines the main policy measures and their underlying framing.

| **Policy area** | **Theoretical framing** | **Example policy** | **Example target** |
|---|---|---|---|
| Carbon pricing | Neo-classical economic theory | EU Emissions Trading Scheme | 21% reduction in EU ETS sector emissions by 2020 (compared to 2005) |
| Support for R&D, demonstration projects and early commercialisation of clean technologies | (Neo-classical) innovation theory/ (evolutionary) innovation systems theory | Feed-in tariffs for renewable energy technologies in many EU countries | 20% share of final energy from renewables by 2020 |
| Overcoming institutional and non-market barriers to deployment | Behavioural economics | Incentives to take-up (cost effective) energy efficiency improvements | 20% reduction in energy consumption by 2020 |

*Table 1. Framing of current climate change mitigation policies.*

As can be seen from the Table, these measures focus largely on the important issue of reducing emissions from energy supply and energy-intensive industries, which are within the scope of the EU Emissions Trading Scheme. There is relatively little focus on wider systems of production and consumption, to stimulate a more general greening of these systems by creating space and incentives for eco-innovators and greening of markets. Whilst markets in tradable carbon permits may have an important role to play, we argue that the wider greening of markets and other incentives to promote wide and deep low-carbon innovation are more important to achieving a long-run transition to a low carbon economy.

In the next section, we discuss current theoretical and policy developments around the concept of eco-innovation. Whilst we think that these represent a step forward in integrating innovation and environmental policies, we argue that so far there is insufficient integration of systems thinking, which is necessary for this agenda to contribute significantly to informing climate policy for meeting challenging long-term carbon reduction targets.

## 3. Innovation systems theory as a basis for climate mitigation policy

### 3.1. Evolutionary economic basis of innovation systems theory

The innovation system framework forms today the basis not only for much national, regional and sectoral innovation analysis but also for much innovation policy. As yet environmental and the upcoming climate policies have been little influenced by this perspective, illustrating the still limited synergy between the two policy areas (see though e.g. Andersen, 2004a, 2004b, Kemp and Andersen, 2004, Foxon, 2005, Foxon and Kemp 2007, Andersen 2007 for discussions of innovation systems theory and environmental policy). We focus here on the organisational approach to innovation systems, which underpins work on national and sectoral innovation systems, as we argue these are most applicable for understanding the economic implications for climate policy. Much recent work in this area has focussed on technological innovation systems, taking a functional approach (Jacobsson and Bergek, 2005; Hekkert et al., 2007), and on more sociological transitions theory (Geels, 2005). These approaches raise other issues that are beyond the scope of this paper (see Andersen, 2007 for a discussion). Important work on regional innovation systems is covered in another paper in this session at the conference (see also Cooke, 2001).

Innovation policy, and the innovation research that forms the basis of it, is grounded in evolutionary economic theory (the national innovation systems approach) which seeks to treat economics as a long-run, real time dynamic process. Environmental and innovation policy hence are based on very different basic assumptions, a factor that tends to be neglected in the current climate debate (see also Andersen, 2004b, 2008).

However, the climate agenda also challenges evolutionary economic theory. As we argue below, the neglect hitherto of environmental problems by evolutionary economic research as well as by innovation policy derived from this, points to some limitations in the capacity to undertake systems thinking within this line of thought despite the claim to do so. The innovation systems theory is by now a well-established framework for a broad evolutionary perspective on innovation and long-run economic change (see e.g. Freeman, 1987; Freeman, 1995; Lundvall, 1988, 1992 (ed.), 1999, 2005; Johnson, 1992; Nelson, 1993; Metcalf, 1995; Edquist, (ed.) 1997, OECD, 2000, Perez, 2000, Freeman and Loucã, 2001, Fagerberg et all. 2008). It has been further operationalized as a policy frame by the OECD and European Commission (OECD 2000, 2001a, 2001b, 2005; European Commission 2003, 2006).

An innovation system (from the organisational approach) is defined as "those elements and relations, which interact in the production, diffusion and use of new and economic useful knowledge" (Lundvall, 1992). The organisational approach to innovation systems emphasises both micro-activities in the 'core' of the system and to the 'wider setting' in which the core operates (Lundvall, 2005). The influential Oslo Manual produced by the OECD (1997) identifies three main elements within innovation systems:

- *The innovation dynamo*: dynamic factors shaping innovation by key knowledge producers and users, notably firms and knowledge organisations, such as universities and technical institutes, and interactions between them.
- *Transfer factors*: human, social and cultural factors influencing information transmission to firms and learning by them, including flows of knowledge and funding in society.
- *Wider institutional setting or framework conditions*: the general conditions and institutions which set of range of opportunities for innovation, including policy conditions and the science and engineering base.

The development of innovation systems theory was originally motivated by a wish to illustrate that national economic performance depends on a lot more than simple labour productivity (Lundvall, 2005). Hence the concept is closely related to the understanding of knowledge based competitiveness and the knowledge economy, or as it is sometimes also referred to, the learning economy (Lundvall, 2005, Gregersen and Johnsen, 2008). The basic assumption on the knowledge economy is that the current high rate of economic change makes knowledge generation, absorption and use and the overall ability to learn the key factors for competitiveness.

The broad national innovation system perspective should not indicate that innovation depends on everything; rather the attempt is to identify the core actors and institutions which influence most on the innovation process and economic development. Innovation systems should be considered open systems in which different systems (regional, sectoral, technological and even global) overlap. The innovation systems frame is primarily applied at the national level. The argument is that despite a globalizing economy, learning is still very localized and a major part of the national institutional setting, noticeably policy but also cultures and various other institutions (Maskell 1999). Increasingly the frame is also applied to broader regions like the EU, treating it as one innovation system that is compared to e.g. the US, Japan and China.

The essence of innovation systems thinking is to view the economy (the innovation system) as resulting from co-evolutionary processes of change in science, technology, organisations and institutions (Lundvall, 2005). Innovation systems develop and transform as firms and industrial sectors interact with, form and are affected by a (predominantly national) public knowledge infrastructure, policies and wider institutions and demand structures. Despite the globalising economy many important framework conditions for innovation remain national or regional (Lundvall, 2005).

The empirical comparative analyses of different innovation systems allow for an understanding of their structural characteristics, specific innovation patterns, and development over time. Such studies show that innovation patterns vary widely between different national innovation systems (Nelson 1993; Metcalfe 1995, Edquist and Hommen, eds. 2006). However, despite the co-evolutionary interest still most empirical innovation system analysis tends to focus more on how national innovation systems perform (undertaking snapshot benchmarking of innovation rates and competitiveness) than how they form and evolve over time (Lundvall, 2005, Andersen, 2006a, 2008a, Fagerberg et. al. 2008). Hence, we argue that the upcoming eco-innovation research agenda should raise attention to neglected research questions such as the evolution of negative externalities of production, the co-evolution of policies and technologies, the dynamics of overall techno-economic paradigm changes and major societal transitions.

### 3.2. Key concepts from innovation systems theory for guiding climate and eco-innovation policy

We argue that four concepts within innovation systems thinking are particularly relevant for the climate and eco-innovation policy debate: the concept of *'system failures'*; the emphasis on *path dependence* and *cumulative causation*; the importance of linking sectoral or specialisation analyses to national and global analyses; and the understanding of long-term industrial dynamics and transformation.

Firstly, as the European Commission's Economic Policy Committee noted, in the innovation systems perspective, innovation and learning are viewed as network activities, and the rationale for policy intervention "shifts from one simply addressing market failures that lead to underinvestment in R&D towards one which focuses on ensuring the agents and links in the innovation system work effectively as a whole, and removing blockages in the innovation system that hinder the effective networking of its components" (EC, 2002). In our context, this relates to the identification and targeting of specific system failures related to eco-innovation in the given innovation system. This draws on a key insight of innovation systems theory. In a context of dynamic change under uncertainty, the neo-classical concept of 'market failures' - deviations from a perfectly competitive allocation of resources by actors with perfect foresight – forms a seriously distorting mirror on which to base policy interventions. The concept of system failures – failures of instituted market mechanisms and boundedly rational firms to achieve socially defined objectives – forms a more appropriate guide to policy interventions (Metcalfe, 1995, 2003; Smith, 2000; Edquist, 2001; Foxon, 2007). For example, in previous work by one of the authors and colleagues, system failures were identified relating to the early commercialisation of new and renewable energy technologies in the UK (Foxon et al., 2005).

Secondly, innovation systems research sees innovation as a historical process, emphasizing the path-dependent and co-evolutionary nature of change (see also Martin and Sunley, 2006, Fagerberg et al. 2008.) Evolutionary theory emphasizes variety creation, selection, adaptation and retention as core factors in the innovation process which are all subject to path-dependency (David 1986, Arthur 1989, North 1990, Pierson 2000, Martin and Sunley 2006, van den Bergh et al., 2006, 2007). The economic path dependency literature focuses on the mechanisms that may give rise to economies of scale, such as the adoption of standards, but also institutions, including policies and informal "rules of the game", may give rise to scale advantages as they are costly to establish but efficient to run with widespread effects once well-established (North 1990, Pierson 2000).

Organisational innovation systems analyses examine how new and economically useful knowledge is produced, diffused and used, through the interactions between and co-evolution of these elements. As noted, such analyses can be undertaken at national, regional, sectoral or technological levels. (Lundvall, 1988; Edquist, 1997; Perez, 2000; Freeman and Louca, 2001; Murmann, 2003; Malerba, 2005; Nelson, 2005; Beinhocker, 2005; Foxon, 2008; Stenzel et al., 2008; Parrish and Foxon, 2009).

The innovation system(s) forms the selection environment for new innovative activities and entrepreneurial ventures; that goes particularly for the national innovation system where most institutions are founded. Established structures and practices in the innovation system seed the selection processes and tend to preserve existing practices while winnowing out new ones that are ill adapted to the existing innovation system. Only the new practices and ideas that at a given time and place are well adapted to the (continuously transforming) selection environment are likely to be applied and form the basis for further adaptation and development.

The co-evolutionary processes of the innovation system may particularly give rise to path dependencies, because of the interdependent nature of its constituents. Changes in one part of the system require complementary changes in other parts. It is therefore important to be attentive to the path dependencies and lock-ins that prevail in different innovation systems.

Thirdly, the specialization pattern, or sectoral composition, forms an essential part of the structural characteristics of the national innovation system. In recent years interest is rising into "sectoral innovation systems" as a new research field (Breschi and

Malerba 1997, Malerba 2002, 2005, Jacobsson and Bergek 2004, Bergek et al. 2005). This research tries to link up in-depth analyses of sector specific innovation patterns with wider national innovation system analyses.

The sectoral composition is important because the innovation patterns and performance of different industries vary considerably (Pavitt 1984, Malerba 2004). E.g. more high-tech industries depend more on codified and science based knowledge and the formal protection of intellectual property rights while other sectors rely more on experimentation, interactive learning with suppliers and customers and secrecy for their innovation performance (Malerba 2004).

The sectoral composition of a given national economy influences the operation and structure of its national innovation system (Fagerberg et. al 2008). To some degree the firms operate within a shared national knowledge and institutional framework, and to some degree sector-specific institutions evolve and may play significant roles for the innovation conditions at the firm level. The relationship between sectoral and national innovation systems is a co-evolutionary one; i.e. sectoral characteristics influence the development of the knowledge infrastructure and institutions at the national level, while at the same time the latter characteristics influence the subsequent evolution of the national economy and its sectoral composition (Fagerberg et al. 2008).

Also informal organisations and institutions such as communities of practices and codes of conduct are considered important constituents when seeking to characterize the innovation system (Lundvall 2005). The focus on the agency of different actors within the innovation system pays attention to the different, possibly conflicting, perceptions of and expectations to the economic development and wider societal trends; a difference which influences the action that different actors might undertake to gain support for their innovative activities.

The above discussion underlines the importance of the structural characteristics of the innovation system and the analysis of the matches and mismatches of the activities and perceptions of different actor groups and hence the need to apply an organisational approach to innovation system analysis.

Finally, innovation systems thinking contributes potentially to the long-term dynamics of industrial change.

"Neo-classical theory tends to abstract from the very processes that make a difference in terms of economic performance. These processes remain as a crucial foundation for innovation systems analysis. The focus is upon how enduring relationships and patterns of dependence and interaction are established and dissolved as time goes by. New competences are built while old ones are destroyed. At each point of time, there are patterns of collaboration and communication that shape the innovation system but, of course, the system is also evolving in a process of creative destruction of knowledge and relationships." (Lundvall, 2005, p.24).

Of particular interest in relation to a transition to a low-carbon economy is understanding transformation of national and sectoral innovation systems over time. The industrial dynamics of innovation systems is seen a process of co-evolution of production structures, technologies and institutions, emphasising the strategic role of knowledge and learning. (Lundvall, 2005).

This builds on ideas, supported by empirical analysis, of gestation times and the changing role of various actors, including incumbent firms, start-ups and knowledge institutions, in different phases of the innovation cycle for a technology or industry. Two major phases are generally identified – the fluid *formative* phase and the *consolidating* or *market expansion* phase, charaterised by stablisation processes around a dominant design (Abernathy and Utterback, 1978; Dosi, 1982; Freeman and Perez, 1988, Perez, 2000). These ideas have major implications for the organisation of production and (green) learning across actors in the innovation system, a factor that has major policy implications, as we shall expand on below. However, so far the innovation cycle literature has not been closely related to the innovation system literature, underlining the still limited attention to innovation system transformations in the literature. We argue for the need to combine the innovation system literature to the evolutionary capability approach in order to strengthen the understanding of the micro-processes of innovation, none the least changes in economic organisation. In the section on eco-innovation below, we bring some examples of this line of thinking.

Overall, innovation system theory can contribute to understanding of the mix of incentives and policies needed to promote a transition to a low-carbon economy at two, inter-related levels. Firstly, at the micro-meso level, innovation theory can inform how innovation occurs in relation to particular technologies, industrial sectors and specific regional and national contexts; what system failures may be occurring; how innovation may be influenced by incentives and policies and create new institutions; and the likely micro-economic costs and benefits of this. Secondly, at the meso-macro level, innovation systems theory can inform how long-term, path-dependent changes may affect the industrial dynamics towards low-carbon techno-economic systems, and the implications of this for economic growth at the macro level.

Below, in the section on eco-innovation, we will seek to expand the above discussion on innovation system dynamics in interpreting the dynamics and trends of the greening of innovation systems.

## 4. Understanding eco-innovation and greening of innovation systems

### 4.1. Emergence of eco-innovation thinking

The environmental agenda has emerged gradually as an important policy issue over the last 45 years. During this period the environmental agenda and its impact on the economy has changed considerably. The last 10-15 years have seen a marked shift from a pure regulatory approach towards the slow rise of greening as a corporate issue. The greening of markets is now becoming apparent, particularly within the last couple of years as a consequence of the topical climate debate (Malaman, 1996, Hitchens, et al. 1998, 2002, Rand, 2000a, 2000b, Andersen, 2002, Ecotec 2002, Esto 2000a, Frondel, Horbach and Rennings 2005, European Commission 2006, Johnstone, 2007, OECD, 2007a, 2007b, 2008, 2009).

However, we know currently only little of the trends and dynamics in the greening of industry and markets because of the lacking theoretical and empirical research in this area. Economic research on environmental issues has hitherto been dominated by neoclassical approaches**.** Evolutionary economic theories have, as mentioned on the other hand, only very recently and so far quite limited been applied to environmental issues. The evolutionary economic contributions to eco-innovation have so far tended to have a strong focus on the innovation effects of environmental regulations (e.g. Schot, 1991, 1992; Kemp and Soete, 1990, 1992; Kemp, 1993, 1994, 1997; Wallace, 1995, Clark, 1996; Malaman, 1996, Foster and Green, 2000, Rennings, 2000, Rennings et al.2003, Beise and Rennings 2003, Kemp and Foxon 2006, van den Bergh et al., 2006, 2007; Gregersen and Johnson, 2008). There are also a few resource based contributions discussing greening as a strategic opportunity (Hart, 1994, den Hond, 1996). The majority of research on firm greening, however, is management literature of a prescriptive nature, technology studies with limited theoretical discussion or sociological research on firm green attitudes or organisational learning.

It goes beyond this paper to engage in an in-depth discussion of eco-innovation theory and analysis. Rather we seek shortly to come up with key insights and definitions which may aid our policy suggestions. Our starting point is that it matters highly for the policy discussion how we understand and frame the eco-innovation and climate mitigation issues and that major but little recognized differences exist here. We argue that the concept of eco-innovation is important because, as defined here, it seeks to intersect climate mitigation, innovation and economic performance, which the climate mitigation concept alone does not. We suggest the need to apply an industrial dynamics approach in developing eco-innovation theory, joining up with recent attempts at synthesising evolutionary and resource based economic theories in seeking to intersect notions of economic organisation, learning, strategy, and dynamic market processes. We suggest more specifically that combining innovation systems theory with an evolutionary capabilities approach may provide an appropriate framework for capturing eco-innovation dynamics and guiding policies in this area.

### 4.2. Defining eco-innovation and climate mitigation

Eco-innovation is a novel and as yet fuzzy concept in need of theoretical and empirical clarification. Sharp, consolidated and operational definitions are lacking and statistical data are poor. There is currently a strong policy interest in developing better classifications and indicators on eco-innovation none the least at EU and OECD levels (see Kemp and Arundel, 1998, Kuhndt et al., 2002a, 2002b, Arundel, Kemp and Parto 2004, Horbach (ed.) 2005, Andersen, 2006, Kemp and Pearson, 2007, OECD, 2009b).

As the environmental agenda has changed so has the notion of eco-innovation. It has been referred to hitherto as “environmental technologies” or “clean technologies”. With a still more preventive and integrated policy approach to environmental issues the focus has changed from End-of Pipe/clean up technologies, to cleaner production processes, cleaner products to the broader eco-innovation or, quite popular lately, cleantech business. In the Environmental Technology Action Plan (ETAP) of the EU Commission, a key policy initiative for the promotion of eco-innovation, environmental technologies are defined as:

*“all technologies whose use is less environmentally harmful than relevant alternatives. They include technologies to manage pollution (e.g. air pollution control, waste management), less polluting and less resource-intensive products and*

*services (e.g. fuel cells) and ways to manage resources more efficiently (e.g. water supply, energy-saving technologies). Other more environmentally-sound techniques are process-integrated technologies in all sectors and soil remediation techniques"* (EU Com, 2004).

Interpreting this somewhat broad statement, two main eco-innovation categories can be identified:

- Pollution- and resource handling technologies and services.
- All technologies, products and services, which are more environmentally benign than their relevant alternatives.

More detailed discussions of eco-innovation definitions and categories are given in Andersen 2006, Andersen 2008b, Kemp and Pearson, 2007, and Carillo-Hermosilla et al. 2009 (forthcoming), as well as OECD, 2009.

From today's broad definitions of eco-innovation it is apparent that eco-innovation is difficult to define and address because of the complexity but also the relativity of the subject. Greening is a moving target; innovations which are considered green today may be outrun by greener alternatives sooner or later.

From this perspective, climate mitigation may be seen as a subfield of eco-innovation. The concept is much clearly defined: Avoiding fossil fuel based global warming by promoting a shift from high-carbon to low-carbon technologies. Core policy interests center on two aspects, promoting respectively renewable energy technologies and energy efficiency, as described in Section 2.

### 4.3. Understanding environmental degradation and eco-innovation

If we look beyond these definitions into the underlying understanding of environmental problems some marked differences in rationale are apparent.

Traditionally, the framing of environmental policies has been defined by neoclassical environmental economics. In this approach, rational, utilitarian agents in perfect competition are preoccupied with short run allocative questions leading to equilibrium. Time is reversible and agents have no history. Environmental problems are seen as market failures deriving from the distribution of property rights and negative externalities from production. Orthodox ecological economics thus centres on getting the prices right under consideration of social welfare. This entails calculations of the costs of polluting and the associated compensation that must be paid as well as the costs of not polluting (e.g. Baumol and Oates, 1988; Pearce et al 1989; Pearce and Turner, 1990, Birk Mortensen, 1991).

This idealised market representation has dominated environmental analyses and policymaking hitherto and still influences the climate agenda strongly.  This has serious shortcomings in relation to environmental analysis. Noticeably, it has failed fundamentally in explaining (and realising) the recent greening of markets. The environment is seen as a burden to companies associated with production and administrative costs, and environmental policy as forcing companies to take on these extra costs. As a result, competitiveness and greening have been seen as strong opposites. This notion has not only penetrated policymaking but has also been widely shared by companies which severely has hampered a shift from reactive towards proactive environmental strategies in companies (Andersen, 2002, Kemp and Andersen, 2004, Kemp, Andersen and Butter, 2004).

An evolutionary economic perspective takes quite a different stand treating externality problems as dynamic (Kemp and Soete,1992, Rennings 2000). The phenomena to which the "externality" tag is applied are related to particular historical and institutional contexts rather than definitive once-and-for-all categorizations.
Nelson and Winter clarifies the externality problem from an evolutionary economic perspective:
"To a large extent the externality problems that dominate the policy discussions… are aspects of economic change. The processes of change are continually tossing up new externalities that must be dealt with one way or other…. The canonical "externality" problem of evolutionary theory is the generation by new technologies of benefits and costs that old institutional structures ignore….There is no reason to believe that the lines between what society wants to leave private and what society wants to make public will remain constant over time. Whereas orthodoxy stresses achieving optimal provision of goods that by their nature are public, the evolutionary approach focuses on the changing circumstances that call for collective-choice machinery" (Nelson and Winter, 1982, pp.368-369).

This line of thinking sees climate issues and wider environmental problems as a function of the co-evolutionary emergence of environmental problems and the government structures to deal with these (see also Kemp and Andersen, 2004, Andersen 2008a). Hence, the environmental and innovation externalities are seen as fundamentally linked (Foxon et al., 2005b, Foxon, 2007). The environmental issues are a very good example of an area where the circumstances for collective-choice action has changed considerably over the last 10-15 years. The evolutionary perspective opens up the possibility that environmental issues can be internalised into the economic process, i.e. a greening of markets. As such the area illustrates important features of modern economies which to a still larger degree depend on well-functioning government structures. The important of social capital for the economic performance in the knowledge economy is well- recognized; e.g. the high innovative performance of the Nordic countries are largely attributed to the welfare system of these countries (Lundvall, 1992 (eds.)). This recognition of the importance of well-functioning institutional structures makes it the more remarkably that the externality discussion generally, and not the least environmental degradation, has received so little attention until now within this frame. Seemingly, eco-innovation has not been considered important to economic performance. The lacking attention illustrates a gap in innovation systems thinking in dealing with externality issues more generally. There is a lacking attention to the negative effects of innovation which are generally unquestioned. In innovation economic research more innovation is per definition a good thing and a core policy goal. In neglecting the negative externalities of production important properties of modern economies are ignored. More fundamentally, it reveals a tendency to focus more on how innovation systems perform than how they form; and attention to their preserving and guiding features rather than their transition processes.

The evolutionary capability approach is helpful for the understanding of the micro-processes involved for central parts of the innovation system transition processes. This perspective, however, has paid very little attention to framework conditions and is little coupled to innovation systems research. The focus is quite narrowly on the firm-market dichotomy and alternative modes of economic coordination in dynamic markets where information is lacking and is in flux. Analyses focus on investigating the relationship between the organisation of labour and knowledge (Penrose, 1959, Richardson, 1972, Teece, 1986, 1988, 1989, 2000, Langlois 1992, 2003, Teece and Pisano, 1994, Dosi and Marengo, 1994, Loasby, 1996).

There is little attention to the role of government intervention for this economic coordination. This approach puts more emphasis on firm agency and hence on strategising and economic organisation than pure evolutionary economic approaches to innovation.

None the less, the framework is helpful for the understanding of the high coordination costs involved when markets and innovation systems are undergoing rapid or major change as is the case in the greening of the economy. There are "dynamic transaction costs" when existing market-supporting institutions are inadequate to the needs of a new technology or profit opportunity (Langlois, 1992, 2003). As markets are given time and scope they catch up and the dynamic transaction costs sink (Langlois, 2003). The dynamic transaction costs discussion is essential for the understanding of the dynamics of the greening of markets, which is highly dependent on the evolution of market-supporting institutions.

There are we argue, unusually high green "dynamic transaction costs" involved in the greening of markets because of some specific characteristics of eco-innovations (Andersen, 1999). They are associated with unusually large information problems (because of the inherent credence characteristics, the variability, the complexity), they are radical in a cognitive sense, and also often in a technical sense, and they have strong systemic features (partly due to the environmental factor being evaluated on a life-cycle basis, partly because of recycling aspects) (Andersen, 1999, 2002, 2006). These special innovation features are important to recognize and address by policy.

Integrating the evolutionary capabilities perspective, attention is brought to how learning and production is organised across different firms and other core innovation actors such as knowledge institutions in the innovation systems.

This wider industrial dynamics perspective on greening takes a starting point in the firm and the way it organises its production and green learning in globalizing markets in rapid change, including the threats and opportunities the greening of market offers. Environmental problems are not a market failure, but rather an integrated part of the imperfections of the market (Andersen, 1999, 2002).

**4.4. Defining eco-innovation from an industrial dynamics perspective**
Eco-innovation from this perspective is defined as *innovations which are able to attract green rents on the market* (see also Andersen, 1999, 2002, 2006, 2008a, 2008b). They reduce net environmental impacts while creating value on the market. The concept is closely related to competitiveness while making no claim on the absolute "greenness" of varies innovations. The firm may seek to enhance its green competitiveness in two ways. Either by acquiring a premium price for its green reputation or product, or to reduce production costs by achieving greater resource efficiency or reducing the costs of costly emissions. The eco-innovations may be

technical, organisational or marketing innovations which improve the “green competitiveness” of a company (Kemp and Andersen 2004, Andersen, 2006). As the economy globalises, competition is intensifying and it becomes increasingly important to compete on other features than costs particularly for the more developed economies. In this context, eco-innovation is increasingly becoming an interesting business opportunity.

The focus of eco-innovation research here is on *the degree to which environmental issues are becoming integrated into the economic process.* Eco-innovation research, then, analyses trends and dynamics in the greening of business strategies, markets, technologies, sciences and innovation systems. More fundamentally eco-innovation research investigates the degree to which innovation and technology development is moving in a green direction at different levels (see Andersen, 1999, 2002).

For the firm the greening process appears as turbulent changes in the selection environment, entailing new legitimacy needs and/or requirements for innovations. Incentives for engaging in eco-innovation strategies, however, vary widely for different types of firms and sectors depending on the “environmental sensitivity” of the firm or the sector (Malaman, 1996). A core argument of this paper, supported by the evolutionary capabilities perspective, is that the greening process is inherently uneven, particularly at the firm level (Andersen, 1999, 2002, 2007a, 2007b) which adds to the high green dynamic transaction costs. Some types of firms are inherently more polluting than others because of the character of their production or product and different sectors have therefore been subjected very unevenly to environmental policy. But regional differences in the biosystem and particular historical processes in different technology areas, regions or for given firms, add to the uneven greening process. However, the limited research into the industrial dynamics of the greening of industry means that possible patterns in the greening of industry, and the identification of the leaders and laggards in the eco-innovation processes have so far not been identified nor addressed by policy.

This perspective views the firm not as polluter but as eco-innovator, which opens up for a radical redefinition of the firms’ or sectors’ possible role in the eco-innovation process (Andersen, 2008b). All firms and sectors play a role for eco-innovation though these processes are currently ill understood. Hence the current still highly uneven greening of firms is an important driver but even more importantly a central barrier to eco-innovation.

### 4.5. Eco-efficiency and eco-innovation

The concept of “eco-efficiency” is closely related to the eco-innovation concept, and has been a pioneering concept in linking up environmental performance to economic performance. It is a business model and a measure of the value from a product or service against the environmental impact (Daly, 1974, 1984, WBCSD 2000). It is important because it links up a given activity to its environmental impact. WBCSD defines eco-efficiency as :“Eco-efficiency can be achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and energy and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity” (WBCSD 2000).

**Box 1. Defining eco-efficiency**

Eco-efficiency measures the improvements of or the degradation in the environmental impact for a given activity.

$$\textit{Eco-efficiency} = \frac{\textit{product or service value}}{\textit{environmental impact}}$$

The environmental impact is measured as both resource use (the source side) as well as emissions to air, soil and water (the sink side) per produced unit/activity. Amounts as well as toxicity is important.

Source: WBCSD 2000

Eco-efficiency analyses measure potentially the progress in environmental performance of different agents. This progress may reflect the degree of eco-innovation or structural changes in the economy (such as outsourcing of resource intensive industries). To some degree, it does represent a measure of eco-innovation output, though the concept only to a limited degree has been connected to innovation analysis so far. Eco-efficiency has mainly been used to measure the environmental performance of either a single plant or the global economy, and it has primarily been applied to analyze the decoupling of environmental impact from economic growth at the macro level. E.g. in 1994, the members of the Factor 10 Club argued for a ten-fold increase in resource productivity to achieve an environmentally sustainable economy, and these discussions are still continuing (Bleischwitz et al. 2003).This decoupling and resource efficiency debate is not very strong in the current climate debate, reflecting a limited innovation orientation.

### 4.6. Greening as techno-economic paradigm change

For a more full understanding of eco-innovation and climate mitigation we need to situate these in a wider paradigm change context. Theories and studies of innovation cycles argue that some changes in technology have so pervasive impacts on the economy that they will entail a techno-economic paradigm change (Dosi, 1982; Freeman and Perez, 1988; Perez, 2000, 2002). Neo-schumpeterian theory emphasize the long wave relationship between economic and technological development arguing that such fundamental technological changes bring discontinuity in economic development but also act as important engines of economic growth (Freeman, 1982, Freman and Soete, 1997, Freeman and Louca, 2004).

Many researchers, also some evolutionary economists, have pointed to the rise of the greening of markets as part of an overall techno-economic paradigm change (Summerer 1989; Kemp and Soete 1990; Kemp, 1994; 1996; Gladwin 1993; Freeman 1992, Andersen, 1999, 2002, 2008b). And lately there is also much reference in the climate debate of the shift from a high- to a low-carbon economy as a paradigm change (Unruh, 2000, 2002).

The green paradigm discussion is not only important because it puts emphasis on the pervasiveness, radicality and path dependency of the greening process. Certainly the economy is currently highly locked-in to carbon based technologies and the shift to a low carbon society is therefore likely to be costly and entail quite a lot of creative destruction. Rather it is even more important because it points to the neglected cognitive roots underlying the greening of the economy.

Particularly Dosi's work on "technological paradigm" emphasises the cognitive aspects of paradigm change. He defines a technological paradigm as "a model and a pattern of solution of selected technological problems, based on selected principles derived from natural sciences and based on selected materials technologies", (Dosi, 1982 p.152). A technological trajectory is defined, quite flexible, as *the pattern of conventional problem solving activity* within a given technological paradigm (Dosi, 1982). Technological trajectories emerge because the technological paradigm embodies strong prescriptions on the directions of technological change to pursue *(positive heuristics)* and those to neglect *(negative heuristics)*. Hence a research organisation or firm's knowledge base is characterized by certain heuristics, which are theory-laden and upholding inner consistency (Dosi, 1982).

We argue (see Andersen, 1999, 2002) that the greening process entails specific heuristics and that it is possible to define a "green trajectory". Despite the complexity of the greening process, we argue that there are some fundamental heuristics and learning associated with the greening process and that it is possible to define a "green or resource efficient trajectory". We may hence perceive of the green techno-economic paradigm shift as a shift from, and a competition between a "wasteful" trajectory, with little attention to the exploitation of resources in normal problem solving activities, towards a "resource efficient trajectory" where there is strong attention to an efficient use of resources (the sink and the source functions, the life cycle impacts) in normal problem solving activities (see Andersen, 1999).

This discussion emphasis that the greening process is more than a technical substitution process, from carbon based to none carbon based technologies, but a more fundamental learning process, involving the creation of new understandings, values, search rules and capabilities and the creative destruction of old practices and capabilities.

A core argument of this paper is that there is a need for a stronger focus on the time- and space dependencies of the greening process. This is where the innovation systems framework links up to the paradigm discussion. We may then perceive of the greening of the economy as a global continuous transition process, which is subject to specific often very different conditions within national, regional and sectoral innovations systems. We also argue that the eco-innovation conditions in the innovation system has changed and will change considerably over time. Hence, this paper argues, the "greening" of the economy may be understood by referring to the "green innovation cycle", see further below.

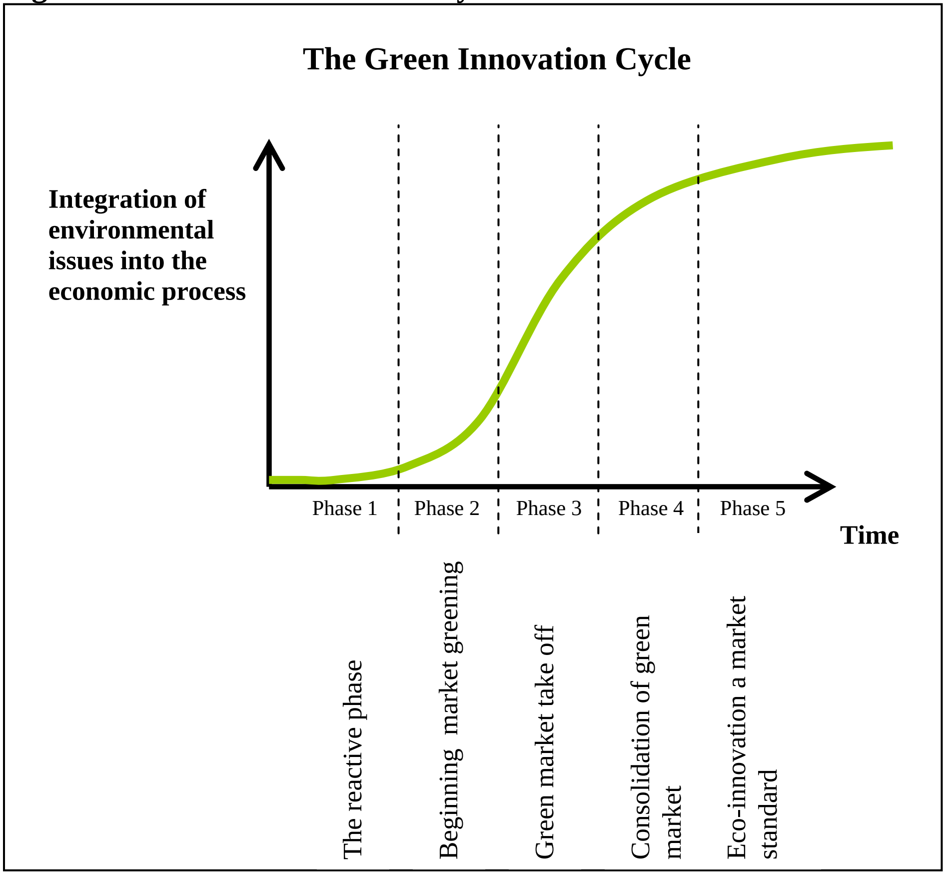
In the next section we seek to elaborate on this and to relate this to the greening of the innovation system. The point is not only that eco-innovation conditions have been undergoing dramatic change over time and are likely to do so in the future, but that different actors currently are at very different stages in the green innovation cycle.

**4.7. The greening of the innovation system**

In this section we will seek to raise the eco-innovation discussion to the system level, first for the entire economy and then for national innovation systems. What do we mean when we talk about a greening of innovation systems? In wiring up the innovation system for eco-innovation a core focus is to address and rectify the “green mismatches” in between different segments of the innovation system e.g. between different policy areas, research areas, financial institutes, technical standards, market information standards.

Below the stages in the greening of the innovation cycle is illustrated.

**Figure 1. The Green innovation cycle**




Source: Own source

The greening process is here focusing on the degree to which environmental issues are becoming integrated into the economic process. The figure illustrates five different stages, during which the conditions for eco-innovations differ markedly. Phase one, the reactive phase, has been dominated by demand and control environmental regulation as the main incentive for eco-innovation. Phase two illustrates the formative phase with a beginning greening of markets. Phase three is the green market take off phase. Phase four is the consolidation phase and, in phase five, eco-innovation has become a market standard.

We may perceive of the greening of the economy as a specific historical phase dominating the global economy though with considerable regional and sectoral differences. The first long phase, beginning in the 1950s as the environmental agenda arose, has prevailed for over 30-50 years and has cemented the environment as a burden to business. The shift between phase 1 and 2, we may point to the beginning of the 1990s, when we saw “integrated product policies” and clean technologies support programs emerging and the first environmental strategizing among pioneering companies. The critical shift between phase 2 and 3 towards the green market take off is happening right now, starting 2-3 years ago and still accelerating. This shift has been surprisingly rapid, particularly considering the long phase 1 and the rather slow phase 2. It is currently difficult to say anything about when a transition to phase 4, market consolidation, and phase 5, eco-innovation as a recognized little discussed market standard, will take place. But it is likely that, as experienced in previous phases, there will be waves in the intensity of the greening process. However, there is no longer any doubt about the climate agenda being generally recognized and here to stay as a driver of this transition.

Below table 2 seeks schematically to illustrate the main co-evolutionary processes taking place within an innovation system in the transition from a wasteful to a resource-efficient techno-economic paradigm. As such, it illustrates what we mean by "the greening of the innovation system" and the related green techno-economic paradigm change.

**Table 2. The green innovation cycle and the co-evolution of the innovation system**

| Phases<br><br>Actors | Reactive | Beginning green market | Take off | Consolidation | Market standard |
|---|---|---|---|---|---|
| **Innovation/ Technologies** | "Wasteful", high-carbon economic paradigm | Resource efficient trajectory emerging | Eco-innovations rising in many business areas | Eco-innovations competitive | Resource-efficient techno-economic paradigm |
| **Institutions** | Regulatory institutions Government clean up role | Market supporting institutions introduced | Market supporting institutions advancing | Institutions seeding eco-innovation | Greening is "in the air" |
| ***Firms*** | Uneven greening, obstructive and reactive strategies to regulation, | Early movers environmental strategizing | Environmental proactive strategies on the rise, | Widespread proactive environmental strategies, | Routine environmental strategies, Standard high environmental profile |
| ***Sectoral Innovation systems*** | Uneven greening | Uneven greening: Polluting industries greening | Development of sectoral env. strategies Building up capabilities & institutions | Widespread proactive env. strategies, Sector specific green knowledge base | All sectors high environmental profile |
| ***Knowledge institutions*** | Attention to environmental issues only in traditional environmental research areas | Attention to environmental issues only in traditional environmental research areas | Rising interest into environmental areas, building up new green capabilities | Widespread green search and education | Routine green search and education |
| ***Consumers/ Families*** | Reactive, No green capability | Few green lead users | Rising green consumerism & knowledge | Widespread but uneven green demand | Widespread/routine consideration of green demand |
| **National/regional/global Innovation system** | No green market or -capabilities except in the clean up area | High friction to early eco-innovation, | Green knowledge base & net works expanding, medium friction to eco-innovation | The selection environment favours eco-innovation, Strong green overall knowledge base | Well-functioning green markets with supporting framework conditions Eco-innovation the "easy innovation" |

Source: Own source

The table focuses on the co-evolution of technologies, institutions, organizations (firms, sectors, knowledge institutions and consumers/families) as well as the overall national/global innovation system. As we move along the green innovation cycle, none-green actors are winnowed out, new green entrepreneurs enter and green competitiveness becomes increasingly important and influences on the selection of suppliers and customers, learning partners, employees, financial institutes etc. As the green market becomes more established, none-green sectors and technologies may be threatened by competing greener technological trajectories. In the final phase, which makes up the vision of “the green innovation system”, eco-innovation has become a market standard and the “easy” and natural innovation which by now is routinized and mainstream.

The above table may aid our understanding of the system failures to eco-innovation and how these differ fundamentally in the different phases. The key point is that we need very different policies for each phase. The essential factor here is the degree of company proactivity towards environmental strategizing and the related maturity of the green market.  Climate- and environmental policies has tended to take a static perspective on climate mitigation and its relation to(eco-)innovation and economic performance and hence has failed to recognize and address firm proactive environmental strategizing and the greening of markets.
In our section 4 on policy recommendations the suggestions are targeted at the current phase 3 market take-off.

Due to the highly uneven greening process, we need to consider the distribution of green strategies, capabilities and search rules in different parts of the innovation system at a given time. Particularly we need attention to the sectoral composition in this regard.

The long reactive phase 1 means that there is considerable lock-in into none-green practices and strategies in the innovation system. There is hence, generally high friction to eco-innovation, though this seems to be changing considerably in the later years with the rising popularity and acceptance of the climate agenda. There seems to be new global expectation that the climate agenda is here to stay as a business case.

The uneven greening and the path dependencies have major implications for the efficient organisation of eco-innovative production and learning across actors in the innovation system. These factors have major policy implications, as we shall expand on in the next section.

Taking on a long run perspective on the economic process attention is brought on how different eco-innovations draw from and contribute to a shared underlying green knowledge base rather than focusing on how they may contribute to direct environmental improvements. This green knowledge base feeds into search practices and strategies and forms the basis for the development of greener technological trajectories and overall techno-economic paradigm change. Acknowledging the significance of this suggests a much stronger knowledge based approach to climate mitigation than generally practiced.

## 5. Evolutionary policies for eco-innovation and climate mitigation

There is worldwide a rapidly increasing attention not only to climate mitigation policies but also to eco-innovation policies, and there are a range of useful policy measures starting to be implemented in specific domains. The OECD has just undertaken a review of innovation oriented environmental policy activities in its member states. This shows that a stronger innovation approach is emerging in many places, but that initiatives differ considerably (OECD, 2009b). The many initiatives may be more or less linked up to climate mitigation. It goes beyond this paper to address these initiatives more specifically. What we argue is that there is a need for a more systematic integrated innovation approach which works horizontally across policy domains. This is far from the case today, where minor eco-innovation policy measures are added on to existing policy initiatives. We argue that for climate policies to become efficient they need to be closely integrated with eco-innovation policies. In fact, we see eco-innovation policies as a necessary means for translating overall carbon reduction goals into action at the level of specific agents such a regional and national governments, multinational companies, small start-ups and knowledge institutions. Such a stronger eco-innovation policy approach would fit well with general innovation policy aims of becoming more horizontal (third generation innovation policy (OECD, 2005). In this section, we suggest some core considerations and principles which may form the basis for linking up eco-innovation and climate policy. Our recommendations hence may both guide climate policy and eco-innovation policy.

An evolutionary economic approach represents, we propose, in many respects a potential new climate policy rationale, first of all in viewing the economy as a long run process, subject to time- and space dependencies. Rather than focusing on immediate environmental goals, this paper suggests *a long run policy for wiring up the innovation system for eco-innovation*. This policy aims to mould the market and create a selection environment that favours eco-innovation.

We suggest that the core carbon reduction targets of climate mitigation policy need to be complemented by the equally important goal of creating a high eco-innovative capacity in the global economy. We argue that the negative reduction targets of the climate mitigation policy area make up poor guidance for (innovation) action. Rather positive visions are needed of a new type of economy, in order to guide the necessary learning and strategy processes. The vision should signal that we are talking about a qualitative or paradigmatic change of the economy. The high- to low carbon shift is here not powerful enough in that it simple refers to a substitution of technology base but no different economy. There is a need to signal a change from a linear to a circular perspective in economic resource thinking. The term the "eco-innovative economy" is also important in directly linking up environmental impact, innovation and economic performance, which is what has been lacking strongly hitherto in environmental policy making.

To wire up the innovation system for eco-innovation thus entails two main overall goals:

1. to strengthen the innovative capacity of the (national) innovation system towards eco-innovation;
2. to make eco-innovation the "easy innovation" in the economy.

The innovation system frame is potentially helpful to the climate policy area in situating eco-innovation in specific time and place. It may shed light on the system dynamics and failures of specific national and sectoral innovation systems that need to be addressed to achieve a high eco-innovative capacity. This is especially important when considering globalisation aspects of climate policy and hence the need to discuss policies in very different specific (national or regional) contexts.

For such a policy approach to be efficient, it is necessary to identify and address the distinct national/regional eco-innovation patterns, i.e. how the green knowledge production is organised within different economic sectors as well as the wider knowledge system in the given national innovation system. And it is necessary to pay attention to the uneven distribution of green strategies, capabilities and search rules.

The European Union has currently one of the strongest eco-innovation policy efforts through the ETAP (Environmental Technology Action Plan) framework. This framework works at three levels: from research to market; improving market conditions and acting globally. Here we outline the key insights from an evolutionary economic perspective that we argue should be incorporated into the ETAP framework at each of these levels.

1. *From research to market*

a. **Promote green search rules and capabilities**: This pillar addresses the cognitive level and seeks to promote the formation of a green knowledge base as well as widespread green search rules, both among firms and knowledge institutions (the innovation dynamo). It is important here to address the knowledge institutions and even knowledge areas, which currently show little attention to eco-innovation, such as e.g. nanotechnology (Andersen and Rasmussen, 2005).
b. Identify and address the specific national, sectoral and technological **system failures to eco-innovation in the innovation system** (paying attention to where firms and other actors are in the green innovation cycle).
c. **Take stock of sectoral/technology areas –** view the company as eco-innovator rather than polluter – target the bottlenecks and the enablers (and not only the high gains) need of strong sectoral approach
d. From green supply chain management to **green industrial dynamics**:
    - how to achieve efficient learning and coordination on eco-innovations across the many actors in the innovation system;
    - attention to how the eco-innovations draw from and contribute to a shared underlying green knowledge base.

2. *Improving market conditions*

a. Making well-functioning green markets: improving the capacity of markets to communicate and handle environmental parameters:
    - target retailers and wholesalers, craftsments, public purchasers, story telling.
    - This means improving the capacity of markets to communicate and handle environmental parameters. In a well-functioning green market environmental parameters are routinely used and understood in transactions. Environmental

issues are credence characteristics that need standards to be verified. These standards are as yet not well-consolidated. But we need more than good market standards. We need more knowledge (green capabilities) among professional and private users to allow more green purchasing and organisational structures to handle green purchasing. ICT may have a considerable potential for improving the green market communication, a factor that needs to be pursued policy wise (see also Andersen, 2004a, 2004b) . The development of 'lead markets' for particular green technologies and processes could play an important role here.

b. Making institutions favour eco-innovation: reward the proactive and eco-innovative as a core principle (more than performance targets)
   – Here the idea is to focus more fundamentally on the need to revisit current policy making towards *rewarding the proactive and eco-innovative as a core principle*. Hence we suggest to supplement the hitherto dominant principle of environmental policy making "the polluter pays" with "reward the eco-innovative". It is necessary to reconsider climate polices as well as other policy areas many of which influence on eco-innovation, to consider how to develop dynamic policies that consistently and with increasing greening creates incentives for eco-innovative action and strategies, particularly for firms but also other actors in the innovation system.

c. Making proactive firms: widespread proactivity/organisational change:
   - It is essential that the majority of firms and industrial sectors hold proactive environmental strategies or they function as bottle necks and inihibit eco-innovation strongly. It is therefore important to identify the green laggards at the firm and sectoral level and try to mobilize them as eco-innovators. Given the current uneven greening, as referred to above, this is a major task.

d. Attention to the spatial/physical dimension of green consumption patterns: - clever ressource efficient buildings/artefacts and cities
   - smart and informative surroundings for continuous eco-innovations in daily activities – ICT (and nanotech) a key role
   - Making green consumption patterns is not only a market problem but also depends on organisational structures embedded in every day life. We learn very much from the way we live and the things that surrounds us and structure our daily activities. Creating clever buildings, infrastructures and cities which make it easy to be resource efficient and inform us on or even regulate our consumption regularly is a key step towards an overall greening of consumption patterns. ICT may play a key role here.

e. Building up knowledge rather than awareness broadly
   - in schools and higher education
   - on the market (smart markets)
   - see 2a….

3. *Action globally*

a. Position the national/regional innovation system in the currently rapidly changing global division of eco-innovative production and learning

b. Situate the greening process in specific national/regional time and place
- attention to the (highly uneven) national conditions

The climate agenda can only be seen in a global perspective. This raises another important issue. The rapid development and diffusion of low-carbon technologies, processes and systems will require high levels of international co-operation in R&D and demonstration projects, and in transfer to developing countries. However, current national innovation strategies often work against effective co-operation, as they are designed around national competitiveness priorities, whereas low carbon innovation contributes to a global public good (Tomlinson et al., 2008). Hence, a major shift in national strategic innovation priorities will be needed in order to achieve faster international co-operation on low carbon innovation. Developing countries will also require support to build effective innovation systems to be able to absorb these new technologies, by developing the skills and capabilities of firms in these countries and the relevant institutional structures. Hence, in forwarding a stronger innovation perspective to climate mitigation, it is important to seek to align the quest for stronger national green competitiveness with the overall goal of strengthening the global innovative capacity for eco-innovation. There is a need for targeted action for acting globally, and securing that the specific conditions for eco-innovation in very different national innovation systems are taking into consideration, also when seeking to transfer technologies and policy measures.

Finally, it is important to note, though, that strong forces militate against the greening of innovation systems that we are proposing. The fear by currently powerful actors that their power and influence will be diluted by this process will lead them to act so as to reinforce the status quo. The linked nature of the changes required also means that there is a danger that change will only be as fast as the weakest link. Hence, there is a need for rapid examples and positive experiments in greening of innovation systems, and learning on what works well and what doesn't. For this, the development of eco-innovation indicators is an important element, and should supplement the measurement of carbon reduction trends; a work that is beginning to be picked up by the OECD, UNESCSAP and the EU.

## 6. Conclusions

This paper has sought to apply an evolutionary economic perspective - the innovation systems frame informed by evolutionary capabilities insights - to guide climate policy and further develop eco-innovation policies. The innovation system concept is increasingly being used on climate and environmental issues but also abused by not taking the core assumptions seriously. If properly used, the system approach could present a framework for promoting climate policies targeted at the specific conditions of different innovation systems around the globe.

This industrial dynamics approach could inform climate policies by:

1. setting up positive targets and visions;
2. translate macro climate goals into action at the national, regional and sectoral level.

The innovation system approach could provide a frame for empirical analyses of the structure of and the specific organisation of green knowledge production within national innovation systems; this may bring important new insights into the dynamics and trends in the greening of innovation systems and its impacts on the overall economy. Such analyses may facilitate more efficient learning and coordination on eco-innovation across the many actors in the innovation system.

The innovation system frame is also important in providing a positive vision of the eco-innovative society. The schematic analysis of the greening of the innovation system linked to the innovation cycle presented illustrates the steps towards this vision and highlights the uneven and cumulative nature of the greening process.

This paper has claimed that an innovation systems perspective represents a potential new evolutionary environmental policy rationale in fundamentally viewing the economy as a long run process subjected to path- and time dependencies. The new rationale is particularly clear in three ways:

1) In adapting a strong knowledge approach to climate mitigation and economic development;
2) In treating the company as (eco-)innovator rather than as polluter;
3) In situating the global transition towards a low-carbon society in a national innovation system context, pointing to the specific system failures.

The innovation systems approach gives attention to the system failures, as well as to the neglected cognitive aspects of the eco-innovation process. Taking a long run perspective on the economic process, attention is brought to how eco-innovative activities draw on and contribute to a shared underlying green knowledge base and search rules (a resource efficient trajectory). This green knowledge base feeds into search practices and strategies, and forms the basis for the development of greener technological trajectories and overall technological paradigm change. Fundamentally, the greening process is a learning process and wiring up the innovation system for eco-innovation means building strong green knowledge. Acknowledging the significance of this suggests a stronger knowledge based approach to environmental issues than generally practiced in climate policy and analysis.

The innovation system policy approach proposed here strives to mould the innovation system so as to make it easy and attractive to engage in eco-innovation for firms as well as knowledge institutions (and to lesser degree consumers). There is, however, a need to identify, through empirical analysis, the specific characteristic and innovation conditions, as well as system failures to eco-innovation, in the given innovation system.  Such innovation systems empirical analysis are currently lacking, meaning that today much climate and eco-innovation policy is taking place in the blind (Andersen, 2007).

Overall, we have argued that the innovation system approach may form an important contribution to linking up the micro-oriented innovation policy aiming to seed the innovation process in a green direction to the macro-oriented climate policy. In this way, climate and (eco-)innovation policies may be further aligned. The assumptions on innovation and system dynamics developed within this framework could guide climate policy development in important ways, leading to a stronger knowledge based and market focused approach.

Finally, the remaining dominance of neo-classical economic thinking in informing policy, despite the current financial crisis, forms another barrier to the take-up of these ideas. However, the recognition of the economic importance of innovation policy, and the strong body of innovation systems research on which it draws, gives cause for hope of adoption and application of this thinking to addressing pressing environmental problems, such as climate change.

This paper has only been able to sketch out broad ideas for re-framing climate change mitigation policies from an organisational innovation systems perspective. Clearly, further theoretical and, particularly, empirical work is needed to flesh out the ideas presented here. Nevertheless, we believe that we have been able to show the relevance of innovation systems thinking for addressing the challenge of mitigating climate change. The upcoming eco-innovation research agenda should raise attention to neglected research questions such as the evolution of negative externalities of production, the co-evolution of policies and technologies, the dynamics of overall techno-economic paradigm changes and major societal transitions.

## References


Andersen, M.M., (1999) *Trajectory Change through Interorganisational Learning. On the Economic Organisation of the Greening of Industry,* Copenhagen Business School, PhD. Series, Copenhagen.

Andersen, M. M. (2002) “Organising Interfirm Learning – as the Market Begins to Turn Green”, in de Bruijn, T.J.N.M. and A. Tukker (eds.), Partnership and Leadership – Building Alliances for a Sustainable Future. Dordrecht: Kluwer Academic Publishers, pp.103-119.

Andersen, M. M. (2004a) “Innovation system dynamics and sustainable development – Challenges for policy”. Paper presented at “Innovation, Sustainability and Policy Conference”, 23-25 May 2004, Kloster Seeon, Germany.

Andersen, M. M. (2004b) “An Innovation System approach to Eco-innovation – Aligning policy rationales”. Paper presented at “The Greening of Policies - Interlinkages and Policy Integration Conference, 3-4 December 2004, Berlin, Germany

Andersen, M.M. (2006) *Eco-Innovation Indicators*, European Environment Agency , Copenhagen.

Andersen, M.M. (2008a) “Review: System transition processes for realising Sustainable Consumption and Production”, chapter in A. Tucker (eds.) Greenleaf Publishing.

Andersen M.M. (2008b) “Eco-innovation – towards a taxonomy and a theory”. Paper for the DRUID conference, Copenhagen, 2008.

Andersen, M.M. and B. Rasmussen (2006) *Nanotechnology development – environmental opportunities and risks*. Risø-R report, Roskilde.

Anderson, D., Clark, C., Foxon, T.J., Gross, R. and Jacobs, M. (2001) *Innovation and the Environment: Challenges and Policy Options for the UK*, London: Imperial College Centre for Energy Policy and Technology & the Fabian Society.

Arthur, W. B. (1989) “Competing Technologies, Increasing Returns, and Lock-in by Historical Events,” The Economic Journal, 99, pp. 116-131.

Arundel, A., R. Kemp, and S. Parto (2004) “Indicators for Environmental Innovation: What and How to Measure”, in International Handbook on Environment and Technology Management (ETM), edited by David Annandale, John Phillimore and Dora Marinova, Edward Elgar, Cheltenham.

Barroso, M (2007), “Europe’s energy policy and the third industrial revolution”, speech by President of the European Commission, 1 October 2007.

Beise, M. K. Rennings (2003) *Lead Markets of Environmental Innovations: A Framework for Innovation and Environmental Economics*. ZEW Discussion Paper No. 03-01, Mannheim

Bleischwitz et al. (2003) *Governance of Sustainable Development. Towards Synergies between Corporate and Political Governance,* Final Report January 2003 Part of the Collaboration Projects under the Trust of Mitsubishi Research Institute (MRI) and the Economic and Social Research Institute (ESRI) of Japan. Wuppertal Institute.

Brown, G (2009), ‘PM calls for a “green new deal”’, official site of the Prime Minister’s Office, http://www.number10.gov.uk/Page18523

Business, Enterprise and Regulatory Reform, UK Department for (BERR) (2003), *Innovation Report – Competing in the Global Economy: The Innovation Challenge*, HMSO, London.

Carrillo-Hermosilla, J, del Rio Gonzalez P and Konnola, T (2009), *Eco-innovation: When Sustainability and Competitiveness Shake Hands,* Hampshire: Palgrave Macmillan, July 2009

Chu, S (2009), Interview by US Secretary of Energy with New York Times, February 11 2009.

Committee on Climate Change (2007), *Building a Low-Carbon Economy: The UK's contribution to tackling climate change*, London: The Stationery Office, available at http://www.theccc.org.uk/reports/

Department for Innovation, Universities and Skills (DIUS) (2008), *Innovation Nation*, HMSO, London.

Dosi, G. (1982). "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technological Change", *Research Policy*, 11, pp.147-162.

Dosi, G. et al. (eds.) (1988). *Technical Change and Economic Theory,* London: Pinter Publishers.

Dosi, G. and L. Marengo (1994). "Some Elements of an Evolutionary Theory of Organizational Competences", in R.W.England (ed.), *Evolutionary Concepts in Contemporary Economics*, Michigan University Press, pp.157-178.

Edquist, C. (2001) "Innovation policy – a systemic approach". In The Globalizing Learning Economy, Archibugi, D and Lundvall, B. (eds.), Oxford University Press.

Ecotec (2002) Analysis of the EU Eco industries, their employment and export potential, report for DG Environment of the European Commission. ECOTEC Research & Consulting Limited.
http://europa.eu.int/comm/environment/enveco/industry_employment/main_report.pdf

ESTO (2000a) *Eco-design; European state of the art - Part I: Comparative analysis and conclusions,* by Tukker, A., Haag, E., Eder, P. ESTO project report, EUR 19583 EN, Joint Research Centre Seville.

European Commission (2002) *Report on Research and Development*, EC Economic Policy Committee Working group on R&D, EPC/ECFIN/01/777-EN Final, Brussels, January 2002.

European Commission (2003) *Developing an Action Plan for Environmental Technology*. Website http://europa.eu.int/comm/environment/etap

European Commission (2004) Stimulating Technologies for Sustainable Development: An Environmental Technologies Action Plan for the European Union. COM (2004) 38 final, Brussels.

European Commission DG Environment (2006) "Eco-industry, its size, employment, perspectives and barriers to growth in an enlarged EU", report prepared by Ernst and Young.

Eurostat/OECD (1999) *The Environmental Goods & Services Industry: manual for data collection and analysis.*

Foster, C. and Green, K. (2000), 'Greening the Innovation Process', *Business Strategy and the Environment*, 9, pp. 287-303.

Foxon, T.J. (2003) Inducing Innovation for a Low-Carbon Future: Drivers, Barriers and Policies, London: The Carbon Trust, also available at http://www.thecarbontrust.co.uk/Publications/publicationdetail.htm?productid=CT-2003-07 .

Foxon, T J (2004), 'Innovation systems as the setting for the co-evolution of technologies and institutions', Proceedings of *'Organisations, Innovation and Complexity: New Perspectives on the Knowledge Economy' Conference,* University of Manchester, 9-10 September 2004.

Foxon, T J, Gross, R, Chase, A, Howes, J, Arnall, A and Anderson, D (2005), 'UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures', *Energy Policy* 33 (16), pp 2123-2137.

Foxon, T J, Pearson, P, Makuch, Z and Mata, M (2005b), *Transforming policy processes to promote sustainable innovation: some guiding principles*, Report for policy-makers, ESRC Sustainable Technologies Programme, March 2005 http://www.sustainabletechnologies.ac.uk/PDF/project%20reports/SI_policy_guidance_final_version.pdf

Foxon, T J (2007), 'The rationale for policy interventions from an innovation systems perspective', in *Governing Technology for Sustainability*, Murphy, J (ed.), Earthscan, London.

Freeman,C., Loucã, F., (2001) *As Time Goes By: From the industrial revolutions to the information revolution,* Oxford U.P., New York.

Frondel, M., Horbach, J., Rennings, K. (2005) *"End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries",* Business Strategy and the Environment.

Geels, F.W. (2005), *Technological Transitions and System Innovations: A Co-evolutionary and Socio-Technical Analysis*, Edward Elgar, Cheltenham.

Gregersen, B. and B. Johnson (2008) A policy learning perspective on Developing sustainable energy technologies, paper for the 6th Globelix Conference, Mexico City, 2008.

Heaton, G.R., and R. Darryl Banks (1999) "Toward a New Generation of Environmental Technology", in L.W. Branscomb and J.H. Keller (eds.) *Investing in Innovation. Creating a Research and innovation Policy that Works*, MIT Press, Cambridge MA, 276-298.

Hekkert, M. R. Suurs, S. Negro, S. Kuhlmann and R. Smits (2007), "Functions of innovation systems: A new approach for analyzing technological change", *Technological Forecasting & Social Change* 74, 413-432.

Hertin and Berkhout (2002) "Practical Experiences on Policy Integration and Recommendations for Future Initiatives on EU and National Level". Paper presented on the 3rd Blueprint Workshop on „Instruments for Integrating Environmental and Innovation Policy". Brussels, September 2002, Hitchens, et al. (1998): Investigating the relationship between company competitiveness and environmental regulation in European food processing: results of a matched firm comparison. *Environment and Planning* A 30: 1585- 1602.

Hitchens et. al. (2002) *Small and Medium-Sized Companies in Europe. Environmental Performance, Competitiveness and Management: International EU Case Studies*, Springer, Berlin.

Horbach, J. (ed) (2005) *Indicator Systems for Sustainable Innovation*, Physica Verlag, Heidelberg.

Hübner, K., et al. (2000) *"Greening of the Innovation System? Opportunities and Obstacles for a Path Change towards Sustainability: The Case of Germany"*, Working paper 47/00, Institute for Ecological Economy Research, Berlin.

ICCEPT (2003) *The UK innovation Systems for New and Renewable Energy Technologies,* report to DTI, Imperial College London, London

Kemp, R and Andersen, M. M. (2004) "Strategies for eco-efficiency innovation", Strategy paper for the Informal Environmental Council Meeting, July 16-18 2004 Maastricht, VROM, Den Haag.

Kemp, R, Andersen, M. M. and Butter, M. (2004) "Background report about strategies for eco-innovation", Background report for the Informal Environmental Council Meeting, July 16-18 2004 Maastricht, VROM, Den Haag.

Kemp, R. and Arundel A. (1998) *Survey Indicators for Environmental Innovation*. IDEA report, STEP Group, Oslo.

Kemp, R., et al. (2000), 'How Should We Study the Relationship between Environmental Regulation and Innovation?', in Hemmelskamp, J., Rennings, K. and Leone, F. (eds) Innovation-Oriented Environmental Regulation: Theoretical Approaches and Empirical Analysis, Heidelberg, New York: Physica Verlag, pp. 43-66.

Kemp, R. (2002) Synthesis Report of 1st Blueprint Workshop on „Environmental Innovation Systems“. Brussels, www.blueprint-network.net

Kemp,R. and Foxon,T., (2006) "Innovation impacts of environmental policies," in International Handbook on Environment and Technology Management (Eds: D.Annandale et. al.), Edward Elgar.

Kemp, R. And P. Pearson (2007), Final Report of Measuring Eco-innovation (MEI project), Bruxelles, http://www.merit.unu.edu/MEI/

Kuhndt, M. et al. (2002) Developing a Sectoral Sustainability Indicator Set taking a Stakeholder Approach. A conceptual paper presented at the 10th International Conference of the Greening of Industry Network 23-26 June, 2002, Göteborg

Kuhndt, M. et. el (2002). Towards a Sustainable Aluminium Industry: Towards Stakeholder Expectations and Core Indicators – Final Report. Online Available http://www.eco-efficiency.de/english/content/ agzu/projects/Aluproject.html

Langlois, R.N. (1992), 'Transaction Cost Economics in Real Time', *Industrial and Corporate Change*, **1**, pp.99-127.

Langlois, R.N. (2003), 'The vanishing hand: the changing dynamics of industrial capitalism', *Industrial and Corporate Change*, **12** (2), pp. 351-385.

Loasby, B. (1996). "The Organisation of Industry", in J. N. Foss & C. Knudsen, *Towards a Competence Theory of the Firm*, London: Routledge, pp.38-53.

Lundvall, B-A (1988) 'Innovation as an interactive process: from user-producer interaction to the national system of innovation', in Dosi, G *et al.* (1988), *Technical Change and Economic Theory,* Pinter Publishers, London

Lundvall, B-A (ed.) (1992), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning,* Pinter Publishers, London

Lundvall, B-A (2005), 'National innovation systems - analytical concept and development tool', paper presented at DRUID Summer Conference 2005

Malaman,R. (1996) *Technological innovation for Sustainable Development: Generation and Diffusion of Industrial Cleaner Technologies,* Fondazione Eni Enrico Mattei

Martin, R. and P. Sunley (2006), "Path Dependence and Regional Economic Evolution," Journal of Economic Geography, pp. 1-43.

Metcalfe, J.S. (1995), 'The economic foundations of technology policy: equilibrium and evolutionary perspectives', in P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change*, Blackwell, Oxford.

Metcalfe, J.S. (2003), 'Equilibrium and evolutionary foundations of competition and technology policy: New perspectives on the division of labour and the innovation process', in P. Pelikan and G. Wegner (eds.), *The Evolutionary Analysis of Economic Policy*, Edward Elgar, Cheltenham.

Milliband, D (2007), 'Time for a green industrial revolution', speech by UK Environment Secretary, University of Cambridge, 5 March 2007.

Murmann, J P (2003), *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology and National Institutions*, Cambridge University Press

Murmann, J.P. and K. Frenken (2006), 'Toward a systemic framework for research on dominant designs, technological innovations, and industrial change', *Research Policy* **35**, 925-952.

Nelson, R.R. and S. Winter (1982). *An Evolutionary Theory of Economic Change*, Cambrige, MA: Harvard University Press.

Nelson, R. (1993) *National Systems of Innovation: A comparative analysis*, Oxford University Press, New York

North, D. C. (1990) Institutions, Institutional Change and Economic Performance, Cambridge, Cambridge University Press.

Obama, B.H. (2009), Speech by President-elect Barack Obama on his plans for an economic rescue, George Mason University, Virginia, January 8, 2009

OECD (1999) *Managing National Innovation Systems*. OECD, Paris

OECD (2000) *Knowledge management in the Learning Society*. OECD, Paris

OECD (2002) *Dynamising National Innovation Systems*, OECD, Paris

OECD (2005) Governance of Innovation Systems, OECD, Paris

OECD (2008)Environmental Policy, Technological Innovation and Patens (ISBN:978-92-64-04681-8, OECD, Paris

OECD (2008) Business, Eco-innovation and Globalisation. OECD Policy Brief, July 2008

OECD (2009a) Sustainable Manufacturing and Eco-innovation. Part I.Building acommon analytical framework . DSTI/IND(2009)5/PART1, OECD, Paris

OECD (2009b) Sustainable Manufacturing and Eco-innovation. Part V. Government policies for promoting eco-innovation: A survey of ten OECD countries. DSTI/IND(2009)5/PART5, OECD, Paris

Parrish, B D and Foxon, T J (2009), 'Sustainability entrepreneurship and equitable transitions to a low carbon economy', *Greener Management International* Issue 55, pp. 47-62.

Perez, C. (2000) "Technological Revolutions, Paradigm Shifts and Socio-Institutional Change".In E. Reinert (ed.), *Evolutionary Economics and Income Equality*. Aldershot: Edward Elgar.

Pierson, P. (2000) "Increasing Returns, Path Dependence, and the Study of Politics," The American Political Science Review, 94 (2), pp. 251-267.

Rand Europe (2000a) *"Stimulating industrial innovation for sustainability: An international Analysis"*, Report for the Dutch Ministry of Housing, Spatial Planning and the Environment, Leiden.

Rand Europe (2000b) *"Stimulating industrial innovation for sustainability: An international Analysis"*, nine country reports, Leiden.

Reid, A. and M. Miedzinski (2008) Eco-innovation – final report for sectoral innovation watch, for Europe Innova, technopolis group

Rennings, K. (2000) "Redefining Innovation - Eco-innovation Research and the Contribution from Ecological Economics", *Ecological Economics*, 32, 319-322.

Rennings, K., et al. (2003) Blueprints for an Integration of Science, Technology and Environmental Policy (BLUEPRINT), Final Report of 5th Framework Strata project, available at http://www.insme.info/documenti/blueprint.pdf.

Richardson, G.B. (1972). "The Organisation of Industry", *The economic Journal*, **82**, pp.883-896.

Rotmans, J., R. Kemp and M. van Asselt (2001), 'More evolution than revolution: transition management in public policy', *Foresight* 3: 15-31.

Smith, K. (2002) Environmental Innovation in a Systems Framework. Paper presented on the 1st Blueprint Workshop "Environmental Innovation Systems", Brussels, January 2002, www.blueprint-network.net

Smith, K (2000), 'Innovation as a systemic phenomenon: Rethinking the role of policy', *Enterprise & Innovation Management Studies*, Vol. 1, No. 1, pp. 73-102

Stenzel, T & Frenzel, A (2007), 'Regulating technological change—The strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets', Energy Policy, 36 (7), 2645-2657.

Stenzel, T., P. Pearson and T. J. Foxon (2008), "Corporate strategy in the electricity sector: An approach to integrating individual agency into the systemic analysis of innovation", submitted to *Industrial and Corporate Change*.

Stern, N (2007), *The Economics of Climate Change – the Stern Review*, Cambridge University Press.

Teece, D. (1986), "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy", *Research Policy*, **15**, pp.27-44.

Teece, D. (1988), "Technological Change and the Nature of the Firm", in Dosi *et al.* (eds), pp.256-281.

Teece, D. (1989), " Economies of Scope and the Scope of the Enterprise", *Journal of Economic Behaviour and Organization*, **1,** pp.223-247.

Teece D. (2000) "Strategies for Managing Knowledge Assets: The Role of Firm Structure and Industrial Context", *Long Range Planning* 33, pp. 35-45.

Teece, D. and G. Pisano (1994). "The Dynamic Capabilites of Firms: An Introduction", Industrial and Corporate Change, **3**(3), pp.537-556.

Tomlinson, S., P. Zorlu and C. Langley (2008), *Innovation and Technology Transfer: Framework for a Global Climate Deal*, E3G/Chatham House, London, available at http://www.e3g.org/images/uploads/E3G_Innovation_and_Technology_Transfer_Full_Report.pdf

UNESCAP (2006) Green Growth at a Glance, the way forward for Asia and the Pacific, United Nations, ST/ESCAP/2407.

Unruh, G C (2000), 'Understanding carbon lock in', *Energy Policy* **28**, 817-830

Unruh, G C (2002), 'Escaping carbon lock in', *Energy Policy* **30**, 317-325

van den Bergh, J, Faber, A, Idenburg, A and Oosterhuis, F (2006), 'Survival of the greenest: evolutionary economics and policies for energy innovation', *Environmental Sciences* 3(1): 57-71

van den Bergh, J, Faber, A, Idenburg, A and Oosterhuis, F (2007), *Evolutionary Economics and Environmental Policy: Survival of the Greenest*, Edward Elgar, Cheltenham, UK

Wallace, D. (1995) *Environmental Policy and Industrial Innovation: Strategies in Europe, the US and Japan*, London: Royal Institute of International Affairs

Weber, M. and J. Hemmelskamp (eds.) (2005) *Towards Environmental Innovation Systems*, Springer Verlag

World Business Council for Sustainable Development (2000) *Eco-efficiency – creating more value with less impact*

Wicken, O. (2008) "Policies for Path Creation: The rise and fall of Norway's research-driven strategy for industrialisation" in Fagerberg, J., D. C. Mowery and B. Verspagen (eds) *Innovation, Path Dependency and Policy: the Norwegian Case*, Oxford University Press.