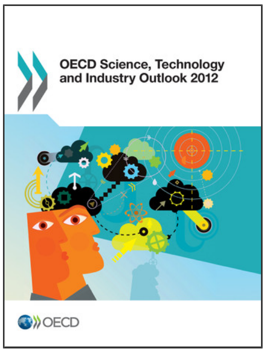


From:
OECD Science, Technology and Industry Outlook 2012

Access the complete publication at:
http://dx.doi.org/10.1787/sti_outlook-2012-en

Transitioning to green innovation and technology

Please cite this chapter as:

OECD (2012), "Transitioning to green innovation and technology", in *OECD Science, Technology and Industry Outlook 2012*, OECD Publishing.
http://dx.doi.org/10.1787/sti_outlook-2012-5-en

OECD

PART II

Chapter 2

Transitioning to green innovation and technology[1]

OECD countries and emerging economies alike are seeking new ways to accelerate the transition to green growth through technology and innovation. This chapter argues that the transition to green innovation will require more than supply-side, technology-push approaches. It will also require demand-side measures and careful organisational and institutional changes. A key challenge is to align the goals of ministries, research funding agencies, higher education institutions and social and market-based institutions so that they focus on green growth in all its dimensions. Strategic policy intelligence can help to enhance policy learning and to avoid government failures.

Introduction

Government efforts to promote greener growth through R&D and innovation have intensified in recent years in the OECD area and beyond. The European Union's Growth Strategy for 2020, Korea's National Strategy and Five-Year-Plan for green growth, the green development focus of China's Five-Year-Plan and South Africa's New Growth Path and Green Economy Accord are just a few initiatives to make green innovation a crucial impetus for competitive and sustainable economies.

Innovation plays a key role in greening growth. One of the key messages of the OECD Green Growth Strategy is that innovation, together with market-based incentives and appropriate regulation and taxation, can accelerate the transition to greener growth and help decouple environmental degradation from economic growth (OECD, 2011a). The OECD Green Growth Strategy therefore called for countries to take a coherent, co-ordinated policy approach to green growth based on a sound overall framework for innovation policies which includes both supply- and demand-side innovation policies and a range of policy tools to create, diffuse and apply knowledge.

While the rationale for public intervention in this area is well established, owing to market and systemic failures, the challenge for science, technology and innovation (STI) policy is to use and combine supply-push and demand-pull instruments to accelerate the development and diffusion of the green innovations needed for a system-wide transition to greener growth.[2]

Making the case for green innovation and technology

The need for innovation to meet the challenge of sustainability

Recent OECD analysis suggests that without intensified policy action, global greenhouse gas (GHG) emissions are likely to increase by 70% by 2050. Other environmental and social challenges are equally urgent: improving the quality and availability of water, dealing with the use and disposal of toxic products, and maintaining or increasing biodiversity. The green growth agenda, however, is wider: its goal is to pursue economic growth and shared prosperity while preventing environmental degradation.

Green growth implies policies that either reduce resource use per unit of value added incrementally (relative decoupling) or keep resource use and environmental impacts stable or declining while the overall economy is growing (absolute decoupling). Over recent decades, OECD countries have been able to achieve absolute decoupling of GDP growth and emissions of certain acidifying substances, such as sulfur oxide (SO_x) and nitrogen oxide (NO_x). However, they have only been able to achieve a relative decoupling of GDP growth from GHG emissions, as these have continued to rise. Indeed, in many areas environmental pressures have continued to increase as economies have grown, notably in non-OECD countries (OECD, 2010a).

A pre-crisis, business-as-usual growth route that undervalues environmental capital will at some point deplete and/or degrade the natural resource base. This will limit growth prospects in the long term. Decoupling growth from environmental pressure requires establishing incentives and institutions that lead to significant green innovations and their widespread adoption and diffusion.

Barriers to development and uptake of green technology and innovation

Policies for green innovation should take account of barriers. Many barriers to technological innovation and diffusion are known and have been studied. The usual entry point for government intervention occurs when market forces provide inadequate incentives for entrepreneurs and firms to invest in either the development or the diffusion of green technologies. The main rationale for public support for R&D is spillovers – large, broadly dispersed societal benefits – that may occur as a result of research. As firms are unable to capture fully the results of R&D, they tend to underinvest in the socially optimal level.

In the case of green innovation, the policy rationale is what is usually referred to as the "double externality" problem (Jaffe *et al.*, 2004). One argument concerns the underperformance of private research owing to knowledge externalities and the disincentives provided by free riding (Arrow, 1962; Nelson, 1959). Other market failures, such as credibility problems or learning-by-doing effects, can also inhibit the development and diffusion of green technology. A second argument arises from the negative externalities of climate change and other environmental challenges and has implications for both the creation and diffusion of technologies. Because GHG emissions are not priced by the market, incentives to reduce them through technology development are limited. Similarly, there is less diffusion and adoption, once green technologies are available, if market signals regarding the environmental benefits of such technologies are weak (Jaffe *et al.*, 2005; Newell, 2010).

Other barriers to innovation may arise from systemic failures (OECD, 1998) that hinder the flow of knowledge and technology and reduce the overall efficiency of the system-wide R&D and innovation effort (OECD, 1999). These include capability failures, institutional failures, network failures and framework failures (Arnold, 2004). The issue is less the divergence between private benefits and social benefits than the insufficient development of the innovation system itself. Such systemic failures can arise from mismatches between different parts of an innovation system, such as incompatible incentives for market and non-market institutions, *i.e.* firms and the public research sector (Faber *et al.*, 2008). This is particularly the case for research and technology infrastructure, such as data collection and dissemination or the training of scientists and engineers, which the market is unlikely to provide fully on its own. From the perspective of transformative change – here defined as a drastic change in governance practice – further types of policy failure that are relevant for green technologies in the context of transition policy can be identified, such as directionality, demand articulation, policy co-ordination and reflexivity failures (Weber and Rohracher, 2012).

Specific barriers to the development and uptake of green technologies

Apart from typical market failures related to innovation, some market failures and barriers to innovation and adoption may be unique to, or more prevalent in, markets for green innovation (UK Committee on Climate Change, 2010; Stavins, 2003; Popp *et al.*, 2009; Geroski, 2000; Gillingham *et al.*, 2009; Aghion *et al.*, 2011). These include dominant patterns in energy and transport markets, uncertainty of success, long timescales for infrastructure replacement and development, a lack of options for product differentiation, liquidity constraints, path dependency, uncertainty and behavioural failures.

Barriers may also relate to firm size. These include a lack of financing and qualified personnel and, in some countries, the relatively small size of the domestic market (OECD, 2011b). Even for large firms, whether multinationals or national corporations, with scale, scope and experience, adapting to rapidly changing market environments and the high costs of R&D are challenges for commercialising new green technologies. Results from the Eurobarometer survey (EC, 2011) show that uncertain market demand, uncertain returns on investment and lack of funds are the three biggest obstacles to the uptake of green innovation.

Implications for science and innovation policy

Potential market and systemic failures suggest that, on its own, the market may not develop green technologies in a timely way and deploy them sufficiently. The OECD Green Growth Strategy shows that a business-as-usual innovation policy is ultimately unsustainable, involving risks that can impose costs and hamper future economic growth and development (OECD, 2011a). A new policy agenda for turning green innovation into a new source of growth is therefore needed. Successful innovation policies will have to address the performance of the system as a whole through a range of policies and customised approaches.

Getting the prices right

For most countries, instruments that directly affect price signals are a necessary, though not always sufficient, condition for greener growth. The main strength of market-based environmental policies is that, if properly designed, implemented and enforced, they implicitly or explicitly make environmental inputs more expensive so that they internalise environmental externalities (*e.g.* pollution). Such price signals enhance firms' and consumers' incentives to adapt and develop green innovations. Pricing mechanisms enhance efficiency and flexibility in allocating resources as they provide incentives to choose the best way to meet the policy goal (OECD, 2011a).

However, while market-based instruments, such as carbon pricing or cap and trade systems, may induce innovation that will lead to green technologies, better pricing of environmental externalities will not be sufficient to deliver green innovation. In order to have a significant impact on technological innovation and diffusion, it will be necessary to pursue additional policies to strengthen green innovation.

The case for broader-based support for green technology innovation and diffusion

The presence of market and environmental externalities suggests that both environmental and science and technology (S&T) policies are needed (Popp *et al.*, 2009, Newell, 2010).[3] However, there are fundamental differences between these policy areas: environmental policies aim at tackling environmental damage caused by past industrial activities, while innovation policies are generally forward-looking and aim to increase productivity (Kivimaa, 2008). Moreover, the policy mix for innovation can be improved through instruments to stimulate the adoption and diffusion of green innovation (*e.g.* demand-side innovation policies), whereas environmental policies stimulate innovation as a side effect (Jaffe *et al.*, 2005). To the extent that adoption and diffusion are limited by more than market failures, environmental policy measures that increase incentives to adopt green technologies or put a price on environmental externalities are necessary, but insufficient. In addition, policies focused directly on enabling and influencing the demand side can reduce the risk inherent in R&D investments through the creation of potential markets.

Policies that focus on one element of the system or one sector are unlikely to enhance overall performance, as different green technologies face different barriers. In particular, the radical and systemic innovations often targeted by policy makers require broad-based modifications on the supply and demand side and in institutional/organisational settings (Box 2.1). Shifting towards a more systemic or horizontal approach is far from straightforward, but holds the promise of greater coherence and better performance. At a minimum, effective long-run green innovation policies require both supply- and demand-side innovation policies which aim both at the overall rate of innovation and at its direction, *i.e.* the environment.

Box 2.1. **The search for radical innovation in the green technology area**

Incremental innovation is the dominant form of innovation and has enabled substantial progress in environmental performance in recent decades. To achieve a sustainable transition to green growth, many observers call for a policy framework able to foster more radical innovation. Radical innovation is generally a complex process, rather than a discrete event. It is often pioneered by smaller firms, or new market entrants, and generally implies a difficult, lengthy and risky process. System-wide adoption and diffusion of radical innovations nearly always depends on incremental improvements, refinements and modifications, the development of complementary technologies, and organisational change and social learning.

Nevertheless, supporters of government action often call for a one-time technological breakthrough in terms of a "Manhattan Project" or an "Apollo Mission" type of programme. Some observers (*e.g.* Mowery *et al.*, 2010) have argued that this is appropriate only when the way forward is relatively clear and when the necessary development work is intrinsically large-scale (*e.g.* ITER fusion reactor); otherwise centralised decision making can suppress innovation.

The uptake of radical innovations, whether the result of a supply push or a demand pull, can be restricted by market dynamics. In some industries radical innovation may be limited because of high rates of concentration and market dominance that provide little incentive for radical and systemic changes. The high cost of capital and barriers to market entry can also limit the entrance of new players with superior technologies. In the electricity supply sector, radical innovation is difficult, often requires clusters of complementary innovations, and tends to occur over long periods of time. In the case of power plant technology, *ex post* analysis shows that radical innovations – unlike incremental innovations – did not succeed owing to strong path dependency (Rennings *et al.*, 2009). In the case of the wind turbine industry, research suggests that that a high-technology breakthrough approach stifles learning processes (learning by doing) that allow new technological paths to emerge. While Denmark's wind technology system followed an incremental path, actors in the United States and other countries may have failed, not despite, but because of, the pursuit of radical innovation (Garud and Karnøe, 2003).

Recent national strategies and priorities in support of green innovation

National plans serve to articulate priorities for research and innovation and to set policies and instruments. A growing number of OECD and non-OECD countries are establishing green growth strategies or prioritising activities within their national S&T strategies to create critical mass and accelerate the transition to green innovation and technology. Indeed most countries continue to place environmental issues, climate change and energy high on the list of priorities for innovation policy in general. However, specific policy priorities for green innovation and technology differ markedly across countries, depending on their scientific and economic specialisation, competiveness goals and societal objectives. Priorities can be expressed through targeted funding instruments such as R&D programmes or through specific sectoral and scientific initiatives. National strategies also include quantitative objectives in terms of R&D spending and monitoring. Some OECD governments have introduced plans through ministry agendas, mainly environment or energy ministries. In practice, however, the mapping and the identification of green growth strategies purely based on STI is difficult, given that most national plans are characterised as "strategy and policy mixes" (Table 2.1).

Revisiting supply-side technology and innovation policies

Supply-side innovation policies play an important role in orienting innovation efforts to help address green growth challenges. Current policy approaches to address market and systemic failures for green innovation generally focus on the supply side; they seek to generate new knowledge or innovations, either by making it less expensive for firms to undertake the relevant research or by performing the research in public institutions. Supply-side policies for innovation include public funding (direct and indirect) to public and business R&D, public support to venture capital funding, creation of research infrastructure, investment in higher education and human resources.

Funding and management of green research at the level of research institutions

Using public research funding as a catalyst to exploit new technology pathways

Science is an essential aspect of greener innovation, but very little attention has been given to the appropriate research funding model and the selection criteria to foster green technology. Indeed, it is difficult to identify specific disciplines as the sources of the scientific knowledge that will make major scientific contributions to green innovation and thus to green growth.[4] A mapping of scientific fields reveals that "clean" energy technologies draw on a diversity of scientific knowledge bases which have a broader focus than research on energy and the environment, such as materials science, chemistry and physics (OECD, 2011c).

The coming together of different fields of science and technology through collaboration among research groups and the integration of approaches originally viewed as distinct can also facilitate radical innovations as it opens up new avenues for technology development. Scientific breakthroughs are typically achieved by small interdisciplinary and multidisciplinary groups. For example, Heinze *et al.* (2009) find that there is less exploration when research groups are large and hierarchically organised. Therefore to advance the frontiers of knowledge will require better interaction across disciplines and appropriate funding systems that encourage such interdisciplinary research at the level of institutions (universities, research centres), departments, and single research units.

Table 2.1. **Green innovation performance and recent country plans in OECD and selected non-OECD countries**

	R&D in energy and environment	Green technology patents[3, 4]								Green regional hotspots[9]	Plan and strategic objectives[10]	Environmental tech/innov. programmes
	As a % of total government R&D budgets[1, 2]	Energy generation[5]		Transportation[6]		Environmental management[7]		Technologies with potential to emissions mitigation[8]				
		Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]			
Australia	8.7% ●●●○	2.0% ●○○○	✓	0.7% ●○○○		2.9% ●○○○	✓	0.7% ●○○○			**Clean Energy Future Plan:** pricing carbon; investing in renewable energy; improving energy efficiency; long-term investments; research into clean energy technologies.	✓
Austria	4.0% ●○○○	1.0% ●○○○	✓	1.2% ●○○○	✓	1.1% ●○○○	✓	0.6% ●○○○		Steiermark	**Energy Strategy:** energy services; energy security; environmental and social sustainability; cost- and energy-efficiency; competitiveness.	✓
Belgium	4.0% ●●○○	0.7% ●○○○		0.3% ●○○○		1.0% ●○○○		0.2% ●○○○		Vlaams Gewest, Region Wallone	**Marshall Plan 2. Green:** environmental technology hub; specific innovation grants; eco-designs; energy-, transport and materials-efficiency; water and air quality. **Flanders in Action:** Smart grid intelligent electricity network; smart living; renewable energy; sustainable materials; eco-friendly transport; socially caring cities.	✓
Canada	10.3% ●●●○	2.4% ●○○○	✓	1.4% ●○○○		2.9% ●○○○	✓	3.1% ●○○○	✓	Ontario, British Columbia	**Mobilizing Science and Technology to Canada's Advantage:** environmental science and technologies; natural resources and energy.	✓
Chile	n.a.	0.0% ○○○○		0.0% ○○○○		0.0% ○○○○		0.0% ○○○○				✓
China	n.a.	2.9% ●○○○		1.2% ●○○○		2.1% ●○○○		2.1% ●○○○			**12th Five-Year-Plan:** reduce fossil energy consumption; promote low-carbon energy sources; and restructure economy; "strategic and emerging" industries.	✓
Czech Republic	5.6% ●●○○	0.1% ○○○○		0.1% ○○○○		0.2% ●○○○		0.1% ○○○○				✓
Denmark	6.9% ●●○○	3.6% ●○○○	✓	0.3% ●○○○		1.1% ●○○○	✓	0.5% ●○○○		Midtjylland, Hovedstaden		✓
Estonia	13.8% ●●●●	0.0% ○○○○		0.0% ○○○○		0.0% ○○○○		0.0% ○○○○				
Finland	12.5% ●●●●	0.8% ●○○○		0.5% ●○○○		1.4% ●○○○	✓	0.3% ●○○○		Etela-Suomi, Lansi-Suomi	**Government Programme:** Cleantech technologies; environmental business; natural resources.	✓
France	7.7% ●●○○	3.4% ●○○○		7.1% ●●○○	✓	5.2% ●●○○	✓	3.4% ●○○○		Ile-de-France	**Ambition Ecotech 2012:** eco-industries; SME support; deployment of green technologies; reinforce EU ETAP-Plan.	✓
Germany	7.1% ●●○○	13.0% ●●○○	✓	31.6% ●●●●	✓	13.1% ●●○○	✓	11.2% ●●○○		Baden-Württemberg; Bayern	**BMBF Framework Programme Research and Sustainable Development (FONA):** earth system and geo-technologies; climate and energy; sustainable management and resources; social development. **Masterplan Environmental Technologies:** lead markets; resource efficiency; climate protection; water technologies.	✓
Greece	4.5% ●●○○	0.2% ●○○○		0.0% ○○○○		0.1% ○○○○		0.1% ○○○○				✓
Hungary	3.8% ●○○○	0.1% ○○○○		0.1% ○○○○		0.3% ●○○○		0.1% ○○○○			**National Sustainable Development Strategy (2007) – National Environmental Technology Innovation Strategy (2011-2020) – National Energy Strategy (2030).**	✓

Table 2.1. **Green innovation performance and recent country plans in OECD and selected non-OECD countries** *(cont.)*

	R&D in energy and environment	Green technology patents[3, 4]								Green regional hotspots[9]	Plan and strategic objectives[10]	Environmental tech/innov. programmes
	As a % of total government R&D budgets[1, 2]	Energy generation[5]		Transportation[6]		Environmental management[7]		Technologies with potential to emissions mitigation[8]				
		Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]			
Iceland	2.7% ●○○○	0.0% ○○○○		0.0% ○○○○		0.0% ○○○○		0.0% ○○○○				
Ireland	4.0% ●●○○	0.4% ●○○○		0.0% ○○○○		0.2% ●○○○		0.0% ○○○○			**National Climate Change Strategy:** meeting Kyoto targets.	✓
Israel	1.3% ●○○○	1.3% ●○○○	✓	0.2% ○○○○		0.9% ●○○○		0.6% ●○○○			**Water Management Master Plan:** natural water sources; sewage system; **National initiative to Develop Technologies That Reduce the Global Use of Oil in Transportation**.	✓
Italy	9.8% ●●●○	2.3% ●○○○	✓	1.5% ●○○○		2.3% ●○○○	✓	0.9% ●○○○		Lombardia		✓
Japan	14.4% ●●●●	14.5% ●●○○		26.8% ●●●●	✓	18.6% ●●●○	✓	34.5% ●●●●	✓	Southern-Kanto; Hokuriko	**New Growth Strategy:** new systems design and regulatory reform; expansion of environmental technologies and products; low-carbon investment and financing; smart grid; expansion of renewable energy market; green cities.	✓
Korea	7.6% ●●○○	3.7% ●○○○	✓	1.1% ●○○○		3.6% ●○○○	✓	5.0% ●○○○	✓	Capital Region	**Five-Year-Plan for Green Growth**: mitigation of green house gases; reduction of fossil fuel use; capacity to adapt to climate change; green technologies; greening existing industries; green transportation infrastructure.	✓
Luxembourg	3.9% ●○○○	0.0% ○○○○		0.0% ○○○○		0.0% ○○○○		0.0% ○○○○			**National Pact for climate and sustainable development:** mobility, housing, energy, nature and biodiversity, eco-technologies and research; **National Energy Efficiency Action Plan.**	✓
Mexico	10.1% ●●●○	0.2% ○○○○		0.1% ○○○○		0.2% ●○○○		0.0% ○○○○			**Green Agenda:** sectoral funds for R&D in water and forestry; investments in environmental studies; ecosystems.	✓
Netherlands	2.8% ●○○○	2.2% ●○○○		0.6% ●○○○		1.7% ●○○○		1.0% ●○○○		Zuid-Nederland, West Nederland	**New industrial policy To the Top:** energy, water, high-tech materials; logistics, agro-food.	
New Zealand	13.5% ●●●●	0.3% ●○○○		0.1% ○○○○		0.4% ●○○○		0.1% ○○○○		North Island		
Norway	5.6% ●●○○	1.3% ●○○○	✓	0.1% ○○○○		0.9% ●○○○		0.2% ●○○○		Oslo Og Akershus	**Energi 21:** solar cells; offshore wind power; utilisation of resources using balance power; flexible energy systems; smart grids; conversion of low-temperature heat into electricity ; carbon capture and storage (CCS). **An innovative and Sustainable Norway:** strategic council for environmental technologies.	✓
Poland	5.6% ●●○○	0.2% ○○○○		0.1% ○○○○		0.2% ●○○○		0.1% ○○○○			**National Reform Programme:** adaption to climate change; materials- and resource-efficiency; clean coal technologies. **National Environmental Policy:** R&D for environmental protection.	✓
Portugal	4.4% ●●○○	0.3% ●○○○		0.0% ○○○○		0.1% ○○○○		0.0% ○○○○			**National Energy Strategy 2020:** competitiveness and growth; renewable energy; energy efficiency and security; **National Low Carbon Roadmap to 2030 and 2050:** R&D and innovation.	✓
Slovak Republic	5.5% ●●○○	0.1% ○○○○		0.0% ○○○○		0.1% ○○○○		0.0% ○○○○			**Innovation strategy:** eco-innovation	✓

Table 2.1. **Green innovation performance and recent country plans in OECD and selected non-OECD countries** *(cont.)*

	R&D in energy and environment	Green technology patents[3, 4]								Green regional hotspots[9]	Plan and strategic objectives[10]	Environmental tech/innov. programmes
	As a % of total government R&D budgets[1, 2]	Energy generation[5]		Transportation[6]		Environmental management[7]		Technologies with potential to emissions mitigation[8]				
		Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]	Country share in total world (%)	Relative speciali-sation[11]			
Slovenia	7.0% ●●○○	0.1% ○○○○		0.0% ○○○○		0.0% ○○○○		0.0% ○○○○				
Spain	7.7% ●●○○	2.6% ●○○○	✓	0.4% ●○○○		1.1% ●○○○	✓	0.3% ●○○○				✓
Sweden	7.2% ●●○○	1.5% ●○○○		2.9% ●○○○	✓	2.1% ●○○○	✓	0.7% ●○○○		Västverige, Stockholm	**Research and innovation bill A boost for research and innovation:** technology, sustainable use of resources, energy and research of marine environments	✓
Switzerland	1.1% ●○○○	1.3% ●○○○		0.6% ●○○○		1.0% ●○○○		0.7% ●○○○		Espace Mittelland	**Cleantech Masterplan:** research/knowledge and technology transfer; regulation and market-based programmes; international markets; cleantech innovation environment. **Energy Strategy 2050:** energy security.	✓
Turkey	n.a.	0.2% ●○○○		0.1% ○○○○		0.1% ○○○○		0.1% ○○○○				✓
United Kingdom	3.2% ●○○○	4.6% ●○○○		2.9% ●○○○		4.8% ●○○○	✓	2.6% ●○○○				✓
United States	2.0% ●○○○	27.4% ●●●●		16.0% ●●●○		25.6% ●●●●		27.5% ●●●●			**A strategy for American Innovation:** smart grid, energy efficiency, renewable technologies, advanced vehicle technologies, energy innovation hubs, energy standards.	✓

1. Based on government budget appropriations or outlays for R&D (GBAORD) data for 2011. Data refer to 2010 for Belgium, Estonia, Hungary, Israel, Spain, The United Kingdom and the United States. Data refer to 2009 for Iceland. Data refer to 2008 for Canada, Greece, New Zealand and Poland. Data refer to 2006 for Mexico.
2. Scale: X < 4 low R&D spenders; 4 < X < 8 moderate R&D spenders; 8 < X < 12 medium R&D spenders; 12 < X < 16 high R&D spenders.
3. As a percentage of world PCT patent applications, 1999-2009.
4. Scale: X < 0.2 = none or very low patent applications; 0.2 < X < 5 = low patent applications; 5 < X < 15 = moderate patent applications; 15 < X < 25 = medium patent applications; 25 < X < 35 = high patent applications.
5. Renewable energy generation, energy generation from fuels of non-fossil origin (*e.g.* biofuels).
6. Technologies specific to propulsion using internal combustion engine (ICE); technologies specific to propulsion using electric motor; technologies specific to hybrid propulsion; fuel efficiency-improving vehicle design.
7. Air pollution abatement; water pollution abatement; soil remediation; environmental monitoring.
8. Energy storage; hydrogen production (from non-carbon sources), distribution, and storage; fuel cells.
9. PCT patent applications in green technologies; TL2 regions, 2005-07. Only regions with more than 30 patents over the period and accounting for more than 22% of total country PCT patent applications in green technologies are included.
10. *OECD STI Outlook* policy questionnaire and national sources. EU's eco-innovation initiatives are not included.
11. The revealed technology advantage (RTA) index provides an indication of the relative specialisation of a given country in selected technological domains and is based on patent applications filed under the Patent Cooperation Treaty. It is defined as a country's share of patents in a particular technology field divided by the country's share in all patent fields. The index is equal to zero when the country holds no patents in a given sector; is equal to 1 when the country's share in the sector equals its share in all fields (no specialisation); and above 1 when a positive specialisation is observed. Only economies with at least 1% of world patents are considered. Data are drawn from the OECD Patent Database.

Source: OECD Patent and RDS Databases, February 2012 and country responses to the 2012 *OECD Science, Technology and Industry Outlook 2012* policy questionnaire.

Funding systems have generally favoured scientific specialisation, but governments are increasingly adapting their research-financing mechanisms in order to facilitate funding of interdisciplinary research relating to green innovation, *e.g.* by making greater use of competitively awarded project funding

At the operational level, national research priorities for green innovation can be also expressed via the missions of research institutions or through more flexible structures such as centres of excellence. But there are limits and risks associated with a top-down approach to steering and managing university research. A too top-heavy approach is unlikely to provide a cumulative and diverse stream of green innovation because it reduces researchers' freedom and the experimentation that could lead to important but unexpected breakthroughs. At the same time, setting priorities only from the bottom-up can lead to research that is fragmented and lacks a critical mass. Ensuring a broader stakeholder involvement in priority setting can guard against the risk that public research crowds out private research in emerging technologies.

Turning science into green business

As PRIs and universities have become more entrepreneurial, there has been an increase in technology-based economic development initiatives, by improving institutional environments and capacities at national and university level, by the promotion of collaborative industry-science linkages (ISL) to hasten the transfer process, and by efforts to nurture university spin-offs.

There are large differences across countries in the degree to which the public research system (PRIs, higher education, hospitals) contributes to green patenting (Figure 2.1). In Portugal and Singapore, for example, the research system accounted for over 20% of all green patents between 2004 and 2009. Research commercialisation and knowledge transfer are considerably broader than patenting, however. Knowledge transfer channels such as industry-science linkages or publications have been found to be more important (Cohen *et al.*, 2002; Foray and Lissoni, 2010).

Redefining public support for business R&D

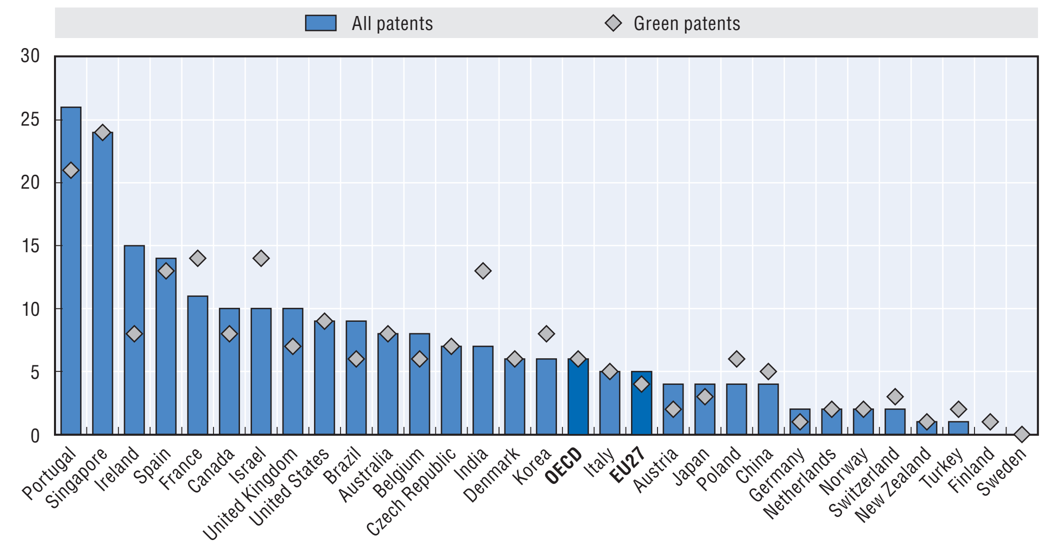
Vertical R&D support policies

While horizontal R&D policies have an impact on the overall rate of innovation, vertical R&D policies have the advantage of addressing precisely defined sectoral and technological opportunities by increasing the rate as well as the direction of innovation. If they favour green technologies, they can, in principle, both facilitate knowledge spillovers and address environmental externalities. However, there is the risk that too narrowly specified requirements will screen out potentially more radical innovations. For example, a funding agency will only fund a proposal if it meets the funder's requirements. To be eligible for funding, therefore, a firm is likely to submit a proposal that is more narrowly defined and likely to be incremental in nature.

Besides targeting less radical innovations, vertical R&D policies and long-term support usually imply higher transaction and administrative costs. Although targeted R&D policy is necessary for a system-wide transition, instruments to offset the weaknesses of this policy approach are also needed. For example, it would have been difficult for policy makers and experts alike to foresee the early uptake of wind technologies compared to solar or biofuels.

Figure 2.1. **Patenting by public research institutions, 2004-09**

As a percentage of patents filed under the PCT



Note: Data relate to patent applications filed under the PCT, at international phase, by priority date and applicant's country of residence (using fractional counts). PRIs include the government sector, higher education and hospitals. Patent applicants' names are allocated to institutional sectors using a methodology developed by Eurostat and Katholieke Universiteit Leuven (KUL). Due to important variations in the names recorded in patent documents, applicants may be misallocated to sectors, thereby introducing biases in the resulting indicator. Technology fields are defined using combinations of codes of the International Patent Classification (IPC) and European Classification (ECLA). For the classification of green patents, see *www.oecd.org/environment/innovation/indicator*.

Source: OECD, Patent Database, March 2012.

StatLink http://dx.doi.org/10.1787/888932689674

Support to SMEs and entrepreneurship

Another supply-side policy area concerns support for small and medium-sized enterprises (SMEs). SMEs often have weak innovation capabilities, and it is harder for them to generate green innovations. Policy can help to improve their access to finance, enable them to participate in knowledge networks, strengthen the skills that can lead to innovation, and reduce the regulatory burden on these firms. Opening (green) public procurement to SMEs may also help strengthen green innovation in such firms.

Evidence shows that small innovative companies have the potential to create new markets and introduce more radical innovations (Veugelers, 2009; Baumol, 2004). New and young firms may exploit technological or commercial opportunities that have been neglected by more established companies, often because they challenge their business models. However, most OECD countries face significant challenges for fostering the growth of new firms. Many have taken steps to simplify and reduce start-up regulations and administrative burdens to entry and have made bankruptcy laws less dissuasive. Consequently, many instruments that support innovative SMEs are being adjusted to favour or encourage green innovation (*e.g.* the US Department of Energy's SBIR/STTR programmes).

Prizes as incentives for private R&D

R&D can also be promoted through programmes that specify demand. Some governments have begun using technology prizes to induce R&D and innovation activities in green areas ignored by business. They can thus address a wide range of potentially relevant technologies and the uncertainties involved in both the technologies and their applications. For example, the US government promotes H-Prizes to seek breakthrough technologies in the hydrogen economy. The prizes can be modified in various ways to alter the outcomes and innovation effects. For example, to increase knowledge spillovers, the winning technology can be made available for licensing and diffusion. Prizes can also be made available for non-technological achievements, such as service innovations that enable firms to restructure their value chains or generate new types of producer-consumer relationships and also enhance environmental performance.

Although prizes may serve a useful role, their impact should not be exaggerated. They can also lead to duplication of R&D efforts, and up-front liquidity constraints can lower firm participation (Newell and Wilson, 2005; Scotchmer, 2004).

Instruments such as matching grants, where it is industry matching the government subsidy rather than the contrary, may allow public funders to screen proposals and to ensure that firms invest appropriately. Also, by inducing competition among applicants – through the use of various auction mechanisms – more information can be obtained about the proposals and some unnecessary funding can be avoided (OECD, 2010b).

Financing green innovation and technologies

While all of the supply-side policies mentioned have a financial aspect, discussions of finance-related technology policy commonly refer to instruments aimed at improving the supply of risk capital via equity, debt, venture capital or changes in capital markets. Access to finance is particularly severe for actors pursuing green innovation, especially new entrants and start-ups. It is difficult to obtain funding at reasonable cost for an immature market with high capital intensity and relatively high risk. Apart from policy relating to debt and equity finance, governments can provide incentives through risk-sharing arrangements or public-private co-investment partnerships in order to overcome investors' resistance.

Institutional investors can provide much of the capital required for green technology and innovation. They use different investment vehicles to access green projects via equity (including indices and mutual funds), fixed income (notably green bonds), and alternative investments (such as direct investment via private equity or green infrastructure funds). To tap into these large assets, governments need to provide clear and consistent policies and regulatory frameworks to signal credibility to potential investors. Institutional investors are not venture capitalists, however. They may look for potential investments with steady income streams and are therefore more likely to invest in established and mature technologies (Della Croce *et al.*, 2011).

Complementary means of increasing the supply-side response

Skills and infrastructures

Government support for training and skill enhancement is central to the development of a highly trained workforce with the technical and scientific expertise needed for green technology and innovation. Several studies and programmes have addressed the need for "green" labour in downstream sectors through the upskilling of the workforce (OECD, 2011d). Meeting the complex challenges of green technologies and innovation will also require efforts on the upstream side: researchers who understand several disciplines, even if they are more specialised in some than in others. The challenge is to adapt or adjust graduate training programmes and curricula to create ecosystem thinking in science. The Green Innovation Management Educational Unit at the Center for the Promotion of Interdisciplinary Education and Research of Japan's Kyoto University may serve as an example of ecosystem thinking in science.

Infrastructure is a prerequisite for the production of knowledge. Research infrastructure has many dimensions, both tangible and intangible. It supports the design, deployment and use of technology. As integrating knowledge from different disciplines becomes essential for green research, large national and international research infrastructures will play an increasing role. Existing multidisciplinary and basic science research infrastructures, for example, have already permitted essential advances in material sciences and in the comprehension of fundamental physics mechanisms, which are the basis of innovation in some green R&D activities. In addition, scientific research can lead to technological advances, but technology also affects advances in science. Large databases have become increasingly important and advances in quantum photonics have significantly affected the mechanisms for moving data faster, as exemplified in the accelerating use of supercomputers (Stephan, 2010).

The sharing of equipment and research materials will play a considerable role as research infrastructure investments are costly. Several initiatives have attempted to leverage resources and achieve economies of scale. In the European Energy Research Alliance, one of the SET Plan initiatives, the research infrastructure issue is central to the development of joint research activities. Policy options also include provision of funding to the research infrastructure facility to subsidise free access, or provision for funding access as part of research grants in the form of technology vouchers. In Australia, for example, the New South Wales government has implemented a system of TechVouchers to encourage collaboration and use of research infrastructure.

Networks and partnerships

Clusters, networks and technology platforms can also be viewed as mechanisms for increasing the supply-side response but also for bringing supply and demand together. In general, agglomeration effects arise when proximate economic activities benefit companies because of access to skilled labour and to specialised suppliers and because of inter-firm knowledge spillovers. They can bring together innovating firms, university laboratories and downstream users, and thereby internalise positive network externalities that might otherwise be lost. For example in northern and southern California, inter-firm and inter-sectoral knowledge spillovers facilitated and nurtured the emergence of green clusters from agro-food, information and communication technology (ICT) and biotechnology industries (Burtis *et al.*, 2006).

For such reasons, knowledge-intensive firms locate in localities/regions with high-quality scientific infrastructure (*e.g.* universities and PRIs) and will co-locate with other knowledge-intensive firms. Clusters and agglomerations may therefore account for a large share of a country's innovative efforts in green industries. For example, about 60% of Finland's environmental business is covered in the Finnish clean tech cluster, and 80% of the sector's R&D is conducted in this framework (Nordic Innovation, 2012).

Public-private partnerships (PPPs) can provide effective ways to mobilise private and public resources for green innovation by drawing on the respective advantages of the private and public sectors. The formation of strategic government-industry R&D consortia has intensified in recent years in OECD and non-OECD countries. The aim is to address the lack of core technological competences and long-standing problems involving general purpose technologies that can hamper promising development paths (*e.g.* Germany's National Platform for Electric Mobility or China's industry-research strategic alliances). Private-private partnerships such as the Electric Power Research Institute (EPRI), which pools the research capacities of US utility firms, illustrate the importance of R&D co-operation in a sector in which no actor has adequate capacity on its own (Lee *et al.,* 2009).

Intellectual property rights and knowledge dissemination

Intellectual property rights (IPRs) play a crucial role in new product development and diffusion of knowledge. On the one hand, they encourage investment in innovation by allowing firms to recover their investment costs. On the other, tensions can arise between technology diffusion and maintaining appropriate incentives to invest in innovation. For green technologies, IPRs can take various forms. For example, in wind-power technology IPRs may include patents for the wind turbine; a copyright for software related to aerodynamics, generators and blade controllers; a design for the turbine; and a registered trademark for the brand. Furthermore, the manufacturing process is covered by the concept of "trade secret".

Various proposals have been made to expand green innovation by using the IPR system as a channel for technology development and diffusion. Some OECD governments have sought to encourage actors to learn about the IPR system and apply for green patents. Still others push for changes to accelerate technology transfer to developing countries.

The effectiveness of an IPR regime relies on effective institutions and procedures such as effective enforcement. Competition authorities play an important role in ensuring that patents are not used anti-competitively (*e.g.* through standard setting). To accelerate the development and diffusion of green technologies, innovation incentives can include lower application fees, prioritised examination, expedited examination, approval procedures and diminished standards in the "green" area (see Maskus, 2010, for an overview). Fast-track programmes for green patents have recently been introduced in some national IP offices (Box 2.2). These vary widely in their eligibility requirements and process parameters (Lane, 2012). Some national and regional patent offices offer access to search and patent mapping services. The Korean Intellectual Property Office (KIPO), for example, launched the Green IP Information Project to collect and analyse various green technologies.

By facilitating access to prior inventions and providing incentives for the disclosure of new inventions, the sharing of public sector knowledge (*e.g.* through "open science") serves as a powerful framework for disseminating knowledge relevant for green technologies. The rationale for public policies that support "open science" focuses on the economic and social efficiency aspects of rapid and complete information disclosure for the pursuit of knowledge (Aghion *et al*., 2009). Open science initiatives that support access to research data and knowledge networking initiatives (*e.g. OECD Guidelines on Access to Research Data from Public Funding*) can help foster the exchange of proprietary knowledge.

Box 2.2. **Examples of green fast-track examination systems**

Canada: In March 2011, the Canadian Intellectual Property Office's (CIPO) initiative to expedite the examination of patent applications related to green technology came into force. No additional fee is required for advancing the examination of patent applications related to green technologies. To have access to the expedited examination service for green technologies, a patent applicant must submit a declaration stating that the application relates to a technology, whose commercialisation would help to resolve or mitigate environmental impacts or conserve the natural environment and resources. In addition, CIPO will be setting new service standards to speed up the prosecution of all patent applications that benefit from expedited examination. The amendments also eliminate undue delays that are contrary to the objectives of the accelerated examination provision.

United Kingdom: The UK Intellectual Property Office has developed a strategy specifically to facilitate the protection, management and appropriate exploitation of intellectual property connected with low-carbon technologies. On 12 May 2009, a Green Channel for patent applications was established. The service is available to any patent applicant whose invention has some environmental benefit. There is no specific environmental standard to meet in order to benefit from the Green Channel, and it is recognised that inventions with an environmental benefit can arise in any area of technology.

United States: In December 2009, the US Patent and Trademark Office (USPTO) launched a pilot programme to accelerate the review of green technology patent applications. It was established to take patent applications that pertain to environmental quality, energy conservation, development of renewable energy or greenhouse gas emissions reduction to the front of the line for expedited examination. Patent applications are examined by filing date. The Green Technology Pilot Program was modified several times. As of the end of April 2012, 3 533 petitions had been granted. The USPTO announced that the programme will be terminated in March 2012. Alternatively, the USPTO instead invites applicants to make use of the *Prioritized Examination (Track I) programme* or the *accelerated examination programme*.

Source: OECD Science, Technology and Industry Outlook 2012 policy questionnaire.

Beyond technology-push: Innovation policies for diffusing green technologies

Many OECD countries increasingly recognise that traditional supply-side innovation policies – despite their importance – cannot on their own improve innovation performance and productivity. Demand-pull theories suggest that the ability to produce innovations is often widespread and flexible but requires market opportunity (*i.e.* demand). Innovative solutions to meet the green growth challenge are hampered not only by technological barriers but also by the lack of supporting market conditions. This is very much an issue for achieving economics of scale.

The range of policies that affect the demand side vary widely and take many forms. It can be argued that demand-side innovation policies should encompass the whole national innovation system, from direct measures such as green public procurement policy to indirect measures such as pricing policies (OECD, 2010c; OECD 2011e). Policies that affect demand for innovation include income policies that affect consumers' purchasing power, market regulations and market mechanisms. Carbon pricing, taxes and subsidies such as feed-in tariffs can induce demand for renewable energies; consumer policy can incite changes in behaviour (*e.g.* municipal recycling rules). Regulation can spur demand for green innovation, although the impact of regulation varies across sectors, industries and technologies. Standards also affect demand for innovation, especially in industries characterised by economies of scope. Networks can facilitate the creation of a critical mass of users to enable technologies to penetrate the market. At the micro level targeted demand-side policies would include green public procurement which can help foster market demand for green products and services.

Demand-side innovation policies

Green public procurement

Public procurement has played a key role in the development of high-technology sectors and industries. In the United States, demand from the military – in conjunction with military R&D programmes – contributed to the development and diffusion of technologies such as the Internet and the Global Positioning System (GPS). As public procurement accounts for 15% of GDP in OECD countries, many governments today aim to include innovation in general public procurement, for example through awareness-raising measures and training of procurement agency personnel, and to stimulate innovation through more direct measures such as specific functional or performance standards in public tenders.

Many OECD countries have introduced programmes to encourage green innovation by providing and enlarging core public demand. Public procurement can create a market for green technologies that face cost disadvantages and can facilitate feedback between experimental users and technology providers. It can also promote diffusion of such technologies and services by overcoming information asymmetries and a potential consumer bias against green products and technologies.

The general procurement framework can have an indirect demand-pull impact if (environmental) regulations and industry standards help make public procurement more innovation-friendly and if green innovation becomes a by-product of general procurement. It can also encourage technological innovation more directly by specifying green innovative goods and services. In 2003, the European Commission called on member states to adopt national action plans for green public procurement. Although they are not legally binding, 21 member states have adopted such plans. The measures and criteria vary.

Studies on semiconductors and other electronic innovations suggest that public procurement contracts can serve the same function as a prize and induce innovative efforts by business (Mowery *et al.*, 2010). Some OECD governments, for example, have guaranteed public procurement for award-winning technologies in energy-efficiency competitions.

Reverse auction is yet another procurement tool that can be used to support the commercialisation of green technology. This would require procurement of green technology outputs (*e.g.* second generation biofuels) up to a given cost, at prices determined through competitive bidding. The US Department of Energy issued in mid-2010 a notice for a first reverse auction, with a budget of USD 4.6 million. It aims to stimulate the production of cellulosic bio-fuels, with a target of 1 billion gallons for 2013.

Regulation

Regulation, the implementation of rules by public authorities and governmental bodies to influence the behaviour of private actors in the economy, has been identified as an important mechanism in terms of diffusion and adoption of green technologies. Regulation influences innovation indirectly, since it affects the framework conditions for firms and involves no direct outlay of public funds (Geroski, 1990). For example, energy efficiency or environmental pollution regulations are used in the absence of market mechanisms to influence agents' behaviour and to achieve certain social or economic objectives. Germany's *Promotion of Renewable Energies Heat Act* (2009) encourages the diffusion of green innovations because it obliges owners of new buildings to use renewable energies.

However, the effects of economic regulation on innovation are far from straightforward. Some of the literature suggests in fact that regulation can both inhibit and stimulate innovation. The impacts of regulation on innovation are also likely to be highly technology- and industry-specific. OECD analysis shows that anticipation of regulatory change has induced innovation in some sectors (OECD, 2011f). To assess the appropriateness of regulatory policy targeting a specific sector, analysts also need to explore whether the market would introduce appropriate technology in the absence of regulation.

Regulations interact with market-based incentives and it can be relatively difficult to isolate the specific effects of regulation. This is due to the complex ways in which regulation may shape innovation, the possibility of long lead times between a regulatory stimulus and an industry response, the simultaneous impacts of an array of supply-side factors, as well as the inherent uncertainties in the dynamics of innovation (including exhaustion of the research frontier).

In the context of green technologies, policy makers have made significant use of environmental regulation in recent years and the effects on innovation have been extensively analysed. The evidence shows that environmental regulation has had positive impacts on green innovation and its adoption (Blind, 2012; OECD, 2011f). Conventional approaches to regulating the environment are often referred to as "command-and-control" (*i.e.* performance- and technology-based) as opposed to market-based environmental regulations and standards. In general, market-based policies provide incentives for constant incremental improvements, whereas "command-and-control policies" punish polluting firms that do not meet the standard, but they also do not reward those that perform better than mandated (Popp *et al.*, 2009, Stavins, 2003). Environmental policy design has thus been used more to reduce environmental externalities than to make targeted use of regulation for innovation purposes.

Standards

At their root, standards are documents based on various degrees of consensus which lay out rules, practices, metrics or conventions used in technology, trade and society at large (OECD, 2010c). Standards can be categorised in many ways and the driving forces include network effects, switching costs, government policy and intellectual property regimes, as well as other environmental factors (Blind, 2004; see Narayanan and Chen, 2012, for an overview). Even if they are developed for a single purpose they often serve several.

Standard-setting activities and organisations need to be understood and monitored by policy makers. The setting of standards is mainly the responsibility of different types of organisations: industry bodies (private), governmental (public) and non-profit technical bodies (hybrid) (Funk and Methe, 2001). Governments can act as facilitators and co-ordinators while industry bodies must be supported by firms as well as by governments. Firms commonly use standards strategically by steering and facilitating the adoption of *de facto* technology standards (Narayanan and Chen, 2012).

Standards may be developed by technical experts working in government agencies but in most cases they adopt standards developed by industry bodies for reasons of expediency and because of a lack of technical expertise (*e.g.* California Air Resources Board). Depending on the nature of the standards, in particular for environmental standards, some are enacted through legislation and are mandatory, whereas others are voluntary but are adopted by entire sectors (*e.g.* EU emission performance regulation) (Contreras, 2011).

A limit on the role of government in standards setting is the fact that for many technologies, standards are set openly at the international level. Efforts to impose national standards through public procurement, for example, are risky and costly as it is difficult to determine in advance what will become the dominant standard in a rapidly evolving area such as green innovation and may lead to technology lock-in. Procedures in standards bodies can also be slow and bureaucratic and may be influenced by large players.

The economic benefit of standards has become clearer to policy makers in recent years. Standards can affect incentives for diffusing green innovation in several ways. They provide information that facilitates the diffusion of innovation and economies of scale and they remove bottlenecks. Technical standards facilitate the organisation of network industries (*e.g.* by promoting interoperability or facilitating the substitution of old technologies or their co-existence with new ones) and value chains. It is sometimes argued that standardisation acts as much to enable as to constrain diffusion.

Technical standards are likely to play an increasingly prominent role in the development, adoption and regulation of green technologies. Most environmental policy and public procurement relies on standards. In the environmental area, performance-based environmental regulation and procurement promote minimum levels of performance for innovators and foster confidence among consumers. The UK government decided to support standardisation in biometrics, with technical standards that support interchangeability and interoperability. A 2009 review of standardisation and innovation programmes in the United Kingdom found that this had facilitated the diffusion of technology in the marketplace, made procurement more cost-effective and eased SMEs' access to the procurement market (OECD, 2010c).

Catalysing the demand-side response

Consumer policies

As consumers and users become catalysts for innovation, by creating demand and facilitating the diffusion of innovation, consumer policy takes on growing importance. Consumer policy regimes and consumer education play a role in promoting innovation in key innovative markets and can help ensure that confident consumers make informed choices. Potential private adopters of green technologies may be uncertain about the technology's quality and performance. It is therefore necessary, for example, to address behavioural biases to foster "greener" consumer choices and to enhance the quality and reliability of information on green goods and services, for example through green labelling. The potential savings to be achieved through resource-efficient technologies depend on scenarios which are uncertain and rely on many assumptions. This may lead firms and consumers to postpone the purchase of the technology.

Consumer policy can be used to counter inertia and scepticism towards new goods and services and help improve the flow of information between users and developers. One way to lower information barriers and to reduce information asymmetries is to improve the quality of claims made by firms that have expanded the use of self-declared "green claims" as a corporate marketing tool. To improve the value and effectiveness of such claims, some governments have prepared guides to help business develop and/or use green claims. The US Federal Trade Commission's *Green Guides* are a case in point. Finland and Norway have developed sector-specific guidance on the use of terms such as "carbon-neutral" and "energy-efficient" (OECD, 2010d).

Adoption and deployment policies

OECD governments provide a wide range of financial or price support mechanisms to business and/or consumers to encourage the adoption of green products and services. These measures are intended to help stimulate adoption and diffusion by reducing the price of the technology being adopted or by affecting behaviour (OECD, 2012a):

- Fiscal and financial incentives to reduce prices can be direct subsidies such as feed-in tariffs, consumer grants or financial transfer payments or tax incentives such as tax reliefs or tax credits (Table 2.2 provides recent incentive schemes for green vehicles).
- Fiscal and financial disincentives (environmental taxes and charges) are designed to influence the behaviour of producers and/or consumers while raising government revenue and covering the costs of environmental services (*e.g.* petrol tax, congestion charges).

In addition, several governments have used tax measures and subsidies to support growth and exports to new markets abroad. As world demand increasingly values green technologies, governments speculate that this could lead to future benefits, more internationally competitive sectors and more innovation.

OECD governments also provide support for large-scale demonstration projects or pilot plans to overcome the "valley of death", with its high technological and financial risk. The aim is to gain first-hand information about operation, maintenance and opportunities for incremental innovation and to create social acceptance. As part of its Economic Action Plan, Canada's Clean Energy Fund is investing in large-scale carbon capture and storage (CCS) demonstration projects and smaller-scale demonstration projects on renewable and alternative energy technologies. A key example is the federal government's CAD 120 million investment in the CCS Shell Quest project. In the same vein, Austria's new Energy Research Initiative (ERI) provides support for the creation of prototypes that use hydrogen and carbon dioxide as energy sources.

A common problem with adoption policies, notably direct subsidies, is that they involve large budgetary costs per unit of effect (including high transaction and monitoring costs). Without adequate phase-out schedules they can trap resources in subsidised "green" sectors. In addition, subsidies can provide perverse incentives that may lead to an increase in energy use ("rebound effects"). Evaluation is required to assess the sustainability claims of the respective sectors and to limit the risk of costly but ineffective intervention.

In practice, adoption policies are often used as an extension of industrial policy. Most OECD countries' support for renewable technologies amounts to industry policy instruments. They may build local manufacturing capacity to support deployment of renewable electricity technologies or provide support to local vehicle manufacturers. Government support may be in conflict with World Trade Organization (WTO) rules if it involves subsidies that can disadvantage foreign competitors and distort competition. However, whether or not subsidies, such as feed-in tariffs, constitute a breach of WTO rules depends on the actual design and implementation of the policy programme.

Table 2.2. **Recent trends in the provision of fiscal and financial incentive schemes for green vehicles in selected OECD countries**

Belgium	Electric vehicles (EV) benefit from a tax deduction of 30% of the purchase price, up to EUR 9 000 in 2011 and EUR 9 190 in 2012. An additional measure provides for a tax deduction of 40% of the investment for the installation of a charging station outside private houses (up to EUR 250 in 2011 and 2012). Further tax incentives are given at the regional level, both in Flanders and in Wallonia
Canada	Several incentive schemes exist at provincial level. For example, Ontario established an Electric Vehicle Incentive Programme in 2010, with incentives from CAD 5 000 to CAD 8 500 for the purchase or lease of a highway-capable plug-in hybrid or battery electric vehicle (EV).
Estonia	Private, commercial and public buyers of fully electric passenger cars are eligible to receive an incentive of 50% of the vehicle price. The maximum amount of the grant is EUR 18 000 per car (in addition to EUR 1 000 for setting up a Mode 3 home charger). The car can be purchased in any EU country, but second-hand vehicles are not eligible. The financial envelope allocated to the scheme allows incentives for 500 electric vehicles.
France	Since 2007 a "bonus-malus" (*i.e.* reward-penalty) scheme has provided any new car buyer a combination of financial incentives and disincentives which depend on the vehicle's CO_2 emissions. This one-time purchase tax (subsidy) levies a malus from EUR 200 to EUR 3 600 or provides a bonus from EUR 300 to EUR 5 000. In addition, there is a "super bonus" of EUR 200 which consists of an additional premium paid in case of the disposal of an old vehicle (more than 15 years old) and the purchase of a new green car.
Israel	Reduced vehicle tax rates apply to electric and hybrid cars (10% and 30%, respectively). In June 2012 new legislation came into force extending the incentives and making them more generous.
Italy	In 2011 the government offered incentives for the conversion of gasoline-powered engines to LPG and methane-powered engines. At the end of April 2011, EUR 23.4 million of incentives had been requested, for the conversion of 45 308 LPG engines and 5 474 methane engines. In addition, holders of EVs are exempted from the motor vehicle ownership tax for a period of five years, after which EVs are taxed at the 25% rate applied to non-electrically powered vehicles in the same category.
Japan	As part of its Next Generation Vehicle Strategy 2010, Japan's government earmarked USD 356 million in fiscal year 2011 for the installation of infrastructure but also incentives for purchasing EVs and PHEVs (plug-in hybrid EVs). Part of this financial envelope aimed at subsidising half of the difference between the price of an EV or PHEV and the base vehicle model.
Korea	The 2010 Strategy for Green Car Development foresees the introduction of a bonus-malus scheme and other incentives for consumers to purchases green vehicles in 2012. In addition, a tax incentive of up to KRW 3.1 million per vehicle is offered for the purchase of hybrid-electric vehicle (HEV).
Netherlands	A package of tax measures creating incentives for energy-efficient vehicles was submitted to Parliament in June 2011. It is proposed to apply a 0% rate to all vehicles with CO_2 emissions of 50 g/km or lower, a standard currently met only by pure EVs and some range-extended EVs and PHEVs. All fuel-efficient cars are exempted from the motor vehicle tax until 2014, but vehicles with emissions of 50 CO_2 g/km and lower will be exempt until 2015, in practice giving electric vehicles an advantage over other fuel-efficient propulsion technologies. Criteria for exemption from the Private Motor Vehicle and Motorcycle Tax (BPM) will gradually become stricter, so that the exemption will remain fully in effect until 2018 only for EVs, PHEVs and range-extended EVs.
Norway	Incentives to promote the use of EVs include: exemptions from the first-time registration tax, VAT and road tolls; reduction of the annual motor vehicle tax; and permission to use lanes otherwise reserved for public transport.
Portugal	In 2010, Portugal introduced financial incentives specific to electric propulsion: EUR 5 000 for the first 5 000 buyers of light-duty EVs; EUR 1 500 for scrapping an old vehicle and acquiring an EV.
Spain	In 2012, the government confirmed the regulatory framework for incentives for EV purchases introduced in 2011, and fixed the maximum budgetary allocation at EUR 10 million. The Ministry of Industry, Energy and Tourism will subsidise 25% of the sales price of the vehicle (before taxes), up to EUR 6 000 for individual users and fleets, and up to EUR 30 000 for large vehicles (*e.g.* buses). If the vehicle does not include the battery, the individual subsidy can reach 35% of the sales price.
United Kingdom	In the United Kingdom, the government, through the Office for Low Emission Vehicles, made GBP 300 million available over the lifetime of the current Parliament for a Plug-In Car Grant (PiCG) for ultra-low-emission vehicles. Motorists purchasing an eligible vehicle (of which there are currently ten, from a range of manufacturers) can receive a grant of up to 25% of the cost of the vehicle, capped at GBP 5 000.
United States	In 2009, a new scheme of green car incentives was introduced as part of the American Recovery and Reinvestment Act, which offers much more generous incentives to PHEVs and EVs. Under the new scheme, buyers of PHEVs or EVs benefit from a tax credit of USD 2 500 to USD 7 500, depending on the equipped battery size. The credit begins to be phased out for each manufacturer after 200 000 qualified vehicles have been sold by that manufacturer, rather than phased out once the total number of qualified vehicles sold by all manufacturers reaches 250 000. In March 2012 the administration proposed to amend the tax credit along these lines: expand the eligibility of the credit to a broader range of advanced vehicle technologies; increase the amount from USD 7 500, up to USD 10 000; make the credit available at the point of sale, so that consumers can benefit from it when they purchase the vehicle rather than when they file their taxes; remove the cap on the number of vehicles per manufacturer eligible for the credit and, instead, decrease and eventually eliminate the credit towards 2020

Source: Beltramello, A. (2012), "Market Development for Green Cars", *OECD Green Growth Papers*, OECD, Paris, forthcoming.

Enabling governance structures to facilitate transition

Governance will play a key role in transitioning to green technology and innovation. The OECD area provides ample evidence that countries' innovation performance depends in part on the quality of the governance of STI, *i.e.* the set of largely publicly defined institutional arrangements, incentive structures, etc., that determine how the various public and private actors engaged in socioeconomic development interact in allocating and managing resources devoted to STI.

Much of the debate on green innovation has focused on the relative importance of supply- and demand-side factors, sometimes opposing "supply-push" innovation induced by public R&D and "demand-pull" innovation induced by competitive market forces. While both frameworks provide insight into how innovations arise, both have shortcomings for analysing the complexity and non-linearity of innovation systems. Technology-push fails to account for market conditions, while demand-pull ignores technological capabilities. As a result, it is argued that both supply- and demand-side factors are necessary for innovation. It is not simply that they both contribute; they also interact. Recognition of the essential interaction between the two is reflected in the broader academic literature,[5] which finds that demand-side innovation policies need to complement supply-side policies rather than replace them. The policy challenge in OECD countries therefore seems increasingly to find means of bridging and linking supply-push instruments with demand-pull instruments in order to influence the rate and direction of green innovation in a decentralised manner. Effectively linking supply- and demand-side innovation policies is a governance challenge at various levels, both horizontally (across ministries, agencies and with industry) and vertically (central *versus* regional governments and with industry).

The challenge of linking supply-side and demand-side innovation policies through governance

Central to governance frameworks are the co-ordination mechanisms that bridge the various policy areas that can foster green innovation. Policy co-ordination is an essential part of a green innovation system. It ensures the coherence of measures to reduce environmental degradation through market mechanisms and regulation and those that aim to do so through innovation measures. Various developments have made this difficult to achieve (OECD, 2010e). Policy co-ordination of separate policy areas (*e.g.* S&T policy, economic policy, environmental policy, transport policy, agricultural policy, industrial policy) encounter hurdles such as inertia of actors, incompatibility of policies or dominance of certain ministries/agents. Even in sub-parts of the system, such as the R&D system, the lack of a shared vision regarding the transition can lead to misaligned or conflicting research agendas and sector/ministerial goals and to excessive competition and unnecessary duplication of effort. Institutional path dependencies can also be an obstacle to adapting governance structures to meet the green growth challenge.

Furthermore, demand-side policies are not always distinct from supply-side policies. Yet, responsibility for demand-side policies such as tax incentives for green technology use, regulations, standards, public procurement or consumer policy is often far removed from the ministries and agencies responsible for promoting R&D and entrepreneurship or for meeting demand from public missions (*e.g.* transport ministries). There are some attempts to integrate demand-side policies, such as public procurement, in the design of supply-side policies such as R&D grants or, as in some countries, the simultaneous use of feed-in tariffs while supporting green R&D. At the same time, not all potential failures and barriers make government intervention necessary or desirable. There is no guarantee that government policy will be able to address a market or systemic failure in a way that effectively improves the outcome, *e.g.* in welfare terms.

However, although the idea of simultaneous use of demand- and supply-side policies is simple and intuitive and is widely accepted in the academic literature, its transposition to a real world situation is not always straightforward. There can be as much variation within policy types, as between them. It may sometimes be difficult to make a sharp distinction between supply- and demand-side innovation policies (Wintjes, 2012).

This has been apparent in the design of a number of policies. Prizes have included demand-side factors and can make the winning technology publicly available, thereby enhancing knowledge spillovers and dissemination; the IPR system may encourage both innovation and diffusion; and systemic policies such as cluster policies can bring together innovative firms and downstream users. Innovation or research vouchers are another policy tool for bridging supply and demand. They subsidise the purchase of research or technology services by SMEs either from other firms or from public research.

Governance decisions are also very much driven by political rather than economic considerations. In view of the fact that the transition to green growth will involve losers and winners, some ministries/agencies may be reluctant to upset their clientele through active co-ordination efforts in the area of green innovation.

New institutions and mechanisms for transformative change

A number of OECD countries have introduced institutions and means of improving the overall coherence of supply- and demand-side innovation policies, such as the creation of mission agencies and joint decision-making modes of governance involving green growth committees (Box 2.3), consortia and public-private partnerships.

For fragmented markets with large information asymmetries, institutions can assume specific co-ordination tasks and responsibilities for creating attractive investment environments. Recent examples include the US Clean Energy Deployment Administration Agency (CEDA), the Slovak Innovation and Energy Agency (SIEA) and the Australian Renewable Energy Agency. However, such programmes have met with mixed success. Research funding structures, the permanence of institutional settings as well as the degree of flexibility within agencies remain a problem. There is also the issue of what a larger centralised organisation sees as priorities and the priorities of different agencies' clientele (Etzkowitz and Leydesdorff, 1998).

Another possibility is for the government to give funds to a network or consortia which uses an internal decision-making process to allocate the funds among different research projects. For example, the Danish Ministry for Science, Technology and Innovation has announced plans to establish a model for a green public-private consortium, consisting of businesses, universities, technological service institutes and technological networks in green areas of research.

Given the difficulty of a systematic analysis of all of a country's programmes and initiatives, locally embedded institutions can provide relevant consultancy services or focus on information dissemination. This can provide a useful arena for mediation and negotiation to achieve policy goals. The UK Energy Technology Institute (ETI) (Box 2.4) and the Spanish Environmental Technology Platform (PLANETA) are examples of institutions that facilitate co-operation and knowledge sharing among policy makers and across the private and public

Box 2.3. **Green growth committees: A model of governance?**

Australia: In 2010, the Australian government announced the establishment of a Multi-Party Climate Change Committee to build a consensus on how to tackle the challenge of climate change and to explore options for policy measures. The Committee's membership was comprised of: Prime Minister, the Hon. Julia Gillard MP (Chair); Deputy Prime Minister and Treasurer, the Hon. Wayne Swan (co-Deputy chair); Minister for Climate Change and Energy Efficiency, the Hon. Greg Combet AM MP (co-Deputy Chair); Senator Christine Milne (Australian Greens) (co-Deputy Chair); Senator Bob Brown (Australian Greens); Mr. Tony Windsor MP (Independent); Mr. Rob Oakeshott MP (Independent). In addition, two members of Parliament were invited to assist the Multi-Party Climate Change Committee: Parliamentary Secretary for Climate Change and Energy Efficiency, the Hon. Mark Dreyfus QC MP and Mr. Adam Bandt MP (Australian Greens).

The committee met regularly and carefully considered a wide range of issues in developing the Clean Energy Future Plan. It was advised by a panel of four experts, who were selected on the basis of their eminence in the fields of climate change policy, economics, social policy and climate science, and were drawn from academia, the community and business sectors. The committee was also supported by a group comprised of the heads of the government departments who would share responsibility for the implementation of a carbon price and the associated programmes.

The government sought input from interested parties on the basis of the proposed architecture. Some 1 300 submissions were received during the consultation period, including from industry associations, non-government organisations and community groups, state and local governments, businesses and private citizens. The submissions were held in confidence and were not made public so as to allow the expression of full and frank views. Individual authors could make their submissions public if they chose. Following the work undertaken by the committee, the government announced the Clean Energy Future Plan. In addition, an independent body, the Climate Change Authority, will start work from July 2012. It will advise the government on the setting of carbon pollution caps and will conduct periodic reviews of the carbon pricing mechanism and other climate change laws.

Korea: The Korean government's National Green Growth Strategy aims to support sustainability in growth and to pursue a low-carbon green growth society. It covers various policy implementation instruments such as direct investment in R&D, enforcement of regulation, incentives for participants and enhancement of civil awareness. The government plans to invest approximately KRW 107 trillion during 2009-13 in the development of new green technologies and the building of soft and hard infrastructure, so as to generate both jobs and high value added and lead to new markets and industry.

In order to co-ordinate R&D policy, the National Science and Technology Council (NSTC, a top advisory entity to the president) is closely linked to the Green Growth Committee. Funding is both top-down and bottom-up and based on open competition. NSTC's semi-annual reviews are important for securing a budget from the government. The first review is usually made to set national R&D priorities and suggest directions for key R&D budget allocations. The second review gives detailed comments, by fields, on R&D budget requests from ministries.

NSTC's comments go directly to MOSF (Ministry of Strategy and Finance, which develops the yearly budget) following a full discussion and co-ordination at NSTC meetings. Then, the Budget Office of MOSF prepares the budget taking account of NSTC's comments on budget requests from the ministries and evaluations of major projects. Budget allocation is based on R&D investment priorities and the nature of each project. One of the top priorities is development of green technology. The Presidential Committee on Green Growth, which co-ordinates the Green Growth Strategy, works closely with NSTC in the budget process. In general, a variety of actors and factors are involved in the budget process at national level, and each ministry takes responsibility at project level.

Source: OECD case study.

Box 2.4. **UK Energy Technologies Institute**

The Energy Technologies Institute (ETI) was set up in 2007 to accelerate the development and deployment of low-carbon energy technologies in order to help meet the United Kingdom's energy and climate change goals for 2020 and 2050. It is a 50:50 public-private partnership between the UK government and its departments involved in energy, environmental and innovation policy and industry partners with strategic interest and influence in these areas.

The ETI is a member of the Low Carbon Innovation Co-ordination Group (LCICG), which co-ordinates the country's major funding and delivery bodies backed by the public sector in the area of low carbon innovation. There are six private-sector members: BP, Caterpillar, EDF Energy, E.ON, Rolls Royce and Shell, (the "industry members"). The Department for Business Innovation and Skills (BIS) leads for the government with funding from the Engineering and Physical Science Research Council (EPSRC); the Technology Strategy Board (TSB) and the Department for Energy and Climate Change (DECC) are observers on the Board. Each of the industry members contributes GBP 5 million a year to the ETI budget, a sum that is matched by the public sector. This gives the ETI access to GBP 60 million a year.

The aim is to fund a range of large-scale projects, usually in the GBP 5-25 million range. Projects are funded on the basis of a set of agreed deliverables and an agreed budget and timeframe. Payment of actual costs is based on milestones achieved and accepted by the ETI. The ETI takes a project-based approach to accelerating the development, demonstration and eventual commercial deployment of a range of energy technologies. As of June 2012, 37 projects had been commissioned for a value of GBP 152 million. By commissioning individual projects the ETI is able to make targeted commercial investments in areas in which it has determined it will have the greatest impact. The projects, undertaken within a number of technology programme areas, arise from and help inform the ETI's technology strategy.

Nine technology programme areas have been identified through strategic analysis as having the greatest impact. These are offshore wind, marine, distributed energy, buildings, energy storage and distribution, carbon capture and storage, transport, and bio energy and the latest programme area to be announced in smart systems and heat. These areas constitute the ETI's current priorities. The portfolio of projects across technology areas is chosen to ensure effective use of resources and quality of output. The portfolio has evolved over time and is continually reviewed against the aims of affordable, clean and secure energy systems.

At the outset, it was envisaged that the ETI would be evaluated according to the following criteria: *i*) the contribution that its activities collectively make to building research capacity in the relevant technical disciplines to achieve the country's domestic and international energy goals; *ii*) the extent to which the Institute demonstrates practical success in helping to accelerate key technologies towards commercial deployment; *iii*) the extent to which its activities collectively help to achieve the United Kingdom's domestic and international goals; and *iv*) the extent to which its activities collectively have wider economic benefits. ETI projects are evaluated individually upon completion against the original project value proposition.

Although most of the ETI's work focuses on the supply side of low carbon energy innovation, the ETI provides an interesting example of how, by linking key players in the low carbon energy landscape and by taking a holistic approach to technology development, demand-side barriers to the development and deployment of low carbon energy technologies can also be taken into account.

Source: OECD case study.

sector. The Flemish government established the Innovation Platform for Environmental Technologies (MIP) to develop joint measures and projects that take advantage of synergies between private and public actors, using both demand- and supply-side measures.

The United Kingdom is considering whether it would be more effective to restructure and readjust current institutional settings. The Low Carbon Innovation Delivery Review, currently under way, looks at how best to co-ordinate government support for low-carbon innovation given the specific challenges it presents. The review will consider options for enhancing the delivery of direct public support for low-carbon technologies during the spending review period and beyond.

Enabling governance through transition management

These examples show that the involvement of public and private actors in agenda and priority setting represents a vital aspect of co-ordination in otherwise fragmented markets. A more far-reaching approach for stimulating system changes is offered by the so-called "transition management", a concept borrowed from the business sector but applied to the development of sustainable technologies. Pioneered in the Netherlands, it is designed for the development and commercialisation of "niche" technologies that might be successfully scaled up or abruptly shift socio-technical regimes towards more sustainable paths.

The government of the Netherlands took a transition approach, which ended in 2010, through the Interdepartmental Project Directorate Energy Transition (IPE). This involved six energy transition platforms and the "unique chances subsidy scheme" to support transition experiments (Arundel *et al.*, 2011; Nill and Kemp, 2009). Finland's recent

Box 2.5. **Finland's TransEco programme**

TransEco is a five year (2009-13) Research Programme on Energy Efficiency and Renewable Energy in Road Transport initiated by experts on vehicle technology and biofuels of the VTT (the Technical Research Centre of Finland). The 20 projects of TransEco fall into five categories: vehicle technology; fuels; traffic systems; international co-operation and networking; co-ordination, dissemination and communication. The research partners of the programme are the VTT Technical Research Centre of Finland, Tampere University of Technology, the Aalto University School of Science and Technology, University of Oulu, Metropolia Polytechnic, Turku Polytechnic and Motiva Ltd. In addition to the research projects firms have projects attached to the programme.

The funding comes from different stakeholders and is directly allocated to the projects. There is no pre-allocated amount of funding for the programme. The biggest financers of the programme are Tekes (the Finnish Funding Agency for Technology and Innovation) and VTT's internal funds. Other financers include ministries (Transport, Economy and Employment, Finance), companies and public institutions.

The main decision-making body of TransEco is a steering group composed of some 15 members. The government is represented by the Ministry of Employment and the Economy, the Ministry of Transport and Communications, the Ministry of Finance, the Ministry of the Environment, the Finnish Transport Safety Agency (Trafi), the Finnish Transport Agency (Liikennevirasto) and Tekes. The TransEco programme has been able to support the development of several emerging technologies to facilitate the transition to more sustainable passenger transport.

Crucial to the success of the programme is broad participation and dialogue among researchers, policy makers and adopters. The main results of demonstration projects are shared even if all partners do not participate in the funding. The interaction of all four ministries and other public offices reduces administration costs and ensures that environmental policies and other sectoral policies are aligned. The administrative and economic support for experimentation (*e.g.* through tax exemptions) offers systematic protection for developing niches and provides an incentive for demand-driven innovation. However, although there is broad stakeholder participation, critical Finnish non-governmental organisations are not involved. In addition, the legitimacy of different biofuels is a challenge that may threaten the vision defined by the groups involved.

Source: OECD case study.

TransEco programme incorporates demand-side policy and transition management elements in the development, demonstration and commercialisation of nascent road transport technologies (Box 2.5).

Systemic initiatives and instruments for linking demand-side and supply-side innovation policies

Recognising the interdependence of demand and supply in the innovation process, a number of OECD countries have introduced measures that address the entire innovation chain and combine supply- and demand-side instruments for more efficient innovation policy.

In Australia, for example, the Victorian state government has introduced a combination of demand- and supply-side measures to help SMEs with high-growth potential to focus their commercialisation efforts on technology that meets market demand. The Boosting Highly Innovative SMEs (BHIS) initiative has two main components: *i)* the Technology Commercialisation programme to support the establishment and development of rapidly growing technology-oriented SMEs by reducing the time and resources needed to bring technology to global markets; and *ii)* the Market Validation programme which uses government technology demand (*i.e.* pre-commercial procurement of R&D) as a driver for technology development and commercialisation by SMEs (OECD, 2010c). Similarly, the Danish Business Innovation Fund seeks to stimulate market development and deployment by focusing on three key areas: *i*) innovation that is either user-driven or attempts to develop "system solutions" in preparation for exports in green growth and welfare; *ii*) market maturation in green growth and welfare; and *iii*) support for the exploitation of new business and growth opportunities in less favoured areas (Nordic Innovation, 2012).

At the supranational level, the European Lead Market Initiative is a co-ordinated innovation policy initiative which uses demand-side instruments in combination with supply-side measures to provide better conditions for the creation and growth of new markets for innovative products and to support the development of worldwide operations by pioneering companies operating in Europe. It is held that the fragmented nature of the internal market and the innovation system slows the creation of lead markets in the European Union. At the national level, Germany's recently revised High-Tech Strategy identified five lead markets of special societal and global relevance for 2009-13, one of which is climate protection and energy. A key element of the strategy is the alignment of policies such as environmental and innovation policies (OECD, 2010c). Similarly, Switzerland's newly established Cleantech Masterplan aims at co-ordinating different policy areas of the central and regional governments as well as private and academic actors.

Sources of strategic intelligence

STI strategies as sources of intelligence

Although few national strategies/plans for green technology and innovation take a whole-of-government approach, they serve to catalyse and focus efforts around common goals and visions. They also help to diffuse strategic information among stakeholders and improve policy co-operation and co-ordination (Table 2.3).

Finland has various sectoral strategies in place and has recently started to develop a more coherent approach and national strategy, including a road-map, for green growth.

Table 2.3. **STI strategies for green technologies at a glance**

	Background and policy rationale	Modes of operation and funding	Policy co-ordination
Australia ***Clean Energy Future Plan (2011)***	**Aim**: reduce carbon pollution; **Target:** cut net expected carbon pollution by at least 23% by 2020. **Consultation process**: Multi-Party Climate Change Committee to explore options to develop policy measures; composed of business, non-government organisations, government and climate experts.	**Clean Energy Future Plan:** policy mix approach; carbon price; renewable energy; energy efficiency; land use. **Series of complementary measures** including: support for renewable energy (*e.g.* Clean Technology Innovation Programme, and Clean Energy Finance Corporation); creating opportunities on the land (*e.g.* Carbon Farming Initiative); and using energy more efficiently (*e.g.* Low Carbon Communities). **Funding:** AUD 5 billion to develop and commercialise clean energy technologies.	**Department of Climate Change and Energy Efficiency:** policy advice, policy implementation and programme delivery. **Domain-specific advisory bodies:** Multi-Party Climate Change Committee (September 2010-July 2012). Climate Change Authority (July 2012 onwards).
Finland ***Green Growth Policies***	The innovation potential for welfare and green growth **well recognised by policy makers**; substantial transformative **potentia**l within the Green Growth framework **for redirecting national policies towards a sustainable path.**	**R&D energy budget** increased from 4.3% in 2001 to 11.1% in 2012. **No holistic S&T** strategy for green innovation, but green growth supported by **thematic technology and innovation programmes** (*e.g.* Trans-Eco, Sitra's Energy Programme, Tekes-funded Green Growth programme). **Complementary measures** include regulatory instruments, *e.g.* taxation, standards and financial incentives.	**S&T policies** developed from sectoral viewpoint; interministerial and cross-sectoral communication limited; **Recent trend** from sector-based towards interministerial, co-operative and horizontal direction.
Germany ***Masterplan Environmental Technologies (2008)***	**Aim**: support the development of green technologies; economic and social dimensions are also highlighted; exploitation of fast-growing markets and orientation towards lead markets. Derived from the **German High Tech Strategy.**	Strategy and policy measures organised **around technology fields rather than markets;** water technologies; resource productivity; climate protection. Scope may later be extended to other technology fields. **Complementary measures** include: innovation-friendly framework conditions; support for technology transfer; support for market introduction; internationalisation; qualification; targeted support for SMEs; **environmental regulation** considered essential.	Joint strategy of the **Federal Ministries for Education and Research (BMBF) and Environment (BMU).** Commitment to regular co-ordination between the two ministries.
Korea ***Green Growth Strategy - R&D Development Plan (2009)***	As part of **Korea's Green Growth Strategy**, the government implemented the **Comprehensive R&D Plan for Green Technologies** (January 2009), and the **Development and Commercialisation Strategy for Core Green Technologies** (May 2009).	**R&D plan:** 27 core green technologies were selected. **Funding:** For 2012, investments of KRW 2.8 trillion for all green technologies and KRW 2.3 trillion for core green technologies are foreseen. In 2011, actual investments for all green technologies reached KRW 2.7 trillion and KRW 2.0 trillion for core green technologies, respectively. **Series of complementary measures:** (supply-side) public R&D grants, tax incentives for green technology development, investments in venture capital, (demand-side) green technology standards, certifications, public procurement for green technologies, assistance for households.	**Presidential Committee on Green Growth (PCGG):** Overall strategy development, policy advice and policy evaluation. **Ministry of Finance:** special focus on budget allocation. **Ministry of Knowledge Economy:** public R&D grants, green certification system, commercialisation strategies, test-bed policies, standards. **Ministry of Education and Science and Technology:** Public R&D grants for green basic research, university human resources development for green innovations. **Small and Medium Business Agency:** Public R&D grants for green SME innovation, public procurement for SMEs green technology products.
Norway ***Energi21 (2008)***	**Aim:** value creation on the basis of national energy sources and utilisation of energy; facilitate energy restructuring; cultivate internationally competitive expertise and industrial activities. **Consultation process**: industry-led board with broad participation from industry, agencies, interest groups and the ministry; number of industry-led working groups; importance of transparent processes.	**Research Council of Norway** (NOK 1.2 billion in 2010); **Innovation Norway** (pilot and demonstration projects, NOK 140 million in 2010); **Enova (**state company); **Transnova** (transport technology projects, NOK 50 million in 2010); **Gassnova** (state company, CCS).	**Research Council, Innovation Norway, Enova, Transnova and Gassnova** although different responsibilities at the technology development stage.

Table 2.3. **STI strategies for green technologies at a glance** *(cont.)*

	Stakeholder and policy dialogues	Evaluation	Lessons learned
Australia ***Clean Energy Future Plan (2011)***	**Multi-Party Climate Change Committee** was advised by a panel of four experts and supported by heads of the government departments. A number of **roundtables and working groups** to provide information and views to ministers and departments. **Public consultation process** on the proposed architecture and implementation arrangements for the carbon pricing mechanism.	The **Climate Change Authority** established as an **independent body** to review key aspects of the carbon price mechanism and climate change mitigation initiatives. A **Clean Energy Future Programme Office** to support the implementation of the Clean Energy Future Plan as a whole. **Individual programmes** administered by the relevant government departments.	**Policy mix** implemented in line with the innovation system approach combines interconnected policy measures addressing different areas of the economy. Integrated approach to **help prevent overlaps** of individual policy instruments and reduce potential inefficiencies. Involves **supply-side and demand-side** measures.
Finland ***Green Growth Policies***	**Tekes Green Growth programme** to foster co-operation on related policies; **network analysis** of different stakeholders in Finland; **fragmented co-operation** in green growth activities; **dominated by public sector organisations**; many **co-operation linkages** focus on specific areas of activity.	Finnish green growth policies largely in preparation phase or very recently launched, **too early to make comprehensive assessments** of policy impacts.	**Need to define clearly the rationale, goals and means** for green growth policies; **little experience to judge successes or failures**; active search and development for **supply- and demand-side policy**; **need to develop horizontal co-ordination** of sectoral policies, need to address explicitly links and intersections between sector-based policies; **high expectations** for newly launched green policies a challenge between state-led regulation and market selection; **broader implementation** of public procurement and standardisation yet to be seen.
Germany ***Masterplan Environmental Technologies (2008)***	**Involvement of additional ministries** foreseen (*e.g.* Federal Ministry of Transport, Building and Urban Development) for the second version of the strategy. Revision currently in negotiation among federal ministries.	***Ex ante* Strengths, Weakness, Opportunities, Threats (SWOT) analysis** of technology fields.	Strategy goes **beyond energy and climate technologies. Limited to the ministries** of Research and Education (BMBF) and Environment (BMU). Both **supply-side and demand-side** measures, but their potential not exploited fully (*e.g.* no public procurement policy).
Korea ***Green Growth Strategy - R&D Development Plan (2009)***	**Inter-ministrial Policy Dialogue:** inter-governmental discussion procedures ensured. PCGG played a fundamental role of coordinating and directing overall inter-governmental strategies. Chief Green Officers, generally Director-General of each ministries, are designated as a focal point for interacting with PCGG. **Public consultation process:** The members of PCGG consisted of governmental officers, industry sectors' representatives, academia and NGOs. A series of presentations and public hearings were undertaken to introduce the green growth strategy to the Korean public.	PCGG conducted interim evaluations on various parts of Korean Green Growth Strategy including R&D parts, which was conducted in Jan. 2012. This interim evaluation report on Green Innovations identified deficiencies of policy implementations and proposed improvement plans. **Individual programmes** were also administered and evaluated by the relevant government departments.	**Comprehensive Green R&D plans along with Green Growth Strategies:** comprehensive strategies provided all possible demand and supply-sided innovation policies including financial investments, public R&D grants, tax incentives, human resource development, green technology certification system, standardisation and public procurement for new green technologies. **Difficulties:** implementation of programme-level co-ordination among ministerial departments.
Norway ***Energi21 (2008)***	**E21 board** provides thematic input: Ministry of Oil and Energy; Energy Norway (non-profit organisation); Industry (Statoil, Statkraft, Vattenfall, Aker Solution); PRIs and universities; government and funding agencies.	***Ex ante* analysis** of government agencies and industry.	**Political commitment**; **mobilisation** of industry and the research community; **increase in budgets.** Both **supply-side and demand-side** measures. E21 to be used for the development of strategies in other areas.

Source: OECD case studies.

Norway's Energi21 strategy was launched by the Ministry of Petroleum and Energy and designed by a range of policy stakeholders; implementation and funding have been ensured by the Research Council and Innovation Norway with the close co-operation of state companies (Enova, Transnova and Gassnova). Germany's Masterplan for Environmental Technologies, which is derived from the High-Tech Strategy, is co-ordinated and implemented by the Federal Ministry for Education and Research (BMBF) and by the

Federal Ministry for the Environment (BMU). Yet another example is Australia's Clean Energy Future Plan, which is administered and co-ordinated by the Department of Climate Change and Energy Efficiency, but was developed by the Government following the work undertaken by the Multi-Party Climate Change Committee to develop the Clean Energy Agreement.

Government R&D funding is an important means of steering and shaping green innovation systems. At first glance, much of the available public support for green technologies is still based on R&D investments. Indeed, R&D policies form the largest part of the green innovation policy mix. Apart from technology adoption policies, such as feed-in tariffs for renewable energies, policies for articulating demand for green technologies are gaining ground, from regulation and standardisation to labelling and consumer policies.

However, several policy considerations are important too. First, a policy-induced increase in R&D, which results in higher demand for S&T personnel, will not necessarily result in more innovation. If too few qualified researchers are available to undertake the necessary research it may even have negative side effects (*e.g.* an increase in research salaries) (Goolsbee, 1998). Second, the impact of a rapid increase in public R&D spending will depend on the quality of research proposed and on the ability of the innovation system to turn that spending into innovation. Third, there is some concern that increased R&D expenditure on green technology may reduce or crowd out R&D expenditures in non-environmental and non-energy areas such as health and result in an ambiguous outcome in terms of overall welfare. In Finland, for example, the share of public R&D funding is expected to decrease to 1.0% of GDP in 2012. As energy is one of the key focus areas, public R&D funding has increased from 4.3% in 2001 to 11.1% in 2012.

A major challenge for providing strategic advice on linking demand- and supply-side policies for green innovation is the lack of indicators for understanding the baseline and plotting future targets. Indeed, the lack of clear definitions of what constitutes green technologies and innovations can hamper benchmarking and policy learning. Measuring investment in green R&D on the supply side, for example, is limited to a range of research fields or technologies such as renewable energy or environmental technologies even though research in areas ranging from the physical to the social sciences contributes to the development of such technologies.

Moreover, there is little empirical evidence about the factors affecting supply of and demand for green technologies and especially about the role and importance of public policy.[6] In fact, most R&D programme evaluations in the energy area are affected by the fact that the main classical global energy systems model technology change as an exogenous variable: future technology costs are entered by the modeller and are not affected by abatement or carbon price assumptions in different control scenarios. This is equivalent to "supply-push" and contrasts with accumulating evidence of market-based technology learning (Grubb, 2005). Empirical evidence on the way in which demand dynamics can affect R&D incentives is also lacking.

Dealing with technology-specific policies

Governments are also struggling with the notion of technological neutrality (Azar and Sanden, 2011), often following unfortunate experiences with "picking winner technologies". For first-generation biofuels, for example, long-term government support, whether R&D investments or deployment policies, has not resulted in large-scale market adoption. In practice, technology neutrality for a greener system is difficult given technology convergence and the different stages of technological development. For creating new technology trajectories, technology-specific policies will be needed to complement technology-neutral policies and to address specific barriers in certain green technology fields. In the earlier stages of technology development, technology-specific supply-side measures are essential and governments cannot avoid setting priorities. However, at the later stages, progressively technology-neutral demand-side measures may be necessary (*e.g.* through performance-based procurement), in particular to move technologies closer to market readiness. The allocation of funding is not and should not be technology-neutral and governments do make choices about what type of research and applications to fund.

Appropriate targeted measures and incentives may depend on the context of the technology. The types of R&D investments or technologies may be predetermined, to some extent, by existing industrial structures, research capabilities and specialisation or other supporting framework conditions. However, it is important for the design of technology-targeted policies to ensure that they meet policy and performance objectives efficiently. The issue is when and how to provide technology-specific policies. Policy makers therefore face a complex challenge for monitoring technological and commercial developments across a wide range of technology fields.

From an operational viewpoint, this process requires mechanisms such as the use of "strategic policy intelligence" based on technology roadmapping, foresight exercises, benchmarking and *ex post* and *ex ante* evaluation of research to define and co-ordinate research priorities for funding and performance more effectively. However, to make full use of them, organisations must be able to process and make sense of the available data in a realistic and detailed manner. Considering the dynamics of technological change, this can be only understood in symbiosis with social changes and social innovation at both consumer and producer levels.

To ensure legitimacy, the priority-setting process also needs to be based on a broad political consensus, especially in terms of the concentration of resources and the prioritisation of relevant research areas. Multi-year budgeting can help develop a long-term vision for innovation and signal the stability required to secure private investment in R&D. Performance budgeting can help position policy goals and costs of innovation with respect to other policy goals.

The international dimension

Green growth and green innovation have global as well as national dimensions. The fact that innovation takes place in a globalised economy (along global value chains) on the one hand and the fact that there are global negative externalities due to climate change and environmental degradation on the other means that the generation and diffusion of green innovations is not a matter for a single country or region.

The development and diffusion of green innovations at world level requires international co-operation in a range of policy areas, not least environmental regulation. While much discussion has focused on issues such as global emissions reductions, and market and policy measures to achieve this, it should be recalled that for many emerging and developing countries the policy focus is on economic development issues, such as poverty, energy, food security and access to water. In many cases this makes them more dependent on exports of natural resources. Green technologies can help these countries achieve development goals while preserving the stocks and flows of natural resources.

Closer to the market for green technologies, international co-operation is necessary for setting global standards on environmental and energy technologies, environmental regulations on industrial production, trade policy and technology deployment mandates. Today, for example, producers of energy-efficient light bulbs face different performance standards in different markets. The result is price effects and impacts on the uptake and diffusion of such energy-saving products. On the supply side, co-operation strategies include: integrated and co-operative R&D in international networks and funding commitments; co-ordination and harmonisation of priorities and research agendas; technology transfer initiatives; and international exchange of scientific and technical information, including mobility of researchers (OECD, 2012b). Among the many perceived benefits are: cost-effectiveness through cost sharing and reduced duplication of efforts; development of absorptive capacity; and accumulation of complementary knowledge by combining the comparative strengths of different countries.

However, difficulties may also arise for international co-operation: lack of continuity of funding at times of constrained budgets; asymmetric benefits and burdens; lack of participation due to insufficient incentives for individual countries, such as unclear technology transfer mechanisms; overall lack of co-ordination and strategic vision; overlap of agreements and programmes.

Given the complexity of the challenges, additional strategies involve greater implication of the private sector, non-governmental organisations, philanthropic organisations, and other stakeholders in the prioritisation and delivery of science and innovation and the use of new financing mechanisms (*e.g.* securitisation, risk sharing) to provide incentives for global and local innovations (OECD, 2011e).

Green innovation as way to foster growth in developing countries

The deployment of green innovations to emerging and developing countries will be a strong driver for expanding markets and sustainable economic development. Various new mechanisms to accelerate the diffusion of innovation to developing countries are being explored. Knowledge markets and networks could potentially play a key role in this transfer, *e.g.* innovative collaboration mechanisms in intellectual property (patent pools are but one example) which allow for a greater flow of research, development and adoption of green technologies in the developing and developed world alike.

While much international policy discussion has focused on adjusting the IPR regime (*e.g.* weakening IP protection for critical green technologies), the limited absorptive capacity of recipient countries is often a stronger obstacle to technology adoption than the price of patented inventions. Technology transfer and adaptive R&D aimed at building local capacities may be more effective for boosting the use of environmental inventions than purely patent-centred measures. These technology transfer initiatives aim to encourage technology diffusion and adoption by providing access to knowledge, in terms of innovation skills, for example, through education and training (disembodied technology transfer) and funding to cover costs of adoption of (parts of) the technology embodied in the imported equipment (embodied technology transfer) (Popp, 2011).

Aside from foreign direct investment, licensing and international trade, aid from governments in the form of development assistance plays an important role in technology transfer as well as in capacity building for green innovation, in terms of support both for agenda and priority setting and for operations and implementation.

Conclusion

This chapter argues that the transition to green innovation will require more than supply-side, technology-push approaches. It will also require demand-side measures and careful organisational and institutional changes. More specifically, the transition to green innovation and technology requires government institutions and mechanisms to sustain it. This creates governance challenges at various levels. Co-ordination problems arise across sectors and levels of government. A key challenge is alignment of the goals of ministries, research funding agencies, higher education institutions and social and market-based institutions so that they focus on green growth in all of its dimensions. The effectiveness of policy design for specific areas will depend on the innovation and knowledge capacity of a given country and its ability to develop the appropriate policy mix for green innovation. Strategic policy intelligence can help to enhance policy learning and to avoid government failures.

On the supply side, many of the enabling conditions are the same for green innovation or for innovation more generally. The fundamental drivers and barriers are largely identical. Green innovation thrives in a sound environment for overall innovation (OECD, 2011e; OECD, 2011f). In order to address the diversity of environmental risks, the growth environment needs in addition to focus on areas explicitly geared towards the creation and use (commercial and non-commercial) of knowledge for green purposes. In short, this means accelerating not only the rate, but also the direction of innovation towards producing knowledge solutions that address environmental problems.

Innovation policy also has a role to play in accelerating the rate of diffusion and adoption. While supply-side policies help facilitate the creation of new green technologies, they provide few incentives for adoption and diffusion. Only when green technology is used and spreads can it generate benefits for the economy and the society overall. To unlock and to create the necessary scale, supply-side policies need to be complemented and linked to specific diffusion and demand-side policies. The governance capabilities required for commercialisation differ significantly from those required to develop new knowledge.

Notes

1. This chapter is largely based on the ongoing OECD Working Party on Innovation and Technology Policy (TIP) project, "Transitioning to Green Innovation and Technology: The Role of Supply and Demand-side Policies", and builds on the recent OECD report *Fostering Innovation for Green Growth, 2011*.
2. Although this chapter distinguishes supply-side and demand-side policies, it is also concerned with their complex interrelationships in generating innovation for greener pathways.
3. In fact, studies evaluating the effectiveness of such policies find that environmental and technology policies work best in combination (Newell, 2010).
4. A disciplinary research field can be defined as a group of researchers working on specific research questions, using the same methods and a shared approach (*e.g.* Kuhn, 1962). In multidisciplinary research, the subject is approached from different angles, using different disciplinary perspectives but without integrating them. An interdisciplinary approach, on the other hand, creates its own theoretical, conceptual and methodological identity.
5. See Di Stefano *et al.* (2012) for a recent discussion.
6. Notable exceptions are Peters *et al.* (2012) and Nemet (2009).

References

Aghion, P., P. A. David and D. Foray (2009), "Science, technology and innovation for economic growth: Linking policy research and practice in 'STIG Systems'", *Research Policy*, Vol. 38, pp. 681-693.

Aghion, P., J. Boulanger and E. Cohen (2011), "Rethinking Industrial Policy", *Bruegel Policy Brief* 2011/04.

Arnold, E. (2004), "Evaluating Research and Innovation Policy: A Systems World Needs Systems Evaluations", *Research Evaluation*, Vol. 13, No. 1, pp. 3-17.

Arrow, K.J. (1962), "Economic Welfare and the Allocation of Resources for Innovation", in R. Nelson (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press, Princeton, pp. 609-625.

Arundel, A., M. Kanerva and R. Kemp (2011), "Integrated Innovation Policy for an Integrated Problem: Addressing Climate Change, Resource Scarcity and Demographic Change to 2030", PRO INNO Europe: INNO-Grips II report, European Commission, DG Enterprise and Industry, Brussels.

Azar, C. and B.A. Sanden (2011), "The elusive quest for technology-neutral policies", *Environmental Innovation and Societal Transitions*, Vol. 1, No. 1, pp. 135-139.

Baumol, J. B. (2004), "Education for innovation: entrepreneurial breakthroughs *vs.* corporate incremental improvements", *NBER Working Paper*.

Beltramello, A. (2012), "Market Development for Green Cars", *OECD Green Growth Papers*, OECD, Paris, forthcoming.

Blind, K. (2004), *The Economics of Standard: Theory, Evidence Policy*, Edward Elgar Publishing, Cheltenham.

Blind, K. (2012), "The Influence of Regulations on Innovation: A Quantitative Assessment for OECD Countries", *Research Policy,* Vol. 41, pp. 391-400.

Burtis, P., R. Epstein and N. Parker (2006), "Creating Cleantech Clusters", Natural Resource Defence Association.

Cohen, W.M., R.R. Nelson and J. Walsh (2002), "Links and Impacts: The Influence of Public Research on Industrial R&D", *Management Science*, Vol. 48, pp. 1-23.

Contreras J.L. (2011), "Standards and related intellectual property issues for climate change technology", *Legal Studies Research Paper Series*.

Della Croce, R., C. Kaminker and F. Stewart (2011), "The Role of Pension Funds in Financing Green Growth Initiatives", OECD, Paris.

Di Stefano, G., A. Gambardella and G. Verona (2012), "Technology push and demand pull perspectives in innovation studies: Current findings and future research directions", *Research Policy*, in press.

Etzkowitz, H. and L. Leydesdorff (1998), "The endless transition: A 'Triple Helix' of university – industry – government relations", *Minerva*, Vol. 36, pp. 203-208.

European Commission (2011), "Attitudes of European entrepreneurs towards eco-innovation. Analytical report", Brussels.

Faber A., R. Kemp and G. van der Veen (2008), "Innovation policy for the environment in the Netherlands and the EU", in C. Nauwelaers and R. Wintjes (eds.), *Innovation Policy in Europe. Measurement and Strategy*, Cheltenham, pp. 171-202.

Foray, D. and F. Lissoni (2010), "University research and public-private interaction", in Hall and Rosenberg (eds.), *The Handbook of the Economics of Innovation*, Vol. 1. North-Holland.

Funk, J.L. and D.T. Methe (2001), "Market- and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication", *Research Policy*, Vol. 30, pp. 589-610.

Gillingham, K., R. G. Newell and K. Palmer (2009), "Energy Efficiency Economics and Policy", *Annual Review of Resource Economics*, Vol. 1, pp. 597-620.

Garud, R. and P. Karnøe (2003), "Bricolage *versus* breakthrough: distributed and embedded agency in technology entrepreneurship", *Research Policy*, Vol. 32, pp. 277-300.

Geroski, P.A. (1990), "Procurement policy as a tool of industrial policy", *International Review of Applied Economics*, Vol. 4, pp. 182-198.

Geroski, P.A. (2000), "Models of technology diffusion", *Research Policy*, Vol. 29, pp. 603-626.

Goolsbee, A. (1998), "Does government R&D policy mainly benefit scientists and engineers?", *American Economic Review*, Vol. 88, pp. 298-302.

Grubb, M. (2005) "Technology Innovation and Climate Change Policy: an overview of issues and options", *Keio Economic Studies* Vol. 41(2), pp. 103-132.

Heinze, P., P. Shapira, J.D. Rogers, J.M. Senker (2009), "Organizational and institutional influences on creativity in scientific research", *Research Policy,* Vol. 38, pp. 610-623.

Jaffe A.B., R.G. Newell and R.N. Stavins (2004), "Technology Policy for Energy and the Environment", in A.B. Jaffe, J. Lerner and S. Stern (eds.), *Innovation Policy and the Economy*, Vol. 4, The MIT Press.

Jaffe, A.B., R.G. Newell and R.N. Stavins (2005), "A tale of two market failures: Technology and environmental policy", *Ecological Economics*, Elsevier, Vol. 54, No. 2-3, pp. 164-174.

Kivimaa, P. (2008), "The innovation effects of environmental policies - Linking policies, companies and innovations in the Nordic pulp and paper industry", Helsinki School of Economics, Helsinki.

Kuhn, T. S. (1962), *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago.

Lane, E.L. (2012), "Building the Global Green Patent Highway: A Proposal for International Harmonization of Green Technology Fast Track Programs", *Berkeley Technology Law Journal*, Vol. 27, No. 3.

Lee, B., L. Lliev and F. Preston (2009), "Who Owns Our Low Carbon Future? Intellectual Property and Energy Technologies", Chatham House Report.

Maskus, K. (2010), "Differentiated Intellectual Property Regimes for Environmental and Climate Technologies", *OECD Environment Working Papers*, No. 17, OECD, Paris.

Mowery, D.C., R. Nelson and B. Martin (2010), "Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won't work)", *Research Policy*, Vol. 39, No. 8, pp. 1011-1023.

Narayanan, V.K. and T. Chen (2012), "Research on Technology Standards: Accomplishment and Challenges", *Research Policy*, *in press*.

Nordic Innovation (2012), *Towards a new innovation policy for green growth and welfare in the Nordic Region,* Nordic Innovation Publication, Oslo.

Nelson, R.R. (1959), "The simple economics of basic scientific research", *Journal of Political Economy*, Vol. 67, pp. 297-306.

Nemet, G.F. (2009), "Demand-pull, technology-push, and government-led incentives for non-incremental technical change", *Research Policy*, Vol. 38, pp. 700-709.

Newell, R.G. (2010), "The role of markets and policies in delivering innovation for climate change mitigation", *Oxford Review of Economic Policy*, Vol. 26, No. 2, pp. 253-269.

Newell, R.G. and N.E. Wilson (2005), "Technology Prizes for Climate Change Mitigation", *Discussion Paper* 05-33, Resources for the Future, Washington, DC.

Nill, J. and R. Kemp, (2009), "Evolutionary approaches for sustainable innovation policies: From niche to paradigm?", *Research Policy*, Vol. 38, pp. 949-963.

OECD (1998), "Special Issue on 'New Rationale and Approaches in Technology and Innovation Policy'", *STI Review* No. 22, OECD, Paris.

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

OECD (2010a), "Interim report on the Green Growth Strategy", C/MIN(2010)5, OECD, Paris.

OECD (2010b), *Business Innovation Policies: Selected country comparisons*, OECD, Paris.

OECD (2010c), *Demand-side innovation policies*, OECD, Paris.

OECD (2010d), "Enhancing the Value and Effectiveness of Environmental Claims: Protecting and Empowering Consumers, Report on an OECD Workshop", OECD, Paris.

OECD (2010e), *Science, Technology and Industry Outlook*, OECD, Paris.

OECD (2011a), *Towards Green Growth*, OECD, Paris.

OECD (2011b), "SMEs and Entrepreneurship: Green Growth, Innovation, and Employment", internal working document.

OECD (2011c), *OECD Science, Technology and Industry Scoreboard 2011*, OECD, Paris, *http://dx.doi.org/10.1787/sti_scoreboard-2011-en*.

OECD (2011d), *Skills for Innovation and Research*, OECD, Paris.

OECD (2011e), "Fostering Innovation for Green Growth", *OECD Green Growth Studies*, OECD, Paris.

OECD (2011f), "Invention and Transfer of Environmental Technologies", *OECD Studies on Environmental Innovation*, OECD, Paris

OECD (2012a, forthcoming), *Driving Eco-innovation: The Role of Demand-Side Policies*, OECD, Paris.

OECD (2012b, forthcoming), *International Co-operation in Science, Technology and Innovation: Meeting Global Challenges through Better Governance*, OECD, Paris.

Peters, M. *et al.* (2012), "The impact of technology-push and demand-pull policies on technical change – Does the locus of policies matter?", *Research Policy*, in press.

Popp, D., R.G. Newell and A.B. Jaffe (2009), "Energy, the Environment, and Technological Change", *NBER Working Paper*.

Popp, D. (2011), "The Role of Technological Change in Green Growth", *mimeo*, The World Bank, Washington DC.

Rennings, K., P. Markewitz and S. Vögele (2009), "How clean is clean? Incremental *versus* radical technological change in coal-fired power plants", *ZEW Discussion Papers* 09-021, Center for European Economic Research.

Stavins, R.N. (2003), "Experience with market-based environmental policy instruments", in Mäler and Vincent (eds.), *Handbook of Environmental Economics*, Vol. 1, Elsevier.

Scotchmer, S. (2004), *Innovation and Incentives*, The MIT Press, Cambridge, MA.

Stephan, P.E. (2010), "The Economics of Science", in Hall and Rosenberg (eds.), *The Handbook of the Economics of Innovation*, Vol. 1, North-Holland.

UK Committee on Climate Change (2010), "Building a Low-Carbon Economy – The UK's Innovation Challenge", London.

Veugelers, R. (2009), "A lifeline for Europe's young radical innovators", *Bruegel Policy Brief*, Issue 2009/01.

Weber, M.K. and H. Rohracher (2012), "Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework", *Research Policy,* Vol. 41, pp. 1037-1047.

Wintjes, R. (2012), "Demand side innovation policies at regional level", Regional Innovation Monitor, Thematic Paper 3.