Planbureau voor de Leefomgeving

Climate and Energy Roadmaps towards 2050 in north-western Europe

A concise overview of long-term climate and energy policies in Belgium, Denmark, France, Germany, the Netherlands and the United Kingdom

Policy studies

Climate and Energy Roadmaps towards 2050 in north-western Europe

A concise overview of long-term climate and energy policies in Belgium, Denmark, France, Germany, the Netherlands and the United Kingdom

Climate and Energy Roadmaps towards 2050 in north-western Europe

The Hague/Bilthoven, 2012
ISBN: 978-94-91506-15-4
PBL publication number: 500269001

Corresponding author
jos.notenboom@pbl.nl

Author(s)
Jos Notenboom, Pieter Boot, Robert Koelemeijer, Jan Ros

Acknowledgements
Acknowledgements: This report has profited from information, comments and other help provided by experts from several countries and institutions. In particular, we thank the following people for their help: Gudi Alkemade (Ministry of IenM, the Netherlands), Dominique Auverlot (CAS, France), Étienne Beeker (CAS, France), Michel Colombier (IDDRI, France), Annemarieke Grinwis (Ministry of I&M, the Netherlands), Koen de Groot (CIEP, the Netherlands), Olivier de Guibert (French Government), Emmanuel Guerin (IDDRI, France), Jan Ole Kiso (DECC, United Kingdom), Richard Lavergne (French Government), Stefan Lechtenböhmer (Wuppertal Institute, Germany), Harry Lehmann (UBA, Germany), Jochen Luhmann (Wuppertal Institut, Germany), Jacques de Jong (CIEP, the Netherlands), Tone Madsen (Energy Agency, Denmark), Joannette Polo (Dutch Embassy, Paris), Vincent van Steenberghe (Belgium Federal Climate Change Section). Furthermore, we thank the participants in two international seminars on climate and energy roadmaps for their valuable input into the discussion; the first seminar was organised by the Dutch Ministry of Infrastructure and the Environment (IenM), and the second by the Clingendael International Energy Programme in collaboration with PBL Netherlands Environmental Assessment Agency.

English-language editing
Annemieke Righart

Graphics
Durk Nijdam, Marian Abels, Filip de Blois

Production co-ordination
PBL Publishers

Layout
Textcetera, Den Haag

PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analyses in the fields of the environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making, by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

Contents

Summary

Many European countries are developing plans for a transition towards a low-carbon economy in 2050. These plans are often named climate and energy roadmaps. Although roadmaps are also developed and discussed at EU level, this paper expressly follows a bottom-up approach by looking at developments in six north-western European countries. These countries' roadmaps are in various stages of development and cannot be compared in detail. Main differences, common approaches and possible needs for closer cooperation are therefore explored in a stylised way. In general, development of low-carbon transition plans remains dominated by national approaches. Interdependencies and cost-efficient common approaches receive little attention. This is remarkable in the light of the development of the common energy market, the transnational electricity and gas infrastructure, and because policy measures in one country may impact the investment climate for low-carbon technologies in another; after all, energy companies increasingly operate on an international level.

Denmark and Germany have ambitious strategies with national targets for emission reduction, renewable energy and energy efficiency, with timetables up to 2050, and 2020 targets going beyond the agreed EU targets. In the strategies of both countries there is no room for nuclear energy, and renewable energy (wind, solar, biomass) plays a central role. Denmark even strives for 100% renewable energy by 2050. In contrast, the United Kingdom, which is a country with ambitious legally binding greenhouse gas emission goals, wants to achieve these goals through reform of the electricity market, with the possibility to expand on nuclear energy. In the past years, Denmark and the United Kingdom have followed a relatively stable climate and energy policy with broad political backing. In the last few years, Germany has had a combination of both stable and unstable policies. Its approach towards the expansion of renewable energy was consistent, but towards nuclear energy the approach has been very unstable. This has created uncertainties for businesses and neighbouring countries. France, Belgium and the Netherlands, relatively speaking, are still searching for new, stable approaches to a cost-effective energy transition.

The system and market integration of solar and wind power is a priority transnational issue for which a higher effectiveness could be obtained if a closer joint approach could be found. This is evident from the study of national roadmaps and this issue is also addressed by the European Commission. Clearly, the balancing of an increasing load of variable solar and wind power in the power system requires integrated strategies which soon will surpass the national level, and electricity market reform cannot be implemented in one country alone. Another priority issue prompting closer cooperation between north-western European countries is the role of gas in the future energy mix. National visions are very different, while transmission systems operators for gas are increasingly working at transnational level. Also the increasing role of biogas must be incorporated.

Other issues for collaboration between countries in designing a low-carbon economy are those around the development of carbon capture and storage (CCS) technologies, low-carbon energy for road transport, and the regulation of sustainable biomass. In this way, more joint approaches by countries with broadly comparable mind sets in the energy and climate debate not only could solve issues of joint interest in a more cost-effective way, but also may enhance the European debate.

The main findings are presented below:

1. National strategies dominate the thinking on the transition towards a low-carbon economy, but national actions will impact investment decisions by energy companies that operate internationally and, hence, may have an impact in neighbouring countries, as well.

2. Driving forces, starting points and possibilities to develop renewable energy sources (RES) differ significantly between the six countries studied. These differences are clearly reflected in the different roadmaps.

3. The Danish roadmap is characterised by the aim to achieve a 100% renewable energy system by 2050; the German roadmap involves deployment of RES and the creation of industrial opportunities; in the United Kingdom, a long-term climate ambition is to be achieved against the lowest costs; the roadmap for the Netherlands provides little information on the long-term strategy and cost considerations prevail in short-term steps to be taken; France and Belgium are just starting their thinking on post-2020 energy and climate policies, with nuclear energy clearly continuing to play an important role in the future energy mix of France.

4. An important similarity between the national roadmaps is their emphasis on the electricity sector. Obvious differences relate to the role of nuclear energy and, to a lesser extent, to the importance of carbon capture and storage (CCS) and non-CO_2 greenhouse gases. Commonly considered building blocks in the roadmaps are the increase in energy efficiency, the generation of CO_2-free electricity and the use of biomass (Section 4).

5. On the basis of the currently available national plans it is expected that mutual interdependencies will increase, particularly in areas such as the integration of renewable energy in the European energy market (especially regarding incentives for renewable energy technologies) and transnational infrastructure (including electricity, gas and ultimately CCS), the introduction of electric vehicles (standardisation), and development and implementation of criteria for the sustainable production of biomass. Many of these issues will require some level of European coordination (Section 8).

6. Because of increasing problems of intermittency of the power systems due to increasing supply of variable wind and solar electricity, the low-carbon plans by these countries may lead to technical problems in their electricity grids. Cooperation could help solve these problems in a cost-effective way (Section 8).

7. Cost-effective strategies for the transition towards a low-carbon economy make certain demands on the functioning of the market, due to increasing upfront investments and expected price volatility. National solutions probably will not be effective and a joint approach could be helpful (Section 8).

8. Many physical interactions exist between the energy systems of the six countries. Moreover, most energy companies operate internationally. Since, generally, these countries have similar ambitions but different policy approaches, they could learn from each other's experiences.

9. Roadmaps towards a low-carbon economy by 2050, in fact, refer to dynamic policy thinking on structural changes to the future energy system. Some countries have made more progress than others in the drafting and implementation of long-term visions. Analytically, the current versions of the individual roadmaps cannot be compared on a detailed level. Therefore, this paper mainly describes the general direction in which each country expects to move in their transition towards a low- carbon economy.

Climate and Energy Roadmaps towards 2050 in north-western Europe

A concise overview of long-term climate and energy policies in Belgium, Denmark, France, Germany, the Netherlands and the United Kingdom

1 Introduction

In March 2011, the European Commission published its roadmap for moving towards a competitive low-carbon economy by 2050 (EC, 2011a). In it, the Commission presents possible actions up to 2050, which could enable the EU to achieve greenhouse gas reductions in line with the political objective of the European Council, which is to achieve reductions of 80% to 95% by 2050 if other developed countries take similar action. The Commission also calls on EU Member States to soon develop national low-carbon roadmaps if they have not done so already. Many EU Member States have drawn up such national plans, or are in the process of doing so.

The Dutch Government has announced in its national low-carbon roadmap ('Klimaatbrief 2050') to discuss its plan with neighbouring countries. To facilitate discussion between countries, the Dutch Ministry of Infrastructure and the Environment has asked the PBL Netherlands Environmental Assessment Agency to compare the long-term climate and energy plans of north-western European countries. This comparison is dedicated to the principles, differences and similarities regarding the long-term climate and energy plans of Belgium, Denmark, Germany, France, the Netherlands and the United Kingdom.

The PBL analysis has been discussed during two working conferences, the first organised by the ministry on 31 May 2012, and the second by Clingendael International Energy Programme (CIEP) together with PBL on 28 June 2012. Aim of these conferences was to learn from the various country experiences and the viewpoints of companies operating in these countries, and to identify issues of interdependencies where enhanced collaborations between countries may be desirable.

Comments made by experts from these countries and the business sector have been incorporated in the present report.

2 Points of departure

The current situation in each of the six countries defines the various points of departure for the decarbonisation paths towards 2050. These starting points are determined by the current energy mix, policies already implemented, existing infrastructure, economic

Roadmaps

The various national policies on the transition towards a low-carbon economy by 2050 are shaped very differently and are in different stages of development. A brief overview is given below.

Belgium

Coherent thinking on the transition of Belgium's current energy system towards one that is low-carbon is still in an early stage. Belgium has a complex federal structure and, in the 2010–2011 period, has had to deal with a time-consuming formation of its current government. This has contributed to a delay in policy development at federal level, but a study that looks towards 2050 is being commissioned by the govenment. At regional levels initiatives are being developed to improve energy efficiency and to stimulate RES electricity.

Denmark

Energy policy in Denmark is based on a long tradition of political consensus, stability and a number of energy agreements. A broad majority in parliament supports the 2050 target of an energy system with 100% renewable energy without any reliance on fossil fuels. Key documents are the 'Energy Strategy 2050' (published in February 2011), and 'Our future energy' (released by the new Danish Cabinet in November 2011). The latter was based on the previous government's Energy Strategy 2050, but raises the bar higher. In March 2012, a new broadly agreed Energy Agreement was reached in Denmark and described in 'Accelerating green energy towards 2020'. This new agreement contains a wide range of ambitious initiatives for steps to be taken until 2020, including the development of RES, increased energy efficiency and more research into energy technologies.

France

In 2005, French energy law already included a greenhouse gas emission target for 2050 (emission reduction by a factor of 4). A subsequent process called 'Le Grenelle Environnement', in which many stakeholders participated, resulted in 2009 in the first 'environmental round table act' ('Loi Grenelle1'), providing policy goals and the main directions for further development. Climate change mitigation and energy are subjects of that policy document. Since then the main focus of climate policy has been on targets for the shorter term (at this moment mainly up to 2020) and on policy instruments supporting these targets. Recently, a number of studies into the development of the energy system up to 2050 have been presented by government advisors, but currently there is no clear governmental roadmap.

Germany

In September 2010, Germany's Federal Government published the 'Energiekonzept', an energy concept outlining its policy for a low-carbon economy by 2050. After the decision to accelerate the phase-out of nuclear power, the Federal Government proposed a package of legislative measures ('Energiewende') in the summer of 2011. Together, they form a roadmap for Germany's low-carbon future. Scenario studies that explore decarbonisation paths have been commissioned by the Federal Ministry for Economics and Technology and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

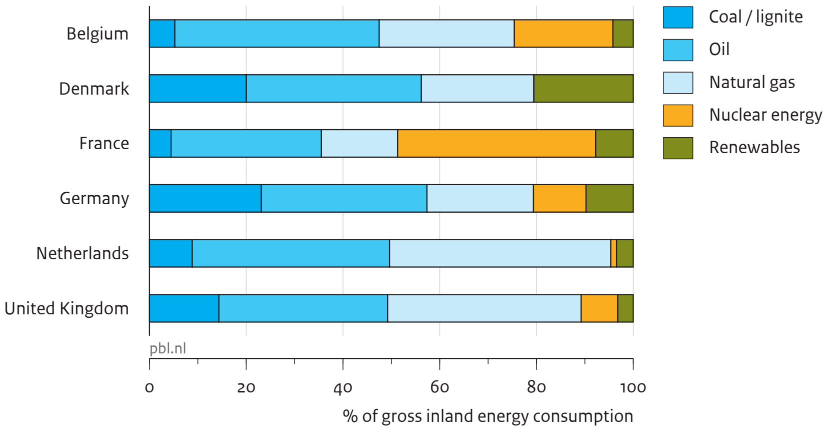
The Netherlands

In 2011, the Dutch Government published its Climate Letter 2050 ('Klimaatbrief 2050'). This letter outlines the challenges that the country faces in the transition towards a low-carbon economy, identifies the building blocks for a low-carbon system and explains the necessity of a greenhouse gas emission reduction target for 2030. The Ministry for Infrastructure and the Environment has commissioned several scenario studies to identify decarbonisation pathways. The energy report 2011 ('Energierapport 2011') is a key document that describes national energy policies.

United Kingdom

The UK Climate Change Act 2008 involves carbon budget reductions over a period of five years. The most recent government proposal focuses on the 2023–2027 period. The UK policy favours technology neutrality as this is assumed to minimise costs; it looks sharply at the potential benefits for the UK economy (clean technology, emphasis on supply chains). A gradually increasing annual reduction in successive carbon budgets provides planning certainty, stimulates innovation, and is expected to reduce costs. An Energy Bill was drafted in May 2012, outlining fundamental legal changes in the power market.

Figure 2.1
Energy mix, 2010



Source: Eurostat

Table 2.1
Some basic features of the national economies, per country (see Annex 1 for details)

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
GDP 2010 (euros/capita)	32,600	**42,500**	29,800	30,300	35,400	27,400
GHG intensity 2008 (g CO_2 eq/GDP)	**437**	376	317	413	373	352
Energy intensity 2010 (Kg oil equivalent /1000 euros GDP)	**213**	104	167	150	182	115
Electricity prices households (euros/100 kWh)	22.2	**30.8**	14.8	27.8	22.0	16.8
Electricity prices industry (euros/100 kWh)	11.8	10.9	7.6	**13.4**	11.8	11.5

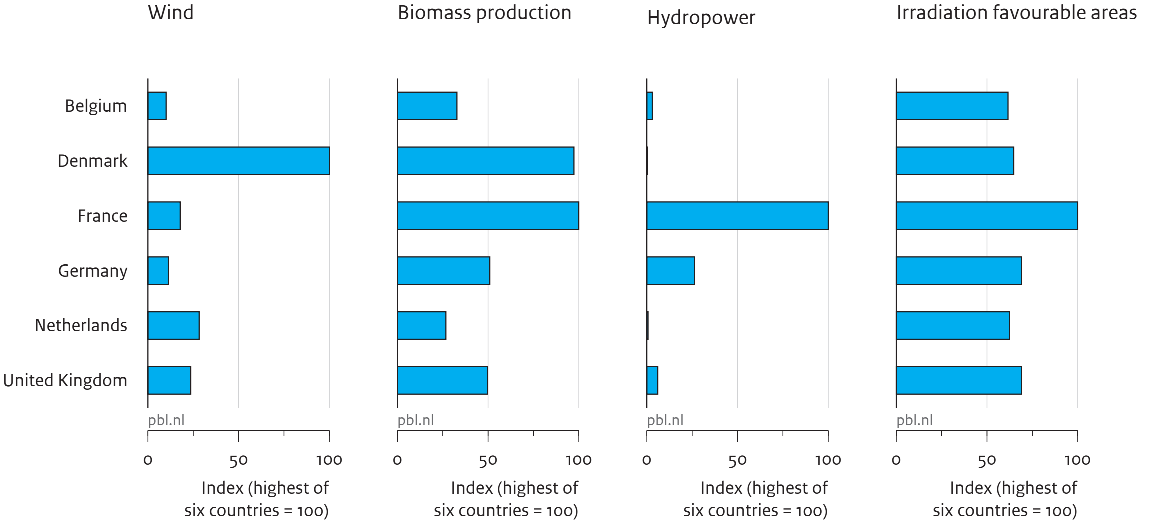
structure, innovation and research. Moreover, public opinion on climate change and energy issues also has a certain impact on political will and choices made for long-term policies that aim for decarbonisation of the economy. For these countries, we found kaleidoscopic differences between the various points of departure.

The resources used by these countries for their final energy production are summarised in Figure 2.1. The overview shows that Germany and Denmark currently depend for 20% or more on coal (including lignite), while nuclear energy contributes about 40% to the energy consumption in France. The United Kingdom and the Netherlands have a 40% to 45% dependency on natural gas, and Denmark has the largest share of renewable energy sources (RES) (20%) and has no nuclear energy. The smallest shares of RES are found in Belgium, the Netherlands and the United Kingdom. Shares of fossil fuels in the energy consumption range from 50% in France to 95% in the Netherlands. These figures illustrate that for all countries profound structural adjustments in the energy mix are required, in order to achieve a low-carbon economy.
Regarding energy use and greenhouse gas emissions, Belgium stands out as the country with the most energy-intensive economy and highest emission levels per unit of GDP. The economy of Denmark, the country with the highest GDP per capita, has the lowest energy intensity and greenhouse gas levels. Germany, the most industrialised country of the six, has a rather high greenhouse gas emission level per unit of GDP, but performs relatively well in energy intensity (Table 2.1). Generally, the countries are highly dependent on fossil energy imports. Exceptions are Denmark, which is an exporter of both natural gas and oil, and the Netherlands, an exporter of natural gas. Of the six countries, France and, to a lesser extent, Germany are current exporters of electricity (Annex 1).

According to rough estimates of the domestic potential to develop renewable energy sources (RES), such as wind, solar, biomass and hydropower, there are very clear

Figure 2.2

Domestic potential of renewable sources per capita, 2009 – 2010



Source: EEA (2009); JRC photovoltaic geographical information system; Eurostat (2009); EurObserv'ER geographic information system (see Annex 2 for details)

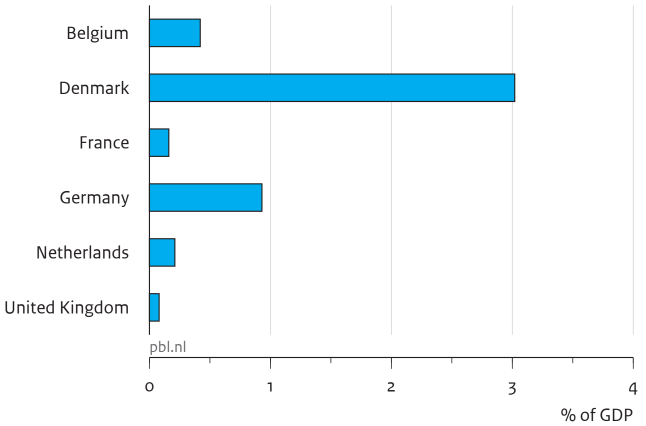
Index values are based on the resource potential, per capita.

differences in the relative positions of the six countries (Figure 2.2). Denmark has the highest potential capacity, per capita, for wind energy, both onshore and offshore. None of the other countries come close to Denmark's position. Of the other five, the Netherlands has a relatively large potential capacity, per-capita, for offshore wind energy, and for France this is true for onshore wind energy. Belgium and Germany have a relatively small potential capacity, per capita, for wind energy. France and Denmark are the countries that have the relatively largest agricultural and forest areas available per capita, which gives an indication of their biomass production potential. Belgium and the Netherlands have fairly few possibilities for bio-energy production, in both agriculture and forestry. To the south, solar irradiation increases. This is advantageous for France, with a relatively large potential capacity, per capita, for solar energy production in the south of the country. France is also the country with the largest amount of hydropower per capita. Figure 2.2 helps to understand the relative positions of the counties. Even if a country scores relatively low, RES may play a significant role in its regional energy production. Examples are solar power in southern Germany and offshore wind parks in the United Kingdom.

Worldwide perspectives for market growth in the renewable energy sector are substantial (IEA, 2011). Countries differ considerably in their abilities to profit from these market developments. The 2011 rankings (Figure 2.3) show the relative importance of the so-called clean technology sector for the national economies and how well countries are positioned to take advantage of the economic opportunities related to this development. According to Van der Slot and Van den Berg (2012), relatively speaking, Denmark is the global leader in the clean technology sector, with Germany in third place (China holds the second position). Although Denmark is a comparatively small country, it is home to large companies in this sector (e.g. Vestas, Siemens and Rockwool). Germany is present in most clean technology segments. The other countries in this study are not in the global top 10 of performers in the clean technology sector, the United Kingdom is not even in the top 25. The success of Denmark and Germany is attributed to a long-lasting combined energy and industrial policy (Van der Slot and Van den Berg, 2012).

Public opinion regarding climate change and energy differs between the six countries. European citizens consider climate change and energy supply to be serious global issues, in addition to topics such as poverty, the economic situation, employment, terrorism and armed conflict. In Denmark, public concern about climate change is the greatest, while it is the smallest in the Netherlands and the United Kingdom. In Germany, public concern about energy supply is relatively large. In countries with a high level of concern, many citizens believe that combating climate change and using energy more efficiently could boost the economy and increase the number of jobs within the EU. The Danes are most

Figure 2.3
Relative added value of clean energy technology, 2011



Source: data by Van der Slot and Van den Berg (2012)

Relative contribution of the clean energy technology sector to the national economies in 2011, for north-western European countries, with added value weighted by GDP (euros) (see Annex 3 for details).

Oil and natural gas reserves in north-western Europe

Four north-western European countries have some fossil-fuel reserves left. The Netherlands, especially, still has large reserves of natural gas. Table 2.2 gives an overview of figures that have recently become available. The first column presents the proven reserves at the end of 2010. The second column shows for how many years of actual national production these reserves would suffice (R/P ratio 2010). This does not necessarily mean that these countries will run out of oil or gas within that period, as in the next decade it may become profitable to extract and exploit new reserves, as has been the case in the past. To illustrate the effects of technological improvements and price changes, the same indicator of the reserves to production ratio that has been used for the past ten years is shown in the third column (R/P ratio 2000). Without the discovery of new reserves, the R/P ratio of 10 would have declined to 0 within ten years. Although this did not happen, the R/P ratio has seriously declined in especially the larger producing countries (the United Kingdom and the Netherlands).

Table 2.2
Fossil-fuel reserves of north-western European countries

		Proved reserves	R/P ratio	R/P ratio
		End of 2010	**2010**	**2000**
Oil	Denmark	0.9 billion barrels	10	9
	United Kingdom	2.8	6	5
Gas	Denmark	0.1 billion m3	6	7
	Germany	0.1	7	10
	Netherlands	1.2	16.6	25.8
	United Kingdom	0.3	4.5	11.1

Source: BP Statistical Review of World Energy, 2011

Table 3.1
Impression of the order of drivers underlying national plans for a decarbonisation path

Belgium	1. Security of supply 2. Affordability 3. Greenhouse gas mitigation
Denmark	1. Security of supply 2. Greenhouse gas mitigation 3. Industrial opportunities 4. Affordability
France	1. Affordability 2. Security of supply 3. Industrial opportunities 4. Greenhouse gas mitigation
Germany	1. Industrial / employment opportunities 2. Security of supply 3. Greenhouse gas mitigation 4. Affordability 5. Ethical issues
Netherlands	1. Affordability 2. Industrial opportunities 3. Greenhouse gas mitigation 4. Security of supply
United Kingdom	1. Greenhouse gas mitigation 2. Affordability 3. Industrial opportunities 4. Security of supply

strongly of this opinion. Many citizens also believe that, by 2050, cars will be fuelled more efficiently. National governments as well as the EU are considered to be relatively important in tackling climate change, according to the people of Belgium, Denmark, Germany and France. German citizens attach relatively great importance to businesses and industry taking climate actions (Annex 4).

3 Visions and targets

There are numerous motivations behind the transition towards a low-carbon economy, such as climate change, energy security, affordable energy prices, opportunities for regional development, innovation, industrial opportunities, and even ethical issues. In the six countries, all these motives can be found, with varying levels of strength. In the plans that are currently being developed by these countries, a mixture of drivers is presented, with clearer accents in some countries than in others. None of the plans show a clearly dominating motive (Table 3.1).

Visions on a future low-carbon economy and the pathways towards it differ strongly between the six countries. In part, this stems from the different points of departure as sketched above. To a certain degree, this is related to different motivations, political debate and policy tradition. The level of support for market reform and the launch of technologies vary per country. The United Kingdom and the Netherlands appear to leave as much as possible to the market, although these countries do realise that significant changes in the actual market frameworks could be necessary. This is clearly seen in their preference for a 2030 greenhouse gas emission target only, whereas Germany and Denmark already have set ambitious post-2020 national targets for greenhouse gas emissions and RES, as well as for the building and transport sectors. These last two countries seem to have another mind set and attach great importance to creating opportunities for industry in low-carbon technologies.

An important stimulus in the transition towards a low-carbon economy is provided by the EU agreements on the 2020 climate and energy goals and the 2050 political objective to reduce greenhouse gas emissions by at least 80% from 1990 levels. In addition to the EU 2020 targets for greenhouse gas emission reduction, renewable energy sources and energy efficiency, particularly Denmark and Germany have self-imposed targets for 2020 and beyond. For 2020, these national targets are tighter than those that have been agreed at EU level (Table 3.2).

4 Future energy system

Available policy documents, studies commissioned by governments, and expert debates all provide information on current visions in the six countries on the possible

Table 3.2

Overview of national targets of climate and energy policies on top of already agreed targets at EU level

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
Targets 2020	energy efficiency (Flanders)	GHG: -34% primary energy consumption 7.6% lower than in 2010 approx. 50% wind in electricity		GHG: -40% primary energy consumption 20% lower than in 2008 RES: 18% 35% RES in electricity		
Targets 2030		0% coal to power 0% oil to heat 100% RES heat and electricity in 2035	GHG: -40% to -45%	GHG: -55% RES: 30% 50% RES in electricity	GHG: -40% (conditional)	GHG: -50% (2023-2027)
Targets 2050		RES: 100%	GHG: -75%	GHG: -80-95% primary energy consumption 50% lower than in 2008 RES: 60% 80% RES in electricity		GHG: -80%

designs of a future low-carbon energy system for 2050. Main elements of the technological designs per country are summarised in Table 4.1.

The roadmaps have many similarities. Reductions in energy use and improvements in energy efficiency are important elements of the national roadmaps. Although there are also differences in the details, such as the role of behavioural changes, in general, the emphasis is on improvements to existing buildings. Other commonly considered elements of a low-carbon energy system by 2050 are the application of biomass, low-carbon power and carbon capture and storage (CCS) (PBL 2011, IEA 2010). Furthermore, the roadmaps, to a greater or lesser degree, all expect a remaining role for fossil fuels without CCS (Table 4.1).

Expansion of renewable energy technologies is a key element in all roadmaps, although there are clear differences in ambition levels. Denmark – with a large potential wind and biomass capacity – has decided on 100% renewable energy, phasing-out all fossil energy. Germany also has a strong focus on the expansion of renewable energy technologies. In most other countries, the future share of RES is more dependent on technological developments and future costs. In general, wind and biomass are the most dominant energy options considered. Because there is a range of options for producing low-carbon electricity, all road maps deal with replacing fuel with power, where possible (electric passenger vehicles, electric heat pumps).

A larger contribution of wind and solar power introduces problems of intermittency within the grid. There are three possible solutions: more interconnections, more storage, and a more flexible demand supported by smart grids. These solutions are found in all roadmaps, but there is no sign of a shared vision on a European infrastructure. Nor is there any clarity about the importance of a direct current (HVDC) network for Europe that possibly is also connected to Northern Africa. Most countries explicitly mention an increase in interconnectivity, but the extent to which is unclear. Denmark already strongly depends on connections with other Scandinavian countries. France currently exports a large quantity of base-load electricity. More wind and solar power in the surrounding countries will lead to additional peak production, which will have an impact on France's export potential.

Electricity storage solutions, mechanically (pumped storage, compressed air, flywheels) or chemically (hydrogen, synthetic natural gas), for balancing fluctuating loads of wind and solar power could lead to more (sub)national approaches. Pumped storage is mainly an option in mountainous areas. Large storage possibilities, such as in Norway, could be part of

Table 4.1
Some technical elements mentioned in national long-term visions

	Low-carbon generation of electricity	Biomass	Fossil energy	Carbon capture and storage or reuse
Belgium	Phasing out nuclear energy up to 2025; ambitions to expand RES and to improve flexibility	Important contribution to meet 2020 targets	More gas in power generation	Potentially important for the use of coal in steel industry and ower generation
Denmark	High ambitions for wind power, no nuclear energy; increase in interconnections	Important for CHP, aircraft and heavy duty vehicles; more imports	The general objective is phasing out	Combination with biomass is an option
France	Nuclear energy is and remains dominant; hydropower remains important; more wind and solar energy; uncertainty about export (more peak demand)	Important contribution especially for transport	More gas for peak electricity	A secondary option, maybe necessary, related to steel industry
Germany	Focus on RES (mainly wind, also solar, maybe imports), phasing out nuclear energy up to 2022; development of storage	Biogas will play an important role, also for flexibility	Additional to RES, if necessary; decreasing contribution of gas	Additional to RES electricity in combination with coal; important for energy-intensive industries; some CO_2 exports; carbon- reuse is an option
Netherlands	Nuclear energy is an option, maybe to bridge the gap towards a completely sustainable system on a European scale after 2050	Increase import of sustainable biomass; priority for air traffic, ships, trucks, small industries and existing buildings	Gas will continue to play an important role in the long term; oil expected to stay; uncertainty about the role of coal	Essential, especially for industry; combination with biomass; export of CO_2 may be necessary
United Kingdom	Increasing share of nuclear and wind energy; more interconnection	A sustainable share of 10% is possible; combination with CCS	Gas will continue to feature strongly in the energy mix; more imports	Considered to play a fundamental role

a European solution. Chemical storage offers opportunities for more national or regional solutions. Especially the option to produce hydrogen and synthetic natural gas is explored in Germany. Frictions between EU-wide balancing strategies by reinforcing the grid and national and sub-national balancing strategies based on storage facilities may occur. Smart grids and demand control, especially in the case of electric cars, are developments that take place in all countries, contributing to short-term balancing, especially during the day.

The role of nuclear energy is widely discussed at this moment. Many uncertainties surround the issue, but basically there are three options: phasing out, extending the lifetime of existing plants, and/or expanding the technology. Denmark and Germany do not consider nuclear energy an option for the future; Germany has decided on an accelerated phasing out (up to 2022). Belgium has also decided to phase out (up to 2025) nuclear energy, although it is a dominant technology today (5900 MW). In present-day France, nuclear energy is the dominant technology for power generation and extending the lifetime of existing plants is seriously considered, because this appears the cheapest option to generate low-carbon power. However, over the coming years, one of the reactors in France will be closed. Expansion of nuclear energy is only discussed in the United Kingdom and the Netherlands, but whether the required funds from private investment can be generated remains uncertain.

All countries expect a strong decrease in the role of oil and coal, but the expectations regarding gas vary. The United Kingdom and the Netherlands continue to invest in gas infrastructure and expect a long-term role for gas due to CCS and an increasing share of biogas. France, Germany and Belgium expect natural gas to provide flexibility in the electric system. Denmark prefers a gradual phase-out, but also invests in biogas that is being fed into local heat networks.

Biomass is a relatively flexible, easily deployable renewable energy source (RES). The six countries rely heavily on its use, which is also visible in their renewable energy plans for 2020. The Netherlands explicitly mentions sustainability issues that restrict its global potential and possible imports in the future. There is also awareness that, because of the restricted supply of biomass, its application should be prioritised to be used in areas for which low-carbon alternatives are lacking, such as fuels for aircraft and heavy-duty trucking (also explicitly mentioned in Denmark), plastics and heat for smaller industries and existing buildings. However, clear choices have not been made yet in the Dutch roadmap. Restricted supply of sustainable biomass does not appear as a major issue in most other roadmaps, as yet, although reflections on prioritised applications and sustainability concerns are encountered. Some countries recognise that the combination of biomass processing with carbon capture and storage (CCS) is technically an important option to realise negative CO_2 emissions.

Belgium, Germany, the Netherlands and the United Kingdom assign CCS as an essential element of a future low-carbon energy system. Its main applications mentioned are energy- intensive industries (such as steel production) and the combination with biomass. In these countries, CCS might also allow coal- and gas-fired power plants to play an important role in their future low-carbon energy systems. Business cases for CCS, however, are difficult to make and implement. There is much public resistance against geological storage of CO_2 below land. Storage below sea seems therefore the preferred option. Storage capacity in empty gas and oil fields is limited. The capacities in aquifers could be sufficient for an energy transition, but are less certain. Germany, Belgium and the Netherlands mention the general possibility to export CO_2.

In several places, the roadmaps mention the importance of cross border transmission of electricity. Belgium depends very much on import and export of electricity. The extent of power exchanges in north-west Europe in a future with a load of more variable RES power has not yet been elaborated and how this should become a reality is not made concrete; for instance, whether AC technologies would suffice, or if eventually a European DC infra-structure would be needed. In the context of CCS, the transport of CO_2 between countries may come into the picture. In the roadmaps, however, this is not mentioned. Furthermore, gas infrastructure and exchange between countries as a technology to create larger flexibility in the energy system also are not elaborated in the roadmaps. The need to import biomass is an issue only mentioned in the Dutch roadmap.

The United Kingdom and the Netherlands point to the future share of all non-CO_2 greenhouse gases, while the German policy only deals with fluorinated (industrial) greenhouse gases. Many options exist for reducing the emission of these gases from industrial sources, but to reduce emissions from land use and cattle is much more difficult. If, by 2050, greenhouse gases would be reduced by 80%, about a quarter of the remaining emissions are estimated to originate from agricultural sources.

5 The European dimension

The influence of European Union legislation in the fields of climate change and energy on national policies can hardly be overestimated. The EU has competences in the areas of climate change and energy policy, although they vary substantially. Existing European treaties provide a legal foundation for EU Regulation on combating climate change (Article 191(1) TFEU). The EU has used this power to promulgate greenhouse gas emission reductions measures. The European Union Emissions Trading System (EU ETS) and the Renewable Energy Directive (RED) are the most striking examples. In the area of energy policy, EU competences are restricted. Article 194(2) of the Treaty on the Functioning of the European Union grants Member States the right to make their own sovereign decisions about which energy resources and technologies to use. Nevertheless, the EU competence to regulate the internal market (Article 114 TFEU) also affects energy markets. Consequently, despite national sovereignty over the energy mix, a Europeanisation trend in the energy sector is visible.

There have been clear steps towards more European governance in recent years, especially in the electricity sector. This is apparent in areas such as the EU ETS, grid development and energy market regulation (Table 5.1). Total electricity production in the EU is subject to joint emission trading and in the long run this could make the higher emitting power stations in the EU unprofitable and squeeze them out of the market – under the condition that carbon prices indeed influence investment decisions. European network operators (associated in ENTSO) in electricity and gas have the obligation to come up with European Ten Year Network Development Plans (TYNDP). Moreover, through the establishment of the European Agency for Cooperation of Energy Regulators (ACER), coordination between national network operators is covered by European policy. These Europeanisation trends constrain the reach of national energy policies.

In 2011, the European Commission published three roadmaps to shape the political debate about a transition towards a low-carbon economy by 2050. The low-carbon economy roadmap (EC, 2011a) provides the broader picture. For two sectors of particular interest in the energy transition, the Commission published separate

Table 5.1
Current EU policy significant for the transition towards a low-carbon economy

Climate change policy	Energy policy
Targets: • GHG emission reduction targets for 2020 • Ambition to reduce greenhouse gas emission by at least 80% to 95% by 2050 compared to 1990	**Targets:** • Renewable energy • Energy efficiency • Internal energy market
Main instruments: • EU Emissions Trading System • Effort sharing decision • CCS directive • CO_2 standards for cars	**Main instruments:** • Renewable energy directive • Energy market regulation • Energy efficiency directive • Ecodesign directive • Energy performance of buildings directive • European grid development plans • Energy infrastructure package

roadmaps: the Transport White paper (EC, 2011b) and the Energy Roadmap (EC, 2011c). Recently, the Commission revealed a renewable energy strategy (EC, 2012), addressing the integration of renewable energy in the European energy market, while reflecting on the appropriate regulatory framework for renewable energy post-2020.

Roadmaps and strategies provide the context and encourage political debate on the transition towards a low-carbon economy, but themselves are not legislative proposals. The debates may point to areas where enhanced European coordination is desirable in the interest of EU Member States' transitions towards a low-carbon economy. Such conclusions may provide a mandate for the European Commission to elaborate specific policy proposals. This is of particular interest in sensitive areas, such as energy policy, in which the European Treaty gives the Commission only limited powers.

6 Main instruments

Aim of this section is to explore main differences and common approaches and the possible need for closer cooperation. This will be done by exploring, in a stylised way, what is understood to be the 'core' of the national policy instruments, looking at:

- Alignment between long-term policy targets and the policy measures chosen to achieve these targets. Stability of policy targets, underpinned by a consistent set of policy measures, is often perceived as a crucial condition for investment in clean technology.
- The way in which countries could learn from each other in using effective measures, and the need for collaboration to effectively achieve a low-carbon economy given interactions between countries against the background of the common market, transnational gas and electricity grids and other Europeanisation trends (Section 5).

Annex 5 gives an overview of the policy measures that aim to support energy transition implemented in the six countries.

Stability and alignment

Over the past several years, Denmark and the United Kingdom have achieved a relatively stable approach. Almost all Danish political parties strive for a fully renewable and highly energy-efficient economy by 2050, and the United Kingdom has broad backing for a low-carbon economy in which legally binding carbon constraints lead the way forward. Both countries align these objectives with a policy approach that combines a long-term orientation with specific actions to be taken today. In the United Kingdom, the main emphasis is on legally binding carbon budgets up to 15 years ahead; in Denmark it is on a combination of efficient district heating networks, investment in biomass and wind energy, smart grids and interconnection to deal with intermittency problems. Both countries try to find a solution for the necessity to finance high upfront investment in a clean energy system: the United Kingdom by issuing bonds for energy companies to implement (and finance) efficiency measures, a new Green Investment Bank following the German example, and a fundamental power market reform. Denmark does so by looking at a combination of green taxes and efficiency bonds for energy companies.

In the recent past, Germany had a combination of stable and unstable policy approaches. Its approach towards RES has been consistent, backed by strong policy instruments and in many respects has been successful.

Roadmaps and energy research, development and demonstration

Energy research, development and demonstration (RD&D) has two aims, namely to foster new energy applications and to strengthen the competitiveness and opportunities of national industries. National roadmaps mainly consider the first RD&D aim although in reality the two aims are always combined – if only because a strong industrial export position cannot be achieved without a home market.
The following five fields in RD&D expenditures may contribute to the development of clean technologies:

- energy efficiency;
- carbon capture and storage (CCS);
- renewable energy;
- nuclear energy;
- a cluster of network applications, storage systems, hydrogen and fuel cells.

Table 7.1 shows RD&D investments in the six countries over the most recent years for which figures are available (2008–2010, except for France 2008–2009, and Belgium 2007 only). Because in some cases figures change considerably from year to year, probably due to administrative reasons, three-year averages have been calculated.

Table 7.1
Energy RD&D. Shares in %, total amount in euros and per unit of GDP

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
Efficiency	25%	9%	14%	15%	**39%**	28%
CCS	0	1%	5%	2%	6%	**9%**
Renewables	16%	**45%**	12%	29%	35%	34%
Nuclear energy	47%	0	**48%**	34%	7%	14%
Network, storage etc.	6%	**28%**	9%	8%	7%	9%
Total (million euros)	99	112	**980**	567	237	358
Per 1000 of GDP, 2009	0.30	0.56	**0.64**	0.27	0.44	0.21

Source: IEA, Country RD&D database; Decisio (2011), Monitor on publically financed energy research 2010 [Monitor publiek gefinancierd energieonderzoek 2010], Amsterdam

Against the background of national roadmaps for the transition towards a low-carbon economy, the figures in Table 7.1. are explained below.

1. Research, development and demonstration related to nuclear energy constitute the highest expenditure in energy research. It is considerably higher than what might be expected given the share of nuclear energy in the energy mix and its role in the transition towards a low-carbon economy. This is especially the case for Germany. Although the German energy roadmap has renewable energy as its focal point, the expenditure on RD&D for nuclear energy in the 2008–2010 period was higher than for renewable energy.
2. Four countries allocate a relatively high share of RD&D funds to renewable energy, namely Denmark, Germany, the Netherlands and the United Kingdom. In Denmark, the emphasis is on biomass and wind energy, which corresponds to the important role of these resources in the Danish energy transition. In the Netherlands, the RD&D effort is directed to solar energy and biomass. In the United Kingdom, the emphasis is on wind energy and biomass. In Germany, the emphasis is on all three resources, while France allocates this type of expenditure only to solar energy. Belgium spends very marginally on renewable energy research. Only Belgium, the Netherlands and the United Kingdom spend a considerable share of RD&D on energy efficiency. The fact that, in general, research on energy efficiency receives limited support does not correspond well with the large role of efficiency in all roadmaps and its relatively large share in ´clean energy technology employment´.
3. Only Denmark consistently allocates a considerable share of its expenditure on RD&D to networks, storage systems, hydrogen and fuel cells. However, in Germany, attention for storage options is increasing rapidly.
4. Calculated as a percentage of GDP, France and Denmark invest the most, with Belgium, Germany and the United Kingdom spending considerably less.

However, its main force – the combination of installation of renewable energy technologies and industrial production within Germany – has come under pressure over recent times, and it will be a challenge to combine cheaper imports of clean technology components with a solid German role in the value chain. The same is true for Denmark, while the other four countries do not have the same level of national clean technology production (Section 2). The German approach to nuclear energy – also a zero-carbon technology – has been very unstable, leading to uncertainty in the power sector in Germany and surrounding countries. The German 'Energiewende', as is the case with all deep transitions, is not easy to implement, due to vested interests and all kinds of short-term problems (infrastructure, affordable energy prices, acceptance of CCS, differences between federal level and federal states, financing of buildings' refurbishments). However, it is built on a strong base of technological knowledge, citizen participation and grassroots activism (in particular the anti-nuclear movement).

France, Belgium and the Netherlands, by and large, are still searching for new, stable approaches. For decades, France had a stable orientation in which nuclear energy was the main contributor to a low-carbon economy. Recently, however, the extent to which France aims for energy efficiency – for example, by means of a carbon tax – and the opted fuel mix in the future power sector have become less clear. The position of Belgium is similar, although more urgent, now that the government has decided on phasing out nuclear power in the 2015–2025 period and a long-term vision and plan are still lacking. This has led to uncertainty about the investment climate. The Netherlands has the clearest difference between its orientation for the medium term (2020) with emphasis on cost effectiveness, and uncertainty about the longer term (2030) with a conditional emission reduction target. At the same time the country has an ambitious approach towards energy technology development by Dutch companies in which the 'push factor' is developed by a reorganisation of RD&D funds, although the strength of the 'pull factor' is unclear.

Learning and interactions

The results from choices made for certain instruments may help countries to learn from each other. This would partly depend on the ambition levels and further elaboration of the policies in the six countries. Nevertheless, although arbitrarily chosen, some examples of relatively successful policy approaches can be given.

- **Denmark**. The country has invested in a process that has been gaining broad political backing stemming from long-term ambition, and involving policy instruments in which 'greening' of taxes plays a crucial role; district heating gradually has moved towards biomass with strong regulatory and financial incentives; and there has been ongoing investment in onshore wind parks with the involvement of local communities.
- **Germany**. The country has built broad political backing for renewable energy sources (RES) and financing of up-front investments by the 'Kreditanstalt für Wiederaufbau'.
- **United Kingdom**. The country has legal certainty in climate policy, aiming at a least-cost approach; it is considering new market structures in clean power investment by its Electricity Market Reform (see text box The Missing Money).
- **France**. The country has a strong 'government–industry–energy' sector, a strong combination of nuclear industry, construction and RD&D.
- **United Kingdom, Denmark and France**. In these countries, there is involvement in and funding by energy companies in energy efficiency, especially in buildings.
- **Denmark, the Netherlands and Germany**. These countries are attempting to use the potential of their societies (see text box Energetic Society) in which citizens and enterprises take the lead in trying to achieve a clean economy by building on strong local traditions (Denmark, Germany) or by providing clarity about which investments will not be subsidised, thus encouraging citizens to start investing themselves, such as in solar PV, or using a bottom-up approach in searching for the most effective way of energy-efficient refurbishment of buildings (the Netherlands).

7 What seems to be missing?

Looking at the various roadmaps of the six countries, shows that for certain sectors almost no measures are considered, even though these sectors play an important role in the transition towards a low-carbon economy. Below, we list a number of issues that stand out, but there are likely to be more.

1. Carbon capture and storage (CCS) does not receive much attention. The United Kingdom and the Netherlands, especially, have tried to set up CCS demonstration plants, but have suffered a variety of set-backs. The United Kingdom could not find an interested investor in a first application round for a large demonstration plant. The Dutch Government received massive public resistance in reaction to its attempt to set up a CO_2 transport and storage demonstration project in a densely populated area, after which the government decided not to

The Missing Money

Low-carbon energy systems are expected to be characterised by relatively high fixed and relatively low variable costs. This is especially the case in the power market. Around a third of overall electricity costs will be related to fixed investments (capital costs) and the other two thirds depend on variable costs. In a future system with a large share of renewable energy, nuclear energy or carbon capture and storage (CCS), around two thirds of the costs could reflect up-front investments with only one third due to operational costs (Boot and Van Bree, 2010). If prices remain equal to variable costs, it will be much more difficult to cover all costs. Or, differently put, companies will be reluctant to invest in a zero-carbon future as they are uncertain about how to recover their costs. The same applies to back-up capacity.

In the actual market, short-term marginal costs are a considerable share (40% to 70%) of long-term costs and therefore enough revenues are earned to warrant investment. In a zero-carbon system, the situation is different. Variable costs of most renewable energy technologies are close to zero. However, peak prices will be set by open-cycle gas turbine technology with high variable costs. Price volatility will become higher than today's level, but for investors it will be uncertain whether their investments in back-up facilities, intended to be used for as short a time as possible, will be earned back. In the economic literature, this is called the ´missing money´ problem. Competitive wholesale electricity markets and operating reserves do not and perhaps cannot credibly provide adequate net revenues to attract investments in back-up generation. This looming problem has been considered carefully in the United Kingdom (both aspects), and France (initially only back-up capacity, but recently also more in general) and is being discussed in Germany. The UK Electricity Market Reform (July, 2011; Energy Bill, May 2012) consists of two key elements and two supportive mechanisms:

1. Feed-in Tariffs with Contracts for Differences, providing long-term stable and predictable revenue streams for low-carbon energy generators (CCS, wind and nuclear energy). These tariffs provide variable payments to those that generate the energy; they receive these payments if the market price is below a certain ´strike price´, and must pay back if the market price exceeds a certain level;
2. A Capacity Market in which energy generators are rewarded for having a certain level of reliable capacity (or a guaranteed reduction in capacity), a number of years ahead. In this way, security of supply may be ensured
3. A Carbon Price Floor is set to prevent the price of carbon from falling below a certain price level;
4. The final element is an Emissions Performance Standard for new investments, obliging them to remain below a certain level of CO_2 per kWh. As a consequence, no new coal-fired power plants could be built.

The Energy Bill proposes different stages in which the new mechanisms gradually replace existing ones, which has been coined 'a complex web of regulation' (Keay, 2012). An important question is how this market reform could be related to the EU ETS, which already has set a cap on CO_2. All changes within the existing cap only make it easier for power plants located elsewhere in the EU to emit more. Another question refers to the possibility of introducing these changes in one country only. Capacity mechanisms may be expensive to implement and, with increasing shares of interconnection, neighbouring countries would also benefit from the resulting adequate capacity, but would not have contributed to the costs. This illustrates how difficult it has become to find suitable solutions in single countries within the European market.

A specific incentive system for renewable energy eventually would not be needed any longer, as the reform aims at general incentives for low-carbon power instead of specific ones for renewable energy. This fits both the UK and the Dutch long-term approach in which a CO_2 reduction target is the main policy aim, but would match the Danish and German long-term ambitions to a lesser extent. It shows, however, that the discussion on effective, long-term incentive systems has to be pursued in light of the policy aims of the specific countries and the position renewable energy is expected to take in this broader context.

Energetic Society

Recently, a new approach towards sustainability emerged, both in political science and in actual policy-making. This has been coined by Hajer (2011) in 'The energetic society'. The essence of this study is that societies are anything but passive. Modern societies consist of autonomous citizens and innovative companies that want to act and change. Also many local authorities and public organisations are willing to take action. The role of governments is to establish the conditions under which markets can work and citizens can act. This implies a clear positioning (what do we want to achieve), corresponding infrastructure, regulation, financial instruments such as environmental taxes, and monitoring and feedback to observe whether society is on track to achieve its goals. If this is done clearly and predictably, then societies are in a position to make the transition towards a clean economy. This theoretical concept appears new, but could already be observed from the early 1990s in countries such as Denmark and Germany. Denmark has a strong tradition of local initiatives. A recent example is that people who live next to wind turbines have been given the legal right to become co-owners of these turbines. In Germany, local initiatives also play a strong role (cities, local energy companies, citizens' cooperative societies) and about 40% of investments in renewable energy sources come from private parties.

pursue CO_2 storage on land in any form, but rather to concentrate on offshore CCS only. Germany had drawn up legislation under which storage for demonstration purposes was made possible. This proposed legislation received strong opposition from the federal states and only after a political stalemate that lasted for months, the 'Bundestag' (Parliament) and the 'Bundesrat' (Federal Council) reached an agreement on it. Furthermore, all countries have the problem that CCS requires a subsequent step following the implementation of demonstrations, in a market situation in which the ETS carbon price probably will not be high enough to compensate for the high additional costs. In official publications only the United Kingdom has seriously considered this problem in its Electricity Market Reform.

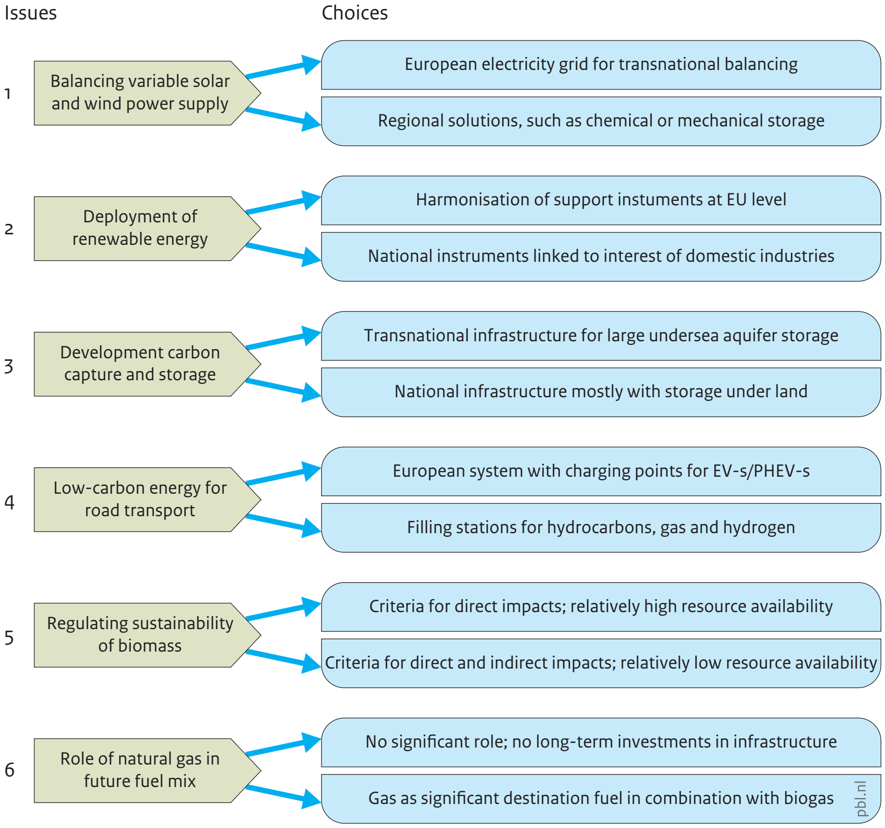
2. More generally, there is the question of whether the electricity market framework is capable of providing the right incentives for investments in clean technologies and offers enough finance (see box The Missing Money). The United Kingdom is convinced this is not yet the case, as are many energy companies. France and Germany are discussing the eventual need to provide additional incentives for new capacity in power generation. Such incentives certainly will cost money and cost-benefit analyses are very dependent on the assumptions made. More important, the question arises whether it makes sense to consider these issues in one country only, as other countries – depending on the interconnection capacity – may benefit from additional capacity without having contributed to the costs. The European Commission (EC, 2012) recently cautiously took the initiative to address this issue, which so far has not yet been debated at supranational level.
3. Long-term transport policies (next to those on infrastructure) focus on modal shifts and electric vehicles, but the low-carbon transition for freight transport receives little attention.
4. Non-CO_2 greenhouse gas emissions, in general, and from agriculture, in particular, are only marginally dealt with, although climate change scenarios in the United Kingdom and the Netherlands, for example, show that a decrease in non-CO_2 greenhouse gas emissions will be difficult to achieve.

8 Reasons for cooperation

In designing a low-carbon economy, countries are faced with choices that also depend on those made by other countries (Figure 8.1). Because the choices made may have external effects, there is a need for alignment, in particular, on the following issues. For all these issues, a wide variety of choices are possible, with very different consequences for technical system integration, market design and European coordination. This does not necessarily mean that countries are forced to make similar choices, but some form of coordination and information sharing appears necessary. Countries can also benefit from experiences resulting from choices made in other countries and may organise some form of collective learning.

1. The increasing load on the grid with intermittent solar and wind power requires balancing solutions to secure a stable European energy supply. This is a pressing issue. In addition to short-term balancing by demand-side management, there are basically two technical solutions. First, strengthening the European power grid infrastructure would enable long-distance

Figure 8.1
Issues and choices in the national climate and energy roadmaps



Source: PBL

Issues for which very different choices are possible, with their consequences for technical system integration, market design and European coordination.

exchange between areas with surpluses and those with deficits. A second solution consists of setting up regional facilities to store power surpluses. Storage can be mechanically (pumped storage, compressed air, flywheels) or chemically (hydrogen, synthetic natural gas). Chemical fuels can be stored within the gas infrastructure, in storage tanks or gas fields. The various storage solutions have different technical characteristics (capacity, efficiency, storage time) and contribute in various ways to balancing variable power from renewable energy sources (RES).
The first solution requires European-wide investments in infrastructure and close cooperation between grid operators. The second solution could be arranged on a national scale and implies a vision on system integration of RES power, possibly even involving the power and gas grids. Countries that opt for storage solutions would be less inclined to invest in improvements of cross-border links within the power grid infrastructure, while those that opt for balancing over a European power grid would, in fact, largely depend on such investments. The question is whether countries would have complete freedom of choice in this matter.
An additional complicating factor is when countries have a large capacity of relatively inflexible power generation (nuclear or coal-fired power plants). This type of power supply delivers a high level of base load electricity in the system at the expense of flexibility. For countries that choose to increase the share of RES power, flexibility is needed to cope with the problem of intermittency. Countries that have high levels of base load electricity are interested in a possible exchange and trade of this inflexible base load electricity.

2. In furthering RES deployment, varying trade-offs exist between the choices made by the individual countries. It is well-known that international companies tend to invest in technologies specifically in those countries where the relationship between profit and risk is the most favourable. However, these are not necessarily the countries where, technically speaking, the price–performance ratio of a technology would be the most favourable. From a

European perspective, this may lead to technically and economically suboptimal solutions. With this in mind, the choices made by the countries are difficult to understand: the United Kingdom has decided to change the incentive system (away from quota obligation); contrastingly, the Netherlands considers whether quota obligations might be an improvement, in relation to its existing feed-in premium; and Germany is gradually combining its acclaimed feed-in tariff with a feed-in premium. Eventually, the choice will be between opting for an economically optimal introduction of renewable energy technologies (RET) from a European perspective, or following a more national stance in which domestic benefits, such as job creation and security of supply, count heavily, as well. The question of RET incentives may be part of a more general discussion on electricity market reform that has led to certain conclusions in the United Kingdom. A national market reform could be suboptimal from both a national and a European point of view. A higher effectiveness could be obtained if a more joint approach could be followed.

3. If countries would choose to apply carbon capture and storage technology to mitigate greenhouse gas emissions, they would have the choice to store that CO_2 below land or under the seabed. Storage below land is mostly a national solution, while under the seabed often requires international collaboration, with the largest European storage potential in Norwegian aquifers under the seabed. Storage below land often encounters strong resistance from inhabitants of those areas and local and regional authorities. Storage undersea often requires close international cooperation.
4. Passenger vehicles in a low-carbon economy may be powered by electricity (electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs)), or by RES generated chemical fuels (hydrogen, synthetic natural gas). The associated infrastructures and investments are very different. From the perspective of inter-European mobility and cost-effective infrastructure investments, countries should make coordinated decisions on this subject.
5. Land-use changes related to the cultivation of bio-energy crops may have significant direct or indirect impacts on greenhouse gas emissions, landscape values, biodiversity and water quality. The degree of regulation of the sustainability of biomass, in general, and related land-use changes, in particular, may have a strong impact on the amount of available biomass on the market. Criteria that exclude all indirect effects (especially indirect land-use change (ILUC) emissions) significantly reduce the potential availability of bio-energy crops, with a subsequent impact on long-term energy strategies. Countries may have very different visions, but as they are operating within a single market, there is a need for uniform sustainability criteria.
6. A final issue is the envisaged role of gas in the future fuel mix. The views in this differ considerably between countries. Denmark aims at gradually phasing out natural gas, decreasing gas consumption and replacing the remaining part with biogas. The United Kingdom and the Netherlands aim for gas to be not only a 'transitional', but also a 'destination fuel', albeit not only in the form of natural gas but also by increasing shares of biogas. These countries do not foresee a 100% biogas share, however, and they are uncertain about the available amount of sustainable biomass in any form. These different visions could go hand in hand. It is not necessary for the countries to have a shared vision, but only where national networks are involved. Transmission system operators for gas – which are increasingly of a transnational nature – have to know the extent to which investments in international networks remain necessary.

9 Conclusions

The issues on cooperation mentioned in the previous section were all recognised by experts from national governments and businesses during two working conferences, organised mid-2012, on the roadmaps of north-western European countries. However, not all issues were given the same priority. Regarding the phases of the transition towards a low-carbon economy, in particular, balancing variable RES power (Issue 1), furthering systems for RES deployment (Issue 2), and the role of gas in the future energy mix (Issue 6) were seen as having the most priority. These issues were suggested as being good starting points for discussing further transnational cooperation. Issues 1 and 2 were also addressed in a recent communication by the European Commission on renewable energy (EC, 2012).

Experts have pointed to the fact that these issues are not separate. Finding solutions to the intermittency problem caused by the increasing load of variable RES power in the grid (Issue 1) could also be linked to the discussion on the role of gas in the future energy mix (Issue 6). The discussion on incentive systems for renewable energy technologies (Issue 2) is part of a broader discussion on the development of the internal power market within the context of the transition towards a low-carbon society. The discussion on decarbonisation of the transport sector (Issue 4) is also linked to Issue 5, on the sustainable potential supply of bio-energy.

The economic, political and energy system interconnections between north-western and other European countries, which are the identified reasons for collaboration, ask for consideration of the European dimension in the development of national low-carbon transition plans. This is further enhanced by Europeanisation trends in energy market development, energy regulation, and infrastructure development. By reinforcing cooperation through the alignment of choices, coordination, and information, and by best-practices sharing, the countries could make a large step towards developing cost-effective low-carbon transition plans. Regional platforms, such as for the countries around the North Sea, may support these forms of cooperation.

References

General

Boot PA and Van Bree B. (2010). A zero-carbon European power system in 2050: proposals for a policy package. ECN-E-10 041.
BP (2011). Statistical Review of World Energy, 2011.
Hajer M. (2011). The energetic society. In search of a governance philosophy for a clean economy. PBL Netherlands Environmental Assessment Agency, The Hague, publication number: 500070012.
IEA (2010). Energy Technology Perspectives. OECD/IEA, Paris.
IEA (2011). Deploying Renewables 2011. Best and Future Policy Practice. Renewable energy, markets and policies. OECD/IEA, Paris.
IEA (2012). Renewable energy medium-term market report 2012. Market trends and projections to 2017. OECD/IEA, Paris.
Kleβmann C. (2011). Increasing the effectiveness and efficiency of renewable energy support policies in the European Union. Thesis Utrecht University, Copernicus Institute for Sustainable Development and Innovation.
Meulman L, Boot P, Van der Linden C, De Jong J and Werring L. (2012). Harvesting Transition? Energy Policy Cooperation or Competition around the North Sea. Clingendael International Energy Programme, 2012/1.
Van der Slot A and Van den Berg W. (2012). Clean economy, living planet. The race to the top of global clean energy technology manufacturing. Roland Berger Strategy Consultants, commissioned by WWF Netherlands.
Teusch J. (2012). Renewables and the EU Internal Electricity Market. The case for an arranged marriage. CEPS policy brief no. 264, March 2012.

European Union

EC (2011a). A Roadmap for moving to a competitive low carbon economy in 2050. COM, 2011, 112.
EC (2011b). Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system. COM, 2011, 144.
EC (2011c). Energy Roadmap 2050. COM. 2011, 885.
EC (2012). Renewable energy: a major player in the European energy market. COM, 2012, 271.
EEA (2009). Europe's onshore and offshore wind energy potential. An assessment of environmental and economic constraints. EEA Technical report No. 6/2009.
EEA (2011). Greenhouse gas emissions in Europe: a retrospective trend analysis for the period 1990–2008. EEA Report No. 6/2011.
Eurostat (2011). Energy, transport and environment indicators. Eurostat pocketbooks.

Belgium

Bossier F, Devogelaer D, Gusbin D and Thiéry F. (2011). Impact of the EU Climate-Energy Package on the Belgian energy system and economy- Update 2010. Study commissioned by the Belgian federal authority. Federal Planning Bureau Working Paper 9-11.
Devogelaer D and Gusbin D. (2011). Energievooruitzichten voor België tegen 2030. November 2011, Federaal Planbureau, Brussel.
Groep Gemix (2009). Welke is de ideale energiemix voor België tegen 2020 en 2030? Eindverslag, September 2009.
IEA (2009). Energy policies of IEA countries. Belgium 2009 review. OECD/IEA, Paris.
Wathelet M. (2012). Het Belgische electriciteitssysteem op een tweesprong: een nieuwe energiepolitiek om de overgang te doen slagen. (Plan agreed by the Belgian Government proposed by Melchior Wathelet, the State Secretary for Energy.)

Denmark

Danish Ministry of Climate, Energy and Building (2012). DK Energy Agreement, March 22 2012.
Danish Energy Agency (2011). Danish Energy Outlook, May 2011.
Danish Government (2011). Energy Strategy 2050 – from coal, oil and gas to green energy, February 2011.
IEA (2011). Energy Policies of IEA Countries. Denmark 2011 review. OECD/IEA, Paris.
Klimakommissionen (2010). Green energy – the road to a Danish energy system without fossil fuels. Summary of the work, results and recommendations of the Danish Commission on Climate Change Policy, 28 September 2010.

Riiskjaer Nygård J. (2011). Denmark Country Case Analysis. Green Growth from Religion to Reality. Berkeley Roundtable on the International economy, 15 June 2011.

France

Cour des Comptes (2012). Les coûts de la filière électronucléaire. Synthèse du rapport public thématique, January 2012.
IEA (2009). Energy policies of IEA countries. France 2009 review. OECD/IEA, Paris.
Percebois J and Mandil C. (2012). Rapport énergies 2050. Ministère de l'economie des finances et de l'industrie, February 2012.
Perthuis Ch de. (2012). Pathways 2020-2050 towards a low-carbon economy in France. Centre d'Analyse Stratégique. Rapports and Documents no. 46, October 2011.

Germany

BMU (2011a). Der Weg zur Energie der Zukunft - sicher, bezahlbar und umweltfreundlich. Eckpunktepapier der Bundesregierung zur Energiewende. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 6 June 2011.
BMU (2011b). Das Energiekonzept und seine beschleunigte Umsetzung. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, October 2011.
BMU (2011c). Erneuerbare Energien. Innovationen für eine nachhaltige Energiezukunft. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, October 2011.
BMU and BMWi (2010). Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit & Bundesministerium für Wirtschaft und Technologie, 28 september 2010.
BMU and BMWi (2012). Energiewende auf gutem Weg. Zwischenbilanz und Ausblick. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit & Bundesministerium für Wirtschaft und Technologie, 23 February 2012.
BMWi (2012). Die Energiewende in Deutschland. Mit sicherer, bezahlbarer und umweltschonender Energie ins Jahr 2050. Bundesministerium für Wirtschaft und Technologie, February 2012.
Buchan D. (2012). The 'Energiewende' – Germany's gamble. The Oxford Institute for Energy Studies, SP 26, June 2012.
DLR, Fraunhofer IWES and IFNE (2012). Long-term scenarios and strategies for the deployment of renewable energies in Germany in view of European and global developments. Summary of the final report. BMU – FKZ 03MAP146.
Fischer S and Geden O. (2011). Europeanising the German Energy Transition. SWP Comments 33, November 2011. Stiftung Wissenschaft und Politiek, German Institute for International and Security Affairs.
Knopf B, Kondziella H, Pahle M, Götz M, Bruckner Th and Edenhofer O. (2011). Der Einstieg in den Ausstieg. Energiepolitische Szenarien für einen Atomaustieg in Deutschland. Friedrich-Ebert-Stiftung, WISO Diskurs, August 2011.
Prognos AG, EWI and GWS (2011). Energieszenarien 2011. Projekt Nr. 12/10 für das Bundesministerium für Wirtschaft und Technologie, July 2011.
Schmid E, Pahle M and Knopf B. (2012). Renewable electricity generation in Germany: a meta-analysis of mitigation scenarios. Submitted to Energy Policy.
Töpfer K and Kleiner M. (2011). Deutschlands Energiewende – Ein Gemeinschaftswerk für die Zukunft. Ethik-Kommission Sichere Energieversorgung, im Auftrag der Bundeskanzlerin Dr. Angela Merkel, 30. May 2011.

The Netherlands

CPB (2011). Analyse Routekaart 2050. Op verzoek van het ministerie van Infrastructuur en Milieu, CPB notitie, CPB Netherlands Bureau for Economic Policy Analysis, 6 November 2011.
Ministry of EL&I (2011). Energierapport 2011. Ministry of Economic Affairs, Agriculture and Innovation.
Energy Forum NL (2012). Energy in the Netherlands. Optimized pathways to CO_2 reduction in the Dutch context.
Ministry of IenM (2011). Klimaatbrief 2050. Uitdagingen voor Nederland bij het streven naar een concurrerend, klimaatneutraal Europa. Ministry of Infrastructure and the Environment.
PBL and ECN (2011). Exploration of pathways towards a clean economy by 2050: How to realise a climate-neutral Netherlands. Energy research Centre of the Netherlands (ECN), Petten / PBL Netherlands Environmental Assessment Agency, The Hague. PBL publication number: 500083016.

The United Kingdom

Bowen A and Rydge J. (2011). Climate-Change Policy in the United Kingdom. OECD Economics Department Working Paper No. 886.
CCC (2010). The Fourth Carbon Budget. Reducing emissions through the 2020s. Committee on Climate Change, December 2010.
DECC (2011). Planning our electric future: a White Paper for secure, affordable and low carbon electricity. Department of Energy and Climate Change, July 2011.
DECC (2012). Electricity Market Reform: Policy Overview, Department of Energy and Climate Change, May 2012.
HM Government (2011). The Carbon Plan: Delivering our low-carbon future, December 2011.
Keay M. (2012). Death by a thousand regulations: the new Energy Bill. Oxford Energy Comment May 2012. The Oxford Institute for Energy Studies.

Annex

Annex 1. Basic statistics describing the countries' various points of departure

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
Area 2009 (1,000 km2)	30.5	43.1	**544.0**	357.1	41.5	243.1
Population 2010 (million)	10.95	5.56	65.08	**81.75**	16.66	62.44
GDP 2010 (euros/capita)	32,600	**42,500**	29,800	30,300	35,400	27,400
GHG intensity(b) 2008 (g CO_2 eq per GDP in purchasing power standard)	**437**	376	317	413	373	352
Energy intensity 2010 (toe/1,000 euros GDP)	**213**	104	167	150	182	115
Gross inland energy consumption 2009 (% net imports)						
Coal	81.6	98	91.7	74.1	124.5	77.8
Oil	95	-55.2	97.7	95.2	97.1	8.6
Natural gas	99	-91.7	100.9	87.9	-61.2	31.6
Net electricity imports 2009 (GWh)	-1,835	334	-25,934	-12,273	4,891	2,861
Share RES in gross final energy consumption 2009 (%)	4.6	**19.9**	12.3	9.8	4.1	2.9
Share RES in gross electricity consumption 2009 (%)	6.1	**27.4**	13.5	16.2	9.2	6.7
Electricity prices households (Nov. 2011, incl. tax, consumption 3500 kWh/year, in euros/100 kWh)	22.2	**30.8**	14.8	27.8	22.0	16.8
Electricity prices industry (Nov. 2011, incl. tax, consumption 2 GWh/year, in euros/100 kWh)	11.8	10.9	7.6	**13.4**	11.8	11.5

Note:

(a) Main source: EUROSTAT database

(b) Data on greenhouse gas (GHG) intensity from EEA (20110

(c) Electricity prices: Europe's Energy Portal, http://www.energy.eu/

Annex 2. Potential domestic renewable energy resources

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
Onshore wind energy potential(a) (MWh/capita)	40.22	**135.68**	81.28	49.11	32.16	71.10
Offshore wind energy technical potential (b) (MWh/capita)	23.15	**490.51**	30.30	20.92	144.8	77.30
Annual global irradiation (c) (kWh/m2)	1,097–1,107	1,109–1,164	**1,157–1,798**	1,117–1,242	1,086–1,124	1,018–1,240
Land use in agriculture (ha/capita)(d)	0.15	**0.50**	0.46	0.23	0.12	0.26
Woodland cover (ha/capita)(d)	0.28	0.77	**0.85**	0.44	0.23	0.39
Hydropower (MWh/capita) (e)	0.03	0.00	**0.95**	0.25	0.01	0.06

Note:

(a) EEA, 2009. Data were used from EEA's Table 6.8 (representing the generation potential for wind energy on land in the total of all cost classes by 2030) and taken from the most recent Eurostat data (2010), in this annex expressed per capita.

(b) EEA, 2009. Data were used from EEA's Figure 3.5 (representing the unrestricted technical potential for offshore wind energy by 2030, based on average wind speed), and taken from the most recent Eurostat data (2010), in this annex expressed per capita.

(c) JRC photovoltaic geographical information system (http://re.jrc.ec.europa.eu/pvgis/).

(d) Eurostat, 2009. Data on agriculture and woodland

(e) EurObserv'ER geographic information system (http://www.eurobserv-er.org/)

Annex 3. Contribution by the clean energy technology sector to national economies

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
Clean technology added value (million euros)	1,385	6,280	2,942	**22,649**	1,197	1,593
Clean technology added value as share of GDP (percentages)	0.42	**3.02**	0.16	0.93	0.21	0.08

Note:

Information provide by WWF and collected by Roland Berger Strategic Consultants for the WWF project 'Clean Economy, Living Planet'. Study results, including background and methodology, published by Van der Slot and Van den Berg (2012).

Annex 4. Public opinion on climate and energy issues

	Belgium	Denmark	France	Germany	Netherlands	United Kingdom
Climate change considered to be the single most serious problem facing the world as a whole (percentage)(a)						
	24	**31**	20	25	18	18
Availability of energy considered to be the single most serious problem facing the world as a whole (percentage)(a)						
	8	4	4	**11**	7	8
What do you think are the two most important issues facing the EU at this moment? (percentage)(b)						
Answer: climate change	7	**12**	4	7	5	5
Answer: energy supply	7	6	9	**12**	4	5
In your opinion, who within the EU is responsible for tackling climate change? (%; multiple answers possible)(a)						
National governments	42	**52**	**52**	50	25	38
European Union	**54**	45	49	48	28	22
Business and industry	47	39	41	**57**	25	16
You personally	34	**38**	29	36	20	20
Fighting climate change and using energy more efficiently can boost the economy and jobs in the EU (%)(a)						
Total 'Agree'	86	**88**	83	79	71	71
Total 'Disagree'	11	9	10	14	**22**	18
Don't know	3	3	7	7	7	**11**
Do you think that in 2050 people will be using renewable energy sources, such as wind and solar power, more than they do now? Yes, definitely (%)(a)						
	56	**82**	42	74	70	54
Do you think that in 2050 cars will still be using petrol or diesel or will cars be fuelled in a more efficient way? (%)(a)						
A more efficient way	**86**	78	77	73	81	74
Petrol or diesel	12	**18**	15	14	14	**18**
Don't know	2	4	8	**13**	5	8

Note:

(a) Special Eurobarometer 372, Climate Change 2011. (b) Eurobarometer 75. Spring 2011.

Annex 5. Overview of main policy instruments as indicated by the six countries, to be used to support the transition towards a low-carbon economy

	Electricity	Buildings	Industry	Transport
Belgium	F: minimum priced green certificates L/S: certificates (regional) for RES and combined heat and power generation (CHP)	F: tax reduction insulation measures	V: benchmarking for voluntary agreements with large industry and audits for small industry	F: tax reduction for low-emission vehicles
Denmark	F: subsidy programmes for RES and biomass CHP F: grid tariffs L/S: efficiency obligation for energy companies	F: subsidy programmes for heat F: security of supply tax on space heating F: support programmes for large-scale heat pumps	F: energy and CO_2 tax V: energy savings agreements	F: fuel efficiency determines registration tax for new cars F: subsidy for clean demon-stration projects
France	F: feed-in tariff F: tax exemptions and tax credits for solar boilers and solar PV	L/S: heat efficiency standards for new buildings		L/S: biofuel use in transport 10.5% by 2020
Germany	F: feed-in tariff F: support schemes for investments in offshore wind parks F: RD&D programmes for renewable energy, smart grid and storage L/S: legally binding shares for renewable energy L/S: simplification of spatial planning for renewable energy L/S: gradual closing of nuclear plants up to 2022	F: support schemes and tax deductions for energy-efficient renovations L/S: 1% to 2% energy efficiency in renovation of existing buildings L/S: low-energy building obligation	F: subsidies for energy-intensive industries V: promotion of continuous improvements to efficiency standards (top-runner programme)	V: 1 million electric vehicles by 2020
Netherlands	F: feed-in premium for renewable energy	V: street-by-street approach (local initiatives)	V: agreements with industry on energy efficiency V: green deals	L/S: biofuel use in transport 10% by 2016 F: electric vehicles
United Kingdom	F: tradable certificates for large-scale renewable energy L/S: national carbon price floor L/S: 'contracts for differences': long- term contracts providing stable revenue for wind and nuclear energy, and CCS L/S: Emissions Performance Standard for new power plants	F: climate change levy F: house insulation stimulus programme for low-income households F: green investment bank L/S: zero-carbon new houses by 2016 L/S: white certificates	F: conditional energy tax for industry F: national carbon price floor (2013) F: renewable heat incentive	F: Local Sustainable Ttransport Fund to improve cycling infrastructure

F: financial instrument; L/S: legal instrument (incl. standards); V: voluntary (facilitating and communicative) instruments

Planbureau voor de Leefomgeving

Postadres
Postbus 30314
2500 GH Den Haag

Bezoekadres
Oranjebuitensingel 6
2511 VE Den Haag
T +31 (0)70 3288700

www.pbl.nl
@leefomgeving

September 2012