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TOWARDS A GREEN POST-CRISIS ECONOMY?

- The position of Finland in environmental technologies

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ABSTRACT: Climate change is a major global challenge and governments around the world are now promoting environmental technologies to address both climate change and realize new employment and growth opportunities in this rapidly expanding area. Investments have reached unprecedented levels and stimulus packages to tackle the recent economic crisis also contain noticeable commitments to green technologies. Innovation policies are now under pressure to capitalize these investments and define priorities in the application of environmental technologies to both boost competitiveness and eco-innovation. The aim of this paper is to clarify foreseen impacts of growing environmental technology investments, 'green' components of economic stimulus packages and the ideas of a 'Global Green New Deal' and 'Green Growth' and to assess how Finland is positioned in environmental technologies. The paper reviews existing studies, analyzes global and Finnish patenting and considers the role of environmental technologies in its industrial context in Finland. The findings suggest that renewable energy is the most rapidly expanding environmental technology area, while the economic stimulus packages will play a lesser role than originally anticipated in transitions to low-carbon economies. Finland is comparatively well positioned in environmental technologies by overall levels of patenting activity. Nonetheless, Finland does not have a specific specialization profile in the area, neither a comparative advantage in renewable energy technologies as the most rapidly expanding fields globally. Environmental technologies are developed in the context of a broad range of Finnish industries whereby the application potentials of these technologies are manifold.

KEYWORDS: environmental technologies, 'Global Green New Deal', 'Green Growth', investments, patenting, Finland

Contents

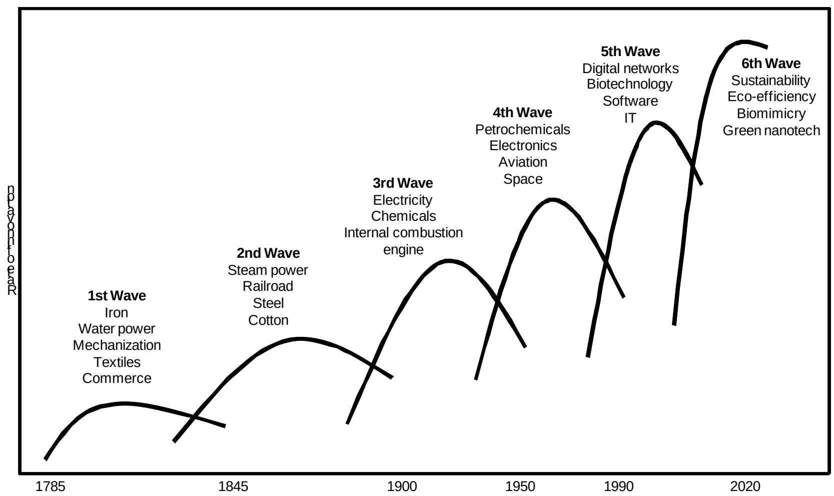
1. Introduction

1.1 Background

Climate change is currently one of the major global challenges that the world faces. The United Nations has played a key role in raising awareness of the reasons for, and societal impacts of, climate change mainly through the work of its Intergovernmental Panel on Climate Change (IPCC) which was established in 1998. Meanwhile leading economists have approximated the effects of climate change on the world economy, projected the investments which have to be made to limit climate change to manageable levels, and highlighted the complex policy challenges involved in a transition towards a greener low-carbon economy (see especially the Stern Review on the Economics of Climate Change and Stern (2007)).

While concerns about climate change, and sustainable development more generally, have been around for decades recent developments elevate environmental 'green' technologies to the top also of innovation policy agendas around the world. Environmental regulations are tightening in line with international treaties (such as the Kyoto protocol to the UN Framework Convention on Climate Change) and regional legislation (e.g. the EU), while consumers are becoming increasingly vary of sustainability issues. As a consequence, companies are seeing new business opportunities in environmental technologies and engaging in eco-innovation.[1] The Worldwatch Institute has gone as far to suggest, in their State of the World report from 2008, that the next wave of innovation will be driven by environmental technologies (such as renewable energy and green nanotechnology) in a similar way that computers have defined the current wave of IT-driven innovation (see Figure 1).

Figure 1. Long waves of innovation



Source: Worldwatch Institute (2008)

Only time will tell to what degree, and which, environmental technologies will define the next wave of innovation. What is clearer is that there currently is a significant push towards stimulating innovation related to emerging environmental technologies. R&D investments into these, and related, fields have already been growing for some time. However, the recent focus on environmental technologies in stimulus packages has raised environmental technology investments to unprecedented levels. There are expectations that these

[1] The EU Environmental Technology Action Plan (ETAP) defines eco-innovation as "the production, assimilation or exploitation of novelty in products, production processes, services or in management and business methods, which aims, throughout its life cycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy)"(see Carrillo-Hermosilla et al. (2009) for alternative definitions).

investments will also contribute to economic growth that is greener than in the past. This twin emphasis on economic stimulus and environmental technologies is often referred to as the 'Global Green New Deal'.

The idea of a Global Green New Deal reflects a belief, advocated among others by the UN Environment Program (UNEP) and the OECD, that the crisis provides a window of opportunity and justification for policy makers to intervene and stimulate economies while encouraging eco-innovation to address two crisis in one. The OECD is now involved in developing a 'Green Growth' strategy as a guideline for national governments, and some countries have introduced their own green growth strategies as part of the stimulus packages. In so far as these economic stimulus packages are truly 'green' and well-targeted the economic crisis can thereby also provide a new momentum to address climate change as the far greater and longer-term global challenge. Further, stimulus packages which promote renewable energy technologies may also diminish the dependency on fossil fuel price fluctuations and thereby contribute to more stable economic growth in the longer run.

The idea of a Global Green New Deal, and Green Growth, has spurred analysis about the optimal level, nature and possible impacts of environmental investments related to stimulus packages. It has been estimated that the share of these investments of the total stimulus packages are in the range of 6-15% and thereby amount to 180-480 billion USD in total (the figures vary across studies) to be distributed across the next two to three years on average. These are very significant sums, for example when considered in the context of some 156 billion USD investments (private and public) in sustainable energy as a whole in 2008 (UNEP and New Energy Finance, 200). The stimulus packages can therefore potentially provide a major boost for environmental technologies and play an important part in setting the stage for the next wave of innovation.

Given these developments innovation policies are now under pressure to capitalize on investments and define priorities in the application of environmental technologies to both boost competitiveness and environmentally sustainable eco-innovation. They are seeking to align framework conditions and business environments with specificities of eco-innovation and key characteristics of environmental technologies.

1.2 Aims and structure

Previous studies have monitored environmental investments and assessed the scope and potential impacts of green components of the recent stimulus packages. However, assessments of the implications of these investments and the idea of a Global Green New Deal and Green Growth, in the context of innovation policy at the country level are few and brief to date. The overreaching aim of this discussion paper is to review these previous studies with an eye to clarifying which the impacts of mounting environmental investments, stimulus packages and the idea of a Global Green New Deal and Green Growth may be as well as how Finland is positioned in the rapidly expanding global environmental technology landscape from the viewpoint of patent data. More precisely, it addresses the following questions:

1. How have environmental technology investments developed in recent years? Which technologies have been targeted, how are the investments distributed globally? To what degree are similar trends observable in environmental technology patenting?

2. What is the rationale behind the ideas of 'Global Green New Deal' and 'Green Growth'? To what extent are countries focusing on environmental technologies in their stimulus packages to battle the economic crisis, could these stimulus packages provide a boost for environmental technologies?

3. How is Finnish innovation policy approaching environmental technologies? What is the position of Finland in the rapidly evolving landscape of environmental technology investments, stimulus packages

and patenting? Which types of companies are involved in environmental technologies, are new competence areas recognizable?

The paper is structured as follows. The second section sets the stage by reviewing environment technology investments in recent years, including the green components and policy approaches related to stimulus packages in some countries. It also considers the policy rationale behind these investments, stimulus packages and the broader idea of a Global Green New Deal and Green Growth strategies. The third section analyses trends in environmental technology patenting to highlight innovative activity globally, subject to the limitation that a linear causality between investments and patenting cannot be assumed. The fourth section shifts to the case of Finland. It draws on publicly available documents and patent data to assess the position of Finland in the global environmental technology landscape, and to identify technological strongholds and the role of environmental technologies in an industrial context. The fifth section summarizes the main findings of the paper and suggests areas of further analysis.

2. From the economic crisis towards a greener economy?

2.1 Environmental technology investments globally

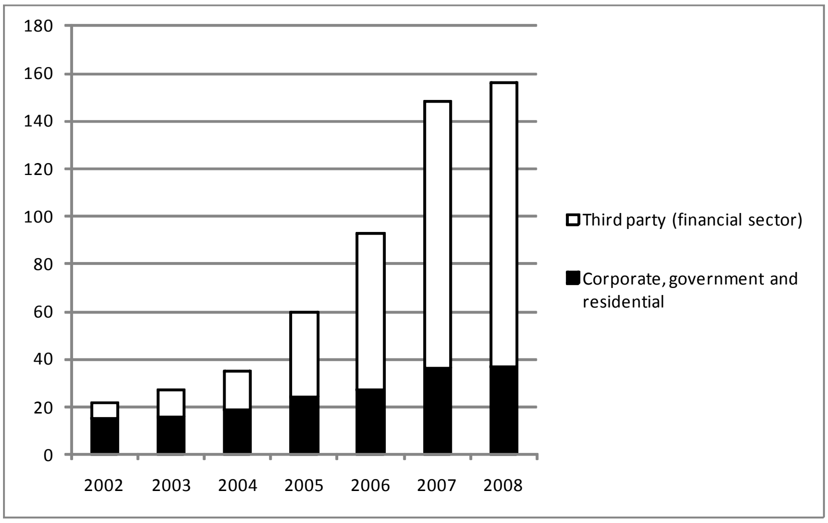
As argued in the introduction, the stimulus packages can provide new momentum in the transition towards a greener world economy. However, sustainable development, concerns over climate change and the environment generally, have been topical issues already for decades and environmental technologies have been promoted already for some time. Companies have also been active as evidenced e.g. by the proliferation of Cleantech partnerships, clusters and association all over the world.

Environmental technologies comprise a broad set of technologies whose delineation is tricky and indicators to monitor developments are hard to develop and compile. Technology and innovation researchers usually stress the importance of measuring activities all along the innovation chain, from R&D inputs (mainly R&D investments) and intermediate outputs (publications, patents, new companies etc.) to innovations and new products as the final outputs (see e.g. Godin 2005). This paper does not assume a linear causality from R&D inputs to innovation outputs. However, it refers to R&D investment data to highlight trends in the dedication given to environmental technologies while turning to patent data for a rough indication of areas where technological and competence developments are particularly rapid. These data together constitute a good setting for analyzing the position of Finland in the environmental technology field.

The annual Global Trends in Sustainable Energy Investments report, compiled by the UNEP's Sustainable Energy Finance Initiative in collaboration with New Energy Finance Ltd., is one of the most authoritative data source for tracking environmental technology investments globally (see http://www.newenergyfinance.com/). These reports draw on the world's largest database of renewable energy investments since the year 2000. It covers investments by venture capitalists, companies and joint ventures as well as public sector organizations, thereby giving the broadest possible viewpoint of these investments. The database enables the breakdown of investments by type, technology, regions and countries. Nonetheless, disclaimers also apply, especially since these data are drawn from a broad range of miscellaneous public sources whereby issues related to definition, data coverage and completeness have to be taken into account. It should also be stressed that renewable energy is merely a sub-area of environmental technologies as a broader field (the latter also includes air pollution control, waste and water management and other more traditional areas).

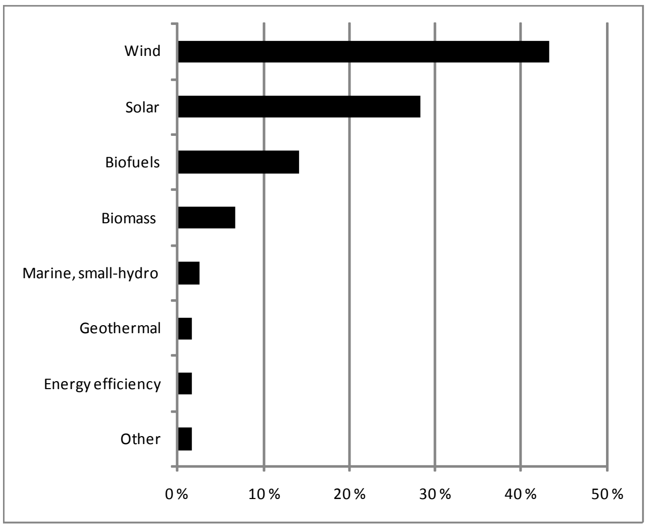
Figure 1 provides an overview of global investments in renewable energy technology since 2002. It distinguishes between investments originating in the financial sector (third party funding by banks etc.) and intramural R&D investments by companies and the government, including small residential projects. Overall there has been growth in renewable energy investments throughout and these investments have accelerated significantly since the mid 2000s. It is noteworthy that the investments appear to defy the current economic crisis even though a decline in the growth of investments is evident in 2008. The lion's share of these investments originates in the financial sector while the role of intramural company and governmental R&D still is relatively small. The overall growth in investments is therefore mainly driven by increasing asset-based funding although VC is the single most rapidly expanding source of investments overall (37% growth from 2007 to 2008).

Figure 1. Global investments in renewable energy technology 2002-2008



Source: UNEP and NEF (2009)

Figure 2. Distribution of global investments in renewable energy technology in 2008 by technology field

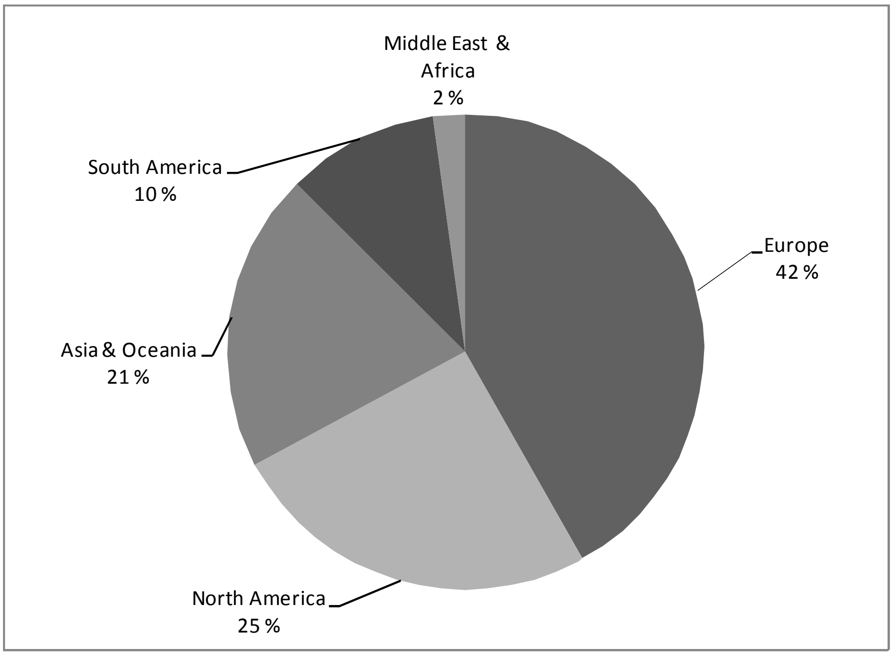


Source: UNEP and NEF (2009)

By technology (Figure 2) wind power attracted the highest share of new investments in renewable energy technologies in 2008, confirming that this field remains the best-established and also most mature one of renewable energy technologies (investments in wind power grew 1% from 2007). Solar power (primarily photovoltaics, or PVs) reached second place followed by biofuels while investments in biomass, marine & small-hydro, geothermal power, and energy efficiency accounted for far smaller shares. Furthermore, analyses of trends show that PVs are the fastest growing field in terms of investments with compound annual growth of 70% between 2006 and 2008. On the contrary, biofuels have experienced a decline in investments during recent years especially related to first-generation biofuels, which have suffered from a combination of higher wheat prices, lower oil prices and an increasingly heated food-versus-fuel controversy.

A breakdown by geographcal region (Figure 3) shows the continued dominance of Europe with a 42% share of global renewable energy investments, followed by North America (25%), Asia & Oceania (21%) and South Africa (10%). According to UNEP & New Energy Finance (2009) differences especially between Europe and the US can be explained by more extensive governmental support for renewable technologies across European countries. The US has seen a slowdown in private sector investments especially for biofuels but also for wind and solar power, the latter two fields of which have suffered the most from the financial crisis. Further, in these regions tax-based incentives for investments are more widespread while also being mostly inefficient in an economic downturn. Nonetheless, UNEP & New Energy Finance (2009) notes that investments in Asia and emerging economies (China, Japan, Australia and Indian as an in particular) have increased from previous years as renewable energy technologies have become prioritized areas. In South America Brazil accounts for almost all investments and these investments mainly relate to first-generation biofuels (e.g. biodiesel, vegetable oil, biogas, bioalcohols).

Figure 3. Global investments in renewable energy technology in 2008 by geographical region



Source: UNEP and NEF (2009)

The report focuses on the renewable energy sector but also places these investments into an overall perspective by examining the contribution of renewables to total new power capacities (e.g. including fossil fuel- or nuclear-based power). From this perspective renewable energy investments account for a majority (around 60%) of all energy investments in 2008, meaning that over 40% of all actual power generation capacity additions related to renewable energy technologies. Renewable energy technologies are therefore, no longer, a set of nice technologies but part of the mainstream energy sector. UNEP and New Energy Finance (2009) also predicts that investments into renewable energy are set to continue in 2009 and beyond to reach half a trillion USD by 2020 if there will be further scale-up of societal commitments to a greener low-carbon post-crisis economy.

2.2 The 'Global Green New Deal' and 'Green Growth'

Above R&D investment data clearly shows increasing investments in the area of renewable energy in particular. On top of these the economic stimulus packages since 2008 are estimated to add another 180-480 billion USD (the figures vary across studies) in total over the next two to three years on average, thus booting investments significantly also through government action. Why are governments stepping up environmental technology investments to unprecedented levels, which is the policy rationale for heavy environmental technology investments to tackle the current economic crisis?

Policies to mitigate climate change have traditionally been in the domain of environmental policy and their justification has been rooted in mainstream economic theory. Emission of greenhouse gases (as the prime reason for man-made climate change) is considered a market failure as the emitter of such gases damage the prospects of others while not bearing the costs of these damages. Markets fail in the sense that the price for using e.g. highly emitting raw materials does not reflect the true cost to society of producing and using those raw materials; the social cost of production and consumption based on these raw materials exceeds private costs. As a consequence, policies should intervene to correct this market failure (Stern, 2009).

Environmental policies, drawing on market failure arguments, has traditionally focused on incentivizing emitters of greenhouse gases (as well as other types of polluters) to reduce these emissions through various regulations, taxes or other market-based approaches. Environmental policies have therefore typically been considered to work against the competitiveness of companies and industries by imposing additional costs on production. Further, environmental policies have traditionally not been viewed as a means to create new business opportunities and stimulate innovation (Carrillo-Hermosilla, 2009). This is substantiated further by a recent OECD survey of policies related to eco-innovation which demonstrates that environmental and innovation policies have long been separated. The separation is most visible in the fact that these policies have been the responsibility of different ministries in most countries (OECD, 2009).

As suggested in the introduction the recent surge in environmental investments, combined with increasing attention given to eco-innovation in industry, is bound to bring environmental policy issues to the closer attention also of innovation policy. Innovation policy will increasingly have to align the promotion of emerging environmental technologies with institutional and regulatory frameworks which environmental policy is imposing on companies to reduce emissions and other environmentally harmful activities. On top of this, innovation policy has to deal with the more common type of market failure due to unintended knowledge spillovers which imply that companies may under-invest in R&D to avoid the diffusion of these technologies e.g. to competitors. This 'double market failure' in the case of emerging environmental technologies is complicated further by the societal desire to maximize the diffusion and industrial uptake e.g. of cutting-edge renewable energy technologies. (Mowery et al., 2009). It is therefore understandable that e.g. Stern (2009) refers to climate change mitigation and environmental technologies as the "biggest market failure of all times" and highlights various policy challenges in this context.

The market failure argument is one of the main arguments also for launching the concepts 'Global Green New Deal' and 'Green Growth'. The concept 'Global Green New Deal' was introduced in a study commissioned by

UNEP in 2009 in response to the current economic crisis (see Barbier, 2009a, 2009b; UNEP 2009a, 2009b). While its' philosophical roots extend back to the New Deal and the Manhattan projects in the 1930s and 1940s the concept has emerged in a very different socio-economic context (see Yang and Oppenheimer (2007) for a discussion about the historic roots of these concepts). It acknowledges the importance of coordinated and global investments in environmental technologies in order to push the world economy towards a greener, low-carbon future. But it also goes beyond a technology push perspective by emphasizing the importance of a policy mix and wider vision to address the complexity of the climate change problem. Further, it stresses that a long term revival of the world economy requires that the financial stimulus should be targeted to activities which best can reduce carbon dependency and improve the management of ecosystems and freshwater resources, and thereby also contribute to mitigating other global challenges (see Box 1).

Box 1. The three broad objectives of a Global Green New Deal

1. Revive the world economy, create employment opportunities and protect environment
2. Reduce carbon dependency, ecosystem degradation and water scarcity
3. Further the UN Millennium Development Goal of ending extreme poverty by 2025

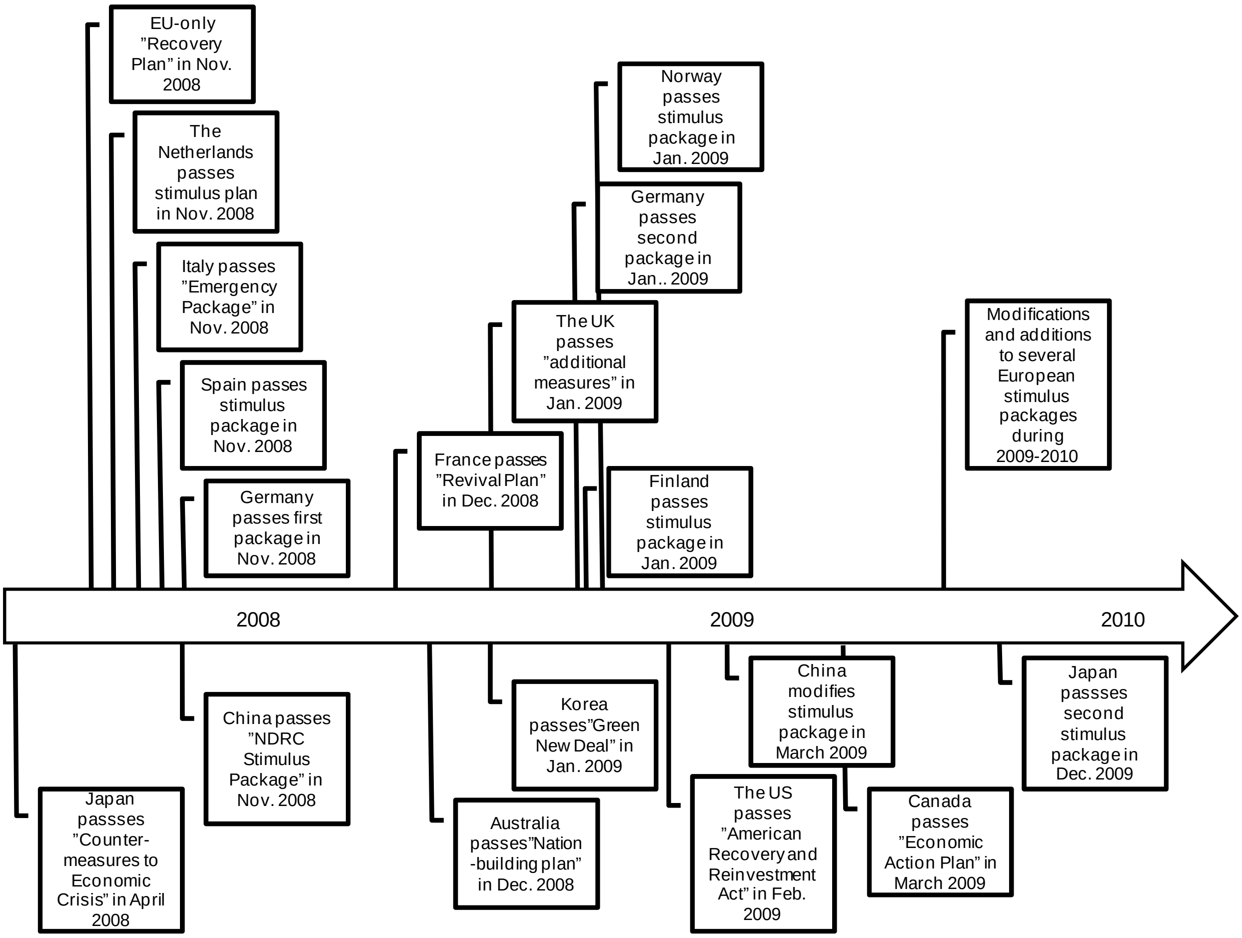
Source: UNEP (2009a)

The 'Global Green New Deal' could best be interpreted as a political manifesto for coordinated global action to address climate change through as part of the economic stimulus. As such it is a powerful and appealing concept. However, if it is to also have an impact policy action at national and international level should follow. Based on the mainly conceptual work by Amidon (1005), Read and Lermit (2005), Sommerville (2006) and Barbier (2009) UNEP in particular, but also the OECD, has elaborated the concept by providing more specific elements and suggestion for appropriate policy mixes for a Global Green New Deal. These include sectorally targeted financial stimulus, domestic policy reforms to ensure that environmental investments can be profitable to domestic economies, and reforms of the international policy architecture to coordinate national initiatives. Further, the situation of developing countries should also be acknowledged.

2.3 Stimulus packages and their green components

Global commitments (e.g. as declared by the G20 countries) to stimulate economies through additional investments in environmental technologies were preceded by national debates and stimulus packages, some of which were passed already during the latter part of 2008 as the magnitude of the financial crisis became evident. In this context the Japanese "Countermeasures to Economic Crisis" plan from April 2008 was amongst the first, followed by the "Recovery Plan" of the European Commission from November 2008 as well as several European national stimulus packages that same month. The EC package stressed the importance of coordinated action also at the level of EU member states. Nonetheless, the European packages contain different policy mixes, some of which are more supply-oriented (e.g. the French and the first German packages) while others are more demand-oriented (e.g. the UK, Spanish, Italian and second German package). Some European countries also complemented their packages with additional measures during 2009 and 2010 (e.g. France, the UK and the second German package). Figure 4 shows the timeline of economic stimulus packages, including only packages which have been judged to contain 'green components'.

Figure 4. Timeline of economic stimulus packages with a green component



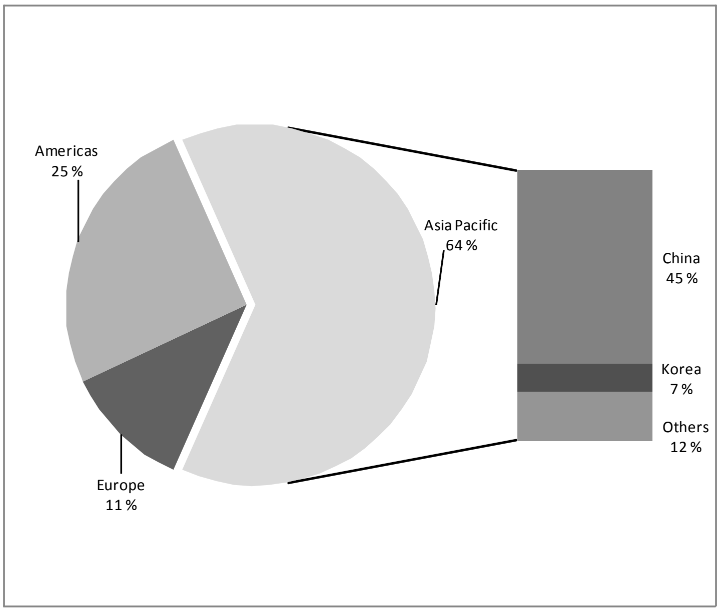
Source: http://www.newenergyfinance.com/

While Japan and European countries individually were first movers with their stimulus packages China and Korea embarked on a similar track soon thereafter. The Korean stimulus package is also noteworthy as it embodies the idea of Global Green New Deal in its title. Furthermore, both the Chinese and Japanese stimulus packages have been extended and modified further towards supporting environmental technologies. In the US the presidential election delayed the launch of the US stimulus package (the "American Recovery and Reinvestment Plan") until February 2009. The Australian "Nation-building Plan" from December 2008 and the Canadian "Economic Action Plan" from March 2009 can also be highlighted. Modifications and additions to many of these stimulus packages have been undertaken during 2009-2010.

According to various estimates the stimulus packages will add another 180-480 billion USD (the figures vary across studies) during the next couple of years to the environmental technology investments reviewed in the section above. However, there is large uncertainty in this figures as the 'greenness' of the stimulus packages are hard to asses and many packages only now are being rolled-out. And a whole different matter is to what extent countries are able to develop complementary policy mixes to facilitate the industrial uptake of these investments and promote eco-innovation which also is transformative enough to really contribute to addressing the climate change challenge. In the following these estimates and assessments of the greenness of the stimulus packages will be reviewed with an eye to framing country examples and developments in Finland to be discussed in the subsequent section of this paper. The primary quantitative estimates include Robins et al. (2009), UNEP and NEF (2009), OECD (2009) of which Robins et al. (2009) is the most prominent and referred to.

Robins et al. (2009) arrive at a grand total estimate of 'green' investments of 478 USD billion, corresponding to 15.5% of all investments of the economic stimulus packages worldwide. This estimate is significantly higher than 180 USD billion suggested by UNEP and NEF (2009), probably because it is more recent and covers a broader set of environmental technologies. The study by Robins et al. (2009) is not constricted to renewable energy technology investments only). It is based on systematic collection and analysis of individual country stimulus packages, as well as subjective judgment of the 'green' components of these monetary investments for an overall view across regions, countries, and environmental technology areas. The study also thereby also covers a broader set of governmental policy schemes, such as tax incentives, compared with the R&D investment report of UNEP and New Energy Finance (2009). It should also be noted the Robins et al. (2009) does not include the most recent additional measures during 2009 and 2010 (additions primarily in France, the UK and the second German package).

Figure 5. Global distribution of 478 USD billion of green components of stimulus packages by regions



Source: Robins et al. (2009)

Figure 5 shows how the green components of the economic stimulus packages are distributed globally by regions. China and the US dominate both in terms of the size of their overall stimulus packages (not shown in the figure however), as well as the share of the green components of these stimulus packages. The case of China is particularly interesting and at least these estimates indicate that China appears to be strongly dedicated to a green growth strategy (see Box 2 for the case of China). Almost 40% of the Chinese stimulus package is allocated to 'green' measures. The apparent greenness of the Chinese stimulus package also explains the proliferation of the whole Asian region in this context, both in terms of the share of the green components as well as by absolute monetary size. Nonetheless, the South Korean "Green New Deal" passed in January 2009 is noticeable not only for its name but also for being nominally the greenest stimulus package in the world (see Box 3 for the case of Korea). European countries appear in Figure 5 with a much smaller share although it should be noted that EU wide green measures are excluded from these data.

Box 2. The Chinese economic stimulus packages and its green components

China has shown an increasing commitment to climate change. In 2007 it published its National Climate Change Programme (CNCCP), followed in October 2008 with a first White Paper in the area. Improving energy efficiency of existing installations remains at the core of these policies, but China is also expanding towards developing renewable energy technologies with a partial focus on new wind installations. In 2008 China doubled its installed wind capacity, making it the second largest market for wind energy technology after the USA, and growth in this sector is set to continue. China's recent pro-environment policy position stems from growing awareness of the vulnerability of its economic growth to climate change and other environmental problems as the country recently has overtaken the US as the world's largest emitter of greenhouse gases. Launched on November 9, 2008, China's stimulus package is the largest one both in terms of its absolute size as well as the size of its nominal green component, totalling to CNY 4 trillion (or 475 EUR billion) to be spend over only two years. The package focuses on boosting investments in railways, roads, public housing and rural infrastructure as well as environmental protection. The schemes of the package are aligned to the long-term development of a low-carbon economy, although there is limited transparency about how these schemes will support a further expansion of renewable energy technologies. Some specific examples, nonetheless, include a cut in the sales tax for cars with smaller engine as well as subsidies to develop alternative-energy cars as Beijing wished to promote the mass production of electric cars for urban areas. Smart grid developments are considered to make it easier to use renewable energy sources, while significant efforts also are made in the area of water and wastewater treatment. In addition, the 2009 state budget added some CNY 420 billion (50 EUR billion) to environmental projects. The Chinese system of five year plans has enabled the rapid implementation of the stimulus package and there are positive signs of both economic recovery and the approval of green projects by public R&D funders although it is too early to assess whether Chinese growth will be greener than before and to what degree the stimulus packages opens up new business opportunities also for foreign companies. The stimulus package has also been criticized for spending too little money on green R&D and innovation. As a consequence of this criticism it was modified in March 2009 with a new allocation of funding, shown in the table below.

Areas for investments	*CNY*	*EUR*
Government-subsidised construction	400 billion	47,5 billion
Construction	370 billion	44 billion
Infrastructure (rail, road etc.)	1,5 trillion	178 billion
Medical care and public health, education and cultural sectors	150 billion	18 billion
Energy conservation, emission reduction and ecological projects	210 billion	25 billion
Independent innovation, structural adjustment and technical innovation	370 billion	44 billion
Post-quake recovery and reconstruction	1 trillion	119 billion

Source: Vinnova (2009), Robins et al. (2009)

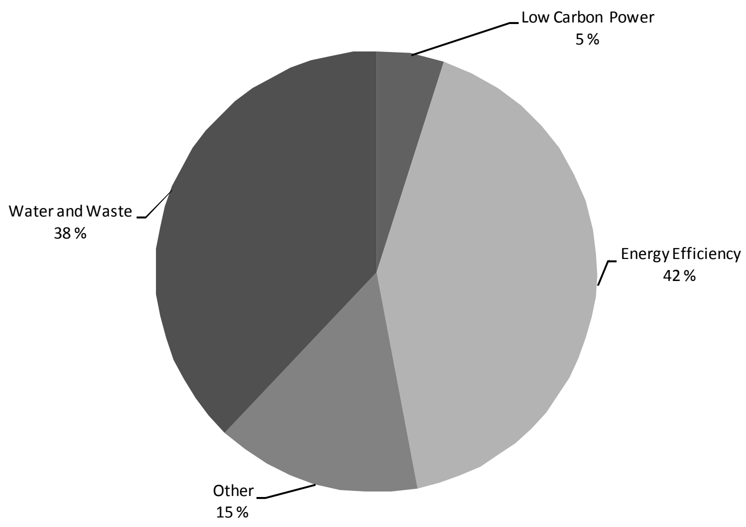
Box 3. The South Korean economic stimulus packages and its green component

Korea suffered significantly from the financial and economic crisis of 2008 with a noticeable decline in its GDP. South Korea is the 10th largest emitter of greenhouse gases although it is still classified as a developing country under the rules of the UN and therefore does not yet have binding emission caps. Despite this Korea has aggressively pursued emission cut targets, and counts as one of the primary example of a country which has endorsed ideas of a Global Green New Deal and Green Growth. This is clearly demonstrated by its "Green New Deal" stimulus packages, launched in January 2009, of which 80% has been estimated to relate to green measures (see Figure 6). The package has nine core projects organized in four main themes:

- Conservation: green cars, clean energy and recycling
- Quality of life: green neighbourhoods and housing
- Environmental protection: revitalizing four major river and securing water resources
- Preparing for the future: IT infrastructure and green transport networks

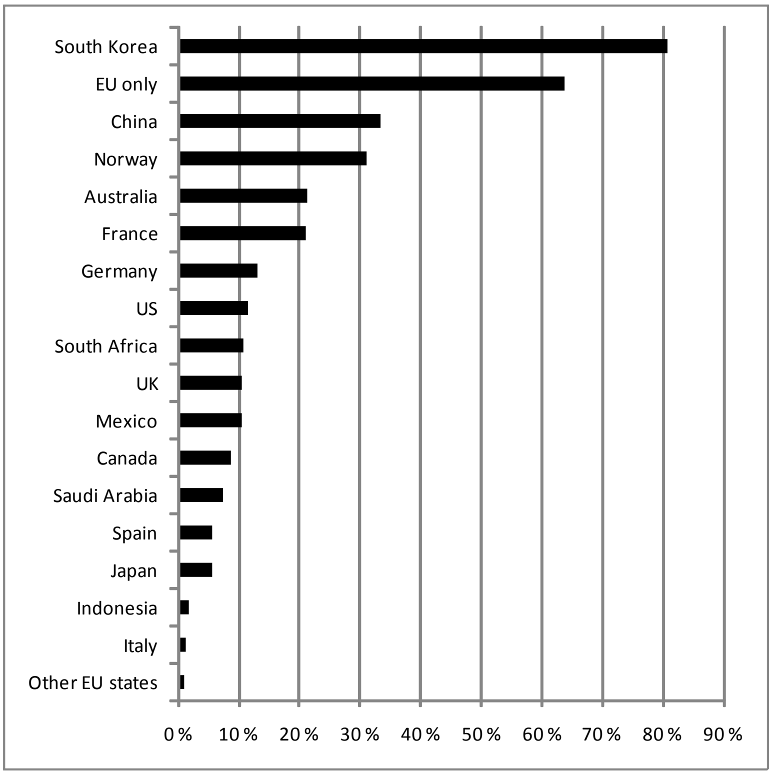
At project level energy efficiency investments account for the main share of all green investments of the Korean stimulus package, followed by water and waste-related investments (se pie chart below in this box). These investments will cover internet infrastructures; building efficient, low-carbon transit systems and establishing a low-carbon work environment. They will also target the development of specific technologies such as high-efficiency solar batteries, LPG hybrid vehicles, highly efficient light emitting diodes (LED) and an advanced electricity metering system as part of smart grids. In the background are also ambitions to create some 530 000 new jobs by 2013.

Breakdown of Korea's Green New Deal by technology area



Source: Robins et al. (2009)

Figure 6. Share of green components of economic stimulus packages



Source: Robins et al. (2009)

Figure 6 shows the intensity of the green investments and other measures in relation to the overall size of the economic stimulus packages of countries. As suggested, South Korea tops the list with an estimated 80% share of green measures out of the economic stimulus package passed in 2009. The figure now also includes EU wide stimulus packages with their green measures in second place followed by China. Beyond this a range of smaller countries also rank high with Norway, Australia and France as noteworthy country examples (see Box 4 for the case of Norway and Box 5 for Australia). The remaining countries have significantly lower intensities of green measures in their stimulus packages with shares around 10% or below. Finland does not appear as an individual country due to the limited green components of the economic stimulus package passed in 2009.

Box 4. The Norwegian economic stimulus packages and its green component

The Norwegian government unveiled its economic stimulus package in January 2009, including 2.2 EUR billion investments by tapping more money than usual from the Government Pension Fund, which contains almost half of the country's vast oil revenues. The main objective of the package is to boost employment in an economy that is also experiencing rising unemployment despite its strong continues overall performance. The package has not been identified as particularly green by Robins et al. (2009) but does include investments into projects to improve energy efficiency in industry and construction, and the environmental friendliness of heating and wind power. In addition, the Norwegian government has been working on a broad set of other issues related to environmental technologies and the transformation of Norwegian industries generally. Some examples are given below:

- An environmental technology focus has become one of the mainstays of policy, as reflected in the tri-party "Soria Moria 2" – agreement.
- The government has cooperated with industry through an Advisory Council on Strategic Environmental Technologies, where the main players in industry and in environmental technology are represented.
- The Government stepped up its grants for environmental issues by announcing a new scheme, totalling to some 18 EUR million in the 2010 budget. The main part of the scheme will be for new generations of biodiesel.
- Research on environmental friendly technology has been stepped up. The Research Council has announced grants for a number of new Centers for Research-based Innovation within environmental technology (the so-called SFI scheme).
- The annual instructions to the public funding actors in research and innovation now underline that environmental technology should be a priority. This includes, but is not limited to, setting priority on wind power and for maritime applications

Source: Internet, personal communications

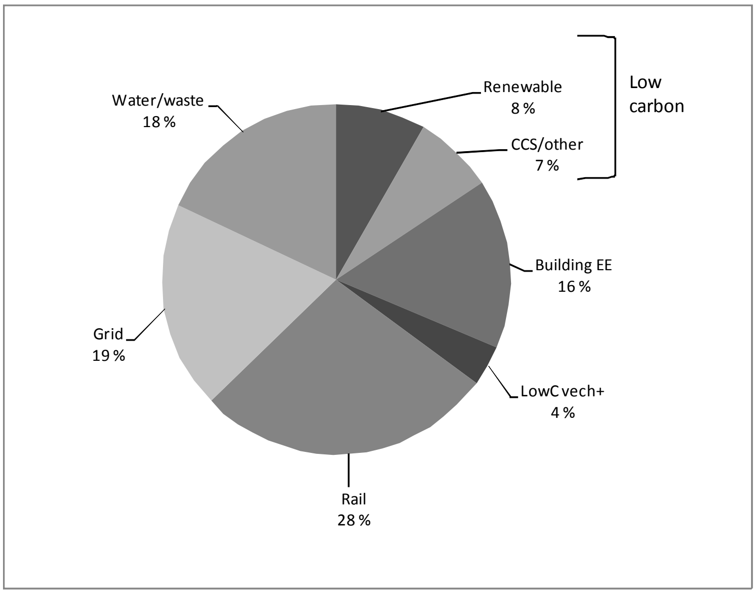
Box 5. The Australian economic stimulus packages and its green component

In February 2009 the Australian government unveiled its 22 EUR billion Nation Building and Jobs Plan (passed through parliament in December 2008). The stimulus package intended to distribute a majority of these investments to schools, roads, hospitals and energy efficiency especially in construction (about 9% of the package). In May of that same year the government turned its budget 2009-201 into a second stimulus package, investing some 16 EUR billion into green energy technologies. This includes a flagship solar technology program over the next six years to drive 1 GW of additional solar generation, the establishment of a new body named the Renewable Australia to promote new and existing renewable technologies, as well as the promotion of new carbon capture technologies likewise through a new flagship program to develop industrial scale demonstration projects over the next nine years. However, energy efficiency is also targeted further through a National Energy Efficiency Initiative for an energy network demonstration project to integrate a 'smart grid' with 'smart meters'.

Source: Robins et al. (2009)

The large share of the US and Asia of green components of stimulus packages is at odds with the dominance of Europe in renewable energy technology investments (see section 2.1). The overall impression is thus that massive governmental economic stimulus packages in the US and Asia partly will compensate for a relatively poorer investment track record of these countries in renewable energy technologies in the past. For most other countries the share of measures to promote renewable energy play a relatively smaller role, the average share devoted to this field being only 8% (see Figure 7)(see Appendix 1 for the complete figures). Instead altogether 66% of the green components of all economic stimulus packages are targeting energy efficiency, including such traditional areas as construction, low-carbon vehicles, rail- and grid-infrastructures (e.g. electricity smart grids). Water-related technologies come next followed by other low-carbon technologies and renewable energy technologies. Many of these more traditional areas can also draw on new/emerging technologies such as nanotechnology, ICT and biotechnology.

Figure 7. Distribution of green components of economic stimulus packages by technology area



The study by Robins et al. (2009) is based on quantitative assessments of the greenness and composition of the economic stimulus packages. Others, such as Höhne et al. (2009a,b) and Bowen et al. (2009)(which only focuses on the UK), have provided qualitative assessments through case studies and scoreboards. The first assessment by Höhne et al. (2009a), surveyed around 100 green stimulus measures globally by different effectiveness factors which also included consideration about the effectiveness of various standard policy instruments; emission reduction potential; marginal abatement costs, positive lock-in effects; removal of barriers to implementation; the degree to which dependency on fossil fuels is reduced and potential negatively compensating effects, such as other measures in the stimulus packages that lead to an increase in energy demand which therefore partially reduces the calculated emissions reduction.[2] The second assessment, Höhne et al. (2009b), elaborated on the broader survey by digging deeper into a smaller number of the policy schemes to provide a scorecard on best and worst policies for a Global Green New Deal and Green Growth.

Although any assessment of the these green stimulus measures are subjective, and based on limited information of intended (rather than realized) policy objectives, they can provide at least some indication of whether a Green New Deal is emerging and Green Growth strategies really are taking off. With these caveats in mind Höhne et al. (2009a) arrive at rather discouraging assessments. For quite a few countries covered the positive climate friendly stimulus in areas like energy efficiency in construction and transport is likely to be outweighed by other spending in construction of e.g. new roads and other 'shovel-ready'- projects which may bring short-term employment benefits but at the cost of longer-term climate change reduction. Further, most countries focus their green measures on only a few environmental technologies – such as energy efficiency in construction and cars – while ignoring more forward looking and transformative technologies. Höhne et al. (2009a) also note that the effectiveness of the schemes will depend on how they are implemented, and in particular which environmental criteria are included in specific project funding selections.

[2] For example, nuclear energy could have a positive effect on emissions although with an associated security risk as e.g. the question of toxic waste disposal remains unresolved. For that reason nuclear energy was not included as a climate friendly area. See Appendix 2 for the composition of the effectiveness factors by environmental technology and policy instrument category.

In summary, this section gives the following insights:

- Global investments in renewable energy have grown rapidly since 2002, despite a decline in the growth rate during 2008 due to the economic crisis
- Renewable energy currently accounts for a majority of all actual power generation additions, implying that renewable energy technologies are becoming part of the mainstream energy sector
- Wind power has attracted the largest share of renewable energy investments followed by solar power and biofuels, while solar power is the fastest growing field
- Europe has accounted for the largest share of renewable energy investments followed by North America and Asia & Oceania, while investments in Asia and emerging economies have increased rapidly in recent years
- Economic stimulus packages to tackle the current economic crisis are adding an estimated 478 USD billion environmental technology investments, or some 15% of their total stimulus spending
- Despite large additional environmental technology investments the 'greenness' of these investments and measures have been questioned in recent assessments

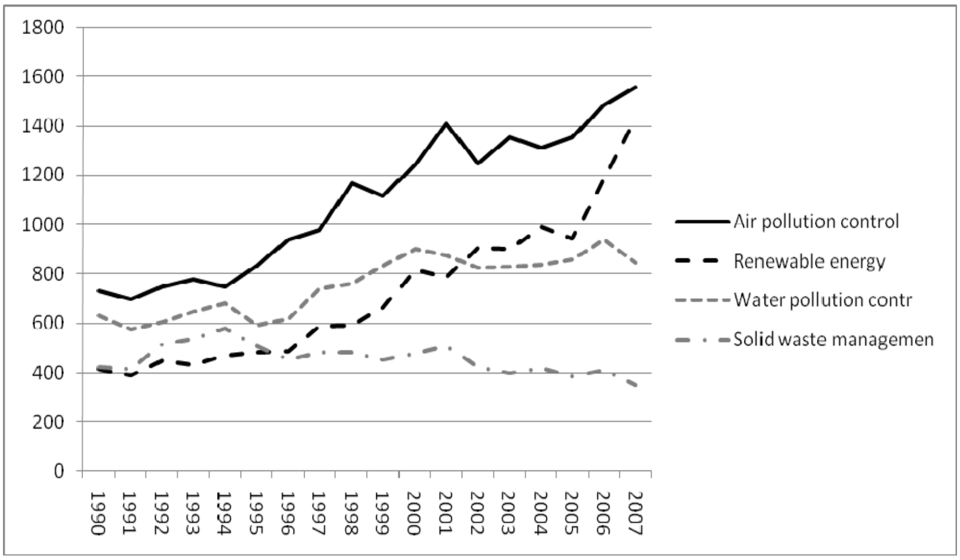
3. Environmental technology patenting globally

3.1 Trends by technology areas

The discussion above highlighted environment technology investment trends and the potential role of the green components of stimulus packages in increasing these investments. It highlighted the rapid increase in renewable energy technologies in particular and suggested that investors are seeing the largest opportunities in wind and solar technologies. While this paper does not assume a linear causality from R&D inputs to innovation outputs it refers to patent data for a rough indication of areas where technological and competence developments are particularly rapid against the backdrop of environmental technology investments. Towards this end the environmental technology area is defined to include the following fields: air pollution control and abatement, water pollution control (including water and wastewater management), solid waste management, and renewable energy (compare with earlier work by OECD (2009) and Johnstone et al. (2010)). The latter is further divided into six sub-areas: wind, solar, geothermal, ocean, hydro power, and biomass (for more on the methodology see Appendix 2).

The increasing public and private investments in environmental technologies have, as discussed above, focused on specific areas where the goal is either to promote the diffusion of existing technologies, in areas such as grids (e.g. electricity smart grids) and building efficiency, or to provide incentives for both public and private actors to engage in innovative activities in more novel areas, particularly in renewable energy sources. These investments are reflected in the patenting activity, particularly in certain areas on environmental technologies.

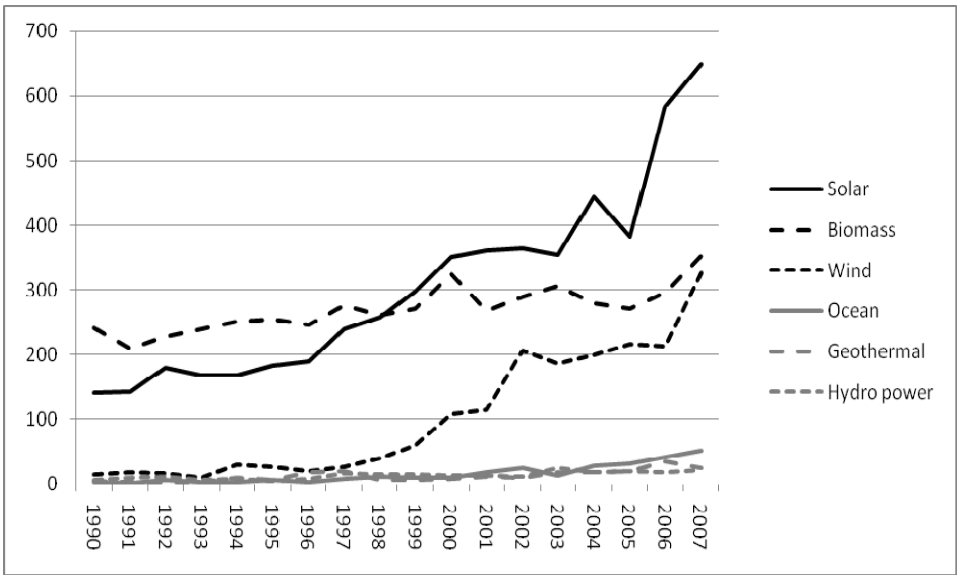
Figure 8. Patenting activity in environmental technologies (EPO applications 1990-2007)



Source: OECD PATSTAT
Note: Based on application year

Figure 8 indicates that the environmental technology areas where most of the development has occurred relate to air pollution control and renewable energy. Also, water pollution control has seen a steady increase in patenting activity. Patenting activity related to solid waste management has been fairly stable and slightly decreasing during the last years over the years. Looking at the last years of the data, it is evident that the most significant growth area is renewable energy, suggesting that the most active technology area in the future relates to identifying alternative sources for energy to fossil-fuel based ones (for similar findings see Aghion et al. 2009). For this reason it is worthwhile to look at the more detailed development of this technology area in Figure 9 below.

Figure 9. Patenting activity in renewable energy (all EPO applications 1990-2007)



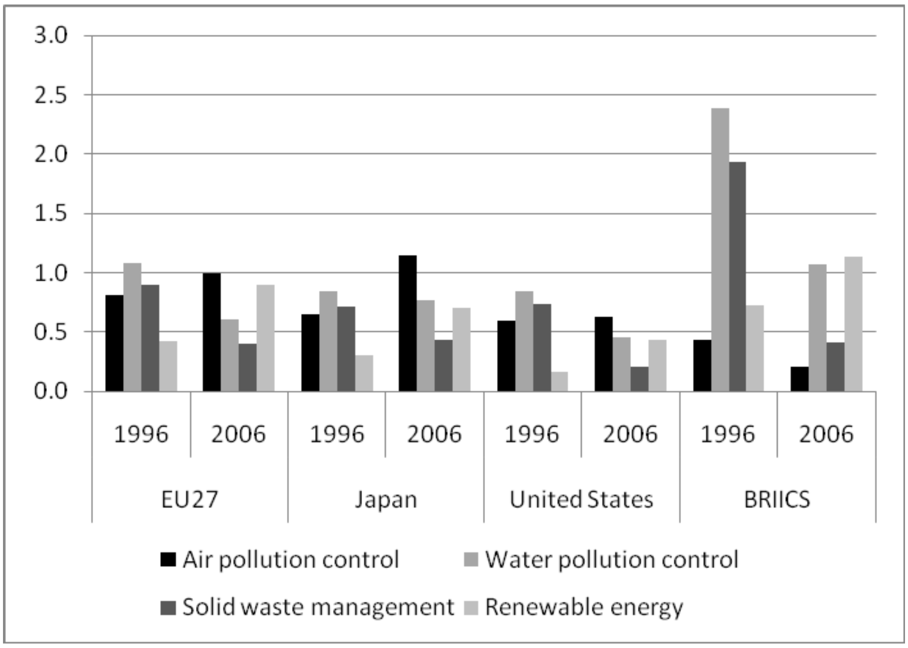
Source: OECD PATSTAT
Note: Based on application year

Looking more closely at the developments in renewable energy in Figure 9, it is evident that the increasing role of this technology area relates to only a few of the technologies. The growth of patenting in renewable energy relates to technologies in the areas of biomass, wind and solar. The growth of patenting activity in biomass technologies has been relatively steady throughout the observation period, whereas activity in wind and solar technologies has increased significantly during the last years of the data. The most significant increase in patenting is in solar technologies. Going back to the discussion of the global investments, this corresponds well also with accelerated investments into this field of environmental technology. The remaining technology areas in renewable energy have seen limited or even marginal growth in patenting. In geothermal, ocean and hydro power related technologies less than hundred patents have been applied annually during the last years of data coverage.

3.2 The position of regions and countries

The aggregate data discussed above provides insights into overall environmental technology trends whereas the activity levels in different geographical regions differ greatly, as shown in Figure 10.

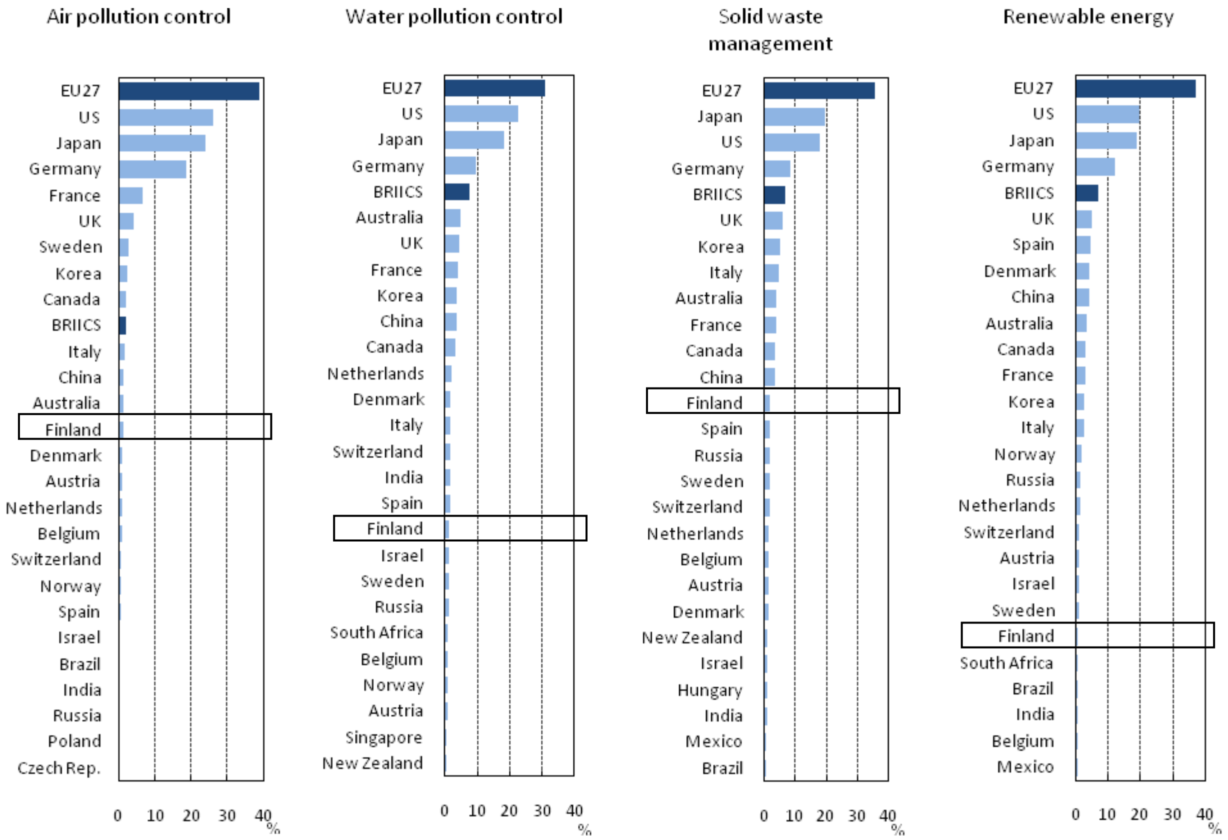
Figure 10. Patents in environmental technologies as a percentage of total PCT patent applications



Source: OECD – Science and Technology Indicators (2009)

Looking first at the development in EU (EU 27), it is clear that there has been a shift from water pollution control and solid waste management to air pollution control and renewable energy. A similar trend emerges in Japan and US. Overall the share of environmental technology patents is fairly similar in these regions. Interesting exception are the BRIICS countries (Brazil, Russia, India, Indonesia, China and South Africa). In these countries the share of activity in water pollution control and solid waste management was significant in 1996, but the emphasis has shifted to renewable energy since then up until 2006. This suggests that new actors, in addition to the established ones, are emerging in the field of environmental technologies and renewable energy in particular. Figure 11 provides more insights into patenting of individual countries.

Figure 11. Share of countries in environmental technology patents filed under PCT (Top 25 countries, 2004-06)



Source: OECD – Science and Technology Indicators (2009)

From Figure 11 it is evident that EU accounts for a large share of innovative activity in all four environmental technology fields. The other two dominant players are the US and Japan, followed closely by Germany. Interestingly, the BRIICS countries emerge as important players in three of the technology areas: water pollution control, solid waste management and renewable energy. The position of Finland is fairly strong as it belongs to the top 25 countries in all fields even in absolute terms. If the shares of Finland would be presented in relative terms, for example per capita, the performance of Finland would be even higher in the rankings.

3.3 The specialization of countries

Whereas the discussion above provided insights into the general development of environmental technologies and positioned countries based on their activity levels, to identify national strengths in innovative activity, more detailed analysis is needed. For this reason Table 1 identifies the relative technological advantage (RTA) of selected countries and compares the position of Finland to them (the results are presented in greater detail in Appendix 3). An RTA index value higher than one indicates that a country has relatively more patent applications in a technology area and is thus is comparatively more specialized in that area. To make Table 12 more readable, we have resorted to a simplified coding, where X equals an RTA vale higher than 1, XX equals an RTA value higher than 2, and XXX equals an RTA value higher than 4.

Table 1. Summarized RTAs in environmental technologies for selected countries (1990-2007)

Technology	Finland - 90s	Finland - 00s	Finland	Austria	Australia	Germany	Denmark	UK	Netehrlands	Sweden	US	South-Korea
Air pollution control						X				X	X	
Solid waste management	X	X	X	X	X							
Water pollution control		X	X	X	X	X	X	X	X	X		X
Total - Renewable energy	X				X		X	X	X		X	X
Biomass	*X*	*X*	*X*					*X*	*X*		*X*	X
Geothermal		*X*		*XX*		*X*			*X*	*X*		
Hydro power		*X*		*XXX*	*XXX*					*X*		
Ocean		*X*	*X*	*XX*	*XX*		*XX*	*XXX*		*XX*		
Solar					*X*				*X*			X
Wind	*XX*		*X*			*X*	*XXX*			*X*		

Source: OECD PATSTAT

Note I: X – RTA higher than 1; XX – RTA higher than 2; XXX – RTA higher than 4.

Note II: An RTA index value higher than one indicates that a country has relatively more patent applications in a technology area and is thus viewed to be more specialized in that area.

Looking first at the technological specialization of Finland over time, it is interesting to observe clear differences between the 1990s and 2000s. In the 1990s Finland was relatively more specialized in solid waste management, biomass and wind technologies. In the 2000s water pollution control (including water and wastewater management) emerged as a specialization field. Interestingly in renewable energy technologies geothermal, hydro power and ocean technologies emerged as specialization fields during the same period. As these technologies are fairly niche areas (see Figure 9), where patenting activity is only very marginal, the specialisation in these technologies cannot be considered very significant. Maybe the most interesting change relates to wind technologies. In 1990s Finland seems to have been very specialized in wind motors, but in 2000s this advantage has been lost. This development may relate to the increasing patenting activity in other countries but also to diminishing activity in Finland in the 2000s.

Looking at Finland's technological specialization for the whole observation period (1990-2007) it seems that technological specialization prevailed in solid waste management, water pollution control, biomass, ocean and wind. In comparison to other countries interesting differences emerge. While similar profiles to Finland exist, many of the countries seem to be very specialized (RTA higher than two) in specific environmental technologies.

Austria, for example, is specialized in somewhat marginal renewable energy technologies: geothermal, hydro power, and ocean. Australia is very specialized in hydro power and ocean technologies. Denmark has a long history in wind technologies, which is evident from its RTA specialisation profile. In addition, Denmark is highly specialized in ocean technologies. United Kingdom is very focused on ocean technologies. Interestingly, Sweden is also highly specialized in ocean technologies. These findings invite further exploration into the national activities in the highly specialized technology areas.

To address the national specialisation in greater detail, in the following company concentrations in patenting is addressed to assess whether a high focus in specific environmental technology areas is based on the activities of a single company or a broader set of companies potentially forming possibly forming a technologically-oriented cluster. Table 2 sheds light on this aspect in the context of the countries with a particularly high specialization in a specific technology area.

Table 2. Industry concentration in highly specialized technologies in selected countries

Country	Technology	RTA index	Companies
Austria	Geothermal	2.73	5
Austria	Hydro power	7.71	3
Austria	Ocean	2.68	4
Australia	Hydro power	4.40	4
Australia	Ocean	3.11	5
Denmark	Ocean	2.40	2
Denmark	Wind	8.12	19
UK	Ocean	4.06	29
Sweden	Ocean	2.40	4

Source: OECD PATSTAT

The results provide more detailed insights into the general results based on the RTA indexes. It seems that very high specialisation in many countries relates to the activities of a small group of companies. Only in two cases can a larger cluster of companies be identified: a wind technology cluster in Denmark with 19 individual companies and an ocean technology cluster in UK with 29 individual companies. In both of these countries there is a strong industrial tradition within in the respective technology areas, which has been coupled with activity policy efforts.

In summary, this section gives the following insights:

- Investment trends are also reflected in patenting although no linear causality between the two should be assumed; within environmental technologies renewable energy has experience the most rapid patenting growth over time
- The rapid growth in renewable energy patenting can mainly be traced to wind and solar power, the latter field of which also has been subject to rapid growth in investments
- The share of environmental technology patenting of total patenting is fairly similar across regions of the world even though BRIICS countries are emerging as comparatively relatively more active in this area
- Finland is comparatively well positioned in environmental technology by overall levels of patenting activity, but does not emerge as a country with a specific specialization profile in the area generally speaking nor in the rapidly expanding field of renewable energy

4. The case of Finland

4.1 Recent policy developments related to environmental technologies

In Finland, as in many other countries, issues related to climate change have been closely intertwined with those of energy. The promotion of Finnish environmental technologies has thus taken place within the broader context of the so-called National Climate and Energy Strategy. This strategy is largely formulated in line with guidelines laid down by the UN Framework Convention on Climate Change as well as the European Union, including specific initiatives undertaken by the EC (such as the Environmental Technologies Action Plan (ETAP)). The key objectives of the strategy have, already for many years, been to increase energy efficiency throughout the economy as well as to increase the development and use of renewable energy. The most recent national strategy, from 2008, sets a 38% target for the share of renewables of total Finnish final energy consumption by 2020 as one important goal towards complying with the UN Kyoto protocol (Valtioneuvosto, 2008).

The main ministerial policy actors related to environmental technologies are the Ministry of the Environment and the Ministry of Employment and the Economy (MEE). These ministries collaborate in overlapping areas through various committees, panels and other types of forum (see e.g. Lemola et al. 2010). However, the Ministry of Environment is mainly involved in regulatory matters and in developing broader guidelines e.g. for energy efficiency in alignment with international climate change treaties and policies (such as the Kyoto protocol). The MEE has a more significant role in promoting environmental technologies, including renewable energy. This role is also a consequence of MEE having a key role in the formulation of innovation policy, which has recognized environmental technologies as key drivers also for innovation. However, according to Kivimaa and Mickwitz (2006) further integration of environmental and innovation policies in Finland would be desirable in order both to streamline policies and to better realize emerging opportunities related to environmental technologies.

Subordinated the MEE, the main organizations and institutions involved in environmental technology promotion and research include the Finnish Funding Agency for Technology and Innovation (Tekes) respectively the Technical Research Centre of Finland (VTT). Tekes is the main R&D funder in Finland and has also played a key role in funding environmental technology programs and projects (see Table 3 for a list of recent Tekes programmes). VTT is the main public R&D performing organizations and important partner in environmental technology programs and projects. Tekes focuses on applied research while the Academy of Finland also has funded several research projects in this area. The Ministry of the Environment also commissions research of relevance to environmental technologies, the most recent example being the Environmental Cluster Programme which has been running since 1997. This programme has been co-funded by the ministries of Environment, Employment and the Economy, Tekes and the Academy of Finland.

Table 3. Recent Tekes programs related to environmental technologies

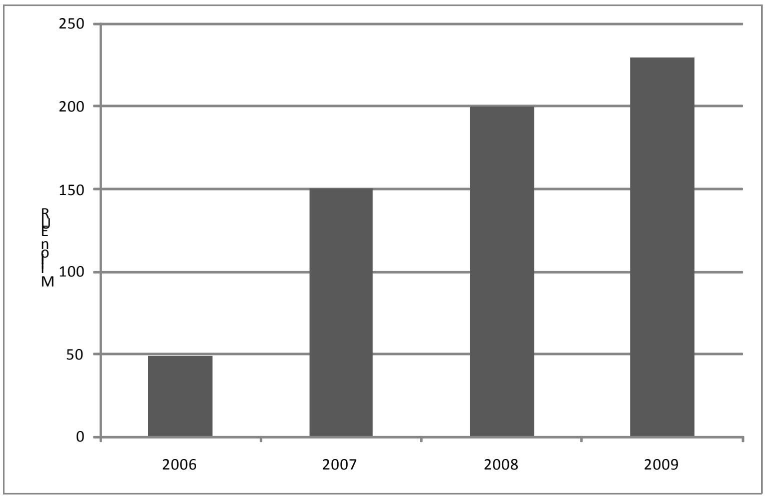
Program name	*Years*	*Volume (EUR million)*	*Focus technology areas*
Ilmastotalous	in preparation	in preparation	Climate change and market change
BioRefine	2007-2012	200	New, biomass-based products
Fuel Cell	2007-2013	144	Products and services based on fuel cell technology
Sustainable Society	2007-2012	100	Sustainable development in real estate and construction clusters
Renewable Energy - Groove	2010-2014	95	Renewable energy
Climbus	2004-2008	70	Cost-effective, climate friendly technologies
Densy	2003-2007	56,7	Distributed energy systems technology
Promotor	1999-2003	51	Technology of internal combustion engines
Water Programme	2008-2012	42	Technology transfer, new applications, business competence and competitiveness of water sector
Wood Energy	1999-2003	42	Wood energy
Cube	2002-2006	40	Building services technology
Streams	2001-2004	27,3	Recycling technologies and waste management
Fine	2002-2005	26	Particles technology, environment and health
Process integration	2000-2004	23	Planning, management and use of industrial processes
Fusion	1999-2002,2003-2006	18	Applications and technology of fusion power
Waste to energy	1998-2001	17	Solutions for integrated energy (material recovery, municipal/industrial waste)
Code	1999-2002	14	Modelling of Combustion Processes
Small-scale production and use of wood fuels	2002-2006	13,6	Production and use of wood-based fuel
Climtech	1999-2002	5	Technology and climate change
Wood firing technology	1997-1999	1,4	Wood firing technology (higher efficiency, lower emission)

In addition, some public funding for environmental technologies is also channeled through the so-called SHOK and Strategic Centre of Centre of Excellence Program (OSKE) programs. The SHOK programs is based on close cooperation between industry, universities and research organizations as well as public R&D funders (Tekes plays an important role also in these programs) with the aim to allocate R&D resources in close alignment with needs especially from the viewpoint of significant companies and industrial areas of strength (Nikulainen and Tahvanainen, 2009). The SHOK programs were launched in 2007-2009 and consist of altogether six sectoral programs of which several are relevant from the viewpoint of the application and commercialization of environmental technologies (e.g. FIMECC related to machinery and equipment, Metsäklusteri related to forestry-based industries, RYM related to the built environment, SalWe related to health and well being and TIVIT related to electric engineering). However, the CLEEN SHOK program is the one of primary relevance to the environmental technology field. CLEEN comprises of a cluster of 40 major Finnish companies in the area of energy- and environmental technologies (Halme, 2010).

The OSKE programs represent a new policy initiative to increase regional specialization and to strengthen cooperation and coordination between regions. It involves 13 so-called Competence Clusters and 21 regionally associated Centres of Expertise with the idea that these clusters and centres can increase critical mass for innovation in various technology areas and application fields as a basis also for international competitiveness. Again environmental technologies can find application in many of these clusters and centres. Nonetheless, two of these Competence Clusters focus on environmental technologies per se, namely the Energy Technology Cluster and the Cleantech Cluster. The Energy Technology Cluster consists of Centres of Expertise in Western Finland, Jyväskylä region, North Karelia, Satakunta, and Tampere with a focus on bioenergy, decentralised energy production, energy solutions for industries, and electrical engineering. The Cleantech Cluster covers around 60% of the Finnish cleantech business and some 260 companies (many of which are SMEs). It consists of Centres of Expertise in the Kuopio, Lahti, Oulu and Helsinki regions with a focus on ICT-related environmental technologies; environmental monitoring; climate, air quality and health and environmental informatics. Activities in the Lahti Centre of Expertise also focus on capital venturing and the promotion of environmental technology-based entrepreneurship. The Environment Programme 2004-2007 and ongoing Energy Programme by Sitra, The Finnish Innovation Fund, has also played an instrumental role in promoting environmental technologies and related Cleantech initiatives in Finland.

The public sector channeled some 230 EUR million in 2009 to environmental technologies through the various above mention organisations, programs and initiatives and these investments have experienced growth also in Finland (Figure 12). This sectoral breakdown suggests that Finnish policies support environmental technologies on a broad front. However, and in contrast with international trends in environmental technology investments, renewable energy does not appear to be a particularly prioritized area to date. Indeed, Finnish R&D priorities also in recent technology programs have been in the areas of energy efficiency rather than more transformative technologies related to renewable energy (see e.g. Vanhanen et al. 2009). Energy efficiency priorities also respond to the need for cost-efficient energy within process-intensive industries which are in abundance in Finland, and many energy efficient technologies are incremental in nature as they mainly focus on process improvements. According to the OECD Environmental Performance Review (OECD, 2009) Finland could do more to promote eco-innovation through e.g. green procurement, environmental labeling and the active involvement of business and other stakeholders, and consider how environmental policy instruments could be better aligned with innovation policy (and vice versa) to promote innovation.

Figure 12. Public energy- and environmental technology investments in Finland 2006-2009



Source: Tekes (2010)

Finnish environmental and innovation policies have also been criticized for paying too little attention to recent calls for a Global Green New Deal and Green Growth in the context of the stimulus packages (OECD, 2009; various press articles). Finland passed its stimulus package in January 2009, including some 2 EUR billion investments with the main aim of reducing cyclical unemployment whereby a majority of these funds were directed to infrastructural projects (transport, broadband) and construction, as well as education. A marginal share of this total was dedicated to innovation policy targets and the potential green component of this stimulus packages is evidently very small or non-existent (see Box 6 for the Finnish stimulus package). In April 2010 the inter-ministerial climate and energy policy working group presented a new package on increasing the share of renewable energy usage, enhancing energy conservation and energy efficiency. This package adds some 340 EUR million of public funding until 2020 with the objective of promoting the use of forest chips and other wood-based energy in particular, alongside wind power, biofuels and heat pumps to contribute to the 38% target in renewable use. Alongside this package, two new licenses for the construction of nuclear power plants were granted (see www.tem.fi).

Box 6. The Finnish stimulus package

In its supplementary bill to the 2009 budget bill, the Finnish government proposes large investments to ease the impacts of international recession. The total effect of the stimulus package amounts to around EUR 2 billion. According to the Finnish government, the stimulus package will directly generate at least 18,000 man-years of employment. If the indirect effects are included, the stimulus package will generate 7,000 additional jobs. It has also been estimated that the stimulus package will increase GDP by 1%. A main goal of the stimulus package is to reduce the cyclical unemployment due to the international recession. A lot of resources have therefore been devoted to measures that directly stimulate job creation. This includes investment in transport infrastructure, broadband infrastructure and construction. A 0.8 percentage point reduction in social insurance contributions will reduce the total labour costs, making it cheaper to employ. As an investment incentive, the right to depreciate investments will be doubled for 2009 and 2010. In addition, resources are being targeted at education by such means as increasing the number of places on vocational courses. The total investment in the innovation policy stimulus package is estimated to around EUR 25 million, of which EUR 6 million will affect the 2009 budget. This includes increased R&D subsidies and loans to companies through Tekes and increased support for public R&D undertaken by bodies such as the VTT Technical Research Centre of Finland. An additional EUR 6 million will be used to digitalise and catalogue databases to promote science. The share of environmental technology investments in the Finnish stimulus package appears to be fairly low even though some other measures, such as infrastructure projects, involve elements of research, development and innovation in related area.

Source: Internet, Vinnova (2009)

4.2 Environmental technology patenting and companies

As discussed above, in Finland the recent policy efforts in environmental technologies are not related to the stimulus packages in the context of the economic crisis. In fact, many of them are responses to the long-term developments related to climate change, the demands and business opportunities arising from it. In the following the focus is on the innovation landscape of environmental technologies in Finland with emphasis on company level activities in the area. Earlier in the paper we positioned Finland in various technology areas with respect to other countries and identified that Finland is not very specialized in any of the technology fields, although the level of innovative activity can be considered to be quite high. This is also evident in Table 4 indicating that the activities in environmental technologies are fairly evenly distributed across the four main environmental technology patent classes.

Table 4. Environmental technologies patents and the share of Finland (EPO applications 1990-2007)

	All	**Finland**	**%**
Air pollution control	20416	176	0.9
Solid waste management	8397	97	1.2
Water pollution control	13974	176	1.3
Renewable energy	13726	124	0.9
Biomass	*5047*	*67*	*1.3*
Geothermal	*264*	*2*	*0.8*
Hydro power	*250*	*2*	*0.9*
Ocean	*303*	*5*	*1.7*
Solar	*5843*	*26*	*0.4*
Wind	*2018*	*21*	*1.0*
TOTAL	**56513**	**573**	**1.0**

Source: OECD PATSTAT

The volume and overall share of Finnish patenting in environmental technologies show that the activity in Finland has concentrated on certain technology areas. For example, water pollution control and solid waste management technologies seem to have slightly larger shares than the other technologies. In renewable energy, biomass and ocean technologies stand out with somewhat higher shares as is also indicated in the earlier discussion on the technological specialization of countries. As the international trends and country comparisons were presented earlier in this paper, in the following the focus is on the innovation environment of environmental technologies in Finnish firms.

There are in total 125 companies behind these environmental patents in Finland. Since not all of these companies are highly committed to environmental technologies, and since environmental technology patents only account for a small share of the overall patent portfolio of these companies, a threshold of the intensity of environmental technology patenting is applied for further analysis. The threshold is set to 20%, meaning that at least 20% of a company's patents have to be classified as environmental technology patents to be included in the further analysis (the full list of companies without the threshold can be found in Appendix 4). A further advantage of using the threshold is that it excludes many of the largest companies in Finland which occasionally have patented in the field but cannot be classified as environmental technology companies proper whereby their inclusion would significantly distort the results. This 20% threshold is used as a basis for the ensuing analysis unless otherwise stated.

Table 5. Environmental technology patent applications of Finnish companies
(1990-2007, companies with more than 2 environmental technology patents, with 20% threshold)

Firm	Environmental technology patents	Share of all patents	Industry	Firm size
Evac International	32	94%	Machine and process design	SME
Foster Wheeler	30	36%	Machinery	Large
Kemira	29	28%	Chemicals	Large
STX Finland	15	22%	Machinery	Large
Ecocat International	15	94%	Machinery	Large
Andritz	12	24%	Machinery	Large
Oras	10	53%	Metals	Large
Wiser	7	78%	Research and development	SME
Winwind	6	100%	Machinery	Large
Vapo	5	56%	Energy	Large
Steris Europe	5	56%	Machinery	SME
KWH Pipe	4	22%	Plastics	Large
BCDE Group Waste Management	4	80%	Electronics	SME
Larox	4	100%	Machinery	Large
Suomen Rehu	3	23%	Agriculture	Large
Maricap	3	60%	Machinery	SME
Etor	3	100%	Construction	SME
Finn Escone	3	100%	Machine and process design	SME
Proventia Emission Control	3	100%	Machinery	SME

Source: OECD PATSTAT and Statistics Finland (authors' calculations)

Note: See Appendix 4 for a complete list

The distribution of patents is skewed with only a few companies having many patent applications in environmental technologies (Table 5). Interestingly, the list of companies is dominated by large firms representing the machinery industry. The second group consists of smaller companies in machine and process design and research and development industries. These findings are in line with earlier studies identifying machinery as a key industry in areas such as pollution abatement (Rodrik 1996; Lanjouw and Mody, 1996; Hanemann 2010). In fact, much of the existing theoretical literature on R&D and pollution abatement assumes that the innovating company is the same as the company which causes pollution and invests in abatement.

Quite often this assumption is false. The vast majority of the innovators are not the polluters but rather machinery suppliers and other outside sources, as suggested by our findings.

The intensity by which the companies are involved in environmental technologies also varies greatly. Larger companies are typically more diverisified in their technological activities whereas smaller companies are more focused on narrower range or areas. To shed more light on company activities in environmental technologies in Finland, in the following we provide more information on some of the companies that have a high number of environmental technology patents alongside a high share of patenting in environmental technologies (Boxes 6-9).

Box 7. Evac International

Evac designs, manufactures and markets environmentally friendly waste and wastewater collection and treatment systems particularly for the shipbuilding industry. Evac is the most experienced supplier of vacuum toilets and wastewater management solutions for the ship building industry. They have recently entered the area of dry waste handling specializing in waste treatment systems preserving sea, land and air.

Evac has its origins in a joint venture Wärtsilä and Euroc AB (Sweden) in 1975 and was established as an independent company in 1979. By 1982 it had activity in Denmark, Sweden and Finland. In 2004 Zodiac Inc. acquired Evac and in 2007 Evac became a part of Zodiac Marine & Pool, which is owned by the Zodiac Group and the Carlyle Group. Evac has premises in Finland, USA, France, China and Norway.

Box 8. Ecocat International

Ecocat provides air purity solutions. Ecocat is a manufacturer of substrates and catalytic converters for motor vehicles, small engines, aftermarket, and industrial applications. Ecocat manages the whole process from designing and manufacturing the substrate to active coatings and the assembly of the catalyst or the filters. The operation of the system is build together with engine and appliance manufactories.

The origins of Ecocat are at Kemira, which in 1986 built a pilot factory in Oulu started serial manufacturing catalytic converters and testing the production technology. In 1987, Kemira decided to build a full-scale catalytic converter factory and investing extensively in R&D. Test production in the new factory started in 1988 and the catalyst unit was strengthened by company purchases and the establishment of a sales company in Germany. Besides car industry customer applications, product development was focused on catalytic converters for small engines and industry. In the following years R&D was emphasised in business activities and co-operation with the car industry tightened. At the same time concern about the greenhouse effect influenced emission standards both in industrialised and developing countries, and thus Ecocat developed a catalytic converter system to meet the exceptionally tight emission standards. Ecocat is owned by Eqvitec Partners Oy.

Box 9. Winwind

Winwind supplies one and three megawatt wind turbines based on the low speed technology. They provide advanced planetary gear solutions and low speed synchronous generators. The product concepts have been created by combining German innovation and expertise with Finnish know-how in energy production. Their key component suppliers are key partners in operations as well as in research and development.

WinWinD head office is located inFinland with assembly plants in Finland and India. The main owners of Winwind are Siva Group (India), Masdar (Abu Dhabi) and Finnish Industry Investment (Finland).

Box 10. Wiser

Wiser provides water treatment solutions for water and gas purification and aeration. Wiser provides dissolved air flotation (DAF) technology to enable the purification of water and an aerator for oxidization of water. Flotation is particularly efficient in the separation of grease and oil, decolouring and separation of humus, chemical treatment of water as well as recovery of raw materials. Aeration is sometimes required prior to chemical treatment or for activating biological processes and is suitable for application at water and wastewater treatment plants, industrial plants, landfills, surface water and fish farms. For the purification of flue gases, Wiser has developed a scrubbing process which consumes less energy when compared to dry filtering. Furthermore, the process results in high reduction rate of hazardous gaseous substances and therefore enable the use of impure fuels. Other application areas of the scrubbing equipment include drop separation, odour elimination and air-conditioning.

Wiser was established in 1986 by a Finnish metallurgical engineer who specialised in chemistry as well as in mechanical engineering and is characterized as a passionate researcher and inventor, who holds 100 patents. Currently the company is family owned enterprise.

The short descriptions of the environmental technology orientated companies illustrates that they quite often result from a spin-off from a larger company or are built around an innovative individual. While the analysis above has provided us with some insights into the companies' active in environmental technologies, it is worthwhile to take a broader viewpoint on company characteristics in environmental technologies. These characteristics, presented in Table 6, include total industry sales and employment weighted with the share of environmental technology patents of all patents of a company to gain an appropriate perspective.

Table 6. Environmental technology related industry characteristics (weighted)

Companies included	**Employment**	**Sales**
	# of employees	*Millions of €*
With threshold	12 094	3 504,4
All	16 127	7 461,4

Source: OECD PATSTAT and Statistics Finland (authors' calculations)
Note: Weighting is based on the share of environmental technology patents of all company patents

The industry level indicators highlight the significant role of environmental technologies in the Finnish economy. Looking at the employment indicators, it could be argued that based on the weighted number of employees the industry employs around 16 000 persons and with the tighter threshold the figure is still quite around 12 000. When looking at the industry sales we can again witness the importance of this sector. Even with the stringiest criteria (with the 20% threshold) the sales are 3.5 billion euro. Without the threshold, the sum of the weighted industry sales rises to 7.4 billion euro.

4.3 Environmental and renewable energy technologies in industry

The significant role of environmental technologies in the economy raises the question about how these technologies link up to Finnish industries in terms of realized or potential applications. Some answers to this question can also be provided through patent data by examining the industrial affiliation of the companies which patent in environmental technologies. In the following the 20% threshold is not applied for including companies as the interest is to also identify weaker signals about both realized and potential linkages between the development and industrial application of environmental technologies throughout the Finnish economy in a broader sense. To highlight these relationships Table 7 shows the industrial and size distribution of all 125 companies behind the Finnish environmental technology patents as a first approximation.

Table 7. Environmental technology related industries by company size

Industry	Large	SME	Total	Total (%)
Agriculture	1	1	2	2%
Chemicals	3	5	8	6%
Ceramics	1	0	1	1%
Construction	1	6	7	6%
Electronics	3	4	7	6%
Energy	2	1	3	2%
Fibers	1	0	1	1%
Foodstuff	1	0	1	1%
Machine and process design	1	12	13	10%
Machinery	11	23	34	27%
Metals	4	5	9	7%
Plastics	3	2	5	4%
Pulp and paper	4	0	4	3%
Research and development	1	15	16	13%
Services	0	8	8	6%
Testing	0	2	2	2%
Waste management	2	2	4	3%
Total	39	86	125	100%

Source: Statistics Finland (authors' calculations)

As mentioned earlier the main environmental technology related industries (as suggested by the industrial affiliation of the patenting companies) are machinery, research and development and machine and process design. Beyond these patenting is spread out across companies in a broad range of industries and representing quite well the overall industrial structure of the Finnish economy. Accordingly, environmental technologies appear to be finding realized or potential application opportunities in many different types of industries throughout the Finnish economy. For the viewpoint of the diffusion of environmental technologies, this finding is promising as there are several potential commercialisation paths, and different types of companies in value chains may also be able to play different roles in commercialization (for more on this see e.g. Nikulainen, 2010). In most of these industries Finland hosts large companies that can act as industrialists in the commercialization and diffusion of environmental technologies e.g. by providing access to complementary assets such as marketing and distribution. Other relevant companies include smaller equipment suppliers and new technology-based firms (e.g. related to ICT, bio- or nanotechnology).

A second approximation for identifying realized or potential linkages between environmental technologies and application industries is to consider the activity of these companies in terms of renewable energy technologies (Table 8). Earlier in this paper we identified solar energy as one the faster growing areas of environmental technologies. Interestingly, Finland seems to have missed out this development trend. Looking at the column for solar energy technologies 11 companies can be identified which have activity in this area, and only one has more than a single patent. A closer look at the company with 8 patents reveals that in fact the main application area of their technology is related to x-ray technologies. Moreover it seems that the company has closed down its operations. These findings suggest that Finland may be left outside of solar technology as one of the main future technology growth areas within environmental technologies. This aspect would require more in-depth analysis, particularly focusing on the developments during the recent years, which may have been underrepresented in the patent statistics.

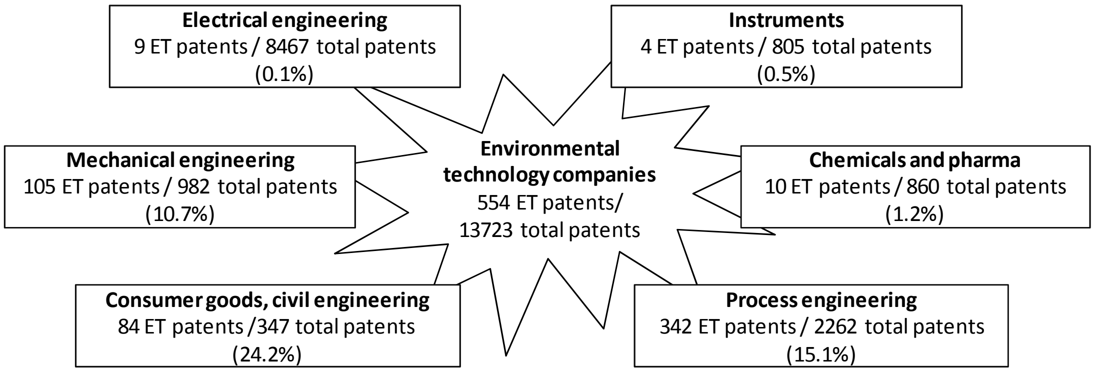
Table 8. Activity of Finnish companies in renewable energy technologies (1990-2007, patent applications)

Firm	**Industry**	**Organisation size**	**Renewable energy**	**Biomass**	**Geothermal**	**Hydro power (no firms)**	**Ocean**	**Solar**	**Wind**
ABB	Electronics	Large	4				1		3
Ahlstrom	Fibers	Large	2	2					
Ajat Ltd	Electronics	SME	1					1	
Alko	Chemicals	Large	1					1	
Andritz	Machinery	Large	8	8					
AW-Energy	Machine and process design	SME	2				2		
Bearing Drive Finland	Metals	SME	1						1
Biolentina	Agriculture	SME	1	1					
Biowork	Research and development	SME	1	1					
Conox	Machinery	SME	1	1					
Detection Technology	Electronics	SME	1					1	
Ecomet	Metals	SME	1	1					
Ekogastek	Waste management	SME	1	1					
Endeas	Machinery	SME	1					1	
Finn Escone	Machine and process design	SME	3				2		1
Fioter	Services	SME	2	2					
Forchem	Chemicals	Large	2	2					
Fortum/Neste Oil	Energy	Large	9	9					
Foster Wheeler Energia	Machinery	Large	1	1					
Fractivator	Machine and process design	SME	1	1					
Helio Therm	Machine and process design	SME	1					1	
Heptagon	Machine and process design	SME	1					1	
HT Engineering	Machinery	SME	1	1					
HT Lasertekniikka	Metals	Large	1	1					
KWH Pipe	Plastics	Large	1					1	
Lassila & Tikanoja	Waste management	Large	1	1					
Mateve	Energy	SME	2		2				
Mediburner	Machine and process design	SME	1	1					
Metso	Machinery	Large	2	2					
Moventas	Metals	Large	1						1
Oxford Instruments Analytical	Electronics	Large	1					1	
Polyrec	Construction	SME	2	2					
Rados Technology	Machinery	SME	1					1	
Setokons	Services	SME	1						1
Simage	Machine and process design	SME	8					8	
STX Finland	Machinery	Large	6	6					
Suinno	Research and development	SME	1					1	
Vapo	Energy	Large	1	1					
Wärtsilä Finland	Machinery	Large	6	6					
Winwind	Machinery	Large	6						6

Source: OECD PATSTAT and Statistics Finland (authors' calculations)

Whereas the discussion above focused on the innovation ladnscape and applicability of Finnish environmental technologies, more information about the technological relatedness between these and other technologies is important especially for innovation policy that primarily targets technology areas (e.g. Tekes technology programs, R&D projects). This viewpoint is taken in Figure 13 where the environmental technology classification is compared with a standard patent classification of technologies (for more about this approach see OECD 1994; Mancusi 2003).

Figure 13. Comparison between environmental technologies and standard technology classifications (# of patents)



Source: OECD PATSTAT and Statistics Finland (authors' calculations)
Note: More details of the comparison and cross-tabulation can be found in Appendix 5

Figure 13 provides interesting findings about realized or potential linkages between environmental technologies and the overall technological activities of the companies covered by the patent data used in this paper. We can observe from Figure 13 that environmental technologies are mainly related to process and mechanical engineering, and civil engineering also plays a significant role. Looking at the results in more detail, we can make several interesting observations (see Appendix 5 for the details).

First, the technology area covering electrical engineering is the field where most of the patents are applied by Finnish companies. This is largely due to Nokia's active patenting strategy and its inclusion in the list of 125 companies active in environmental technologies. Nonetheless, the main observation is that the environmental technology patent applications which are related to electrical engineering, in the standard classification, can mainly be found in the field of solar energy, while the linkages to ICT is non-existent.

A second observation is the low number of environmental technologies related to instrumentation and in particular to control and measurement, and that these patents mostly relate to solid waste management. A third observation is the low technological relatedness between these environmental technology patents and chemicals. The few patents which can be identified in this context concern solid waste management and relate to the areas of materials & metallurgy, food & agriculture.

A fourth observation is that environmental technology patents mainly relate to process engineering. This finding is less surprising when one takes into account industries, such as machinery, have a strong association with process engineering. The strongest connections can be identified between, chemical engineering and biomass, surfaces and air pollution control, thermal processes and waste management, oil & basic material and air pollution control, and, not very surprisingly, the overlapping standard classification "Environmental technology" and all the main environmental technology patent classes. These findings, particularly when reflected to the total patenting activity, provide further evidence of the strong relationship between the machinery industry and environmental technologies. A majority of the patenting activity of the machinery industry occurs in the areas of process and mechanical engineering (Nikulainen et al. 2005; Nikulainen 2008).

The fifth and final observation from Figure 13 (and Appendix 5) is linked to the previous finding. Mechanical engineering has strong ties with environmental technologies. The identified connections relate to links between machines & tools and waste management, engines & pumps and air pollution control, and wind technology, handling and waste management, nuclear engineering and solar energy. A strong link can also be identified with civil engineering and water pollution control.

In summary, this section gives the following insights:

- Finland has ambitious targets for increasing both energy efficiency and the development and use of new renewable energy technologies and many R&D programmes and other measures have been undertaken towards these aims
- Finnish environmental technology patenting is spread out across a large number of companies and broad range of application industries even though their share of all patents in these companies and industries generally is low
- Of the more environmental technology-intensive companies a majority are affiliated to the machinery industry and process engineering and these companies tend to be larger; companies active in renewable energy specifically tend to be smaller
- A more detailed analysis indicates that Finnish environmental technology patents do not significantly relate to instrumentation nor to ICT, both areas of which are considered as traditional strongholds in Finland

5. A summarizing discussion

Climate change is one of the major global challenges that the world faces and governments around the world are promoting environmental technologies to both address climate change and realize new employment and growth opportunities in this rapidly expanding area. The growth in environmental technology investments has been spearheaded by renewable energy and solar power in particular. These investments have been especially noteworthy in Europe and the US while strongest growth in the most recent years is recorded in Asia (China, Japan, Australia and India). Venture capital investments account for most of the growth across all countries but many governments have also stepped up their environmental technology investments through economic stimulus packages, adding approximately 480 USD billion of investments globally during the next 2-3 years on average. These investments are noticeable add-ons to already significant environmental technology, and renewable energy, investments which have been undertaken since the early 2000s. Many commentators refer to a Global Green New Deal and Green Growth to describe the elevation of climate change concerns, environmental technology investments and eco-innovation to the top of innovation policy agendas all over the world. Although no direct causality can be assumed increasing environmental technology (investment) activity is also clearly visible in patent data.

Increasing climate change concerns, investments, green stimulus packages and environmental technology patenting is creating both opportunities and challenges for many countries, including Finland as a small open economy. This paper analyses the investments, green components of the stimulus packages and global patenting trends with an eye to assessing the position of Finland in the changing environmental technology landscape. In the background are also concerns about the sources of future Finnish technological and industrial stronghold in rapidly emerging technologies of which environmental technologies are particularly promising. The paper primarily draws on literature research and patent data, linked to company register data. It takes a future-looking perspective that is geared towards provide providing conceptual and empirical insights of relevance both to innovation and environmental policies.

The overall policy framework for environmental and energy technologies in Finland is stipulated by the National Climate and Energy Strategy, which is formulated in line with guidelines laid down by the UN Framework Convention on Climate Change as well as the European Union, including specific initiatives launched by the European Commission. Within the context of these strategies and guidelines Finland has recently actively promoted environmental technologies primarily through several technology programs by the Academy of Finland, Finnish Funding Agency for Technology and Innovation (Tekes) as well as the Ministry of Environment. Company participation has also been facilitated through the so-called SHOK and OSKE programs, the latter of which covers various regional initiatives related to Cleantech and energy technologies. The Finnish Innovation Fund (Sitra) has also played an instrumental role in promoting environmental technologies and related Cleantech initiatives.

Globally speaking, patent data point to most rapid growth in innovative activity related to renewable energy with biomass, wind and solar power in the lead. The environmental technology landscape is also changing through the entry of new countries on the scene with most relative growth in patenting occurring in BRIICS countries. Finland is well positioned in the environmental technology area by overall levels of patenting activity and belongs to the league of top 25 countries by the absolute number of patents. Nonetheless, the position is more worrying in terms of the distribution of these patents set against global trends. Specifically, Finland does not emerge as a country with a specific specialization profile generally speaking neither in relation to renewable energy technologies where most growth in investments and patenting can be detected globally. This finding is in contrast e.g. with the specialization profile of countries such as Austria and Australia (hydropower), Denmark (wind technology), and the UK (ocean technology). Furthermore, a partial Finnish specialization in wind technologies appears to have eroded over time. These findings appear at odds with the dual policy priority to promote both energy efficiency and renewable energy. However, it should be noted that patenting may also have occurred in areas not covered by the patent-based environmental technology definition that this paper uses (e.g. in machinery, equipment, instruments).

The discussion about energy efficiency versus renewable energy often centres around the idea that energy efficiency mainly supports incremental technological change based on existing energy sources which often may be of the non-renewable kind (mainly fossil based fuels). In contrast, renewable energy technologies can potentially provide the basis for technological change and innovation of the more transformative for greener and more sustainable longer-term growth. This comparison may not always hold as energy efficiency also can imply that quite transformative and radical technologies and innovations are involved, for example related to nanotechnologies (e.g. smart windows, sensors, new materials, fuels cells). A closer examination of the green components of economic stimulus packages suggests that policy priorities also elsewhere remain on energy efficiency rather than renewable energy as the more dynamic and rapidly growing area globally. Furthermore, first assessments suggest that these green components of stimulus packages probably will not have the potential to add significant new momentum to greener and more sustainable growth in the aftermaths of the economic crisis. Despite all of this, an important issue for Finland is how to strike a balance between promoting both energy-efficiency and renewable energy technologies.

The data on Finnish environmental technology patent applications identified 125 companies active in this area of which a sub-sample with over 20% of such patents in their portfolio was analyzed in greater detail. Of these more environmental technology-oriented companies a majority are classified to the machinery industry in confirmation of extant research that also locates environmental technology patenting globally to this more traditional industry. Accordingly, it seems that most of these companies are not major process-intensive and polluting companies but they instead supply such companies with new environmental technologies. Further, the company size distribution is rather skewed and dominated by a few large companies. The smaller companies have often been founded around an innovative individual as a spin-off or spin-out from research or other companies. The economic significance of these companies is relatively noteworthy, accounting for approximately 12 094 employees and 3.5 billion euro in terms of sales.

The economic significance of Finnish environmental technologies should also be assessed by the degree to which it finds industrial applications throughout the economy. This paper also uses patent data for this purpose by considering how environmental technologies link up to industries through the affiliation of the companies patenting in the area. The data shows that the total sample of 125 companies is affiliated to a wide range of different industries, beyond the machinery industry as the main one. This diversity suggests Finnish environmental technologies appear to be finding realized or potential application opportunities in many different types of industries throughout the Finnish economy. Accordingly, there may also be a range of different commercialization paths where different types of companies (small versus large) can play different roles. More detailed analysis identified a large set of smaller design and R&D-focused companies that might play a critical role in developing more radical technologies alongside more incremental development within larger companies.

In conclusion, follow-up assessments of how green components of the economic stimulus packages are implemented across countries would be important, in particular regarding their ability to engage companies and stimulate innovation of the more radical kind. In the Finnish context the patent analysis of this paper should be deepened and complemented with other data (e.g. case studies) for a richer assessment of the comparative and also competitive position of Finland especially in renewable energy technologies as a rapidly expanding area. From a policy viewpoint it would be important to consider further possibilities for a more systematic approach towards promoting environmental technologies both with respect to enhancing the efficiency of existing energy technologies as well as emerging renewable energy technologies. Such an approach may need further integration of innovation (e.g. R&D funding and programmes), environment (e.g. regulations) and also other policy domains.

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Appendix 1: Details of stimulus packages across countries

	Total stimulus (USD billion)	Period	Green stimulus (USD billion)	Green share (%)	*Low carbon power*		*Energy efficiency (EE)*				
					Renewable	CCS/other	Building EE	LowC vech+	Rail	Grid	Water/waste
Countries											
Other EU states	207,1	2009-2010	1,9	0,01	0,8		0,60	0,3			0,1
Italy	103,5	2009-	1,3	0,01					1,32		
Indonesia	5,9	2009	0,1	0,02	0,07				0,03		
Japan	639,9	2009-	36,0	0,06	1,07	12,93	18,33	3,70			
Spain	14,2	2009	0,8	0,06							0,83
Saudi Arabia	126,8	2009	9,5	0,07							9,45
Canada	31,8	2009-2013	2,8	0,09		1,08	0,24		0,39	0,79	0,27
Mexico	7,7	2009	0,8	0,10			0,75				
UK	34,9	2009-2011	3,7	0,11	0,10	0,64	0,79	1,72	0,41		0,05
South Africa	7,5	2009-2011	0,8	0,11					0,61		0,10
US	972,0	Ten years	112,8	0,12	32,78	6,55	30,74	4,76	9,92	11,92	16,10
Germany	104,8	2009-2010	13,8	0,13			10,39	0,69	2,75		
France	33,7	2009-2010	7,1	0,21	0,87		0,83		1,31	4,13	
Australia	43,8	2009-2013	9,3	0,21	1,4	1,77	2,65		3,46		
Norway	2,9	2009	0,9	0,31	0,20		0,20		0,30		0,20
China	647,5	2009-2010	216,4	0,33				1,5	193,6	70	30,69
EU only	38,8	2009-2010	24,7	0,64	0,65	12,49	2,85	3,88	2,75		
South Korea	38,1	2009-2012	30,7	0,81	1,80		6,19	1,80	7,01		13,89
Regions											
Asia Pacific	1518,9		302	19,88	4,3	14,7	27,2	7	114,1	70	64,7
Europe	539,9		54,3	10,06	2,5	13,1	15,7	6,6	6,1	9	1,2
Americas	1024,1		121,2	11,83	32,8	7,6	31,7	4,8	11,3	12,7	20,3
TOTAL	*3083*		*478*	*15*	*40*	*35*	*75*	*18*	*132*	*92*	*86*

Source: Robins et al. (2009)

Appendix 2: Methodology for analysing environmental technology developments through patent data

The developments in environmental technologies are approximated through patent statistics. This methodological choice introduces some challenges that need to be addressed. The problem in using patents is their limitations in capturing broader technological developments as patents relate more to product than process inventions. Therefore, the key question is whether patent statistics provide a valid approximation of the innovative activities of companies.

Patent statistics should be seen as an intermediate output measure for innovative activities (Griliches, 1990; OECD, 2009b). R&D investments represent input to the innovative processes within companies, whereas innovations are products and processes successfully commercialised in markets. Patents lie somewhere in between. They are not direct inputs for the internal innovative processes of companies, nor are they innovations that have been commercialised, although they may be someday. Patents indicate a certain level of inventive activity within companies, which is a preliminary stage for actual commercialisation. In fact, only a small number of patents are commercially valuable and can be seen as innovations (Harhoff et al., 1999).

The advantage of using patent statistics as an intermediate innovation indicator is that they are readily available, with only a short lag from the actual innovative activities within companies (Griliches, 1990). They are also fairly objective, as they are screened by external examiners in patent office's who determine whether or not the patent application is valid. The main drawback of using patent statistics is that they usually do not measure inventive activities related to process innovations but, instead, mostly relate to product innovations. The degree to which this is a problem depends on the industry in question. In industries where manufacturing components and equipment is essential (for example, electronics), patents play a significant role in protecting intellectual property rights. In other industries, where equipment play a lesser role and manufacturing processes are more important, other means of protection, such as secrecy and lead-time, are more intensively used alongside with patenting (Cohen et al., 2000).

Even when taking into account the shortcomings of patent statistics, it is evident that they are and will continue to be used widely as indicators of innovative activity. Patents are used by policymakers, analysts and other parties, such as OECD, for measuring technological development and identifying national differences in technological specialisation.

In the context of environmental technologies, using patent statistics poses particular problems. Patents fail to capture the latest technological developments due to the lags between filing for patent and the publication of the patent document. In addition, patent statistics operate on fairly aggregate level due to technological classifications. For this reasons very detailed information of specific technologies often remains hidden. To address the developments of these more detailed non-aggregated technologies specific technological expertise and data would be needed, which are outside the focus of the current research. In addition, developments in specific technology areas can be classified in patent statistics under other technologies. For example, the developments related to fuel injections systems in electric cars are classified to belong to technology classes that relate to the fuel injection systems of standard cars. Therefore, it is difficult to isolate the developments of some of the environmental technology related technologies.

Another criticizing relates to the ET patent classifications used in this paper. The classification used here is based on OECD work of environmental technology patents (OECD, 2009b). It could be argued that these technologies represent a standard approach to environmental technologies leaving out relevant developments in emerging technology areas, such as bio- and nanotechnology, and indirectly related areas, such as instrumentation and software. This may be true, but as discussed above isolating the contributions in these technology areas to environmental technologies is difficult to establish without more detailed and narrow focus on the potential of these technologies in environmental technology related areas. For example, the latest and potential the most radical technologies may be related to the concept of geoengineering, which takes a proactive role in identifying innovative methods to command climate change (for more details see The Royal Society, 2009).

Appendix 3 – Revealed technological advantage indexes in environmental technologies (1990-2007)

Technology	FI - 90s	FI - 00s	FI	AT	AU	DE	DK	GB	NL	SE	US	KR
Air pollution control	0.89	0.82	0.85	0.58	0.34	**1.05**	0.65	0.78	0.62	**1.07**	**1.07**	0.95
Solid waste management	**1.10**	**1.22**	**1.15**	**1.61**	**1.31**	0.98	0.76	1.00	1.28	0.90	0.80	0.66
Water pollution control	0.98	**1.46**	**1.23**	**1.26**	**1.58**	**1.03**	**1.01**	**1.22**	**1.01**	**1.22**	0.92	**1.03**
Total - Renewable energy	**1.12**	0.76	0.90	0.99	**1.21**	0.91	**1.68**	**1.11**	**1.39**	0.72	**1.11**	**1.25**
Biomass	***1.25***	***1.36***	***1.31***	*0.87*	*0.74*	*0.79*	*0.84*	***1.70***	***1.96***	*0.64*	***1.49***	***1.30***
Geothermal	*0.00*	***1.35***	*0.85*	***2.73***	*0.42*	***1.25***	*0.31*	*0.54*	***1.23***	***1.31***	*0.72*	*0.00*
Hydro power	*0.64*	***1.16***	*0.94*	***7.71***	***4.40***	*0.72*	*0.98*	*0.80*	*0.92*	***1.39***	*0.51*	*0.00*
Ocean	*0.55*	***2.07***	***1.76***	***2.68***	***3.11***	*0.32*	***2.40***	***4.06***	*0.59*	***2.40***	*0.60*	*0.08*
Solar	*0.86*	*0.20*	*0.44*	*0.80*	***1.60***	*0.86*	*0.30*	*0.60*	***1.15***	*0.48*	*0.97*	***1.56***
Wind	***2.62***	*0.79*	***1.06***	*0.46*	*0.67*	***1.43***	***8.12***	*0.74*	*0.84*	***1.20***	*0.74*	*0.75*

Source: OECD PATSTAT

Note: An RTA index value higher than one indicates that a country has relatively more patent applications in a technology area and is thus viewed to be more specialized in that area.

Appendix 4 – Finnish companies with an affiliation to ET

					Main technology					**Main renewables**				
Firm	**ET patents**	**Share of all patents**	**Industry**	**Size/Type**	**Air pollution control**	**Solid waste management**	**Water pollution control**	**Renewable energy**	**Biomass**	**Geothermal**	**Hydro power (no firms)**	**Ocean**	**Solar**	**Wind**
ABB	4	2%	Electronics	Large				4				1		3
Ahlstrom	9	19%	Fibers	Large	2	3	2	2	2					
Ajat Ltd	1	17%	Electronics	SME				1					1	
Alko	2	40%	Chemicals	Large		1		1					1	
Altimeco	1	100%	Research & development	SME		1								
Andritz	12	24%	Machinery	Large	2	2		8	8					
ATP-tuote	1	50%	Construction	SME		1								
AW-Energy	2	100%	Machine & process design	SME				2				2		
BCDE Waste Management	4	80%	Electronics	SME	1		3							
Bearing Drive Finland	1	100%	Metals	SME				1						1
Beneq	1	6%	Machinery	SME			1							
Biodata	1	13%	Research & development	SME		1								
Biolan	1	13%	Chemicals	SME			1							
Biolentina	1	100%	Agriculture	SME				1	1					
Biowork	1	100%	Research & development	SME				1	1					
Borealis Technology	5	1%	Plastics	Large	4		1							
Cellkem	1	100%	Chemicals	SME		1								
Chempolis	1	14%	Research & development	SME			1							
Clewer	1	100%	Plastics	SME			1							
Conox	1	100%	Machinery	SME				1	1					
Corenso United	1	33%	Pulp & Paper	Large		1								
Cuycha Innovation	1	100%	Research & development	SME	1									
Danisco Finland	2	5%	Research & development	SME			2							
Detection Technology	1	50%	Electronics	SME				1					1	
Eco Technology JVV	1	100%	Machinery	SME		1								
Ecocat International	15	94%	Machinery	Large	15									
Ecomet	1	100%	Metals	SME				1	1					
Ecospec	1	100%	Research & development	SME		1								
Ekogastek	1	100%	Waste management	SME				1	1					
Ekokem	1	50%	Waste management	Large		1								
Endeas	1	50%	Machinery	SME				1					1	
Etor	3	100%	Construction	SME		1	2							
Evac International	32	94%	Machine & process design	SME			32							
Ficote	2	100%	Machinery	SME		1	1							
Finn Escone	3	100%	Machine & process design	SME				3				2		1
Fioter	2	100%	Services	SME				2	2					
Forchem	2	67%	Chemicals	Large				2	2					
Formia Technology Group	1	100%	Machinery	SME	1									
Fortum/Neste Oil	14	15%	Energy	Large	4		1	9	9					
Foster Wheeler Energia	30	36%	Machinery	Large	28	1		1	1					
Fractivator	1	25%	Machine & process design	SME				1	1					
Greenvironment	1	100%	Machinery	SME		1								
Halton	1	17%	Machinery	SME		1								
Heikki Laiho Oy	1	100%	Metals	SME			1							
Heinolan Sahakoneet	1	33%	Machinery	SME		1								
Helio Therm	1	100%	Machine & process design	SME				1					1	
Heptagon	1	7%	Machine & process design	SME				1					1	

					Main technology					**Main renewables**				
Firm	**ET patents**	**Share of all patents**	**Industry**	**Size/Type**	**Air pollution control**	**Solid waste management**	**Water pollution control**	**Renewable energy**	**Biomass**	**Geothermal**	**Hydro power (no firms)**	**Ocean**	**Solar**	**Wind**
Hitech Chemicals	1	100%	Chemicals	SME			1							
HJA-Engineering	1	100%	Research & development	SME		1								
HT Engineering	1	50%	Machinery	SME				1	1					
HT Lasertekniikka	1	100%	Metals	Large				1	1					
Hydex	1	100%	Machine & process design	SME		1								
Hydrocell	1	50%	Testing	SME	1									
IDO Kylpyhuone	2	29%	Cheramics	Large			2							
Increa	1	25%	Machine & process design	SME	1									
Innovation Trust	1	100%	Services	SME	1									
Inventio	1	50%	Testing	SME	1									
Ion Blast	2	100%	Machinery	SME	2									
Jeven	1	14%	Machinery	SME	1									
Jorpelehto	2	100%	Services	SME		2								
Kaakon Pintapelti	1	100%	Metals	SME		1								
Kappelinranta	1	50%	Services	SME			1							
Kemira	29	28%	Chemicals	Large	12		17							
Keskuslaboratorio - KCL	2	15%	Research & development	Large			2							
KWH Pipe	4	22%	Plastics	Large			3	1					1	
Lamor Corporation	2	100%	services	SME			2							
Lappeenrannan tekn. YO	1	25%	Public research		1									
Larox	4	100%	Machinery	Large	1		3							
Lassila & Tikanoja	1	100%	Waste management	Large				1	1					
Lifa IAQ	1	50%	Chemicals	SME	1									
LMP Patents	2	100%	Research & development	SME			2							
Maricap	3	60%	Machinery	SME	2	1								
Marimatic	1	100%	Machinery	SME			1							
Marioff	1	9%	Machinery	Large	1									
Mateve	2	100%	Energy	SME				2		2				
Matti Ettala Oy	1	100%	Research & development	SME		1								
Mediburner	1	100%	Machine & process design	SME				1	1					
Megatech	1	50%	Electronics	SME			1							
Megatrex	1	20%	Machinery	SME		1								
Merinonita	1	100%	Research & development	SME		1								
Metsä-Botnia	1	100%	Pulp & Paper	Large	1									
Metso	33	3%	Machinery	Large	13	15	3	2	2					
Molok	1	100%	Plastics	SME		1								
Moventas	1	25%	Metals	Large				1						1
M-real	1	1%	Pulp & Paper	Large		1								
MTT	2	40%	Public research				2							
Närpes Trä & Metall	2	100%	Machinery	Large		2								
Natwat	1	100%	Services	SME			1							
Nimatek	1	100%	Services	SME		1								
Nokia	1	0%	Electronics	Large	1									
Odoroff	1	100%	Machinery	SME	1									
Oras	10	53%	Metals	Large			10							
Outokumpu/Outotec	32	10%	Metals	Large	17	4	11							
Oxford Instruments Analytical	1	6%	Electronics	Large				1					1	
Paroc	1	2%	Construction	Large		1								
Partek (Kone)	1	25%	Machinery	SME		1								

					Main technology					**Main renewables**				
Firm	**ET patents**	**Share of all patents**	**Industry**	**Size/Type**	**Air pollution control**	**Solid waste management**	**Water pollution control**	**Renewable energy**	**Biomass**	**Geothermal**	**Hydro power (no firms)**	**Ocean**	**Solar**	**Wind**
Polyrec	2	100%	Construction	SME				2	2					
POM Technology	1	7%	Research & development	SME		1								
Pöyry Finland	1	50%	Machine & process design	Large			1							
Preseco	1	33%	Waste management	SME			1							
Proventia Emission Control	3	100%	Machinery	SME		3								
Rados Technology	1	33%	Machinery	SME				1					1	
Raisio Chemicals	1	11%	Foodstuff	Large		1								
Rummakko	1	33%	Metals	SME		1								
Sammet Dampers	1	14%	Machinery	SME	1									
Sandvik	2	3%	Machinery	Large	2									
Savcor Group	2	67%	Research & development	SME		2								
Savonlinnan PR-Urakointi	1	50%	Construction	SME		1								
Setokons	1	100%	Services	SME				1						1
Simage	8	19%	Machine & process design	SME				8					8	
Skyor Ky	1	100%	Machine & process design	SME		1								
Steris Europe	5	56%	Machinery	SME			5							
STX Finland	15	22%	Machinery	Large	8		1	6	6					
Suinno	1	50%	Research & development	SME				1					1	
Suomen Rehu	3	23%	Agriculture	Large		3								
Tekno-Forest	2	100%	Chemicals	SME		1	1							
Tomra Systems	1	100%	Machinery	SME		1								
Turun Yliopisto	1	20%	Public research		1									
UPM-Kymmene	4	18%	Pulp & Paper	Large		3	1							
Uponor	1	13%	Plastics	Large			1							
Vapo	5	56%	Energy	Large	2	1	1	1	1					
Vesi-Eko	1	100%	Construction	SME			1							
VSJ Holding	1	100%	Machine & process design	SME	1									
VTT	14	6%	Public research		9	2	3							
Wärtsilä Finland	21	14%	Machinery	Large	14		1	6	6					
Waterix	1	50%	Construction	SME			1							
Winwind	6	100%	Machinery	Large				6						6
Wiser	7	78%	Research & development	SME	2		5							

Appendix 5 – Comparison between environmental technologies and standard technology classifications (# of patent applications)

Standard technology classification	Environmental technology classification											Total patenting by Et related firms
	Total ET patenting	Air pollution	Solid waste mng.	Water pollution	Renewable energy	*Biomass*	*Geothermal*	*Hydro power*	*Ocean*	*Solar*	*Wind*	
Electrical engineering												
Electronic devices	2	-	-	-	2	-	-	-	-	2	-	307
Audio visual technology	-	-	-	-	-	-	-	-	-	-	-	115
Telecommunications	2	-	-	-	2	-	-	-	-	2	-	6,376
Information technology	-	-	-	-	-	-	-	-	-	-	-	1,630
Semiconductors	5	-	-	-	5	-	-	-	-	5	-	39
Instruments												
Optics	-	-	-	-	-	-	-	-	-	-	-	115
Control and measurement	4	-	3	-	1	-	-	-	-	1	-	663
Medical technology	-	-	-	-	-	-	-	-	-	-	-	27
Chemicals and pharma												
Organic chemistry	-	-	-	-	-	-	-	-	-	-	-	32
Macromolecular chemistry	-	-	-	-	-	-	-	-	-	-	-	579
Pharma and cosmetics	-	-	-	-	-	-	-	-	-	-	-	16
Biotechnology	-	-	-	-	-	-	-	-	-	-	-	53
Materials and metallurgy	6	-	6	-	-	-	-	-	-	-	-	126
Food and agriculture	4	-	4	-	-	-	-	-	-	-	-	54
Process engineering												
Chemical engineering	11	1	1	1	8	8	-	-	-	-	-	118
Surfaces	66	59	6	-	1	1	-	-	-	-	-	460
Materials processing	-	-	-	-	-	-	-	-	-	-	-	192
Thermal processes	25	1	24	-	-	-	-	-	-	-	-	1,033
Oil and basic material	34	28	-	-	6	-	2	-	-	4	-	234
Environmental technology	206	54	21	90	41	41	-	-	-	-	-	225
Mechanical engineering												
Machines and tools	13	3	10	-	-	-	-	-	-	-	-	128
Engines and pumps	49	20	1	-	28	8	-	2	4	-	14	174
Mechanical elements	6	2	1	-	3	-	-	-	-	1	2	244
Handling	18	2	15	-	1	1	-	-	-	-	-	259
Food processing	2	-	1	1	-	-	-	-	-	-	-	33
Transport	5	1	-	2	2	-	-	1	-	-	1	94
Nuclear engineering	11	-	-	1	10	-	-	-	-	10	-	45
Space technology	1	-	1	-	-	-	-	-	-	-	-	5
Cons. goods and civ. eng.												
Consumer goods	3	3	-	-	-	-	-	-	-	-	-	160
Civil engineering	81	2	2	74	3	-	-	-	1	1	1	187
Total	**554**	**176**	**96**	**169**	**113**	**59**	**2**	**3**	**5**	**26**	**18**	**13,723**

Source: OECD PATSTAT and Statistics Finland (authors' calculations)

Note: Standard technology classification is based on OECD (1994) and Mancusi (2003).