

Climate change mitigation and security of energy supply will benefit from technological innovation

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*Heleen Groenenberg^{1,2}, Francesco Ferioli², Stijn van den Heuvel³,
Marcel Kok⁴, Ton Manders⁴, Stephan Slingerland³, Bas Wetzelaer²*

Abstract

Today's EU energy policies are evaluated with respect to their capacity to stimulate promising energy technologies so as to meet present EU objectives of mitigating climate change, securing energy supply and improving competitiveness. Many promising energy technologies may contribute simultaneously to curbing CO₂ emissions and improving supply security, and technological innovation will be vital to both. However, energy innovation policies need to meet a number of requirements to be successful. They should not only seek short term efficiencies in the present energy system, but also facilitate the development of a wide range of relatively immature technologies, while using a long time horizon (e.g. up to 2050) and attempting to avoid lock-ins in traditional technologies. The present EU energy policy mix appears not to meet all of these requirements. Apart from a short to medium term horizon in both the EU-ETS and supply in security policies, deficiencies include inter alia targeted support for technologies that still need large scale demonstration, stimulation of hybrid and flex-fuel vehicles, and exploitation of possibilities for labeling and standard setting in industry and transport. Moreover, current policies lack a vision as to how exactly the present energy system should evolve into a low carbon and secure system. There is an apparent need to prioritize future action for an energy transition in the EU in a transition roadmap.

1. Climate policies and supply security policies: synergies and trade-offs

The consumption of fossil fuel for energy production is by far the most important source of greenhouse gas emissions in the world. Consequently, policies that aim to reduce greenhouse gas emissions need to target foremost a range of technologies to curb fossil fuel related greenhouse gas emissions, including technologies for improved energy efficiency, a switch to from coal to natural gas and low emission sources (such as renewable and nuclear energy) and CO₂ capture and storage. In its Communication 'Winning the battle against climate change'⁵ the European Commission emphasized the importance of a portfolio of climate change policies and technologies.

Apart from climate change mitigation, security of energy supply has re-emerged as a chief concern in European energy policies, which was demonstrated once more by the Commission's

¹ Corresponding author. Email: groenenberg@ecm.nl, phone +31 224 564516.

² Energy research Centre of the Netherlands (ECN)

³ Clingendael International Energy Program (CIEP)

⁴ Netherlands Environmental Assessment Agency (MNP)

⁵ COM(2006)676 final.

energy policy package⁶. A reduced supply security may arise from a number of causes. Short term disruptions in energy supply may originate from extreme weather and accidents, which damage energy infrastructures. In addition, a properly functioning electricity supply requires good short term balancing of the supply and demand of electricity to warrant quality and avoid black outs. On the long term, fossil fuel depletion and the concentration of fossil fuel resources in politically unstable regions of the world may affect security of energy supply. It is particularly this role of fossil fuels in energy supply which will affect the possibilities to curb greenhouse gas emissions in the long term. Policies for long term supply security will therefore seek to reduce the role of imported oil and natural gas and to stimulate low carbon energy sources.

A number of studies have recognized that a range of technologies may contribute to simultaneously curbing greenhouse gas emissions and improving the security of energy supply (e.g. Berk *et al* 2006, Bardley and Lefevre 2006). These include energy efficiency technologies, capture and storage of CO₂ from coal-fired power generation, renewable energy sources, including biofuels in transport, and nuclear energy. By 2050 world wide contributions from the most important technologies for CO₂ emission reduction may amount to 31-53% from energy efficiency measures, 20-28% from CO₂ capture and storage, 11-16% from fuel switching, 5-16% from renewable energy, 2-10% from nuclear energy, and about 6% from biofuels in transport (IEA 2006).

Synergy will not occur in all cases. A greater reliance on natural gas instead of coal will lead to both a cleaner electricity production and an increasing import dependency. If on the contrary focus is on decreasing the imports of gas and increasing the use of coal in power generation, the climate is worse off.

2. Need and policy requirements for technological innovation

2.1 Need for technological innovation

As mentioned above, various technologies may contribute simultaneously to mitigation of climate change and securing energy supply. However, few low carbon technologies are fully commercial and able to compete with fossil fuel based energy. Therefore, further innovation and market diffusion of energy technologies are vital to accomplish emission reductions and to warrant supply security in the long term.

In addition, technological innovation is considered beneficial for the economy in a country or region (Jochem and Madlener 2003). Firstly, many new technologies, particularly those improving energy and material efficiency, will ultimately reduce costs, both for production processes and for consumers. New technologies are often still expensive when they are introduced in the market, and for many of them costs may be reduced by improving economies-of-scale. Secondly, innovating industries and countries that enter new markets early have a competitive advantage, which they may exploit to increase profits. Thirdly, the introduction of new technologies may trigger efforts to improve the performance of traditional technologies. Fourthly, saved costs in a resource efficient economy may be re-invested. In many cases this will move capital from a few power generators and energy-industry industries to a range of small and medium consultants and companies providing equipment and capital goods. Finally, overall economic efficiency will benefit from increased recycling, improved capital and labour productivity, and intensified product use.

Obviously, these beneficial effects for the economy will not be equal for distinct innovative technologies. For instance, a cost reduction and reinvestment of resources will likely occur mostly for energy efficiency measures.

⁶ SEC(2007)12

2.2 Requirements for effective innovation policies

Although transition from a fossil fuel intensive energy system to a low carbon energy system requires also changes in regulations, infrastructures, habits, and capital flows, we will focus only on the need for a technological change. Many authors (e.g. Kemp *et al*, 2000, Geels, 2004; Suurs and Hekkert, 2005, Van Den Berg *et al*, 2007) have reflected on fundamental ingredients for a successful long term strategy for technological innovation. These may be summarized as follows.

Allow for diversity and co-evolution - Crucial to an effective strategy for a long term energy transition is a varied knowledge base and support for a diverse portfolio of innovative and promising technologies. This implies not picking a particular technology, e.g. biofuel or CO₂ capture system as a winner, but rather encouraging all of them. This will allow so-called co-evolution of candidate technologies over time. Future technological developments, cost reductions, and preferences among consumers and companies will then eventually resolve which technology will become dominant. However, while a variety of technologies needs to be supported to allow the best technology to develop and take over, this does not exclude the need for setting priorities in the allocation of available public resources over the portfolio of promising technologies.

Use a long term horizon - A long term horizon for energy policies is needed to provide companies and consumers confidence that investments in climate friendly technologies eventually will be paid back. A long term horizon is important for instance in an emissions trading scheme, but also for other policies reducing the financial risk of investments, such as a feed-in scheme or a CO₂ price guarantee. A long term perspective will also increase the likelihood that research and development efforts in innovative technologies will be rewarded. As such, a long term horizon of policies is fundamental to a transition to a low carbon energy system.

Seek short term efficiency - While in the long run a transition to a low carbon economy is imperative, this should not rule out opportunities for reducing emissions and improving supply security in the present energy system. Opportunities for such short term efficiency gains are numerous, including in particular a host of energy efficiency measures in all economic sectors. In other words, while system transition is under way, optimization of the present system must not be forgotten.

Consider path dependence - Path dependence refers to the fact that it may be difficult to replace technologies and infrastructures in place, since investment costs may be high, technological and economic lifetimes may be long and processes may be standardized. People tend to decide on the basis of limited knowledge, and generally have a limited foresight period, which may hamper the evolution of innovative technologies. Examples of factors contributing to path dependence include the standardization of processes, especially when combined with economies of scale, long life-times of technologies and high investment costs of processes and infrastructures. Path dependence implies that any modification needs to fit within the existing framework. This hampers the breakthrough of innovative, superior technologies and is referred to as the lock-in effect. Thus, prior to providing policy support to any energy technology implications for other promising but possibly less mature technologies should be considered. For instance, widespread deployment of micro CHP will reduce the potential for central CO₂ capture and storage; widespread deployment of CCS will continue reliance on fossil fuels and reduce the need for renewable energy.

Facilitate - Finally, governments need to facilitate the development of a variety of promising technologies. Authorities may adopt a number of roles in this respect. Firstly, they may exert an innovation push by providing financial support. Secondly, they may stimulate demand for new technologies by formulating environmental or technical standards or by providing economic incentives. Thirdly, they may involve a range of actors and promote the diffusion and exchange of knowledge among those.

3. Challenges to the uptake of innovative energy technologies

Above we argued that technological innovation is needed to effectively mitigate climate change, to warrant the security of energy supply, and to improve competitiveness. Next, we gave an overview of principal ingredients of effective innovation policies. Prior to evaluating present EU policies in this respect, in this section an overview will be provided of the maturity of a range of key energy technologies, and of important barriers to their further expansion.

Technologies may be conveniently grouped into categories representing the development stage they are in. Table 3-1 provides an overview of technologies in respectively the R&D, demonstration, upscaling and commercialization phases.

Technologies in the R&D phase still face major technological and cost barriers. In fossil fuel based power generation it is particularly stationary fuel cells and CO₂ capture using oxyfuel combustion that need substantial R&D still. Renewable energy sources in these phase include photovoltaics and ocean energy. Also fourth generation nuclear power plants need considerable research and development. In the transportation sector, the most important technologies in need of massive R&D include hydrogen fuel cell vehicles, the production of cellulosic ethanol as a transport fuel, a number of process innovations in commodity production (welke), feedstock substitution in industry

In the demonstration phase are technologies that still need to overcome some cost and technological barriers, but that in principle are ready for first time large scale deployment. Technologies that could be demonstrated at a commercial scale include post-combustion CO₂ capture in pulverized coal plants and NGCCs, as well as precombustion capture in IGCCs and CO₂ capture in industries. Concentrated solar power is also in this phase. A number of material and energy saving processes in industry are also ready for demonstration.

Technologies that need further upscaling do no longer face major technological barriers. A reduction of the financial risk associated with their deployment would promote their expansion, while additional barriers need to be overcome as well. These technologies comprise power generation from a range of renewable sources, including on and offshore wind, biomass, and geothermal. Solar heating and cooling is also in this phase. In the transportation sector, it is hybrid vehicles that in principle could be deployed at a wider scale to further bring down costs, just as biodiesel and ethanol from sugar or starch. In industry, fuel substitution in commodity production could be introduced at a wider scale.

Finally, technologies that are ready for commercialization do not need any financial support, but policies would still need to address a number of remaining barriers. In power generation, it is particular nuclear energy technologies from the second and third generations that are not being deployed massively for safety concerns and limited public acceptance. In transportation, more efficient vehicles and energy saving technologies not related to the engine (aerodynamics, tyres) are options that face limited interest from the consumer. In industry, more efficient motor and steam systems are often hampered by a lack of awareness of potential energy savings, lack of expertise of managers, or split budgets for energy efficient investments and for paying energy bills. Barriers to a further diffusion of CHP relate to a lack of appreciation of the environmental benefits of the option and discriminating connection charges for electricity fed into the grid. Material and product efficiency are often not improved because there is insufficient incentive for industries to reduce these impacts throughout the life cycle of their products. The diffusion of ethanol flex fuel vehicles is hampered by the lack of ethanol supply at gas stations. Finally, important savings may be realised cost-effectively in buildings and appliances. However, high investment costs, a lack of awareness, and split incentives obstruct a rapid expansion of many of these technologies.

Table 3-1 Innovative energy technologies in distinct innovation phases and overview of principal barriers to their uptake (based on IEA 2006)

	<i>Technological</i>	<i>Cost</i>	<i>Other barriers</i>
R&D PHASE			
Hydrogen fuel cell vehicles	X	X	
Ethanol (cellulosic), Fischer-Tropsch diesel (biomass-to-liquids)	X	X	Higher CO ₂ reduction than 1 st gen ethanol not awarded
Hydrogen	X	X	Need for infrastructure
Industry - Process innovation basic materials	X	X	
Industry - Feedstock substitution	X	X	
Photovoltaics	X	X	
Ocean energy	X	X	Available sites
Stationary fuel cells	X	X	Need for infrastructure
CCS – oxyfuel combustion	X	X	
Nuclear generation IV	X	X	
DEMONSTRATION			
Industry - Material/product efficiency	(X)		No consideration life cycle enviro impacts
Industry - CCS	(X)	X	
Concentrated solar power	(X)	X	
CCS – post/precombustion	(X)	X	
UPSCALING			
Hybrid vehicles		X	
Biodiesel from oil seeds, Ethanol (grain/starch, sugar)		X	Feedstock supply
Fischer-Tropsch diesel (biomass-to-liquids)	X	X	Food versus fuel competition
Industry - Fuel switch		X	
Industry – Cogeneration		X	
Wind on and offshore		X	Public resistance onshore
Solar heating and cooling		X	Intermittency
Hydro		X	Lack of information
Biomass gasification, co-firing		X	Lack of regulatory framework
Geothermal		X	Env & social concerns (large systems)
COMMERCIAL			
Vehicle fuel economy & non-engine techn			Consumer behaviour
Ethanol flex-fuel vehicles			Feedstock supply at gas stations
Industry - Motor and steam systems			Lack of awareness
Buildings: miscellaneous efficiency measures			Lack of expertise
			Lack of awareness
			Split incentives
Nuclear generation III			
			Safety
			Disposal of waste
			Proliferation
			Public opinion

4. EU energy policies

In the previous sections we discussed policy requirements for ongoing technological innovation, and we gave an overview of the maturity of barriers to the uptake of key energy technologies. In this section we will evaluate to what extent EU energy policies are instrumental in meeting challenges to the further diffusion of technologies outlined above.

4.1 Objectives of EU energy policies

Objectives of EU energy policies were proposed by the EC in the energy policy package⁷. Ideally, such policies would contribute to mitigating climate change and enhance the security of energy supply at a reasonable cost. In addition, energy policies should contribute to a stronger competitive position of the European Union. Policy objectives were formulated in qualitative and quantitative terms for climate change mitigation, security of supply (Table 4.1). Quantitative targets are formulated in particular for climate change mitigation. Greenhouse gas emissions should be reduced by 20%, and by 30% if other countries commit themselves to reduction targets as well. Additional targets have been set for renewable energy sources, bio-fuels and energy efficiency: 20% renewables in 2020, 10% biofuels in 2020 and 20% energy efficiency. The former two are binding, the latter is not.

Objectives for improving security of supply are qualitative and emphasize the importance of the internal energy market, external energy relationships, and mechanisms to ensure Member States solidarity. However, no timelines or specific actions are set for actions to improve supply security. As for competitiveness, the proposal claims that a competitive market will inevitably lead to improved energy efficiency and investments. Investments in energy efficiency and renewable energy should advance innovation. No specific actions or timelines were proposed in this respect.

The European Council attached to its March 2007 Council Conclusions an action plan for European energy policy in the 2007-2009 period, largely based on the EC proposal. The Action Plan comprises a number of priority actions (Table 4-1). Five priority actions are distinguished, which to some extent overlap. For instance, security of supply will also benefit from a proper regulation of the internal market for gas and electricity, from an effective international energy policy, wider deployment of energy efficient technologies and renewable energy, and from the development of innovative technologies.

In the long list of actions measures to advance technological innovation only take up a minor share. While the importance of new technologies is underlined, the only action formulated to promote technological innovation is to strengthen R&D and the technical, economic and regulatory framework for CO₂ capture and storage by 2020. A detailed roadmap to provoke the technological revolution needed to realize a low emission society is absent.

⁷ SEC(2007)12

Table 4-1 Priority actions and key points in European energy policy 2007-2009; European Council March 2007

<i>Priority action</i>	<i>Key elements</i>
Internal market for gas and electricity	– Implementation of legislation on opening up of energy markets – Appropriate investment signals, including development of regulatory framework – Separation of supply and production (unbundling) – Independence national energy regulators – Co-operation national regulators – Coordination network operation
Security of supply	– Diversification – Crisis response mechanisms – Transparency of data on oil stocks and supplies – Analysis of potential and costs of gas storage – Assessment of impact energy imports on MS supply securities – Establishment of Energy Observatory
International energy policy	– Negotiating of partnerships and cooperation agreements with Russia; – Strengthen relationships Central Asia, Caspian and Black Sea regions; – Intensify partnerships US, China, India, Brazil, and others for reducing GHG, energy efficiency, renewables, CCS; – Implement Energy Community Treaty, with possible extension to Norway, Turkey, Ukraine, Moldova – Use all instruments under the European Neighborhood Policy – Enhance relationships Algeria, Egypt, others in Mashreq/Maghreb region – Build dialogue with and enhance decentralized renewables and energy access in Africa – Promote energy access in context of UN-CSD
Energy efficiency and renewable energies	– 20% efficiency improvement over 2020 level – Five priorities: transport, dynamic efficiency requirements of equipment, consumer behavior, technology & innovations, buildings – Commission proposals for efficient lighting regulation – International negotiations for sustainable production and trade in efficient goods and services – Review of guidelines for State Aid – 20% renewables by 2020 – 10% biofuels by 2020 – Aim for framework with differentiated national targets and national action plans, and provisions for sustainable biomass production – Implementation Biomass Action Plan, especially for demonstration of 2nd generation biofuels – Analysis of potential for cross-border and EU-wide synergies and interconnection for reaching renewable target – Exchange of best practices
Energy technology	– Importance of generation efficiency and clean fossil fuel technologies – Strengthen R&D and technical, economic and regulatory framework for CCS by 2020 – Welcomes Commission's intention of mechanism to stimulate realization of up to 12 demonstration of sustainable fossil fuel technologies

In addition to the actions listed in the European Council Conclusions, main features of the EU external energy policy had been outlined previously in a speech of the High Representative for the Common Foreign and Security Policy, Secretary general of the council of the EU (Solana 2006). These are mainly concerned with security of supply issues, but also involve energy efficiency, renewable energy sources and the Kyoto mechanisms (Box 1). Also in these principles for external energy policy the role of technological innovation is modest. Low emissions technologies should be 'encouraged', but no reference is made to a stepwise strategy for realizing the much needed technological reform.

Box 1 Guiding principles of EU external energy policy (Solana, 2006)

1. Improving production and export capacities in producer countries and developing and upgrading energy transportation infrastructure in producer and transit countries.
 2. Improving the climate for European companies' investments in third countries and opening up the production and export of energy resources to EU industry.
 3. Improving conditions for trade in energy through non-discriminatory transit and third party access to export pipeline infrastructure.
 4. Enhancing physical and environmental security as well as the energy infrastructure safety.
 5. Encouraging energy efficiency, use of renewable energies including bio fuels, low emission technology and rational use of energy worldwide.
 6. Implementing the relevant Kyoto Protocol mechanisms.
 7. Diversifying energy imports by product and country.
 8. Creating an international regime for the supply of enriched uranium to countries that have chosen the nuclear option, in line with non-proliferation commitments and taking into account the EURATOM treaty provisions.
 9. Promoting strategic reserve stocks and encouraging joint stock holding with partner countries.
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4.2 The EU Emissions Trading System

A principal policy instrument for mitigation of climate change CO₂ emissions in the EU is the EU Emission Trading System (EU-ETS)⁸. While the present system already encompasses 45% of all CO₂ emissions and 30% of greenhouse gas emissions in the EU, the intention is to further elaborate this system. It would be expanded to other gases and sectors, including carbon capture and storage and be linked where possible to other compatible schemes (e.g the Californian and Australian systems).

The EU ETS was introduced as a market-based approach to reduce CO₂ emissions in a cost-effective manner. Such a market-based approach to environmental problems should ideally solve two common market failures: the externality of environmental impacts, and the lack of incentive for technological change (Jaffe *et al.*, 2005). The ETS is a market-based instrument that gives a price to the environmental externality of CO₂ emissions. This price depends on the supply and demand for CO₂ emission allowances, and therefore on the allowances initially allocated at the start of a trading period in the scheme. In this way, the common market failure of not internalizing environmental damage in production costs is addressed to a certain degree by a cap-and-trade regime.

However, cap-and-trade approaches do not provide the incentives needed to compensate innovators for inducing technological change. In addition to not addressing this technology market failure, the ETS has design features that make it worse. The short-term horizon of the trading periods, without perspective of long-term deep emission reductions, will make participants in the scheme prefer the technological options that are more competitive and cost-effective in the short term rather than highly innovative, step-change technologies, such as CCS. This is likely to deter the development of technologies that involve particularly high demonstration costs, as the return on investment in innovation is unlikely to be sufficient. For the ETS to work more effectively to promote such technologies there would need to be a clear long-term perspective of deep emission reduction requirements, preferably operating at a global level.

4.3 Other EU energy policies

Apart from the EU-ETS a host of Directives and supporting policy documents have been prepared by the European Commission to meet objectives of its energy policies.

⁸ 2003/87/EC

Since the early 1990s, various measures have been taken to improve energy efficiency. Implemented directives specify standards for energy efficiency in hot water boilers⁹, domestic refrigerators¹⁰, and ballasts in fluorescent lighting¹¹, and household appliances must have their energy efficiencies labeled¹². Minimum standards for the energy performance of new and renovated buildings have been set, and certification of buildings and inspection of energy systems therein regulated¹³. The promotion of cogeneration in the internal energy market has been regulated¹⁴, and a recent framework directive on ecodesign requirements defines conditions for setting standards for energy-using appliances¹⁵, including e.g. heating, water heating, electric motors, lighting domestic appliances, office equipment, consumer electronics, ventilation and air conditioning.

The promotion of renewable energy has also been taken up by the EU, and Member States are required to set and achieve targets for renewable energy¹⁶. In addition, Member States must meet the EU-wide target of 5.75% biofuels to replace diesel or petrol for transport purposes by 2010¹⁷. A Biomass Action Plan¹⁸ and a Strategy for biofuels¹⁹ were formulated, although these do not hold any specific measures or binding requirements. The former relates to the promotion of the use of biomass in heat production, electricity production and transport, while the latter addresses in particular the possibilities to ensure the supply of sustainably produced biomass.

CO₂ Several measures and plans exist to reduce CO₂ emissions from transport. Voluntary agreements have been made with automobile manufacturers in Europe, Korea and Japan²⁰, to reduce average CO₂ emissions from vehicles to 140g CO₂/km in 2008, 2009 and 2009 respectively. A strategy to further reduce emissions to 120 g CO₂/km has been proposed²¹. The Commission also considers standards for rolling resistance, the promotion of tyre pressures, as well as more stringent rules on vehicle labeling. It aims to include aviation in the EU-ETS²², and to connect ships to the electricity grid while they are in the harbor²³.

As a cross-cutting measure tax incentives can be a powerful tool. The Commission plans to revise the Community framework for the taxation of energy products and electricity²⁴, and has proposed to tax private cars according to their pollution levels²⁵. Nevertheless, taxation is as yet a Member State competence, which hampers the introduction of far-reaching green tax measures.

On top of these policies, research as outlined in the Seventh Framework Programme will contribute to the development of low carbon technologies. In addition, following the Commission's Environmental Technologies Action Plan for the EU²⁶, more than 30 technology platforms have been launched to stimulate the take-up of environmental technologies.

As to the security of energy supply, a number of directives and regulations have been adopted to secure supply of natural gas and electricity. Common rules on the storage, transmission, supply and distribution of natural gas and on organisation of the gas sector have been laid down²⁷.

⁹ 92/42/EEC

¹⁰ 95/57/EC

¹¹ 2000/55/EC

¹² 92/75/EEC

¹³ 2002/91/EC

¹⁴ 2004/8/EC

¹⁵ 2005/32/EC

¹⁶ 2001/77/EC

¹⁷ 2003/30/EC

¹⁸ COM(2005)628

¹⁹ COM(2006)34

²⁰ Resp 1999/125/EC, 2000/304/EC, 2000/303/EC

²¹ COM(2007)19

²² COM(2005)459

²³ 2006/339/EC

²⁴ 2003/96/EC

²⁵ COM(2005)261

²⁶ COM(2004)38 final

²⁷ 2003/55/EC

Likewise, generation, transmission and distribution of electricity, and the organisation of the electricity sector, market access, authorisations, and system operations have been regulated²⁸, as well as conditions for access to the network for cross-border exchanges in electricity²⁹. Furthermore, Community financial aid is granted to enhance the development of trans-European energy networks³⁰. Security of natural gas supply is promoted by a common framework within which Member States can define gas supply security policies³¹.

5. Contribution of EU domestic energy policies to the uptake of innovative technologies

How do the policies aforementioned affect the development of promising energy technologies? This section will provide an overview of the distinct policies and measures that affect the diffusion of technologies of distinct maturity. Policies that are typically applied to stimulate technologies in the R&D phase are R&D subsidies or a technology platform for diffusion of knowledge. Technologies in the demonstration phase would typically need investment support. EU policies for upscaling include the EU-ETS and the possibility to exempt clean technologies from taxes. Commercial technologies may be stimulated further by standards, labelling or other instruments. However, we will demonstrate that policies characteristic to a particular innovation phase may act on technologies of distinct maturities. For instance, the EU-ETS is considered a typical instrument for upscaling, but may advance relatively undeveloped or commercial technologies as well.

In the *R&D* phase are technologies in industry, power generation and transportation, for which major technological improvements and cost reductions are necessary (Table 5-1). In fossil fuel based power generation it is particularly stationary fuel cells and CO₂ capture using oxyfuel combustion that still need substantial R&D. Renewable energy sources in these phase include photovoltaics and ocean energy. Also fourth generation nuclear power plants need considerable research and development. In the transportation sector, the most important technologies in need of massive R&D include hydrogen fuel cell vehicles, the production of cellulosic ethanol as a transport fuel, a number of process innovations in commodity production, feedstock substitution in industry. Existing EU policies for these technologies consist of R&D support in the Seventh Framework Program and support of a technology platform, following the EC's Environmental Technology Action Plan³².

Technologies that are ready for large scale *demonstration* include post-combustion CO₂ capture in pulverized coal plants and NGCCs, as well as precombustion capture in IGCCs and CO₂ capture in industries. Concentrated solar power is also in this phase. A number of material and energy saving processes in industry are also ready for demonstration (Table 5-2). For most of these technologies ongoing R&D is being supported by EU R&D programs, apart from CO₂ capture from industrial processes in e.g. ammonia production, the iron and steel industry, or cement production. A policy that may be help to upscale concentrated solar power is the exemption of an energy tax allowed under the Community framework for taxation of energy products and electricity³³. Furthermore, most of these technologies could in principle be deployed by participants in the EU-ETS, although CO₂ capture and storage operations will need to be opted in under the EU ETS Directive before the trading scheme can effectively incentivize the option. It must be noted that the CO₂ market price would need to be sufficiently high to make deployment under the ETS profitable. Models suggest that CCS would be deployed at substantial levels for a CO₂ market price of 25-30 €/t CO₂ (IPCC 2005). While the effect of the

²⁸ 2003/54/EC

²⁹ Regulation 1228/2003

³⁰ Regulation 2236/95

³¹ 2004/67/EC

³² COM(2004)38 final

³³ 2003/96/EC

EU-ETS on expansion of these technologies is uncertain, no targeted support for demonstrations exists at the EU level. Potential other barriers, such as a lack of information or public acceptance, are not being addressed yet by EU policies.

A wide range of abatement technologies have been demonstrated already, and need *upscaling* to realize large scale deployment (Table 5-3). For these technologies, a wide range of instruments were implemented at the EU level to reduce technical and financial risks. These technologies comprise power generation from a range of renewable sources, including on and offshore wind, biomass, and geothermal energy. Solar heating and cooling is also in this phase. In the transportation sector, it is hybrid vehicles and ethanol flex-fuel vehicles that in principle could be deployed at a wider scale to further bring down costs, just as biodiesel and ethanol from sugar or starch. In industry, fuel substitution in commodity production could be introduced at a wider scale. For some technologies in this phase EU policies were designed to overcome additional barriers. For instance, an adequate fuel supply, competition with food crops and environmental concerns related to the production of biofuels and the use of biomass in power production were addressed in the Biofuels Directive and the EU Strategy for Biofuels. A lack of information and the lack of a regulatory framework to advance solar heating and cooling were addressed in particular by EU legislation on the performance and certification of buildings³⁴.

Finally, a range of *commercial* abatement technologies exist that are cost-effective but which have not managed to expand rapidly for various reasons (Table 5-4). In power generation, it is particular nuclear energy technologies from the second and third generations that are not being deployed massively for safety concerns and limited public acceptance. In transportation, more efficient vehicles and energy saving technologies not related to the engine (aerodynamics, tyres) are options that face limited interest from the consumer. In industry, more efficient motor and steam systems are often hampered by a lack of awareness of potential energy savings, lack of expertise of managers, or split budgets for energy efficient investments and for paying energy bills. Further diffusion of CHP is hampered by the high costs of natural gas, and the need for industrial CHP installations to be operated day and night, while cheaper coal capacity tends to set electricity prices during the night. Material and product efficiency are often not improved because there is insufficient incentive for industries to reduce these impacts throughout the life cycle of their products. Finally, important savings may be realised cost-effectively in buildings and appliances. However, high investment costs, a lack of awareness, and split incentives obstruct a rapid expansion of many of these technologies. Obviously, little R&D or investment support exists for these technologies. Some of these technologies are incentivized by the EU-ETS, in particular industrial motor and steam systems, as well as cogeneration. However, since costs are not considered the most important obstacle to these technologies, no cost-reducing incentives have been implemented. EU policies mostly focus on overcoming other barriers, such as a lack of information or interest, or barriers to an adequate supply of biomass.

³⁴ 2002/91/EC

Table 5-1 EU policies for CO₂ abatement technologies in need of substantial R&D: the Seventh Framework Program and Technology Platforms under the ETAP

	<i>R&D</i>	
	FP7	ETAP
Transport vehicles		
Hydrogen fuel cell vehicles	X	X
Transport fuels		
Ethanol (cellulosic)	X	--
Hydrogen	X	X
Fischer-Tropsch diesel (biomass-to-liquids)	X	X
Industry		
Process innovation in commodity production	X	X
Feedstock substitution	X	--
Power generation		
Photovoltaics	X	X
Ocean energy	X	--
Stationary fuel cells	X	--
CCS – oxyfuel combustion	X	X
Nuclear generation IV	--	--

Table 5-2 EU policies of CO₂ abatement technologies ready for demonstration at a commercial scale

	<i>R&D</i>		<i>Demo</i>	<i>Upscaling</i>		<i>Commercial</i>		
	FP7	ETAP	Investment support	EU-ETS	Tax benefits³	Standards	Labelling	Other policies
Industry								
Material/product efficiency	X	--	--	X ¹	--	--	--	--
CCS	--	--	--	X ²	--	--	--	--
Power								
CSP	X	--	--	X	X	--	--	--
CCS post combustion coal	X	X	--	X ²	--	--	--	--
CCS post combustion NGCC	X	X	--	X ²	--	--	--	--
CCS - IGCC	X	X	--	X ²	--	--	--	--

¹ Dir 2003/87/EC

² forthcoming

³ allowed under Dir 2003/96/EC

Table 5-3 EU policies for CO₂ abatement technologies that need upscaling for further cost reduction

	<i>R&D</i>		<i>Demo</i>	<i>Upscaling</i>		<i>Commercial</i>		
	FP7	ETAP	Investment support	EU-ETS	Tax benefits ²	Standards	Labelling	Other policies
Transport vehicles								
Hybrid vehicles	X	--	--	--	--	--	--	--
Transport fuels								
Biodiesel	X	--	--	--	X	X ³	--	X ⁴
Ethanol (grain/starch, sugar)	X	--	--	--	X	X ³	--	X ⁴
Industry								
Fuel switch commodity prod.		--	--	X ¹	--	--	--	--
Cogeneration	--	--	--	X		--	--	X ⁶
Power								
Wind on and offshore	X	--	--	X	X	--	--	--
Solar heating and cooling	X	--	--	X	X	--	--	--
Hydro	X	--	--	X	X	--	--	--
Biomass	X	--	--	X	X	--	--	X ⁵
Geothermal	X	--	--	X	X	--	--	--

1 2003/87/EC, 2 under Dir 2003/96/EC, 3 Biofuels Dir - 2003/30/EC, 4 EU Strategy Biofuels - COM(2006)34 final,

5 Biomass Action Plan- COM(2005)628, 6 2004/8/EC

Table 5-4 EU policies for CO₂ abatement technologies facing other than cost barriers for wide scale deployment

	<i>R&D</i>		<i>Demo</i>	<i>Upscaling</i>		<i>Commercial</i>		
	FP7	ETAP	Investment support	EU-ETS	Tax benefits ¹	Standards	Labelling	Other policies
Transport								
Ethanol flex-fuel vehicles	X	--	--	--	--	--	--	--
Vehicle fuel economy	--	--	--	--	--	--	--	--
Non-engine technologies	--	--	--	--	--	--	--	--
Industry								
Motor systems	--	--	--	X	--	--	--	--
Steam systems	--	--	--	X	--	--	--	--
Materials/product efficiency	--	--	--	--	--	--	--	--
Buildings & appliances								
many...	--	--	--	--	--	X ²	X ³	--
Power								
Nuclear II and III	--	--	--	--	--	--	--	--

1 under Dir 2003/96/EC;

2 92/42/EEC, 95/57/EC, 2000/55/EC, 2002/91/EC, 2005/32/EC

3 92/75/EEC, 2004/8/EC

In section 2.2 we gave an overview of requirements for effective policies to realize an energy transition. Such policies would typically allow for diversity and co-evolution of different technologies, and facilitate the development of promising technologies by stimulating R&D, creating demand, and promoting exchange of information. They would combine short term optimization of the current energy system with a long term horizon, and consider path dependence to avoid a lock-in in a particular technology. To what extent does the present EU energy policy mix meet these requirements?

Diversity and co-evolution - Analysing the EU energy policy mix and its contribution to the further expansion of innovative energy technologies, it may be concluded that EU policies allow for a variety of technologies to develop simultaneously. Development of these technologies is stimulated both by ‘innovation push’ instruments, i.e. R&D support programs that should all be instrumental in overcoming major technical and cost barriers, and by pull instruments, which create a technology demand by labelling, imposing a standard or creating a financial incentive. In particular the recent setup of a range of European technology platforms (ETAP) may prove an important stimulus for the advancement of a number of promising technologies.

Facilitation - Nevertheless, the policy mix applied is suboptimal since not all policies are tailored to the barriers that distinct technologies face. In principle, the financial risk related to technologies in the demonstration phase could also be reduced if they would be deployed by participants in the EU-ETS to limit CO₂ emissions. Concentrated solar power could in addition benefit from tax exemptions³⁵. However, it is uncertain if these instruments will be sufficient to overcome the high upfront costs that may be associated with realizing non-commercial technologies at a large scale. As to technologies in the up-scaling phase, no genuine cost incentives exist to promote hybrid vehicles, or first generation biodiesel or ethanol in transport, although Member States are allowed to offer tax benefits to energy from renewable sources³⁶. Furthermore, some of the additional barriers to the expansion of technologies in the up-scaling phase have not been addressed by EU policies. These include e.g. public resistance against onshore wind energy, and the intermittency of wind-based power. Structural EU policies to overcome environmental and social concerns related to large scale hydropower have not been implemented either. Regarding policies for stimulating commercial technologies a large scope seems to exist for standard setting and labelling in industry and transport. Such measures could help to steer consumer behaviour during the purchase of cars, and to address the lack of awareness or expertise in industry related to energy efficient technologies. Thus, there is scope for EU energy policies to better accommodate the particular development needs of technologies in different stages of maturity.

Short term efficiency - The present policy mix seeks foremost to realize the emission reductions that may be realized in the present energy system, since these are most easy to accomplish.

Long time horizon and path dependence - The long term horizon of policies is merely reflected in the R&D subsidies for innovative technologies that are far from the market still. The time horizon and emission ceiling of the EU-ETS are presently too low to induce substantial technological change. However, the wide variety of technologies that is being supported suggests that a clear vision as to how to account for path dependencies and how to avoid a lock-in in particular technologies is lacking. It is this aspect in particular that would need more attention in the present EU energy policy mix. A road map for the evolution of the energy system is needed to effectively mitigate climate change and secure energy supply, both in the short and the long run. Such a roadmap needs to take into account path dependencies: wide deployment of decentralized electricity production will impede large scale deployment of CCS; large scale deployment of CCS will reduce the need for a breakthrough of hydrogen technologies. However, short term optimization of the present energy system is required to curb GHG emissions today, and the risk of a lock-in in a fossil fuel based energy system cannot be excluded entirely.

³⁵ Dir 2003/96/EC

³⁶ 2003/96/EC

6. Contribution of EU international collaborations to the uptake of innovative technologies

In the previous section we have seen shortcomings of EU domestic policies in the promotion of innovative and promising energy technologies. To what extent do the EU's external relationships and international collaborations make up for these shortcomings?

6.1 Partnerships for securing fossil fuel supply

A large share of the EU partnerships for improving supply security is focused on an adequate supply of fossil fuels. These external relationships are needed to keep the EU's current fossil fuel based energy supply up and running. In the conclusions of the European Council in March 2007 the Energy Dialogue with Russia and the Energy Community Treaty with South-East Europe are mentioned explicitly as actions to be taken further. Regional co-operations of the EU exist in particular with the Caucasus/ Central Asia region ('Baku Initiative'), Baltic Sea region (BASREC), Southern Mediterranean (EUROMED) and South East Europe ('Energy Community Treaty'). More recently, also an EU – Africa energy dialogue has started. Aim of these co-operations is on one hand to assure flows of gas and oil to Europe (in particular from the Caucasus region and Northern Africa), on the other hand to stimulate market opening similar to that in the European Union in neighbouring countries. Recent involvement of China in Africa has also spurred the EU – African energy relations, which partly overlap with development cooperation but are also meant to give Europe access to Africa's fossil energy resources. Important bilateral energy co-operations exist furthermore with China, India, Norway, Russia, Ukraine and the USA. These countries are either main producers of fossil fuels (Norway, Russia), crucial transit routes (Ukraine) or main consumers of energy (United States, China, India).

6.2 International technology collaborations

Apart from the partnerships for securing fossil fuel supply discussed above, the EU is involved in a range of international technology collaborations. These were all established to advance the development of specific technologies, and a selection is listed in Box 2. These partnerships are all very useful for exchanging information and experiences among participants and political agenda setting, and allow a wide range of technologies to further develop simultaneously. Their focus on relatively immature technologies implies a longer time horizon than most EU domestic policies. However, while they all focus on one or a limited subset of technologies, they will not provide an overall vision for realizing an energy transition, in which path dependencies and remedies for potential lock-ins are suggested. Strong leadership and political will is needed to compose such a vision and to set priorities.

Box 2 EU technology collaborations

IEA Energy Technology Implementing Agreements

41 agreements with varying participation, ranging from advanced fuel cells to wind energy systems

Carbon Sequestration Leadership Forum

21 countries and EU participating, aim is to stimulate research, demonstration and development of carbon capture and storage technologies

International Partnership for the Hydrogen Economy

16 countries and EU participate, goal is to accelerate the transition to a hydrogen economy.

Renewable Energy and Energy Efficiency Partnership (REEEP)

Public private partnership backed by more than 200 governments, businesses and ngos. Its aim is to structure policy and regulatory initiatives for clean energy, and facilitates financing for energy projects.

Methane to Markets Partnership

Partnership of 20 countries with high methane emissions. Aim of the cooperation is to reduce methane emissions in particular in agriculture, coal mines, landfills and oil and gas systems.

World Bank Gas Flaring Reduction Initiative

Cooperation of 5 donor countries and EU, 12 target countries, 9 oil companies and 2 multilateral organisations (OPEC, World Bank) aiming to reduce gas flaring at oil production.

Extractive Industries Transparency Initiative

Initiative of 20 countries that supports improved governance in resource-rich countries through the verification and full publication of company payments and government revenues from oil, gas, and mining.

ITER Nuclear fusion Project

ITER is a joint international research and development project in which 7 countries cooperate. It aims to demonstrate the scientific and technical feasibility of fusion power

7. Conclusions

In this paper we assessed adequacy of the EU energy policy mix for meeting the three objectives of the EU energy policy, as formulated in the EC's energy policy package: climate change mitigation, a secure energy supply, and competitiveness. Many technologies may contribute simultaneously to reducing CO₂ emissions and improving the security of energy supply, although exemptions exist as well, such as a switch to natural gas technologies. As to the latter objective, we started from the presumption that technological innovation is a vital precondition for competitiveness, since technological innovation will ultimately lead to cost reduction, it will provide to a competitive advantage, push improvement of traditional technologies, lead to re-investment of saved resources and to an improved capital and labor productivity.

Ongoing technological innovation and expansion of energy technologies are key elements of a transition to a low carbon energy system. A successful long term strategy to realize such a system allow for a wide range of promising energy technologies to further develop simultaneously; it has a long term horizon to provide companies and consumers confidence to invest in clean technologies; it seeks to optimize the present energy system to realize short term emission reductions; it attempts to avoid a lock-in in existing technologies; and it facilitates the development of a range of promising technologies by providing financial support, stimulating demand and/or promoting the diffusion of knowledge and expertise amongst stakeholders.

Today's EU energy policies are most likely not sufficient to mitigate climate change and secure energy supply in the long term. Current EU policy documents tend to flag a wide range of issues that are relevant for mitigating climate change and securing energy supply. Quantitative targets have been formulated for renewable energy, biofuels and energy efficiency, which may help to put some pressure on the expansion of nearly commercial technologies. However, no objectives have been specified to speed up technological innovation in the EU. The EU-ETS, which is the

cornerstone of EU climate policy, in its present form does not provide the incentive for major investments in innovative technologies. Therefore, complementary policy objectives and instruments for stimulating specific technologies will prove useful. Policies for security of supply have a short to medium term horizon and focus on securing an adequate fossil fuel supply, and measures to stabilize the electricity grid. Securing energy supply on the long term (e.g up to 2050) would require energy policies to be focused more on technological innovation. Although a range of domestic energy policies and international technology collaborations allow for a range of energy technologies to further develop simultaneously, not all barriers that technologies face are addressed adequately. Important deficiencies include *inter alia* targeted support for technologies that need to be demonstrated still, stimulation of hybrid and flex-fuel vehicles, and exploitation of possibilities for labelling and standard setting in industry and transport. In general, current policies focus on realizing short term efficiency gains in the present energy system and lack a vision as to exactly how the present energy system would eventually evolve into a new intrinsically low carbon and secure energy system.

Therefore, while continuation and strengthening external relationships is vital for an adequate fossil fuel supply in the short and medium term, and while technology collaborations with the rest of the world are crucial to further develop a range of promising energy technologies, there is an apparent need to prioritize future action for energy transition in the EU in a transition roadmap. In particular, such a roadmap to an energy transition would hold a program for future diffusion of promising technologies, indicating not only R&D priorities, but also stepwise actions to advance demonstrations and subsequent upscaling of technologies. It would also provide insight into how innovative technologies could be accommodated by existing and new energy infrastructures. How would the present electricity grid need to be adjusted to allow for large scale deployment of decentralized electricity production from intermittent renewable sources? How would a future hydrogen distribution network be designed? Would it require adjustment of existing the gas network, or construction of new pipelines? Would a separate CO₂ pipeline network be required to transport CO₂ to suitable underground storage locations, in anticipation of a breakthrough of hydrogen technologies? What would need to be the timing of required actions, and what would be the role of industries, the European Commission, national governments, and financial institutions? All these issues would need to be addressed in a long term energy strategy for the EU. That will provide the fundamental basis for innovative technologies to curb CO₂ emissions and secure energy supply in the long term.

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