EU policy options for climate and energy beyond 2020

Policy studies

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Introduction

In 2009, the EU climate and energy package with targets for 2020 (the so-called 20-20-20 targets) were formulated. For the period after 2020, however, there are no legally binding targets at the EU level, except for a decreasing ETS cap which will not be sufficient in light of the ambition for 2050. This leads to uncertainty for market players, as project lead times are long and high upfront investments need to deliver returns well beyond 2020. In its Green Paper on a 2030 framework for climate and energy policies (EC, 2013), the European Commission recognised the need for clarity regarding the post-2020 policy framework. Currently under discussion is whether the approach for 2020 should be continued towards 2030 in the form of three more stringent targets or that other approaches would be more appropriate. Within this context, the Dutch Government asked PBL Netherlands Environmental Assessment Agency and Ecofys for advice. PBL and Ecofys have subsequently analysed possible options for an EU policy framework for 2030 that will steer towards a low-carbon economy by 2050 in a cost-effective way. The main conclusions are summarised below.

Main conclusions

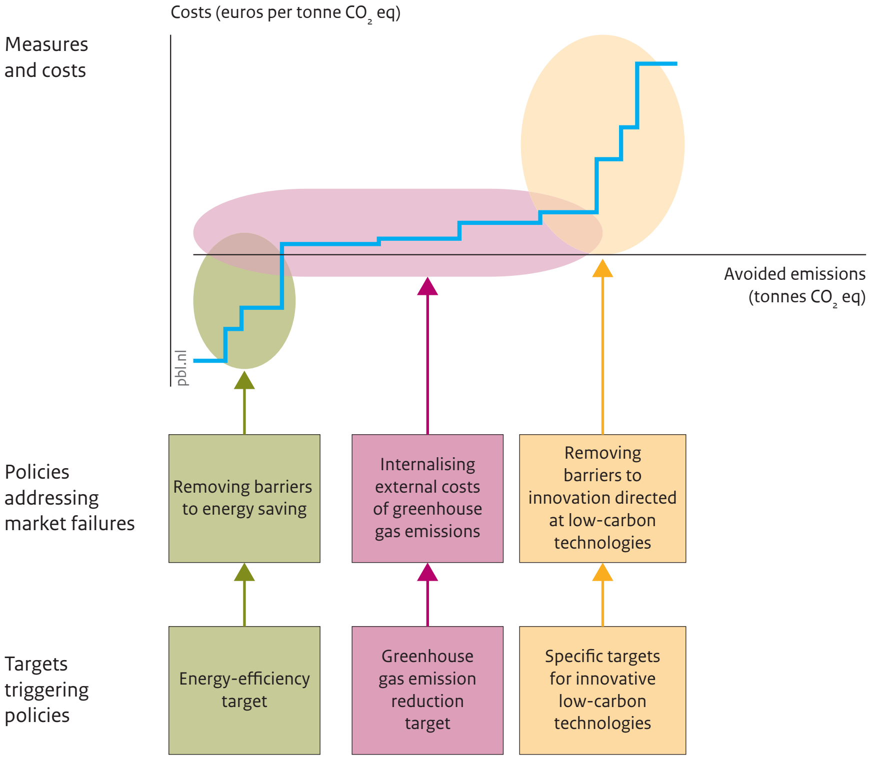
For effective and efficient policies to achieve drastic emission reductions, a mix of instruments is needed that addresses three main market failures: (1) negative externalities from greenhouse gas emissions; (2) underinvestment in energy-efficiency improvement mainly due to a lack of information, split incentives and high upfront costs; and (3) underinvestment in low-carbon innovation due to knowledge spillovers and high upfront costs (Figure S.1).

Realisation of such a policy mix is more likely when backed by a renewed mix of complementary targets for greenhouse gas reduction, energy efficiency, and low-carbon innovation. Setting an interim target for greenhouse gas reduction only and implementing policies to achieve this target against the lowest costs may lead to higher costs in the long term, compared to policies to achieve a set of complementary targets for greenhouse gas reduction, energy efficiency and low-carbon innovation. Achieving drastic emission reductions in the long term would require an unconditional greenhouse gas target for 2030. The development of complementary and non-contradictory policies by the EU and all Member States, directed at energy-efficiency improvement, avoidance of further lock-in into carbon-intensive assets, and innovation of low-carbon technologies may enhance cost efficiency in the long term. Such policies may be triggered by establishing complementary targets that will provide clarity to market players.

A general target for renewable energy, similar to the current 2020 target, is not optimal to stimulate low-carbon innovation. The existing targets for renewable energy do support the deployment of such energy sources, but are not sufficient nor are they tailor-made,

Figure S.1

Relation between emission reduction measures, policy instruments and targets



Source: adapted from Hood (2011) and IEA (2012a)

Stylised cost curve, identifying various market failures and policy approaches to address these.

from the point of view of the necessary investments in innovation, up to 2030 and beyond, to achieve a low-carbon economy by 2050. The targets for renewable energy, to date, have stimulated the development and cost-price reduction of several important low-carbon technologies, such as wind power and solar photovoltaic (PV) systems. However, especially in the case of biomass, having a general renewable energy target is not sufficient to stimulate innovations. There is a wide variety of biomass streams and applications that differ in relevance for long-term decarbonisation. The 'low-hanging fruit' in biomass application, as stimulated by the renewable targets up to now, has mostly been based on biomass streams or applications of biomass with limited potential to realise drastic, long-term emission reductions, or concerns the use of unsustainable biomass. The targets for 2020 have not proven to be a real incentive for the more promising, innovative, yet more expensive biomass options. Moreover, other low-carbon technologies, such as carbon capture and storage (CCS) and technologies directed at electrification (in transport and heat production, and indirectly by using hydrogen produced with clean electricity), are not being stimulated by the existing renewable energy targets.

A renewed approach to trigger innovation needs to support those (groups of) technologies that have both a large potential for long-term emission reduction and for cost-price reduction. Such a renewed approach is not one of picking winners, but of stimulating the most promising options; those options that can make a significant contribution to emission reductions in the long term, and have sufficient potential for cost-price reduction, but will not yet be competitive after 2020, from a greenhouse gas emission reduction point of view. Examples of such innovative low-carbon technologies are offshore wind power, innovative biomass conversion (other than direct combustion), concentrated solar power (CSP) and carbon capture and storage (CCS).

In practice, such policies could be triggered by making the current general renewable energy target more specific by excluding or limiting accounting for non-innovative options, or by setting a target to stimulate innovative low-carbon generation technologies (see also Figure 3.3). Such a target could be achieved by legislation that would require a certain share of final energy demand to be met by innovative low-carbon technology, rather than by renewable energy in general. In addition to creating a market perspective, low-carbon innovations will benefit from enhanced RD&D. To stimulate innovative low-carbon end-use applications or production processes, specific targets could be set, for example, for the number of zero-emission vehicles, the application of heat pumps, or the application of advanced low-carbon industrial processes. This approach would offer Member States more flexibility to choose between stimulating only renewable energy, or also other innovative low-carbon technologies.

The need for carbon pricing

Carbon pricing is a vital element of efficient policies to reduce greenhouse gas emissions. Putting a price on carbon internalises – at least to some extent – harmful external effects of greenhouse gas emissions. Policy instruments that put a price on carbon include emission trading and carbon taxation. In contrast, subsidies for fossil-fuel production and/or consumption are counterproductive to arrive at a cost-effective policy mix.

The EU ETS will need to remain an important instrument to guarantee emission reductions in industry and electricity generation – its primary objective. However, since the supply-side of the market for emission allowances is fixed (as determined by the emission cap), and the demand-side depends among other things on economic fluctuations and policies, the CO_2 price will fluctuate over time. Because the supply of emission allowances is relatively high and the demand low, the CO_2 price is much lower than foreseen at the time the ETS directive was adopted. If the ETS will not be reformed, the market expects the price to remain low for the next years, in which case the ETS would insufficiently steer investments in a low-carbon direction and would insufficiently support low-carbon innovation. Therefore, whether or not the ETS should be structurally reformed is currently under debate. A structurally higher CO_2 price, for example, resulting from introducing a price floor in combination with a tighter emission ceiling, can be an important stimulus for low-carbon innovation. However, efficient innovation policies will require more than a higher CO_2 price only.

Regarding an ETS target for 2030, this should be in line with the long-term conditional target of 80% to 95% emission reduction by 2050. To guarantee the achievement of the overall emission reduction target, the ETS target needs to be supported by a target for the non-ETS sectors, to capture all emissions of all sectors and include non-energy-related emissions such as agricultural methane and nitrous oxide emissions. A legally binding target for greenhouse gas reduction by 2030 will help to guarantee that emission reduction measures are taken. Based on equal costs as a share of GDP, the EU should reduce emissions by 45% to 47%, as its contribution to the target of limiting global temperature increase to 2 °C. In case of other effort-sharing regimes, an EU emission reduction of 40% by 2030 would suffice to keep the 2 °C target within reach.

Although a cap-and-trade system may be the preferred instrument for cost-effective emission reductions, the current ETS is limited in time (there is uncertainty about the emission cap for the long term), space (no global system) and sectoral coverage. Because of these limitations, and because of the existence of other market failures, a carbon pricing policy needs to be complemented by other policies to arrive at an efficient policy mix, while taking into account the interactions that will occur between different instruments.

The need for complementary policies to stimulate energy efficiency

Carbon pricing alone will not be effective in achieving energy-efficiency improvements. Although energy taxes for consumers in some countries correspond to CO_2 prices of 100 to 200 EUR/tonne, much potential for energy-efficiency improvement remains untapped, also where this would have net benefits from a national perspective. Among the many reasons for this are split incentives (cost are carried by others than by those who benefit), high upfront investment costs along with limited access to capital, lack of information, and other investment and consumption priorities. Similarly, current taxes on road transport fuels provide price signals of 200 to 300 EUR/tonne CO_2. The incentives for energy saving by end users would be even higher because these relate to total energy prices rather than only to taxes. Expanding the ETS to include the residential and tertiary sectors and road transport may thus be expected to have only a minor impact on energy-efficiency improvements in these sectors. Hence, complementary policies are needed.

Complementary policies directed at energy efficiency will improve the overall cost efficiency of policies. Such complementary policies may be triggered by a target for energy-efficiency improvement, complementary to a greenhouse gas reduction target. However, a legally binding target for energy efficiency would have only limited added value if binding EU legislation would be implemented at the same time. In that case, a non-binding (indicative) EU target could suffice. EU regulation of standards for energy efficiency is important to contribute to the internal market. Examples of effective policies are the EU Ecodesign Directive, the Energy Performance of Buildings Directive and the EU regulation setting emission performance standards for new passenger cars. Although instruments to improve energy efficiency in ETS sectors would not lead to additional emission reductions if the ETS ceiling is not changed at the same time, they may improve the overall cost efficiency of policies as they could trigger certain cost-effective measures that would otherwise not have been taken.

The need for complementary policies to stimulate low-carbon innovation

Market players tend to underinvest in innovation, because innovating companies generally do not fully profit from successful innovations. Part of the knowledge spills over to other firms that also benefit from the innovation. Therefore, private investments in innovation are likely to fall below the social optimal level. Public support for innovation may correct this. Putting a sufficiently high price on carbon emissions may trigger low-carbon innovation.

Carbon pricing alone, however, will not stimulate investments in innovative low-carbon technologies in a cost-effective manner. The high prices that would be needed to make several promising low-carbon technologies cost-competitive, in the short term, would render much currently installed installations unprofitable (e.g. existing coal-fired power plants). For example, CO_2 prices of more than 100 EUR/tonne would be necessary to stimulate offshore wind power or CCS without additional subsidies. Such CO_2 prices would result in a very rapid decline in greenhouse gas emissions as well as in high stranded costs. In this sense, the ETS can be regarded as being the 'stick' that needs to be complemented by 'carrots' (innovation support through RD&D and deployment) to establish a cost-efficient policy mix. For this 'stick' to have effect, clearly, CO_2 prices higher than the current level of 5 EUR/tonne are needed.

Policies on low-carbon innovation need a two-track approach, stimulating both technology push (for technologies that are in the RD&D phase) and market pull (for technologies that are closer to the market). Innovation policies should not only stimulate learning by searching (RD&D) but also learning by doing (deployment). These two tracks are likely to reinforce each other as the market will be more interested in RD&D if a market perspective is present, while application in practice may steer the direction of more basic research and may trigger actions directed at non-cost-related barriers.

A dynamic rather than a static view on costs of policies is needed, because energy transition will take many decades, energy technology costs evolve over time and the lifetime of physical assets is long. Emissions will need to decrease further after 2030. This simple fact has important consequences for policy design, to make this more efficient over the whole energy transition period (up to 2050). Enhancing policy efficiency requires action today to avoid that up to 2030 only 'low hanging fruit' is harvested, while the potential of such obvious options may be exhausted by 2030. In that case, much more expensive measures need to be deployed, on a large scale, after 2030, while the necessary technologies have not been developed through pilots, demonstration projects or in niche markets, nor will necessary institutions and infrastructure have been developed. This has two important implications.

First, a further lock-in in high-carbon technologies should be avoided. For example, many of the coal-fired power plants built today will still be operational in 2050. Such high-carbon electricity generation will not fit in a low-carbon economy. Current policies will not prevent investments in new coal-fired power plants that have no carbon capture and storage (CCS) systems (they merely need to be 'capture ready'), while many CCS demonstration projects are being postponed or abandoned. The setting of an emissions performance standard for new power plants at around 400 g CO_2/kWh, in the short term, will prevent further lock-in into the most carbon-intensive electricity generation (using coal and lignite without CCS).

Second, stimulating innovation will improve policy efficiency, in the long term. In the short term, policies that support innovation will increase policy costs without affecting overall emission levels (assuming no change to the greenhouse gas emission reduction ambition). The reason for this is that emission reductions stemming from deployment of innovative technologies (e.g. wind power, solar PV or CCS) will oust cheaper emission reduction measures (e.g. fuel switching from coal to gas) or cheaper energy-efficiency improvements. However, policies ultimately will be more efficient when sufficient progress is made to drive down the costs of currently expensive technologies that have a large potential for emission reduction in the long term and hold a substantial potential for cost-price reductions.

In general, interactions will occur between the various instruments in the policy mix. On the one hand, energy efficiency improvement will make it easier to reach a certain share of renewable or low-carbon energy in final energy demand. On the other hand, emission reductions induced by policies to support renewable energy or low-carbon technology, energy-efficiency policies and emissions performance standards, together, do not lead to additional emission reductions within the ETS if the emission cap is not changed, as well. Moreover, such policies will always have some impact on the carbon price in the ETS, which may weaken the effect of CO_2 prices spurring on low-carbon innovation. The magnitude of such interactions will depend, among other things, on the definition and height of complementary targets and the design of policy instruments. However, the effect of a slightly lower CO_2 price that would result from complementary policies to stimulate innovation may not necessarily be problematic, as low-carbon innovations after all would be stimulated directly through those specific, complementary policies. In general, such interactions ask for thorough (ex ante) analysis to carefully align policies, and for regular, announced reviews to keep instruments aligned once they are implemented.

FULL RESULTS

ONE

Introduction

1.1 Policy context

Decarbonising the EU economy by 2050 – an ambition repeatedly expressed by political leaders in Europe – will require an overhaul of energy production and consumption patterns. In the EU Energy Roadmap 2050, the European Commission sketches various decarbonisation scenarios, showing the technical feasibility of an 80% greenhouse gas emission reduction by 2050 (compared with 1990 levels), by enhancing energy efficiency, the use of renewable energy (biomass and non-biomass), carbon capture and storage, nuclear energy, and by increasing the use of electricity in final energy consumption. Although, according to the European Commission, overall costs of the energy system do not greatly differ between the various decarbonisation scenarios and the current policies scenario (averaged over the period up to 2050; EC, 2011b), the effort required to realise such an energy transition can hardly be overestimated. Efforts include financing high upfront costs of low-carbon technologies, changing market regulations to deal with intermittent and non-dispatchable electricity generation, the need for new infrastructure, enhanced international cooperation, new institutions and securing the social acceptance of energy technologies.

In the 2009 climate and energy package, policy targets were formulated for greenhouse gas emission reduction, renewable energy and energy efficiency to be achieved by 2020. However, there are no legally binding targets for the period following 2020, apart from a decreasing ETS cap that will not deliver sufficient emission reductions in light of the 2050 ambition. This leads to a lack of clarity for market players, as capital investments in energy technologies need to deliver a return on investment well beyond 2020. In the Energy Roadmap 2050, the European Commission recognised the need to provide clarity regarding the post-2020 policy framework. Under discussion is whether the approach for 2020 should be continued towards 2030 or that other approaches would be more appropriate. The political discussions are broader than decarbonisation only, as energy security, affordability, competitiveness, market opportunities and job creation play an important role, as well.

Within this context, the Dutch Government asked PBL and Ecofys for advice. PBL and Ecofys have subsequently analysed possible options for an EU policy framework for 2030 that will steers towards a low-carbon economy by 2050 in a cost-effective way. For this analysis, PBL used results from recent analyses and arguments in the debate on the EU Energy Roadmap 2050 and on the strategy on renewable energy after 2020.

This report is structured as follows. Chapter 1 describes the policy context and sketches the main building blocks for a low-carbon economy. Chapter 2 summarises insights from the literature on policy instruments that could steer society into a low-carbon direction. Chapter 3 further elaborates the role of various policy targets in triggering specific technology developments. Chapter 4 evaluates the pros and cons of various policy options, in the light of the steps that must be taken over the next decade towards realising a low-carbon economy by 2050.

1.2 Building blocks for a low-carbon economy

This section summarises the main elements of a low-carbon energy system, based on scenarios described in the EU Energy Roadmap 2050 (EC, 2011a). These elements are consistent with findings of many other scenario studies (e.g. ECF, 2010; Ros et al., 2011). In general, there is no blueprint for achieving a low-carbon society by 2050. Many technological options are available and numerous combinations could be made. However, important building blocks can be distinguished. It is a robust strategy to develop all building blocks to a certain extent.

Energy efficiency

In the low-carbon scenarios of the EU Energy Roadmap 2050, primary energy demand will have decreased by some 32% to 41% by 2050, compared to the peak demand in 2005, while current policies are projected to achieve a decrease of 12% between 2005 and 2050.

Renewable energy sources

Currently, renewable energy sources (RES) contribute about 10% to gross final energy consumption. All decarbonisation scenarios suggest increased shares of renewable energy, up to some 30% of gross final energy consumption by 2030 and between 55% and 75% by 2050. Renewable energy sources, thus, will dominate the energy mix in all low-carbon scenarios for 2050. Biomass can be used to replace fossil fuels in many applications, including non-energy-related use of fossil fuels (e.g. in plastics). In addition to biomass, non-biomass renewable energy may substantially contribute to electricity generation (e.g. solar PV, CSP, wind power, hydropower, geothermal power, tidal and wave power) and heating/cooling (solar heat and heat exchanged with the underground or the air through heat pumps).

Carbon capture and storage

According the EU Energy Roadmap 2050, carbon capture and storage (CCS) will be important in all decarbonisation scenarios for 2050 (19% to 32% share in electricity generation), except for the high renewable energy scenario in which its role is limited to 7%. Also in the IEA decarbonisation scenario, CCS is projected to play an important role towards limiting global warming to 2 °C, as it is assumed to account for about 20% of the emission reductions needed globally up to 2050 (IEA, 2012a). Although relatively many alternatives exist for low-carbon electricity generation, CCS is the only currently available technology that would allow industrial sectors (e.g. iron and steel, cement, natural gas processing) to achieve large emission reductions (IEA, 2012a).

Electrification and low-carbon electricity

In all EC decarbonisation scenarios, the share of electricity in final energy consumption increases, from about 20% in 2005 to between 36% and 39% by 2050 ('electrification'). Electric vehicles and heat pumps will be important to decarbonise light-duty transport and the residential and tertiary sectors. Relatively many options for low-carbon electricity generation exist: renewable energy (many options for non-biomass as well as biomass, eventually in combination with CCS), fossil energy with CCS and nuclear energy.

In the EC decarbonisation scenarios, the power sector would achieve a significant level of decarbonisation (57% to 65% by 2030 and 96% to 99% by 2050). Regarding nuclear energy (with a 30% share in Europe's electricity generation in 2005), all EC scenarios show a declining share (also in current policies), but it continues to make a substantial contribution to low-carbon electricity generation in three decarbonisation scenarios (14% to 19%). In two other scenarios (high renewable energy and low nuclear energy), its share declines to between 3% and 4%.

Infrastructure

An increased share of intermittent electricity generation provides many challenges with respect to balancing production and demand, during the daily cycle as well as in the longer term (from weeks to seasons). Technical solutions would be a flexible back-up capacity (typically gas-fired power plants), strengthening the transmission grid to cope with variations in production and demand, increased storage possibilities (pumped hydropower, batteries, power to gas), and the development of smart distribution grids and demand-side management. Significant investments in infrastructure will be needed to modernise the energy system, both with and without decarbonisation.

Effective and efficient policies towards a low-carbon energy system

2.1 Carbon pricing: The cornerstone of efficient policies

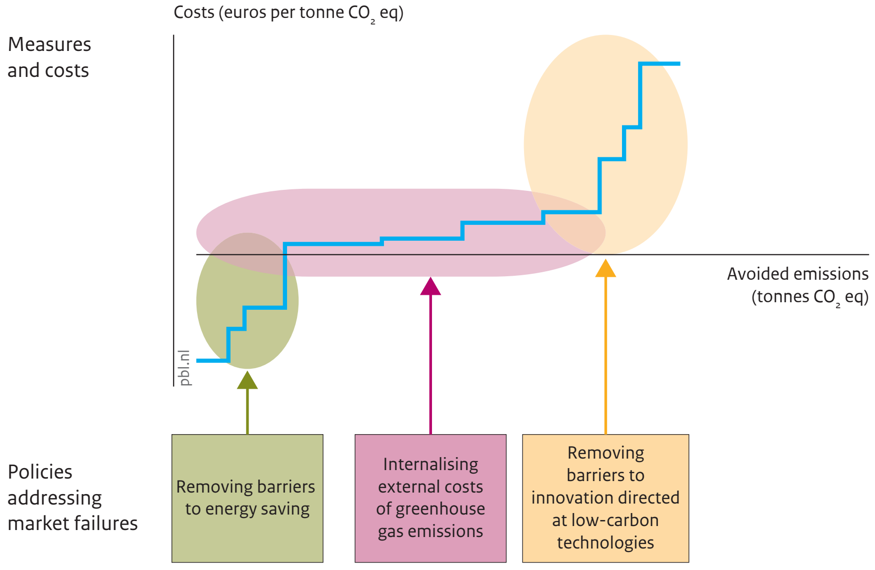
Policymakers seek to establish effective and efficient policies. Policies are effective when they deliver an emission reduction by 2030 that is in line with the 2 °C target. Efficient means delivering this emission reduction at the lowest costs, measured over the whole period that the energy transition will take.

When discussing policy efficiency, Figure 2.1 could be helpful as it shows a stylised cost curve in which various greenhouse gas mitigation measures are ordered according to increasing abatement costs (y axis) and their cumulative effect shown on the x axis. Costs are considered at the national level, and include investment costs and fuel costs, but exclude subsidies and taxes that only distribute costs between actors. Also, other welfare effects, such as those stemming from fewer greenhouse gas emissions or behavioural changes, are not considered in this curve.

From the economic literature, it is clear that putting a price on carbon emissions is at the heart of efficient policies to reduce greenhouse gas emissions (e.g. Hood, 2011; IEA, 2012a). Putting a price on carbon internalises harmful external effects of greenhouse gas emissions. To what extent a certain carbon price internalises external effects is extremely difficult to say. Damage and adaptation costs of climate change are very uncertain and may increase over time and may differ across the globe. Mitigation costs are not fixed but also may change over time, because of technological progress. Therefore, it is virtually impossible to determine the optimal carbon price (a Pigouvian tax) to fully incorporate those external effects (Hope and Newbery, 2008; Gross et al., 2012). Rather than reflecting the price of external effects, within the ETS, the carbon price reflects marginal abatement costs involved in meeting the emission cap.

Although carbon pricing is efficient, in many parts of the world, fossil-fuel production and/or consumption is currently being subsidised rather than taxed. End-use 'subsidies' for fossil-fuel use in 37 IEA countries representing 50% of global fossil energy consumption, amounted to USD 523 billion in 2011, up 30% from 2010 (IEA/OPEC/OECD/World Bank, 2012; IEA, 2012b). In this estimate, subsidies include lower tax rates for fossil fuels. Since the choice of the reference tax level can be disputed and differs widely between countries, the interpretation of such figures is difficult. Nevertheless, European countries also continue to provide direct financial support for fossil-fuel production. Examples are German subsidies for coal mining, and support of the European Investment Bank (EIB) to fossil-fuel-fired electricity generation (CEE Bankwatch Network, 2011). Subsidies for fossil-fuel production and/or consumption are counterproductive for a cost-effective policy mix. In general, progress is made to gradually phase out such support. For example, German subsidies for coal mining fell from 4.9 billion

Figure 2.1
Relation between emission reduction measures, policy instruments and targets



Source: adapted from IEA (2012a) and Hood (2011)
Stylised cost curve, identifying various market failures and policy approaches to address these.

euros in 1999 to 2.1 billion in 2009, and should be phased out entirely by 2018 (OECD, 2012).

Carbon pricing may be done through a carbon tax or through a cap-and-trade system. Both forms of carbon pricing have their advantages and disadvantages, depending on the slopes of marginal cost and benefit curves (Hepburn, 2006). An advantage of a cap-and-trade system is that the environmental effect is known in advance, as opposed to a tax. However, a cap-and-trade system also means that the price of CO_2 emissions is established by the market, and may show unpredictable fluctuations, thus providing less clarity to investors. Also, hybrid systems have been proposed and discussed, such as introducing a carbon price floor to guarantee a minimum carbon price. The latter system was introduced in the United Kingdom in April 2013. A cap-and-trade system has been chosen in the EU also for practical reasons; taxation is a competence of Member States and EU legislation has proved politically unfeasible. This report does not discuss the issue of taxation versus a cap-and-trade system any further and assumes that carbon pricing will continue to be established by the EU ETS.

The EU ETS will need to remain an important instrument to guarantee emission reductions in industry and electricity generation – its primary objective. However, since the supply-side of the market for emission allowances is fixed (as determined by the emission cap), and the demand-side depends among other things on economic fluctuations and policies, the CO_2 price will fluctuate over time. Because the supply of emission allowances is relatively high and the demand low, the CO_2 price is much lower than foreseen at the time the ETS directive was adopted. If the ETS will not be reformed, the market expects the price to remain low for the next years, in which case the ETS would insufficiently steer investments in a low-carbon direction and would insufficiently support low-carbon innovation. Therefore, whether or not the ETS should be structurally reformed is currently under debate. This issue is discussed further in Section 2.3.

The ETS target for 2030 should be in line with the long-term conditional target of 80% to 95% emission reduction by 2050. In order to guarantee that the overall emission target will be achieved, an emission reduction target for the ETS needs to be complemented by a target for the non-ETS sectors, to capture all emissions from all sectors and to include non-energy-related emissions, such as agricultural methane and nitrous oxide emissions. A binding target for greenhouse gas emission reduction for 2030 will help to guarantee that reduction measures will indeed be taken. Based on equal costs as a share of GDP, the EU should reduce emissions by 45% to 47% as a contribution to the target of limiting global temperature increase to 2 °C. In case of other effort-sharing regimes, an EU emission reduction of 40% by 2030 would suffice to keep the 2 °C target within reach (Hof et al., 2012).

Although the ETS, if properly implemented, triggers low-cost mitigation measures, it does not account for the knock-on effects of such abatement measures on the economy. This is particularly a concern for companies competing on the global market and in case the emission trading system has no global coverage (at least for the sectors concerned). For example, the European primary steel sector cannot fully pass on the costs of emission reduction measures by incorporating them in the prices of their products without risking loss of market share. Therefore, sectors exposed (or deemed to be exposed) to international competition or those that are energy-intensive receive part of their emission allowances for free. In the absence of a global emission trading system, the position of such companies asks for compensation measures to avoid carbon leakage and negative effects for the European economy. The extent to which compensation measures are necessary depends on the CO_2 price. In practice, dealing with the carbon leakage issue complicates a structural reform of the ETS in which a high and stable CO_2 price is achieved and that could stimulate low-carbon innovation (see Section 2.3).

2.2 Complementary policies on energy efficiency

Some argue that a legally binding greenhouse gas reduction target and an expanded EU Emissions Trading System (ETS) (one that includes all sectors), would be most efficient for achieving the targeted emission reduction.

However, Figure 2.1 illustrates that certain abatement measures that would have net national cost-benefits are nevertheless not being implemented. Many of these measures relate to energy efficiency (Wesselink and Deng, 2009). For these measures, the savings from fuel-efficiency improvements accumulated and discounted over the lifetime of the technology involved would exceed initial investments. Among the many reasons why these measures are not taken, are split incentives (costs are carried by others than by those who benefit), high upfront investment costs along with limited access to capital, lack of information, and other investment or consumption priorities .

Much of the energy-saving potential is found in sectors currently not covered by the EU ETS. However, expanding the EU ETS to include such sectors is expected to have only a minor impact on energy efficiency improvement. For example, although in some EU countries (Denmark, the Netherlands), energy taxes for consumers correspond to prices of 100 to 200 EUR/tonne CO_2, much potential remains untapped (EC, 2011c). Similarly, current taxes on road transport fuels (EC, 2012a) send out price signals of 150 to 300 EUR/tonne CO_2. Actual incentives for energy saving by end-users are even higher because they depend on energy prices rather than on taxes only. Even under a structural ETS reform with CO_2 prices that would be considerably higher than current prices (in 2012 about 7 EUR/tonne CO_2), including the residential, tertiary and road transport sectors in the ETS is expected to have no or only a minor impact on energy-efficiency improvement in these sectors, as energy demand has a low price elasticity. Hence, complementary policies directed at energy savings may improve the overall efficiency of policies.

Complementary energy-efficiency policies may be triggered by an energy-efficiency improvement target, complementary to a greenhouse gas reduction target. A question is whether this target should be legally binding, as that may not have much added value in case policies are implemented through EU legislation in which binding energy efficiency standards are set. In combination with such legislation, a non-binding (indicative) target could be sufficient. The strength of regulation on EU-level, such as to establish energy efficiency or emission standards for products, buildings, and production processes, is that it contributes to the common market. In case national targets are formulated, these would need to leave room for national governments to tailor their approach to fit specific solutions on a national level.

Energy-efficiency standards for battery charging systems that will enter into force in 2013 in California are an example of how introducing standards may lower overall societal costs. Currently, nearly two thirds of the electricity consumed by battery chargers is wasted as heat. Producers of battery chargers are not interested in producing more efficient chargers (although this would add only about USD 0.50 to the production costs per charger). However, the obligation for producers to produce more efficient chargers would save consumers USD 9 in electricity over the lifetime of the device. A similar example can be given for passenger vehicles. The estimated additional costs involved in achieving an emission target of 95 g CO_2/km for passenger vehicles by 2020 would be approximately 1000 euros per vehicle (Meszler et al., 2012), which would easily be compensated by lower fuel costs during the vehicle's lifetime. Untapped energy-saving potential exists not only in non-ETS sectors, but also in industry and energy sectors under the ETS. A study by Martin et al., in 2011, found that firms generally require a payback time of four years for investments in energy-saving measures. This was based on interviews with almost 800 manufacturing firms in

Table 2.1
EU energy-saving potential for 2050 and net cost reductions

	Final energy demand (in million tonnes of oil equivalent (Mtoe))					
	2008	**2050 baseline**	**2050 exploiting full savings potential**	**Final demand reduction (%)**	**Net cost reduction (billion euros 2005)**	**Remarks**
Households	297	290	83	71	124	Half of the savings relate to the building shell refurbishment of existing buildings
Tertiary sector	147	149	59	61	71	Two thirds of the savings are building-related
Industry	317	370	178	52	102	75% of savings from cross-cutting technologies (efficient steam and hot water generation as well as optimisation of entire systems relying on electric drives)
Transport	374	344	163	53%	191	Nearly half of the savings are related to technical improvements in road transport. Behavioural measures and modal shift would contribute 13% and 7%, respectively
Total	1135	1153	483	57%	488	

Source: Fraunhofer ISI (2012)

6 EU countries (Martin et al., 2011). Examples of energy-saving measures in industry with net cost-benefits are the use of more efficient electric motors, the application of demand-related control systems, and the use of waste heat (Eichhammer et al., 2009).

A recent study by Fraunhofer ISI concluded that, by 2050, overall final energy demand in the EU could be reduced by 57% compared to baseline projections, with annual net cost savings of about 500 billion euros (Fraunhofer ISI, 2012; see Table 2.1). Their estimation of the energy-saving potential exceeds that of other studies, including the EU Energy Roadmap 2050. In the scenarios of the EU study, some 62% of the overall saving potential for 2050, as identified in the Fraunhofer study, is exploited. In the EU study's high efficiency scenario, 72% of the Fraunhofer study's potential is exploited. The estimated cost savings depend on the assumed fuel prices. In the Fraunhofer study, fuel-price developments have been chosen according to the reference scenario of the EC (EC, 2010a). Based on these results, the majority of possible energy-saving measures would be cost-efficient over their lifetimes, but would need to be triggered by policy instruments that address barriers such as high up-front investments.

Although the setting of an energy-efficiency target may trigger related policies and enhance policy efficiency, an overambitious target could also lead to inefficiencies. Not all energy-saving measures have net benefits, as such measures may occur throughout the cost curve. For example, energy-efficiency gains in industry may require a total re-design of production chains with high associated costs. Another example would be insulation measures in the residential sector which will generally be cheaper when combined with other renovation or reconstruction activities. Linking insulation works to such 'opportune' moments may be more cost-efficient than forcing these measures to be taken earlier. An energy-efficiency target which also addresses sectors within the ETS, will not lead to additional greenhouse gas reductions (given a fixed greenhouse gas cap), but may enhance overall efficiency if it triggers measures with short payback times.

2.3 Complementary policies directed at innovation

Static versus dynamic efficiency

When considering the cost curve (Figure 2.1), it is apparent that some abatement measures (indicated in the green area) will not be implemented if a certain emission cap is to be met through a low-cost cap-and-trade approach. It could be argued that this is exactly what an efficient policy should deliver: introducing only those measures that are cost-effective. This is true when considering cost optimisation in the short term, in which case the cost curve can be considered as being known and fixed, and the target to be met is the ultimate policy target aimed for (not an interim target).

1 Dynamic regulation may stimulate a race to the top

EU policies setting efficiency standards for new products have proven to be effective. Action at the EU level is important to contribute to the internal market. Examples of effective energy-saving policies are the Ecodesign Directive, Energy Performance of Buildings Directive (EPBD) and the EU regulation setting emission performance standards for new passenger cars (EC No.443/2009). These directives need to be updated regularly to account for progress in energy efficiency.

Dynamic regulation is not (yet) part of EU energy-efficiency regulation. In case of dynamic regulation, future product standards are determined by the currently best performing products. Such an approach stimulates competition between manufacturers to produce the most energy-efficient products. An example is the Top Runner programme in Japan, introduced in 1999, which sets efficiency standards for 21 products (e.g. air conditioners, TVs, cars) sold in Japan. On a regular basis, the most energy-efficient model is determined and its efficiency is set as the new standard. Manufacturers have the obligation to try and achieve this new standard within four to eight years. Products that comply with the standard receive an efficiency label. This Top Runner Programme has led to a 9.5% increase in the R&D expenditures of appliance producers. However, the programme and the labelling system for motor vehicles had little or even a negative effect on the innovative activity of motor vehicle producers, whose R&D expenditures may have increased in response to the exhaust gas regulation instead (Hamamoto, 2011).

In Japan, 'naming and shaming' is used as enforcement tool. Alternatively, enforcement could be guaranteed by imposing a ban on the sale of non-compliant products, or by establishing a bonus-malus system to stimulate the market for energy-efficient products. For example, in the Netherlands, a budget-neutral reform of the purchase tax on passenger vehicles – with penalties on the purchase of the most polluting vehicles while introducing a bonus for the least polluting ones – has stimulated the rapid increase in efficient cars over the last years.

However, such a view is an oversimplification when considering a lengthy and extremely complex process such as the transition towards a low-carbon energy system. Policies seeking to realise an energy transition at the lowest possible costs should consider the long term, and their efficiency needs to be assessed over the whole transition period. Over long-term periods, cost curves cannot be considered to be known and fixed, but rather are time dependent, and will even be influenced by policies. Moreover, cost curves present a simplified picture by treating all abatement measures independent of each other. In reality, all parts of the energy system are coupled and influence each other. For example, although the shift from ICE cars to electric cars may seem an expensive option when considered in isolation, it also enhances the potential of relatively cheap options such as onshore wind power, through enhancing the use of electricity as a final energy carrier (and through the role of electric cars in demand-side management and short-term balancing). Another complication related to a cost-curve approach is that the emission reduction achieved, for example, through onshore wind power, depends on the electricity mix and this may change over time.

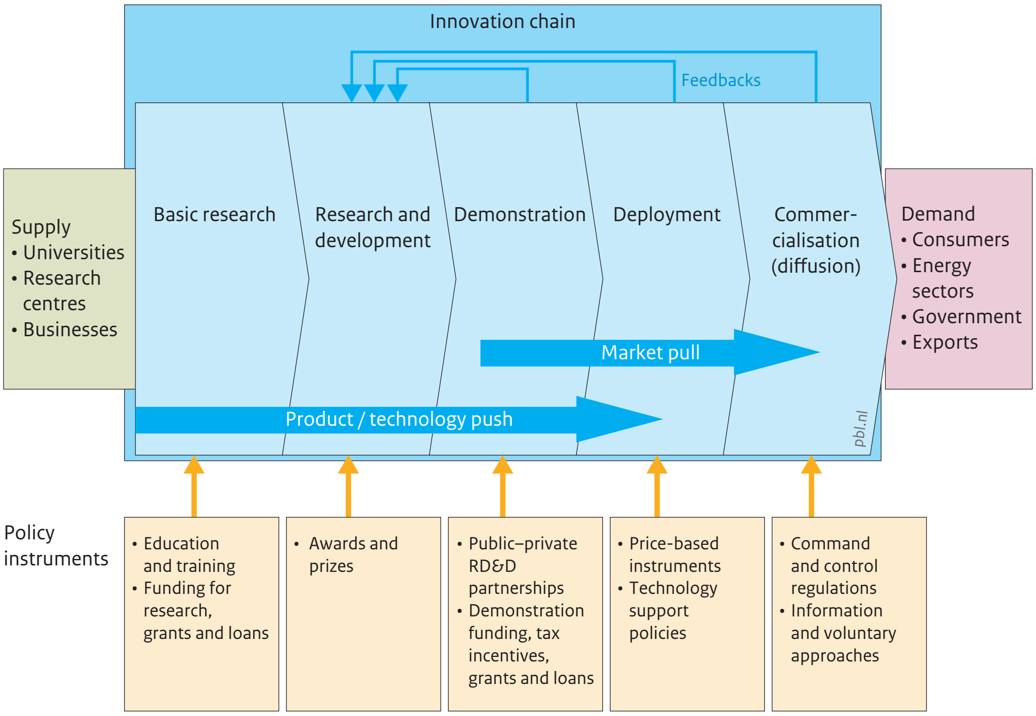
Furthermore, establishing an energy transition also involves many measures and actions that do not have a direct impact on emissions. Examples are the development of infrastructure, changes to market regulations, setting up financing schemes, and establishing new institutions. Because of these reasons, using cost curves to optimise policies is not suitable for longer term analyses. This also implies that a cost-effective approach of achieving targets for 2020 or 2030 is not necessarily the most cost-effective approach for achieving the 2050 target (see also Vogt-Schilb and Hallegatte, 2011) (see Annex 2 for an illustration).

Dynamic efficiency: avoiding further lock-in and stimulating innovation

The simple fact that, after the 2030 interim target has been achieved, further emission reductions will be required has important consequences for the design of efficient policies. Enhancing policy efficiency for the long term requires that action is taken today, to avoid that only 'low hanging fruit' will be harvested up to 2030, with the risk of such options being exhausted by 2030. In that case, much more expensive measures would need to be deployed at a large scale after 2030, while the necessary technologies will have not been developed through pilots, demonstration projects or niche markets, nor will necessary institutions and infrastructure have been developed. In this respect, two issues ask for attention.

First, a further lock-in into high-carbon technologies should be avoided to enhance policy efficiency in the long term. For example, many of the coal-fired power plants that are being built today will still be operational by 2050. Although some coal-fired electricity generation without CCS may well comply with a 2030 interim greenhouse gas

Figure 2.2
Phases of innovation and corresponding policy support instruments



Source: IEA (2012a)

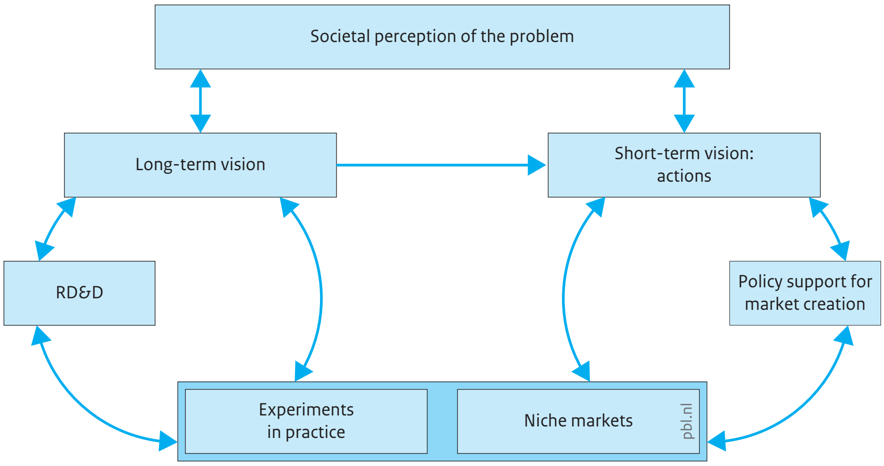
target, it will not fit in a low-carbon economy where electricity generation needs to involve close to zero-carbon emission levels (EC, 2011a). In the long term, such power plants need to be retrofitted with CCS if a low-carbon economy is to be realised by 2050. Current policies do not prevent investments in new coal-fired power plants without CCS (they merely should be 'capture ready'), while many CCS demonstration projects are being postponed or abandoned. Therefore, the United Kingdom is implementing an emissions performance standard, even if this does not benefit short-term greenhouse gas reduction. In this context, it also must be noted that enhancing the energy efficiency of existing industrial stock can be relatively cheap in the short term (e.g. improving the conversion efficiency of fossil-fuel-fired power plants or stimulating fossil-fuel combined heat and electricity generation), but may also increase the barrier for real system innovation.

Second, stimulating innovation may improve policy efficiency, in the long term. In the short term, policies to support innovative technologies in various developmental phases will increase policy costs without substantially affecting overall emission levels. Emission reductions stemming from deployment of innovative technologies – such as offshore wind power, solar photovoltaic (PV) systems, concentrated solar power (CSP) and carbon capture and storage (CCS) – will oust cheaper emission reduction measures such as fuel switching (coal to gas) or cheaper energy-efficiency improvements. The extent to which this occurs depends on the level of deployment of innovative technologies and their cost reductions. In the long term, however, policies will be more efficient when sufficient progress has been made to drive down costs of currently expensive technologies that have a large potential for emission reduction in the long-term and for substantial cost-price reductions.

A two-track approach to stimulate innovation

It is a well-known fact that private companies tend to underinvest in innovation from a societal perspective. Various market imperfections play a role in this.
An important one is that innovating companies cannot fully profit from successful innovations. Part of the knowledge spills over to other firms that also benefit from the innovation. Therefore, private investments in innovation are likely to fall below the social optimal level (e.g. Jaffe, 2005). Public support through innovation policies may correct this market failure.

Figure 2.3
'Motors of innovation' in the transition process



Source: Ros et al. (2009)

In the literature on innovation, various phases in innovation are distinguished; from basic laboratory research, to development directed at market applications, to industrial-scale demonstrations, to deployment and further diffusion (Figure 2.2). Technological innovations can be encouraged by stimulating push (RD&D support) and pull factors (policies to stimulate a market pull).

Recent innovation literature describes a more dynamic view on innovation than the linear picture presented in Figure 2.2. It describes innovation as being fostered in a well-functioning technological innovation system (TIS) that consists of actors, institutions, technologies and the interrelations between them (Carlsson et al., 1991; Suurs, 2012). The build-up of such a TIS may accelerate due to a number of system functions that interact and reinforce each other over time:

- Activities and initiatives of the entrepreneurs
- Developing knowledge
- Exchanging knowledge
- Directing the process of exploration
- Creating markets
- Increasing the availability of human and financial resources
- Lobbying and communicating to overcome resistances.

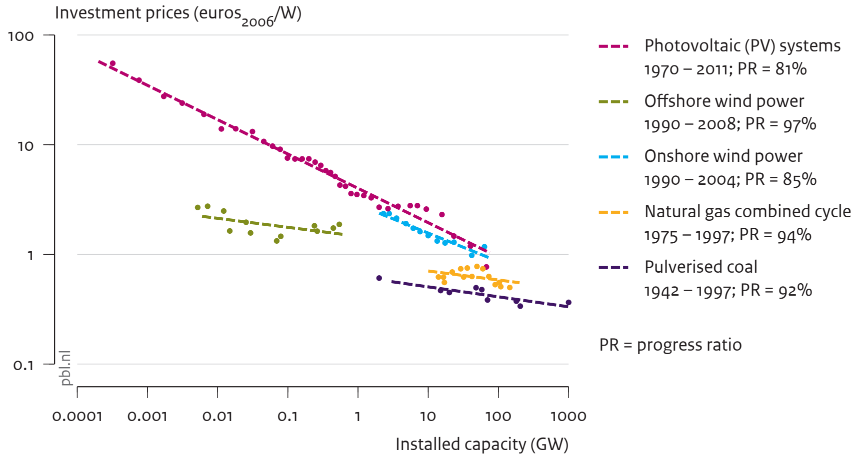
Hence, system functions include push and pull factors, but also consider other issues such as counteracting parties with vested interests that may form a barrier to change. Empirical studies have identified various 'motors of innovation' in which the different system functions work together to stimulate innovation (Suurs and Hekkert, 2012).

In a simplified form, the 'motors of innovation' based on these functions are presented in Figure 2.3 (Ros et al., 2009). The motors of 'learning by searching' and 'learning by doing' can be recognised, as well as the relation between the development of a shared long-term vision and short-term actions. Radical changes on system level require public support, based on a common feeling that continuation of the present system may impose great risks to future welfare, such as concerns about energy security and climate change. Not only research on and communication about these risks, but also involvement in the exploration of solutions may increase public support. The target of limiting the temperature rise to 2 °C is a result of such processes.

Striking the balance between RD&D and deployment

An important question is how to strike an optimal balance between RD&D support (learning by searching) and deployment (learning by doing). Some argue that stimulating learning by searching through RD&D, almost up to the stage of technologies becoming market competitive, would be more cost-effective than also stimulating learning by doing through early deployment. On the other hand, relationships between technology costs and cumulative installed capacity (learning curves) suggest that cost reductions are realised through deployment, although this may also work the other way; the market will also increase if costs decrease (Figure 2.4). This issue is discussed by Philibert (2011) who concludes that early deployment of renewable energy

Figure 2.4
Learning curves of energy supply technologies



Source: Juringer et al. (2008); updated for solar PV and offshore wind power

technologies is a cost-effective measure for long-term climate change mitigation, even if it looks too costly when only short-term reductions are considered. In that paper, also Fisher and Newell (2007) are quoted, who conclude that 'if learning is more firm-specific and less likely to spill over, policies subsidising renewable energy are less appropriate to compensate for knowledge externalities. In contrast, if learning is more difficult to patent to appropriate rents, then renewable subsidies may be relatively more justified'. According to IEA (2012a), the relative importance of support for RD&D versus deployment may differ from case to case and emphasis will shift from push to pull as technologies mature.

It is important to realise that feedbacks do occur between different innovation stages. Market players are more willing to invest in RD&D if a market perspective is present or at least is a glimmer on the horizon. This is also noted by Philibert (2011), who stated: 'Not only are market prospects the most vital stimulant of industry R&D efforts, but more importantly the deployment of technologies in a competitive marketplace is a key source of information on their strengths and weaknesses, and thus on the directions of applied R&D efforts might take. Market development and technology development go hand in hand.' This is illustrated by the current standstill in CCS projects. Investors lack a market perspective for CCS – with low CO_2 prices in the EU ETS and market expectations that prices will remain low for the next 10 years (Verdonk and Vollebergh, 2012). This has made industry reluctant to invest in CCS projects at this moment, even when relatively high subsidy levels are being offered.

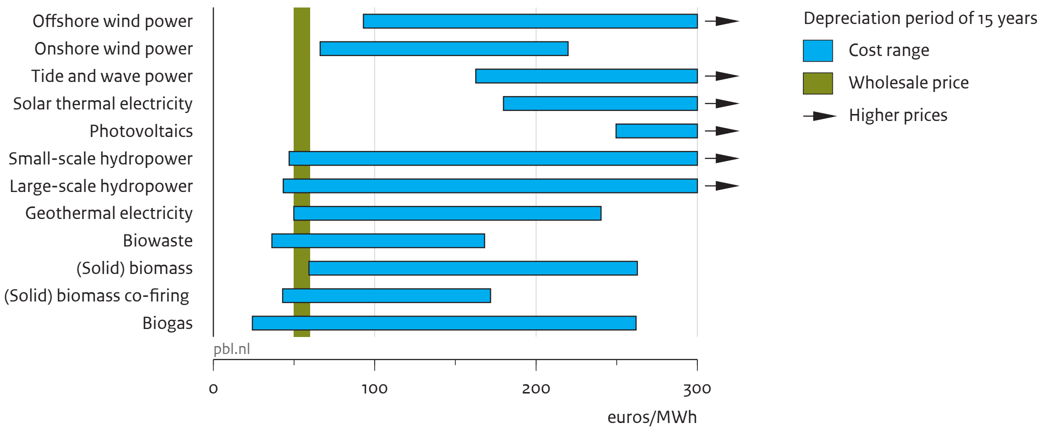
The challenge: Getting through the valley of death

The policy costs of supporting R&D can be relatively limited. Also, in the late diffusion phase, technologies have decreased so much in price that targeted financial support is no longer needed, as low-carbon technologies compete on the market, albeit helped by general carbon pricing.

However, costs of policies to support large-scale demonstrations or support for deployment may be high. At this stage, also investment risks are at their peak. It is widely recognised that this phase, known as the 'valley of death', is the most difficult phase for technologies to go through (Murphy and Edwards, 2003; Grubb, 2004). Clearly, this valley of death can be narrowed by an improved ETS that would result in a higher carbon price. At present, many renewable-energy and other low-carbon technologies cannot compete on the market without targeted support in addition to the ETS.

The latter can be observed in Figure 2.5, depicting levelised costs of electricity generation in the EU in 2010. The figure shows that levelised production costs for many low-carbon technologies in 2010 were considerably higher than wholesale electricity prices; for many low-carbon technologies between 0.05 and 0.15 EUR/kWh higher than fossil-fuel-based electricity generation. To overcome such cost differences, a current CO_2 price of 100 EUR/tonne (coal-fired power plant) to 200 EUR/tonne (gas-fired power plant) would be needed for many technologies to become competitive without additional support. Although, by 2020, investment prices of low-carbon technologies are expected to have dropped further and the required CO_2 price may be lower,

Figure 2.5
Costs of renewable electricity generation in the EU27, 2010



Source: TU Vienna's Green-X model (De Jager et al. 2011)

additional support would still be required for certain technologies.

The ETS alone will not stimulate innovation in a cost-effective manner. The high prices needed for low-carbon technologies to make them cost-competitive would make many currently installed installations unprofitable in the short term (e.g. coal-fired power plants). This would result in a very rapid decline in CO_2 emissions but at high stranded costs; for example, because of prematurely shutting down coal-fired power plants. In this sense, the ETS can be regarded as being the 'stick' that needs to be complemented by 'carrots' (innovation support through RD&D and deployment) to arrive at a cost-efficient policy mix. For this 'stick' to have effect, clearly CO_2 prices are needed that are higher than the current level of 5 EUR/tonne.

Interaction between different policy instruments

In general, interactions will occur between different instruments in the policy mix. Energy efficiency improvement will make it easier to reach a certain share of renewable or low-carbon energy in final energy demand. On the other hand, emission reductions induced by policies to support renewable energy or low-carbon technology, energy-efficiency policies and emissions performance standards, together, will not lead to additional emission reductions within the ETS if the emission cap is not changed, as well. Also, such policies will always have some impact on the carbon price in the ETS, which may weaken the effect of CO_2 prices spurring on low-carbon innovation. The magnitude of such interactions will depend, among other things, on the definition and height of complementary targets and the design of policy instruments. However, the effect of a slightly lower CO_2 price that would result from complementary policies to stimulate innovation would not necessarily be problematic; after all, in that case, low-carbon innovations would be stimulated directly through explicit complementary policies for low-carbon innovation. In general, such interactions ask for thorough (ex-ante) analysis to carefully align policies, and for regular, announced reviews to keep instruments aligned once they are implemented.

The primary objective of the ETS is to guarantee emission reduction. There is little doubt that the ETS will deliver in this respect. However, as discussed earlier, it was also expected that the ETS would trigger investments in low-carbon technologies. Indeed, innovative low-carbon technologies could be stimulated if the trading system would lead to a sufficiently high and stable carbon price. At present, the ETS hardly affects investment decisions and low-carbon innovation, because of the low price of emission allowances. This low price and the surplus of allowances is caused primarily by the fierce economic recession. Additionally, overallocation, the possibility of using CDM/JI credits, and emission reductions from other policies have contributed to low prices (Egenhofer et al., 2012). A stable higher price is likely to ask more than a single adjustment of the emission cap. With a fixed cap, the supply side is inelastic, and markets with inelastic supply or demand tend to be volatile (Egenhofer et al., 2012). A more dynamic adjustment of emission allowances, such as through the establishment of a carbon price floor, could lead to more price stability and thus to more clarity regarding return on investment in low-carbon technologies. A structurally higher CO_2 price; for

2 Options to reform the EU ETS

In November 2012, the European Commission tabled the State of the European carbon market in 2012 (EC, 2012c). It signalled the growing supply–demand imbalance of emission allowances in the ETS, leading to CO_2 prices much lower than anticipated. The commission presented 6 possible structural measures that could be taken to diminish the surplus of allowances, as a starter for the debate:

a. increasing the EU reduction target for 2020 to 30%;
b. cancellation of a number of allowances in the third trading period;
c. adjustment of the annual linear emission reduction factor;
d. expanding the scope of the EU ETS to also include other sectors;
e. limiting the access to CDM/JI credits (after 2020);
f. discretionary price management mechanisms.

Verdonk et al. (2013) assessed the impact of several of these options. They conclude that options to reduce the supply of emission allowances would further reduce emissions and boost emission prices, but would provide only an ad-hoc solution to the fundamental issue of the robustness of EU ETS in an uncertain world. This also holds for an expansion of the EU ETS to also include other sectors, which may be an indirect way to introduce additional scarcity on the carbon market and, thus, create a stronger price signal. An auction reserve price would make the EU ETS more robust to unexpected changes in supply and demand of emission allowances, and would result in more emission reductions if abatement proves to be cheaper than expected. Moreover, by providing a price floor, an auction reserve price would result in a more predictable price path, which will provide more investment security for low-carbon technologies.

example, resulting from the introduction of a price floor in combination with a tighter emission ceiling, may be an important stimulus for low-carbon innovation. However, as explained above, efficient innovation policies will require more than only a higher CO_2 price. Various options to reform the ETS such that a higher price would result are summarised in text box 2.

Targets and technologies

This chapter illustrates the role that various policy targets may have in triggering specific technology developments. It shows that sometimes substantial differences exist between measures taken to achieve targets at low cost and in the 'short' term (2030) and those that are needed from the perspective of a cost-effective decarbonisation approach for the long term (2050). Three cases are discussed: bio-energy production and applications, low-carbon electricity generation, and carbon capture and storage (CCS). Section 3.4 discusses the role of targets in a new policy mix.

3.1 Bio-energy

System innovation for bio-energy involves sustainable production of biomass, technologies to convert biomass into suitable energy carriers, new or adjusted infrastructure for collection and transport, and the establishment of institutions for new biomass markets.

Table 3.1 shows different types of biomass streams and indicates their importance from both short-term and long-term perspectives. Agricultural products that compete with food production are cost-effective in the short term. From the long-term perspective, they have limited potential and their use leads to indirect emissions from land-use change. The development of new streams, such as grasses grown on degraded land and algae, should be stimulated from a long-term perspective, but will not be cost-efficient in the short term.

Similar differences between short- and long-term perspectives hold for biomass applications (Table 3.2). Technically, biomass can replace any fossil fuel in any application. However, the global availability of sustainable biomass is limited. Realising this, biomass will be particularly important to decarbonise heavy-duty transport as there are few alternatives for this sector, as well as to decarbonise parts of existing industry, the residential sector and the tertiary sector, for which other options such as CCS would be difficult to implement (because of the small-scale combustion), and to replace fossil fuels for non-energetic use (e.g. in plastics).

Large-scale application of biomass in these sectors will require large-scale conversion of woody biomass to liquids and gas. This will require the further development of biomass conversion technologies. For achieving greenhouse gas or renewable energy targets for 2020 and/or 2030, however, the cheapest options for biomass use concern the generation of electricity or heat through direct (co-)combustion. From a long-term perspective, however, the availability of sustainable biomass may be too limited to use for large-scale electricity generation.

The overview makes clear that taking a low-cost short-term perspective to achieve intermediate targets for 2020 or 2030 against the lowest possible costs points to other types of biomass and other types of applications of biomass than would be preferred from a long-term perspective. This is reflected in the effects of current policies, which to date have given stronger stimulus for

Table 3.1
Biomass streams and their importance from a short-term and long-term perspective

Type of biomass	Stimulated by greenhouse gas/renewable energy targets 2020/2030	Relevance for the long term (2050)	Remarks
Agricultural products	++	--	Cost-effective for short-term greenhouse gas reduction, but unsustainable due to land-use change emissions
Wood from forests and plantations	++	+/++	Cost-effective for short-term greenhouse gas reduction, but sustainability is a point of attention and therefore its long-term potential may be limited
Agricultural and forest residues	+	++	Requiring new collection systems and infrastructure; new technology for pre-treatment (torrefaction) close to market-ready
Organic industrial and household waste	+	+	Available in the short term, but limited long-term potential
Grasses on degraded land	--	+	In the phase of small-scale demonstrations; no attractive business cases; lack of infrastructure
Algae	-	0 / ++	For energy only still very expensive, in the phase of research and small-scale demonstrations

Table 3.2
Types of application of biomass and their importance from a short-term and long-term perspective

Application of biomass	Stimulated by greenhouse gas/ renewable energy targets 2020/2030	Relevance for the long term (2050)	Remarks
Electricity	++	--	Technology for co-firing with coal available, many long-term alternatives (solar, wind, nuclear, water)
Light-duty road transport	o (+ to achieve renewable energy target)	-	Short-term contribution based on agricultural products can be substantial (only without including emissions from indirect land-use change (ILUC)). Technology to produce biogas from waste with high moisture content is available, but the biomass potential is limited. Gasification or fermentation to produce liquid fuels from dry biomass is in the phase of demonstration units on quite a large scale.
Heavy-duty road transport	o (+ to achieve renewable energy target)	+/++	
Air traffic + shipping	o	++	
Heat for industry	+	o	Does not require much technological innovation
Heat for new buildings	+	-/+	Technology for combustion and heat distribution is available. Future role dependent on local situation (availability of heat and/or gas infrastructure). Gasification to add biomethane into the gas grid is in the phase of demonstration units on quite a large scale
Heat for existing buildings	+	+/++	

Table 3.3
Effects of targets or other policies to stimulate important technologies for the long term

Development	Greenhouse gas target (about 40% reduction) for 2030	Renewable energy target (about 30%) for 2030	Other policy options (examples)
Biomass production from grasses on degraded land	Not likely, because it can be expected there are enough cheaper options	Maybe, but definition of degraded land in sustainability criteria is critical (risk of emissions from indirect land-use change (ILUC))	Public–private cooperation for some large-scale projects
Biomass production from algae	Not likely, because enough cheaper options are expected to be available	Not likely, because it can be expected there are enough cheaper options	Further development still supported by subsidies
Conversion of agricultural and forest residues for liquid biofuels for the transport sector	Not likely, because of too high costs	Depending on the level, but uncertain	Specific targets for its contribution in the transport sector
Conversion of agricultural and forest residues for biogas	Not likely, because of too high costs	Depending on the level, but uncertain	Obligation for a share of gas to be produced in this way in the total gas flow

options with short-term potential. It may be argued that setting broad and relatively technology-neutral targets for emission reduction or renewable energy only does not sufficiently stimulate the necessary developments needed for long-term decarbonisation (Table 3.3). The last column in Table 3.3 identifies other options that are more likely to stimulate such developments.

3.2 Low-carbon electricity generation

A low-carbon energy system requires an almost full decarbonisation of electricity generation. Possible technologies include those of renewable energy, carbon capture and storage (CCS) and nuclear energy. Table 3.4 shows several technologies for low-carbon electricity generation and discusses their importance from a short-term and long-term perspective.

From a short-term perspective, shifting from coal to gas is among the cheapest options to reduce greenhouse gas emissions from electricity generation. However, from a long-term perspective, gas-fired electricity generation without CCS will not be clean enough for base-load generation. It is apparent that some technologies that are not cost-effective for short-term emission reduction, but that are important from the long-term perspective (solar PV, wind power), actually have been stimulated by renewable energy policy support instruments in European countries (mostly through Feed-in Tariff (FIT), Feed-in Premium (FIP) or quota systems). The competitiveness gap between renewable energy and fossil fuel has substantially narrowed over the last years, due to technology development, economies of scale, and progress towards market maturity. This trend is likely to continue in the near future. Provided that the right steps are taken for the integration of renewable energy into the electricity grids and markets, wind and solar power are expected to rely progressively less on these dedicated financial support schemes in an increasing number of circumstances. However, specific economic support may still be required beyond 2020 in certain situations where technologies will still not be fully competitive (e.g. incentives for solar PV in central and northern European countries or offshore wind power and CSP in general).

National support schemes for renewable energy have been boosted by the EU renewable energy target for 2020. It has stimulated various important technologies, such as onshore and offshore wind power, and solar PV. Since solar PV is a relatively expensive renewable energy option, in the short term, renewable energy support policies have been criticised for not being cost-efficient. For example, in Germany, subsidies provided for solar PV systems have contributed by 9% to subsidised electricity generated under the Erneuerbare-Energien-Gesetz (EEG), but accounted for 40% of subsidies costs. In response to increasingly rapid deployment of solar PV and the cost reductions for PV panels, the subsidies for solar PV have since been revised, following market developments (Capozza and Curtin, 2012).

However, the renewable energy target has also triggered the co-firing of biomass in power plants for example,

Table 3.4

Technologies for low-carbon or lower carbon electricity generation and their importance from a short-term and long-term perspective

Low-carbon electricity generation	Stimulated by greenhouse gas/renewable energy targets 2020/2030		Relevance for the long term (2050)	Remarks
	Greenhouse gas target	Renewable energy target		
Gas replacing coal	++	o	-/o	Gas-fired electricity generation without CCS will not be clean enough in the long term for base load. Clean enough for back-up.
Solar PV	-	o/+	++	Although not cost-efficient for short-term greenhouse gas reduction and increase in renewable energy up to 2020, it has been stimulated by national support systems. May become cost-competitive after 2020 in southern Europe
Wind onshore	o	++	++	Cost-efficient for short-term increase in renewable energy, but not for short-term greenhouse gas reduction. Both, however, are likely to become cost-competitive at favourable locations, around 2020.
Wind offshore	--	++	++	Not cost-efficient in the short term, but likely to be important for low-carbon electricity generation in north-western Europe in the long term
Hydropower	o	o	o	Cost-efficient, but most installations have been installed decades ago. Further growth potential is relatively limited in Europe
CSP	-	+	++	Only in southern Europe / northern Africa ; no intermittency problem
Biomass (co-)firing	+	++	-	Biomass for electricity generation through co-firing is a low-cost option to achieve short-term renewable energy targets. However, because of the limited availability, sustainable biomass will be needed for other applications than electricity generation, particularly for the decarbonisation of heavy-duty transport
Coal+CCS	-	-	++	Not cost-effective to achieve the 2020 (and probably also the 2030) greenhouse gas reduction target. If CO_2 storage capacity is limited, it might be preferable to use storage capacity for other CO_2 streams (e.g. industry, gas-fired power+CCS)
Gas+CCS	-	-	++	Not cost-effective to achieve 2020 (and probably also the 2030) greenhouse gas reduction target.

which holds less potential for cost reductions (biomass prices could rise), and may in the long term be limited in its application because sustainable biomass will be needed for other purposes as well (Section 3.1). In that sense, a renewable energy target can be considered as being too broad – also stimulating options that have limited potential for cost reductions and at the same time too narrow – as a renewable energy target does not stimulate CCS deployment.

The market integration of electricity generated from renewable energy raises the question of what a power market design that enables low-carbon investments could be like. Low-carbon power options will be more capital-intensive and have lower marginal costs than current ones. Furthermore, intermittent wind and solar power may lead to long periods of low or even negative prices and spikes of high ones. Investment in such a market will become increasingly difficult. Especially when incentive systems to stimulate renewable energy will be economised due to increasing volumes and costs, investments will decrease. At this moment, individual countries are searching for solutions for this looming problem. These solutions could have important effects for neighbouring countries, but try to optimise the national situation only, without taking these external

Table 3.5

Effects of targets or other policies to stimulate important technologies for the long term

Development	Greenhouse gas target (of about 40% reduction) in 2030	Renewable energy target (of about 30%) in 2030	Other policy options (only examples)
Solar PV	Not likely, as there are cheaper alternatives to reduce greenhouse gas emissions	Likely to become cost-competitive to contribute to a renewable energy target for 2030	
Wind offshore	Not likely, as there are cheaper alternatives to reduce greenhouse gas emissions	Likely to become cost-competitive to contribute to a renewable energy target for 2030	Those technologies can be stimulated by a target for innovative low-carbon technologies as well
CSP	Not likely, as there are cheaper alternatives to reduce greenhouse gas emissions	May perhaps become cost-competitive in southern Europe to contribute to a renewable energy target for 2030	
Fossil+CCS	Not likely, as there are cheaper alternatives to reduce greenhouse gas emissions	Not stimulated, because fossil+CCS is not renewable	Can be stimulated by a target for innovative low-carbon technologies or by an emissions performance standard for electricity production

effects into account. Moreover, the back-up shortage and market design solutions for increasing shares of intermittent renewable energy are treated separately, whereas a more holistic approach could be more effective. A sustainable solution implies a long-term approach to this problem, in which neighbouring countries search for a cooperative regional solution.

3.3 Carbon capture and storage

Carbon capture and storage (CCS) is not a cost-effective method to achieve the 2020 target for emission reduction. However, for long-term decarbonisation, CCS is an important technology. It is not only relevant for low-carbon fossil-fuel-fired electricity generation, but also for industrial applications, such as in steel, cement, biofuel and hydrogen production. Moreover, the combination of biomass and CCS leads to negative emissions which could compensate emissions from other sources.

The individual components of CCS technology are to a large extent commercially available. RD&D is still needed to further develop these individual components of CCS. However, integrated operations combining large-scale CO_2 capture, transport and storage technology still needs to be demonstrated. Although CO_2 transport through pipelines is a proven technology, the development of a large-scale infrastructure strategy is needed to optimise future CO_2 transport. The first full-scale post-pilot projects are expected to be commissioned after 2030, if sufficient pilot and demonstration projects are realised in the years before.

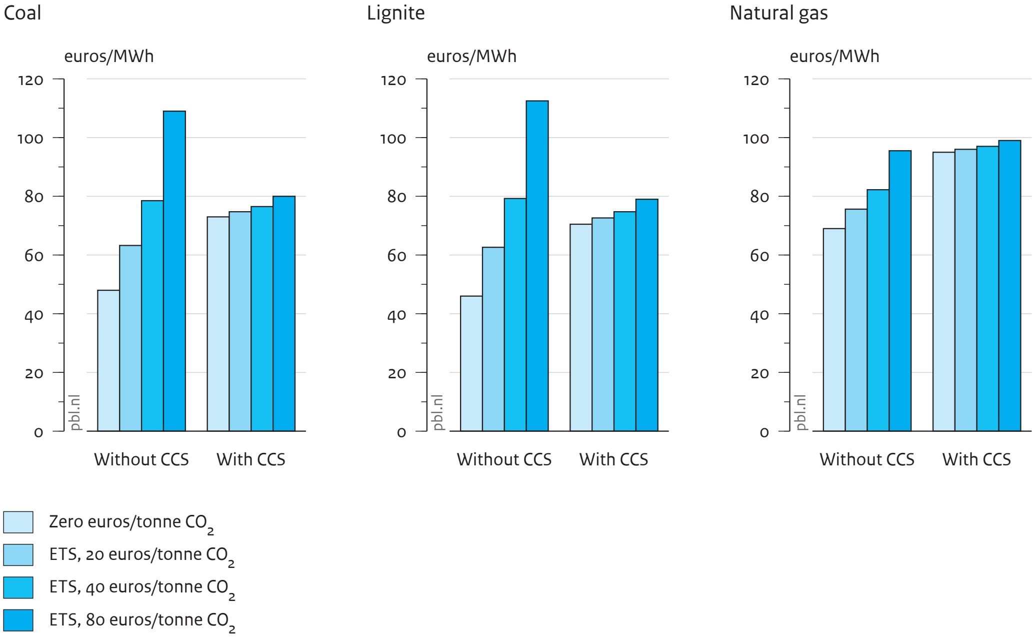
At this moment, only six integrated CCS demonstration projects are planned (but their execution is definitely not certain) in Europe and two large projects (related to natural gas production) are operational: the Sleipner project and the Snøhvit project (ZEP, 2012; GCCSI, 2012). The European Commission recently made an awarding decision under the first call for proposals of the NER300 funding programme (EC, 2012b). Only one CCS projected is being awarded NER300 funding: the Ultra Low CO_2 Steelmaking (ULCOS) project in France. However, the realisation of this project is also uncertain; ArcelorMittal, which is in a consortium with nine other steelmakers, has informed the European Commission that it cannot proceed because of 'the current state of research and the technical difficulties'. Another reason behind the postponement of investment decisions, is the low CO_2 price, which is currently at 5 EUR/tonne, and the lack of confidence about higher carbon prices in the foreseeable future.

To summarise, there is currently no certainty on any CCS pilot project in Europe, mainly because of a low emission allowance price and the lack of prospects of higher prices in the future. Also, the subsidies were mainly determined when CO_2 prices, or expected future prices, where much higher; as CO_2 prices dropped, subsidy levels were not adjusted, creating a less attractive business case.

Levelised costs of electricity have been estimated for post-demonstration-phase CCS projects (ZEP, 2011). After the demonstration phase, CCS would structurally add about 0.02 to 0.03 EUR/kWh to electricity generation costs, assuming moderate fuel price increases and onshore storage (Figure 3.2). According to ZEP (2011), the price of Emission Unit Allowances (EUAs) should range between 34 EUR/tonne (for lignite) and 90 EUR/tonne (for natural gas) to break even (compared to similar power plants without CCS). The GCCSI study estimated the

Figure 3.2

Estimated future levelised costs of electricity production (post-demonstration-phase prices)



Source: ZEP (2011)

Post-demo-phase prices for CCS, and assuming moderate fuel price growth and onshore storage.

mitigation costs associated with CCS to range between 18 and 69 EUR/tonne (GCCSI, 2012). IEA (2009) estimated the costs of CCS applied to electricity generation to range between 27 and 56 EUR/tonne (IEA, 2009). Cost could increase with increasing average transport distances. For industrial applications, CCS prices may even show wider ranges. For some applications (natural gas processing and hydrogen production), CCS may already be cost competitive at CO_2 prices below 20 EUR/tonne (SBC Energy Institute, 2012). In contrast, CCS application may be more expensive for relatively small industrial plants as compared to power plants.

Further cost reductions (after the demonstration phase) are expected to be relatively limited as a large share of the costs is associated with energy costs to compress the CO_2. Before abovementioned cost levels are reached, pilot and demonstration projects are needed and substantial infrastructural investments have to be made. Since a CO_2 pipeline transport infrastructure requires substantial investments, a stable investment climate should be present for the long term (decades), so that pipelines can be built with sufficient capacity to transport not only the relatively limited CO_2 streams in the first years but also larger streams in later years.

Table 3.6 describes the effect of various policy targets to trigger CCS developments for four important applications. Some applications of CCS may be triggered by a greenhouse gas-target, when an improved ETS is assumed such that this leads to a higher and more stable CO_2 price. A problem for investments in CCS is that it involves capital with very long lifetime (40 years). An investment will only be done if there is enough trust in a stable high CO_2 price during this time. Even when the carbon price is high enough for several subsequent years, an investor will always consider the chance that the carbon price will be lower in future years. This might result from lower political ambitions, more use of international carbon trading, or from development of competing low-carbon technologies. Such investment risks are smaller for many renewable energy technologies, which are not directly affected by carbon prices and have shorter lifetimes. More investment security for CCS may result from the timely announcement of future emission standards for electricity generation and/or production processes, or by introducing a target for the deployment of innovative low-carbon technology.

3.4 Towards a renewed policy mix

The preceding sections showed that only a greenhouse gas target for the short term not necessarily stimulates technologies that are important from the long-term perspective. The setting of complementary targets may

Table 3.6

Effects of targets or other policies to stimulate important technologies for the long term

Development	Greenhouse gas target (about 40% reduction) for 2030	Renewable energy target (about 30%) for 2030	Other options (examples)
CCS in electricity generation	Maybe for coal-fired power plants	Negative, because the related CO_2 reduction decreases CO_2 prices	Emissions performance standard for electricity generation or target for innovative low-carbon technology. Public–private cooperation for infrastructure and storage
CCS in industry	Likely only in some cases (with low capture costs)	Negative, because the related CO_2 reduction decreases CO_2 prices	Public–private cooperation for infrastructure and storage Emission standards for production processes
CCS in biofuel or green gas production	Not likely because of low incentives for biofuel or green gas production	Maybe because of an increase in biogas production and related upgrading for grid injection; less likely for large-scale production (see bio-energy)	In the first phase depending on policies to promote bio-energy
Capture of CO_2 and reuse in power-to-gas	Not likely; it is a long-term option in a system with a large share of solar and wind power	Not very likely, but it may stimulate demonstration projects	Further development supported by subsidies

overcome this, and improve overall policy efficiency in the long term. Such targets should be well designed to strike the right balance between correcting market failures and at the same time avoiding policy failures:

- Targets should be technology neutral (or wide) enough to trigger the creativity of the market to come up with new technologies, but narrow enough to trigger only those technologies that are important for the long term. Target setting can be both too wide (i.e., also triggering technologies or applications that are cost-effective in the short term but are not very important for the long term or have only little potential for cost price reduction) or too narrow (i.e., not triggering alternative technological options that could be important for the long term).
- Targets should strike a balance between not being too low such that they are redundant and do not bring the efficiency improvements, but also not too high to avoid that they force a too high deployment rate of identical technologies which adds too little to cost-price reductions (only economies of scale).

A renewable energy target can be considered as being too broad – also stimulating options that have limited potential for cost reductions and at the same time too narrow – as a renewable energy target for example does not stimulate the uptake of CCS.

How could a more dedicated approach to stimulate innovation in the different phases look like? Enhanced support for RD&D can be established through strengthening EU research programmes (such as Framework Programmes, Horizon 2020, NER300) and national RD&D support policies. For the diffusion phase, a practical approach would be to support those (groups of) technologies that both have a large potential for emission reduction in the long term and also have a large potential for cost reduction. This does not mean picking the winners, but picking the currently most promising options, such as those technologies identified in the Strategic Energy Technologies (SET) Plan (EC, 2007), see text box 3.

In practice, such policies could be triggered by the setting of one or several complementary targets for innovative low-carbon technology deployment; for example, through a legally obliged share of final energy demand to be met through innovative low-carbon energy generation technologies rather than through renewable energy only. Such an innovative low-carbon technology deployment target would offer Member States more flexibility to choose between stimulating renewable energy only or also other innovative low-carbon technologies.

In designing cost-efficient policies to achieve such a low-carbon technology target, support should be technology-specific to account for different development stages, generation costs and future potential of technologies. This can be accomplished through making FIT/FIP systems technology-specific, since many options exits to design the tariffs or premiums on the basis of the generation costs of the different technologies. However, also quota-based systems can be designed to be technology-specific; an example is the introduction of banding of the various technologies in the United Kingdom and Italy (Bergmann et al., 2008).

3 Strategic Energy Technologies

The SET plan (EC, 2007) describes the following key EU technology challenges.

Key EU technology challenges for the next 10 years to achieve the 2020 targets:
- make sustainably produced second generation biofuels competitive alternatives to fossil fuels;
- enable the commercial use of technologies for CO_2 capture, transport and storage;
- double the electricity generation capacity of the largest wind turbines, with offshore wind as the lead application;
- demonstrate the commercial readiness of large-scale Photovoltaic (PV) and Concentrated Solar Power;
- enable a single, smart European electricity grid able to integrate renewable and decentralised energy sources;
- bring to mass market more efficient energy conversion and end-use devices and systems;
- maintain competitiveness in fission technologies, together with long-term waste management solutions;

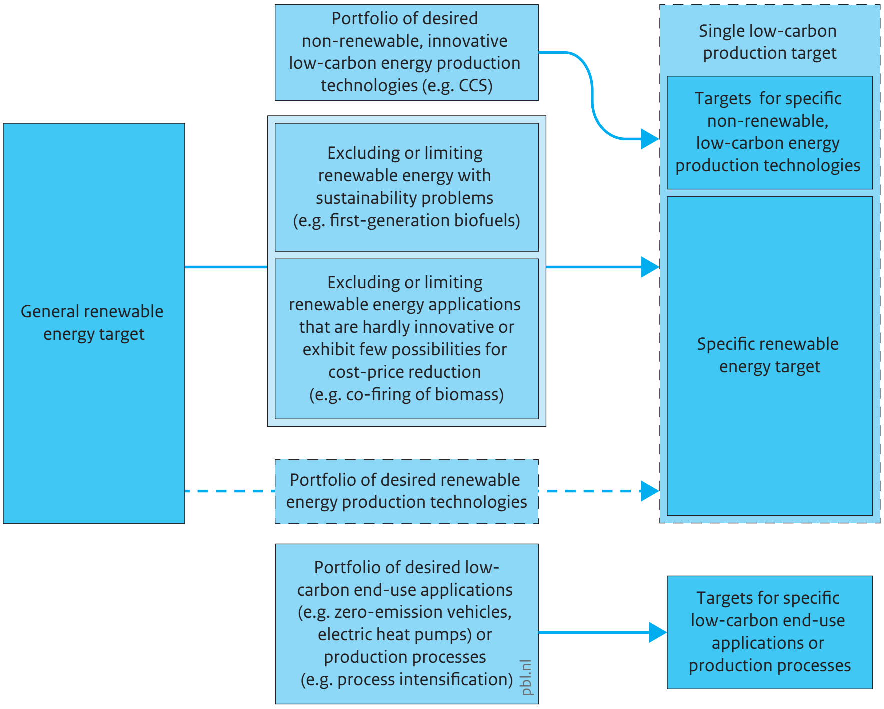
Key EU technology challenges for the next 10 years to meet the 2050 vision:
- bring the next generation of renewable energy technologies to market competitiveness;
- achieve a breakthrough in the cost efficiency of energy storage technologies;
- develop the technologies and create the conditions to enable industry to commercialise hydrogen fuel cell vehicles;
- complete the preparations for the demonstration of a new generation (Gen IV) of fission reactors;
- complete the construction of the ITER fusion facility;
- elaborate alternative visions and transition strategies towards the development of the future trans-European energy networks;
- achieve breakthroughs in enabling research for energy efficiency.

Figure 3.3 illustrates how a general renewable energy target could be transformed to one or more targets for deployment of innovative low-carbon energy generation technologies and low-carbon end-use technologies. Starting from a general renewable energy target, a more specific renewable energy target is obtained by excluding the less desired or less innovative renewable energy options. Alternatively, a specific renewable energy target can be arrived at by directly specifying desired renewable energy options. A target for the deployment of innovative low-carbon technologies can be arrived at by including innovative non-renewable energy technologies as well, or by separately establishing additional targets for non-renewable low-carbon technologies. To stimulate innovative low-carbon end-use applications, specific targets could be set, for example, for the number of zero-emission vehicles, or the application of heat pumps.

In fact, the setting of the renewable energy target for biofuels, and its subsequent improvement to also include greenhouse gas emissions related to land use for the growth of biofuels is an example of how a general target can be improved to a more specific target which is more tailored to stimulate the desired technologies only. The suggestion of an innovative low-carbon technology target may be considered as a generalisation of the developments that have been implemented in the case of biofuels in road transport.

Figure 3.3

Possible targets to stimulate innovative low-carbon technologies



Source: PBL

A more specific approach (compared to an extrapolation of the current general renewable-energy target to 2030) will be more effective to trigger investments and deployment of innovative low-carbon technologies.

FOUR

Options for future policies

4.1 Assessment of policy options for 2030

In this section, we discuss the effects of various policy targets on triggering effective and efficient policies to steer towards a low-carbon economy by 2050. To this end, we have compared three policy options which differ in the type of targets and assumed instrumentation (Table 4.1).

All policy options consist of carbon pricing (through ETS), which is underpinned by a greenhouse gas reduction target for 2030. In option 1, this is the only target. In this option, the ETS will be the dominant policy instrument; only low-carbon RD&D is also stimulated. However, renewable energy deployment subsidies are abandoned and energy efficiency regulation is not further strengthened. In option 1, we assume that the ETS is broadened to cover all sectors and the ETS cap is lowered in line with the greenhouse gas target.

In options 2 and 3, the ETS cap is lowered as well and in line with the greenhouse gas target, but the sectoral coverage is kept identical to the current ETS. It assumes national greenhouse gas ceilings for non-ETS. In options 2 and 3, additional energy-saving policies are in place that have been triggered by an energy efficiency target complementary to the greenhouse gas target. In option 2, the policy mix also includes a target for renewable energy deployment, while in option 3 a target is set to trigger some level of deployment for innovative low-carbon technology, as described in the previous section. Hence, option 2 is in fact an extrapolation of the current 2020 approach to 2030.

We assume that the renewable energy and low-carbon technology targets require more expensive measures to be taken in the short term (2030) than those necessary to comply with a greenhouse gas target only.

Effects on groups of technologies

A qualitative score of effects on groups of technologies deemed to be important for a low-carbon economy (see Annex 1) is presented in Table 4.2. Note that effects in Table 4.2 are scored relative to policy option (1), which is by definition scored as 0 for all effects.

Below we give our motivation for the scores of Table 4.2.

- Policy options (2) and (3) lead to additional incentives for energy savings in the residential, tertiary and transport sectors (non-ETS), as energy savings in these sectors will require CO_2 prices that are higher than necessary to comply with the greenhouse gas target (see Section 2.2).
- (Near-)market competitive renewable energy after 2020 may consist of hydropower, onshore wind power, geothermal heat at selected locations, and solar PV in sunny areas, and perhaps several biomass applications. We assume that these will be stimulated in all policy options either through targeted subsidies (options 2 and 3) or through the CO_2 price (options 1).

Table 4.1
Assumed instrumentation for the various policy options considered

Assumed instrumentation	(1) Greenhouse gas target only	(2) Greenhouse gas + energy efficiency + renewable energy targets	(3) Greenhouse gas + energy efficiency + low-carbon deployment targets
Energy-saving policies	No further strengthening of energy-efficiency legislation	Energy-efficiency directive and main instruments (Ecodesign, EPBD, CO_2 standards for cars) strengthened	
Greenhouse gas target (compared to 1990 levels)	Short term (2030): 40% to 45% reduction; indicative target long term (2050): 80% to 95% reduction		
Scope of ETS	Al sectors included in ETS; possibilities for trading outside EU; free allocation of exposed sectors through benchmark	ETS for industry and power sector; possibilities for carbon trading outside EU; free allocation of exposed sectors through benchmark	
Deployment support for innovative technologies	Phase-out of national support schemes for renewable energy	Enhanced coordination and cooperation among Member States or EU-wide harmonised support schemes for renewable energy	Enhanced coordination and cooperation among Member States or EU-wide harmonised support schemes for selected low-carbon technologies
RD&D	Enhanced RD&D financing through carbon markets		

Table 4.2
Qualitative assessment of effects of policy options on technologies

	(1) Greenhouse gas target only	(2) Greenhouse gas + energy efficiency + renewable energy targets	(3) Greenhouse gas + energy efficiency + low-carbon deployment targets
Energy savings non-ETS	0	+	+
(near) market competitive renewable energy	0	+	0
Not yet competitive renewable energy	0	+	+
CCS	0	-	+
Nuclear energy	0	0/-	0/-
Preventing further lock-in in high-carbon technologies	0	0/+	0/+

+: technology likely to be stimulated by policy option; -: technology not likely to be stimulated by policy option.

We may assume that low-cost renewable energy is stimulated most in option (2) as it specifically creates a market for renewable energy and the market will tend to achieve the target through the lowest cost options.

- Renewable energy that is not yet market-competitive (offshore wind power, CSP, solar PV in less sunny areas, other renewable energy at less favourable locations, biomass gasification) would be stimulated to a greater degree by policy options (2) and (3) through the existence of additional support mechanisms such as feed-in tariffs.
- Regarding CCS, it may be expected that this is stimulated the least in option 2. Although option 2 provides an extra stimulus for renewable energy, the CO_2 prices in the ETS will be lower than in option 1, hence providing a lower stimulus for CCS, while option (3) explicitly stimulates innovative low-carbon technologies, which includes CCS.

Table 4.3
Qualitative assessment of the overall effects of policy options

	(1) Greenhouse gas target only	(2) Greenhouse gas + energy efficiency + renewable energy targets	(3) Greenhouse gas + energy efficiency + low-carbon deployment targets
Greenhouse gas reduction, short term and long term	0	0	0
Cost efficiency, short term (2010–2030)	0	-/+	-/+
Cost efficiency, long term (2010–2050)	0	+	++
Improving diversity of energy mix	0	+	++
Industrial opportunities clean-technology sector	0	++	++
Effects on air quality	0	0	0

0: neutral; +: positive development; -: negative development

- The share of nuclear energy will primarily depend on national policies. In case of options 2 and 3, this share could be slightly lower than in option 1, because the active stimulus of renewable energy or innovative low-carbon technologies will allocate investments towards these technologies, thereby lowering investments in current market competitive technologies including nuclear energy.
- The same reasoning goes for preventing further lock-in in high-carbon technologies. Actively stimulating renewable energy or low-carbon technologies will reduce the capital available for investment in current market-competitive technologies. An emissions performance standard for new power plants, for example, of 400 g CO_2/kWh, however, is likely to be more effective to prevent the most carbon-intensive electricity generation options (from coal and lignite) without CCS.

Overall effects

In this section, we assess the overall effects of the policy options (Table 4.3). We summarise effects on cost efficiency (costs considered from the national perspective), and also consider other effects of decarbonisation policies: co-benefits for air quality, chances for the clean-technology sector, and effects on energy security or diversity of the energy mix. Although such positive side effects occur, they are unlikely be the main driver for decarbonisation, however, because these benefits might also be arrived at through other policies and probably at lower costs.

For example, although renewable energy production is likely to lead to more jobs than fossil-fuel-based production, it is unlikely to be more labour-intensive than several other activities that governments could fund in order to generate societal benefits (Bowen, 2012). In addition, total labour consequences of decarbonisation policies entail more than just the clean-technology sector, as decarbonisation policies will have macroeconomic effects and affect employment in many sectors. Nevertheless, if decarbonisation policies are pursued, this will deliver several co-benefits as described below.

The scores in Table 4.3 are elaborated below.

Effects on cost efficiency

Greenhouse gas emission reductions are assumed to be the same in all scenarios, as the targets for the 'short' term (2030) and long term (2050) are the same. As is extensively discussed in Section 2, policy options (2) and (3) will lead to a higher cost efficiency in compared to option (1), because they trigger energy-saving measures that have negative national costs. Policy options (2) and (3) will also trigger measures that are not cost-effective in the short term, but at the same time improve cost efficiency in the long term. Option (3) will trigger measures to reduce costs in the long term most through specifically supporting important low-carbon technologies.

Effects on diversity of energy mix and energy security

All decarbonisation scenarios will lead to a decreasing share of fossil fuels and an increased share of renewable energy. Non-biomass renewable energy (e.g. solar, wind and hydropower) will reduce energy import dependency. Biomass will also need to be imported to some extent, however. In the short term, enhancing the share of renewable energy will improve diversity of the energy supply. In the long term, a phase-out of fossil fuel will negatively affect this diversity. CCS enables the use of fossil fuel to some extent, leading to a more diverse energy supply than without CCS. In the short term, the diversity of the energy mix is improved in case of a relatively strong growth of renewable energy (option 2), but in the long term (2050) the energy mix may be most diverse with option (3), as this would allow for a higher share of fossil fuel through the application of CCS and for a higher share of nuclear energy, if both are included in the EU technology portfolio of target 3.

Industrial opportunities for clean technology
The targeted promotion of renewable energy since the 1990s has been an important stimulus to the emergence of the renewable energy sector in various Member States (Germany, Denmark).

Currently, about 30,000 companies and private citizens are affiliated to the German Renewable Energy Federation (BEE). In 2011, the sector was responsible for 381,600 full-time jobs (on a total labour force of about 42 million) and a turnover of about 25 billion euros. From the first census in 2004, employment related to the sector increased by around 140% (BMU, 2012). In 2010, the renewable energy sector in the EU was responsible for 1,114,210 direct jobs, a 25% increase compared to the preceding year, and a turnover of 127 billion euros, a 15% improvement on 2009 (EurObserv'ER Report 2011). These figures do not automatically mean that net employment has increased by these numbers, because in other sectors, job losses may have occurred because of climate and energy policies.

In the impact assessment to the European Commission proposal for the 2009 climate and energy package it was estimated that achieving the 20% renewable energy target in 2020 could have a net effect of creating around 417,000 additional jobs. Getting on track to achieve the 20% energy efficiency improvement is forecasted to boost net employment by some 400,000 jobs in 2020 (EC, 2008a). Regarding the Energy Performance of Buildings Directive (EPBD) the European Commission estimates that its implementation has the potential to create 280,000 to 450,000 new jobs by 2020, mainly in the construction sector, energy certifiers and auditors and inspectors of heating and air-conditioning systems (EC, 2008b).

When assessing the effects of different policy options, we expect that industrial chances for clean technology will be higher with options (2) and (3) as compared to option (1), because of the larger chances for the construction and installation branches (for insulation works). The clean-technology sector also profits from higher deployment of renewable energy and low-carbon energy production technologies in general with options (3) and (4).

Effects on air quality
All decarbonisation scenarios are likely to lead to improvement of air quality. Energy savings, non-biomass renewable energy and nuclear energy contribute to improvement of air quality. For biomass it is more complex. In end-use applications, if biogas, liquid biofuels and solid biomass replace fossil gas, oil and coal respectively, this will in general not lead to reduction of air polluting emissions (Hammingh et al., 2010). Processes to make biogas and biofuels are generally slightly more polluting than fossil-fuel-based processes at present. This is partly related to the current relatively small scale of biomass conversion installations; air pollution emission standards are generally less strict for smaller installations. Sulphur content of biomass is lower than that of coal making desulphurisation less demanding. The varying quality of biomass compared to fossil fuels, however, makes de-NO_x technology more demanding. Application of CCS will lower sulphur emissions but enhance NO_x emissions if no additional emission measures are taken. Given these opposite effects, it is hard to identify which policy scenario would generate highest benefits for air quality. In general, in decarbonisation scenarios with high use of biomass, air quality improvement is less than other decarbonisation scenarios. However, this can be mitigated through setting tighter emission standards for processes involving biomass combustion.

Overall, the transition to a low-carbon economy will bring about substantial benefits for air quality which in turn leads to public health improvement and protecting biodiversity. Decarbonisation may reduce total emissions of NO_x, SO_2 and primary $PM_{2.5}$ by nearly 10% in 2030 and some 30% in 2050 compared to reference (EC, 2011d). Compared to 2005 this would represent an emission reduction of these air pollutants of some 65% in 2030 and 2050.

The impact of improved air quality on reduced mortality can be awarded an economic value. For 2030 the damage reduction is estimated at 7 to 17 billion euros, and for 2050 at 17 to 38 billion euros. In addition to these health benefits, control costs for current air pollution policies – estimated at some 88 billion euros annually – will diminish (Amann et al., 2011). By 2030, annual costs of controlling traditional air pollutants could be over 10 billion euros lower; and by 2050 even close to 50 billion euros could be saved every year.

The case for a multiple target approach
The discussion in this report emphases market failures to make the case for more targets than an emission reduction target only. Other arguments for a multiple target approach include:

- A multiple target approach can also be considered as a ‘hedging strategy’. Despite the many theoretical studies performed in advance, it remains to be seen how targets and instruments work out in practice. The height of targets and their interpretation will be a political compromise and the height and stability of carbon prices resulting from an (improved) ETS will be difficult to predict – as is the effect on triggering low-carbon investments. Setting more targets will better secure progress towards a low-carbon energy system.
- Enhancing energy efficiency and renewable energy will reduce import dependency of fossil fuels, reduce vulnerability to volatile energy prices, and reduce the EU’s annual external fossil-fuel bill (of 488 billion euros in 2011). Enhancing energy efficiency and renewable energy may contribute to competitiveness and jobs. Although installations equipped with CCS require more energy and thus negatively affect import dependency and energy efficiency, CCS at the same time provides the possibility to longer use coal and gas, which is positive from the viewpoint of diversification of the energy mix and security of supply.
- Targets for energy efficiency, renewable energy or innovative low-carbon technologies actively contribute to the build-up of a low-carbon system. This may be more inspiring than setting only a target for reducing polluting emissions that are hardly visible to the general public and which is only effective if the rest of the world also reduces their emissions.
- When relying on a stable and high carbon price to stimulate low-carbon investments in the EU, it may become more difficult to couple an EU system to carbon pricing systems in non-EU countries, such as in Australia and in several US states.
- A multiple target approach allows for different ambition levels such that the more ambitious targets only affect sectors that are not exposed to international competition. This alleviates the problem of distortion of the level playing field and the issue of carbon leakage.

4.2 Pros and cons of various types of targets

If targets for energy efficiency and for deployment of low-carbon technologies are formulated that are complementary to the greenhouse gas target, consideration should be given to a number of aspects: should targets be formulated EU-wide or at the national level; should targets be legally binding or non-binding/conditional; and how technology specific should targets be.

EU-wide versus national targets

From a theoretical perspective, EU-wide target setting could be more efficient. This holds particularly when large differences exist between Member States in marginal costs for emission reduction, energy efficiency improvement or renewable energy deployment.
The issue of national versus EU-wide targets and technology support mechanisms has been extensively debated in case of renewable energy. Through harmonised renewable energy support schemes, the allocation of resources would be optimised, such that solar PV would be installed at places with the highest irradiation and wind turbines would be built in areas with favourable wind conditions. This would reduce generation costs and consequently also the necessary support costs to achieve European renewable energy targets. The degree to which such a harmonised approach would reduce costs is subject of debate. Fürsch et al. (2010) estimate cost savings through introducing a harmonised quota system for renewable energy of 174 billion euros (net present value accumulated over the 2008–2020 period), which compares to 412 billion euros under a non-harmonised support scenario. However, Resch and Ragwitz (2012) ague that for several reasons this cost saving is largely overestimated, and mention cumulative savings in terms of generation costs for a harmonised technology-neutral renewable energy support of only between 7 and 28 billion euros, depending on national policy.

Pros and cons of harmonisation of national support systems for renewable energy have been described by Gephart et al. (2012). They conclude that ‘the academic debate explored arguments for and against harmonisation. It focused strongly on economic efficiency arguments, particular when looking at the potential benefits of harmonisation, but also when rejecting a harmonised European quota scheme. Further arguments against harmonisation are of a political and distributional nature: e.g. diverging interests and preferences in the Member States, the challenge of distributing direct and indirect costs and benefits, and technical and geographical barriers.’
To summarise, arguments favouring EU-wide target and harmonised support are:

- For the technological development process it is irrelevant where the learning takes place, as the knowledge will spill over to other Member States (and even globally).
- Harmonised support for renewable energy enhances efficiency, although studies greatly differ in estimations to what extent this would occur.

– An EU-wide approach fits better with the common market. In this case, the industry is in the 'driver seat' rather than national governments. Industries can make their investment decisions without having to deal with 27 different national support systems.

Arguments favouring national targets and national support systems are:
– Part of the learning process – regarding the installation and use of low-carbon technologies, will have to take place at the local level
– Harmonised support will lead to net capital flows from one Member State to another. This may conflict with differing national ambitions regarding the preferred decarbonisation approach and preferred energy mix (Notenboom et al., 2012).
– National governments cannot steer where investments take place, and hence, whether or not positive side effects (employment and clean-technology chances, air quality, energy security) will occur within their country borders or elsewhere.

The relative importance attached to different arguments are reflected in the different positions of stakeholders and Member States in this debate.

In this context it is important to note that the current renewable energy directive already has several mechanisms with increasing levels of cooperation between two or more Member States (statistical transfers, joint projects and joint support schemes) allowing to improve efficiency of renewable energy development (Klessman et al., 2010). Current National Renewable Energy Action Plans (NREAPs) show that Member States are not planning to make much use of these mechanisms, but prefer to exploit their own renewable energy potential to comply with the national renewable energy target. This would reflect the desire of most Member States to reap the economic social and environmental benefits of developing renewable energy sources nationally (Klessman et al., 2010; EC, 2010b).

The arguments listed above also play a role in case of complying with a EU-wide greenhouse gas target. This can also be met at lower costs through coupling with other trading schemes that emerge outside the EU and/or through CDM. This will also involve capital flows that may be viewed differently upon. Besides, in case of high use of CDM possibilities, the resulting CO_2 price may become lower and be less useful to trigger innovation.

Legally binding versus non-binding and/or conditional targets

Legally binding targets provide long-term clarity to market players and secure that the EU and all Member States develop policies to achieve the targets. Establishing a low-carbon economy will take decades and involves investments with long payback periods, while political priorities may shift every few years. An important role of climate and energy legislation is to overcome such time inconsistency problems and provide long-term credibility to policies (Fankhauser, 2012). Non-binding EU targets for Member States may be taken seriously in one period, but be ignored in a later period, for example when national political ambitions change after elections. Non-binding targets at the Member State level will therefore not contribute much to investment security for market players.

A conditional target for greenhouse gas emission reduction that only is applicable if other developed and/or developing countries also make a proportional contribution is attractive from the viewpoint that only EU policies will never be effective in limiting global warming (EU emissions currently contribute about 10% of global emissions and this share will decrease), and to guarantee an international level playing field for industry. There are several arguments for setting a non-conditional target, however:

(1) Internationally, unconditional targets are more credible and effective in provoking other countries to pledge ambitious targets. Also other developed and developing countries have pledged to reduce emissions by 2020, and some announced long-term goals for 2050 (http://climateactiontracker.org). A European emission reduction for 2030 of 40% does not differ much from efforts announced by other countries (Hof et al., 2012).
(2) Conditional targets are not likely to enhance low-carbon investment security. Market players ask for clarity and stability in the policy approach. Conditional targets do not provide much clarity, because it is not known in advance whether or not conditions will be met and when. In case of conditional targets, business cases developed by market players should consider the probability that a target will become mandatory and when, and take this into account in their risk assessment.
(3) Concerns regarding the level playing field between domestic and foreign producers and carbon leakage can be addressed through mechanisms such as free allocation of emission allowances or introduction of border tax adjustments (such as an import levy or export refund). However, it will be challenging to make border tax adjustments compatible with World Trade Association rules (Manders and Veenendaal, 2008). The problem of dealing with exposed (or deemed to be exposed) sectors can also be tackled by a multiple target approach, which allows for more ambitious targets that apply to non-exposed sectors only (e.g. electricity generation).

The level of technology neutrality
This issue was already discussed in Section 3.5. We conclude that targets should be technology neutral enough to trigger the creativity of the market to come up with new technologies, but at the same time provide sufficient directionality to avoid that the market seeks a cheap way out into technologies that have limited potential in the long term.

4.3 Positions of stakeholders/ Member States

Most stakeholders have not yet established detailed views on the design of post-2020 EU climate and energy policies. Nevertheless, some trends are visible.
Among the EU Member States, the United Kingdom has the clearest position. The option preferred by the United Kingdom is to have a single greenhouse gas reduction target for 2030. In addition, it favours technological neutrality as this is assumed to minimise costs. France is also leaning towards this option. The position of Germany in the EU debate is not yet clear, although the country has self-imposed targets for emission reduction, energy efficiency, and renewable energy for 2020 and beyond. Poland is still reluctant to commit to any EU climate policies after 2020. Having national ambitious policies with nationally imposed targets for emission reduction, energy efficiency and renewable energy sources (as in Germany or Denmark) does not necessarily mean that such Member States would support a similar policy approach on EU level, as well. Given subsidiarity, proportionality and the right to choose their own energy mix, Member States may prefer a very general EU policy direction with much flexibility for national policy design. Member States have agreed on a thorough analysis for decisions on the future mix in 2014–2015 for the 2030 framework (European Council, 2012).

Environmental NGOs (Friends of the Earth, Green Peace, WWF) have a clear preference for a multi-target approach. These organisations would like to see tightening of the current 2020 targets as well.

Business seems to be divided. The renewable energy sector (European Renewable Energy Council) is in favour of legally binding commitments to deployment of renewable energy as part of a multi-target approach and a long-term 100% renewable energy vision. The power sector (Eurelectric) regards the EU emission trading system as the key driver for investment and advocates the market integration of renewable energy technologies. In this position seems to be room for support schemes for immature renewable energy technologies. The European engineering industries (Orgalime) advocate a technological neutral framework and European harmonisation in supporting renewable energies. They carefully try to find a balance between the opportunities a transition towards a low-carbon economy provides and affordable energy prices needed to be competitive on the world market. The energy-intensive industries (European Alliance of Energy Intensive Industries) are mainly concerned about the global level playing field and make the post-2020 EU climate policy strictly conditional to an international climate agreement.

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Annexes

Annex 1: Technological options for a Dutch and a European low-carbon energy system

There is no blueprint for the low-carbon society in 2050. Many technological options are available and numerous combinations can be made. In a backcasting approach for the Netherlands hundreds of combinations have been designed and analysed with the help of a specific model (E-design) (Ros et al., 2011). The relative importance of a specific technology has been studied by leaving it out of the design and checking if the target could still be met under different conditions of quantitative availability of other technological options. The results are shown in Table A.1. The results give a good indication for the importance for technological options on the European scale as well. If not, it is especially indicated.

Table A.1
A comparison of the importance of the availability of technologies for a clean economy by 2050 in the Netherlands

Technology	**Relative importance in the Netherlands *(and the EU)***	**Explanation**
Isolation measures in existing buildings	Very large	The biggest part of the houses and other buildings in 2050 is already built; the potential to improve the energy efficiency by technical measures is substantial.
Isolation measures in new buildings	Large	It is already common practice to build more energy efficient houses; further improvement is no regret with limited impact for 2050 but even more on the longer term.
Reduction of energy demand in industrial processes	Large	The actual measures to take are process specific. Alternative options for reducing greenhouse gas emissions in industry are not always easy to implement.
Lighter and more aerodynamic vehicles	Limited	A no regret option for improvement, but alternative transport technologies and/or fuels are indispensable in the long term.
Onshore wind power	Limited *(Large)*	The technology fits in closely with the future vision but the potential for the Netherlands is thought to be limited, therefore not using this option can be compensated for by other technologies. *On the European scale its relative importance is large or even very large.*
Offshore wind power	Large *(Limited-Large)*	The technology fits in closely with the future vision and has a large potential. Not using this option will require the greater import of clean energy or a larger proportion of nuclear energy. *Especially for countries around the North Sea area; for most European countries the relative importance is limited*
Solar PV *+ CSP*	Limited *(Large)* *(Large)*	The limited use of this technology fits in well with the future vision. However, it has its limitations (more so than wind power) regarding the matching of supply and demand. *Especially for southern European countries PV and CSP have large potential*
Nuclear energy	Large	The technology fits in closely with the future vision and has a large potential. Not using this option can be compensated for by wind and solar power (supplementary solutions for matching supply and demand will then also be required).
Gas-fired power plant with CCS	Limited	This will become much more important if no pan-European electricity grid is built with a large exchange capacity. Gas-fired power plants are important in providing a flexible supply.

Technology	Relative importance in the Netherlands *(and the EU)*	Explanation
Coal-fired power plant with indirect co-firing of biomass and CCS	Very limited	Although a form of electricity generation with low, sometimes even negative emissions, there are also clean alternatives, and many variants at the system level in which better use can be made of biomass and CO_2 capacity for the production of fuels or green gas.
Heat from geothermal energy	Limited	The technology fits in closely with the future vision but the potential for the Netherlands is limited, therefore not using this option can be compensated for by other technologies. *Only in a few European countries the potential of geothermal energy (also for electricity) is relatively high*
Solar heating	Limited	The technology fits in closely with the future vision but the potential for the Netherlands is extremely limited as supply is mainly available in the summer and additional technology is required in the winter.
Electrical heat pumps	Large	This technology plays an important role in the electrification of industry, horticulture and buildings, helping increase the proportion of clean electricity used.
Micro CHP with hydrogen	Limited	Hydrogen can be produced using electricity, but the energy losses are high if this hydrogen is then used to generate electricity. It would only be useful if hydrogen was used as a storage medium (a less obvious choice) or if it would be produced from biomass.
Micro CHP with methane *Mini CHP with methane*	Very limited *(Limited-Large)*	Decentralised electricity generation that makes use of natural gas does not result in emission reductions if the centralised electricity generation system produces no, or very few emissions. Local application with biogas may be a useful supplement. *In countries with more (decentralised) district heating systems its importance is relatively larger*
Biomass gasification for fuels (+CCS)	Very large	The production of biofuels (green gas, transport biofuels) is crucial for sources for which there are few clean alternatives. It also has the advantage that biomass gasification with the capture of CO_2 released during the process has negative emissions.
Electric cars	Large	This type of vehicle may make an important contribution to electrification and therefore to the role of clean electricity, partly due to the flexibility provided by charging.
Hydrogen cars	Large	These vehicles could provide an alternative to electric vehicles but may be more useful as an additional option for road traffic over long distances such as road haulage.
CCS for industrial emissions	Large	For many processes there are no alternatives, or the alternatives are shrouded in uncertainty.

Remarks on differences with the European scale are italicised.

Annex 2: Illustration of dynamic efficiency

Below we illustrate that policies that have lowest costs in the short term do not always lead to lowest costs when considered over a longer period. Figure A.1 shows costs and cumulative installed capacity on a log-log scale, for two low-carbon electricity generation technologies (left) and total investment costs (right). Assumed parameters for this example are given in Table A.2.

In this example, technologies have the same globally installed capacity at the start of period 1 and their capacities are expanded by a similar amount in the two periods considered (with a larger absolute capacity increase in the second period, as the x axis shows the logarithm of installed capacity). Technology 1 has lower initial costs (costs at the start of period 1), but has a less favourable progress ratio compared to technology 2. In period 1, a low-cost policy would stimulate technology 1 only. If technology 2 would have been used in period 1, however, costs of technology 2 would decrease such that the costs in period 2 become lower with technology 2 compared to technology 1.
Overall policy costs (period 1+ 2) are lower using technology 2 only instead of technology 1 only. Note that the total investment costs in period 2 are several times higher than in period 1, despite the cost reductions per GW added capacity, because the added capacity is much times larger in period 2 than in period 1.

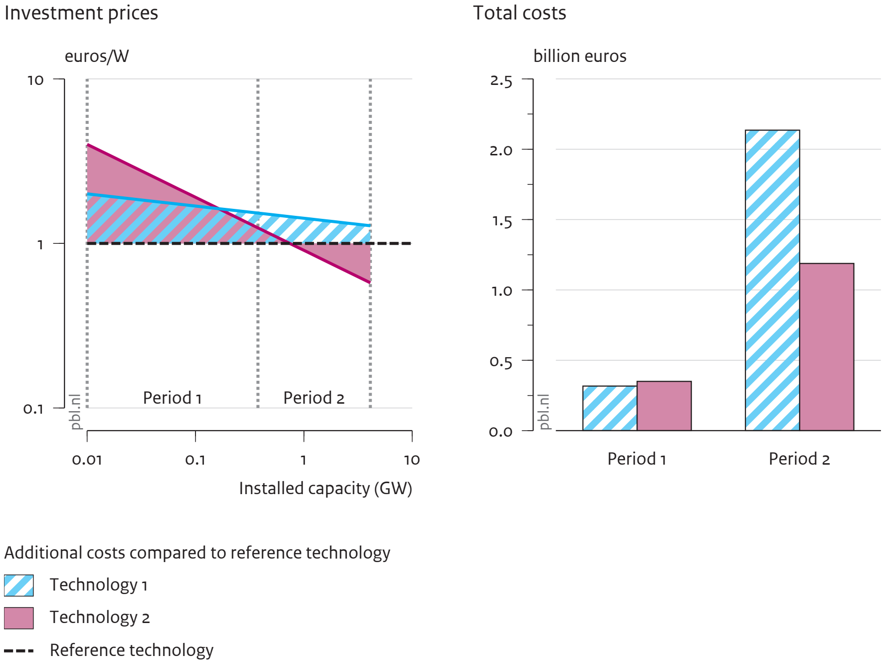
If the maximum technical potential of technology 1 is reached at the end of period 1 such that further expansion of low-carbon capacity needs to be realised through technology 2, the total policy costs of using both technologies, one after the other, would be more expensive than if technology 2 was used right from the start.

Table A.2
Assumed parameters of technologies

	Technology 1	Technology 2
Initial costs	EUR 2/W	EUR 4/W
Progress ratio[1]	0.95	0.80
Added capacity period 1 (10 years)	0.3 GW	0.3 GW
Added capacity period 1 (10 years)	3.8 GW	3.8 GW

[1] A technology with a progress ratio of 0.8 exhibits a 20% cost-price reduction after a doubling of global installed capacity. Both technologies have an initial installed capacity of 1 GW.

Figure A.1
Costs of electricity generation for two different renewable energy technologies



Costs of electricity generation with two renewable technologies (technology 1 and 2), compared to a reference technology (left) and total investment costs (right). Assumed discount rate 5%.

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