EUROPEAN COMMISSION

Brussels, XXX
[…](2011) XXX draft

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Energy Roadmap 2050

1. INTRODUCTION

People's well-being, industrial competitiveness and the overall functioning of society are dependent on safe, secure, sustainable and affordable energy. The energy infrastructure which will power citizens' homes, industry and services in 2050, as well as the buildings which people will use, are being designed and built now. The pattern of energy production and use in 2050 is already being set.

The EU is committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050 in the context of necessary reductions by developed countries as a group[1]. The Commission has analysed the implications of this in its "Roadmap for moving to a competitive low-carbon economy in 2050".[2] The "Roadmap to a Single European Transport Area"[3] focussed on solutions for the transport sector and on creating a Single European Transport Area. In this **Energy Roadmap 2050** the Commission explores the challenges posed by delivering the EU's decarbonisation objective while at the same time ensuring **security of energy supply** and **competitiveness**. It responds to a request from the European Council[4].

The EU policies and measures to achieve the **Energy 2020 goals**[5] are ambitious. They will continue to deliver beyond 2020 helping to reduce emissions by about 40% by 2050. The key for 2050 is to reinforce existing policies. They will however still be insufficient to achieve the EU's 2050 decarbonisation objective. If additional policies are not put in place, only less than half of the decarbonisation goal will be achieved in 2050. This gives an indication of the level of effort and change, both structural and social, which will be required to make the necessary emissions reduction.

Today, there is inadequate **direction as to what should follow the 2020 agenda**. This creates uncertainty among investors, citizens and governments. Scenarios in the "Roadmap for moving to a competitive low-carbon economy in 2050" suggest that if investments are postponed, they will cost more and create greater disruption in the longer term. The task of developing post-2020 strategies is urgent. Energy investments take time to produce results. In this decade, a new investment cycle is taking place, as infrastructure built 30-40 years ago needs to be replaced. Acting now can avoid costly changes in later decades and reduces lock-in effects.

Looking 40 years ahead is not possible. 40 years ago, nobody would have envisioned the energy system, let alone the political and economic environment of today. The scenarios exploring possible pathways, presented in this Energy Roadmap 2050, show how our energy landscape might look like if certain **routes towards decarbonisation** are taken. All of the scenarios **imply major changes in**, for example, carbon prices, technology and networks.

A roadmap involves making a number of **assumptions**. It is impossible to anticipate whether an oil peak will come, since new discoveries have occurred repeatedly; whether shale gas in

---

1 European Council, 29/30 October 2009.
2 COM(2011)112, 8 March.
3 COM(2011)144, 28 March.
4 Extraordinary European Council, 4 February 2011
5 European Council, 8/9 March 2007: By 2020, at least 20 % reduction in greenhouse gas emissions compared to 1990 (30% if international conditions are right, European Council, 10-11 December 2009); saving of 20 % of EU energy consumption compared to projections for 2020; 20 % share of renewable energies in EU energy consumption, 10% share in transport

Europe will prove itself viable; whether Carbon Capture & Storage (CCS) will become commercial; what role Member States will continue to seek for nuclear power; and most importantly, if a global climate deal can be achieved.

This **uncertainty is a major barrier to investment**, technological and behavioural change. However, an analysis of scenarios, both by the EU and other organisations, gives a better understanding of the risks and requirements which investors need to deal with. Based on this analysis, this Energy Roadmap draws a number of conclusions on the direction of the future policy framework, identifying areas for action which are most likely to deliver desired results and confirming some key conclusions on "no regrets" options in the European energy system.

The Roadmap does not replace national efforts to modernize energy supply, but seeks to **develop a European framework** in which national policies will be more effective, and Member States can continue to develop the options which are most appropriate to their circumstances. It argues that a European approach to the energy challenge will increase security and solidarity as well as lower costs compared to parallel national schemes by bringing economies of scale and a wide market for new products and services. As such, the Roadmap gives direction in showing common features of decarbonisation scenarios. It also helps to provide certainty by identifying the policy areas in which actions have to be developed and the principles and objectives of these actions. The global energy future is uncertain, but a European approach, where all Member States share common goals, will help to create the certainty and stability which are needed.

2. A SECURE, COMPETITIVE AND DECARBONISED ENERGY SYSTEM IN 2050 IS POSSIBLE

Energy produces the lion's share of man-made greenhouse gas emissions. Therefore, reducing greenhouse gas emissions by 2050 by over 80% will put particular pressure on energy systems. A number of scenarios to achieve an 85% reduction of energy related CO2 emissions in the energy system, including in transport, have been examined.[6] The Commission has also analysed Member States' and stakeholders' scenarios and views.[7] Naturally, given the long time horizon, there is substantial uncertainty associated to these results, not least because they rely on assumptions which themselves are not certain.[8] Nor can they anticipate extraneous factors, such as geopolitical changes. Due to these uncertainties, the **scenario analysis undertaken is of an illustrative nature**, examining the impacts and risks of possible ways of modernizing the energy system. They are not "either-or" options but show the common elements which are emerging and support longer-term approaches to investments.

If, as seems likely, global energy markets become more interdependent, the EU energy situation will be directly influenced by the situation of its neighbours and by global energy

---

6 The model used for this purpose is the PRIMES energy system model.

7 See annex "Selected Stakeholders' Scenarios". The scenarios from stakeholders analysed include seven selected and representative studies, including, among others, the International Energy Agency, Greenpeace/EREC, the European Climate Foundation and Eurelectric. Further studies and reports have been closely analysed, such as e.g. the independent report of the Ad hoc Advisory Group on the Energy Roadmap 2050.

8 These uncertainties include among others the pace of economic growth, the extent of global efforts to mitigate climate change, geopolitical developments, the level of world energy prices, the dynamics of markets, the development of future technologies, the availability of natural resources, social changes and public perception.

trends. The results of the scenarios depend notably on finalising a global climate deal, which would also lead to lower global fossil fuel demand and prices. This is far from certain.

Overview of scenarios analysed for the Energy Roadmap 2050

Current trend scenarios

- Reference scenario. The Reference scenario includes current trends and long-term projections on economic development (gross domestic product (GDP) growth 1.7% pa). The scenario includes policies adopted by March 2010, including the 2020 targets for RES share and GHG reductions as well as the Emissions Trading Scheme (ETS) Directive. For the analysis, several sensitivities with lower and higher GDP growth rates and lower and higher energy import prices were analysed.

- Current Policy Initiatives (CPI). This scenario updates measures adopted and being proposed in the context of the "Energy 2020 communication" including the "Energy Efficiency Plan" and the new "Energy Taxation Directive". The policy assumptions used in this scenario are the basis for all decarbonisation scenarios with a strengthening of specific aspects according to the character of the decarbonisation scenario.

Decarbonisation scenarios (all building on CPI scenario and including stringent climate policies to reach 85% energy related CO2 reductions by 2050 as well as measures for transport as reflected in the Transport White Paper; the scenarios have lower fossil fuel prices coming as a result of lower global demand for fossil fuels reflecting worldwide carbon policies (oil price is 84 USD'08 per bbl in 2020; 79 in 2030 and 70 in 2050):

- High Energy Efficiency. Political commitment to very high energy savings; it includes e.g. more stringent minimum requirements for appliances and new buildings; high renovation rates of existing buildings; establishment of energy savings obligations on energy utilities. This leads to a decrease in energy demand of 41% by 2050 as compared to the peaks in 2005-2006.

- Diversified supply technologies. No technology is preferred; all energy sources can compete on a market basis with no specific support measures. Decarbonisation is driven by carbon pricing assuming public acceptance of both nuclear and Carbon Capture & Storage (CCS).

- High Renewable energy sources (RES). Strong support measures for RES leading to a very high share of RES in gross final energy consumption (75% in 2050) and a share of RES in electricity *consumption* reaching 97%.

- Delayed CCS. Similar to Diversified supply technologies scenario but assuming that CCS is delayed, leading to higher shares for nuclear energy (18% in primary energy consumption by 2050 with decarbonisation driven by carbon prices rather than technology push).

- Low nuclear. Similar to Diversified supply technologies scenario but assuming that no new nuclear (besides reactors currently under constriction) is being built resulting in a higher penetration of CCS (around 32% in power generation).

Ten structural changes for energy system transformation

No single scenario serves as a forecast of what will happen to energy supplies, but in combination, it is possible to extract some important conclusions which will help shape strategies for the post-2020 period.

(1) Electricity plays an increasing role

All scenarios show **electricity will have to play a much greater role** than now (almost doubling its share in final energy demand from current levels to 36-39% in 2050) and will have to contribute to the decarbonisation of transport and heating/cooling (see graph 1). Electricity would provide around 65% of energy demand by passenger cars and light duty vehicles in all decarbonisation scenarios. Final electricity demand increases even in the High energy efficiency scenario. To achieve this, the power generation system would have to undergo structural change and achieve a significant level of decarbonisation already in 2030 (57-65% in 2030 and 96-99% in 2050).

(2) Decentralisation and centralised large-scale systems depend on each other

Decentralisation of the power system and heat generation increases due to more renewable generation. However, as the scenarios show, **centralized large-scale systems** and decentralised systems will increasingly have to work together. In the new energy system, a new configuration of decentralised and centralised large-scale systems needs to emerge and will depend on each other, for example, if local resources are not sufficient or are varying in time.

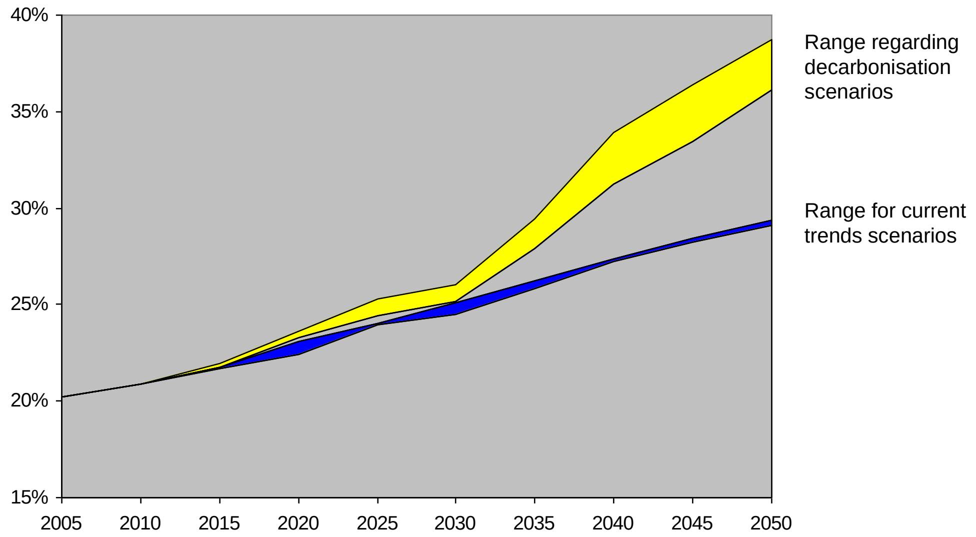
(3) Energy savings throughout the system are crucial in all scenarios

Very **significant energy consumption reductions** would need to be achieved in all decarbonisation scenarios. Primary energy demand drops between 32% to 41% by 2050 as compared to peaks in 2005-2006.

(4) Renewables rise substantially in all scenarios

The **share of renewable energy (RES) rises substantially** in all scenarios, achieving at least 55% in gross final energy consumption in 2050, up 45 percentage points from today's level at around 10%. The share of RES in electricity consumption reaches 64% in a High Energy Efficiency scenario and 97% in a High Renewables Scenario that includes significant electricity storage to accommodate varying RES supply even at times of low demand.

Graph 1: Share of electricity in current trend and decarbonisation scenarios (in % of final energy demand)



(5) Carbon capture and storage has to play a pivotal role in system transformation

Carbon Capture and Storage (CCS), if commercialised, will have to contribute significantly in most scenarios with a particularly strong role of 32% in power generation in the case of constrained nuclear production.

(6) Nuclear energy provides an important contribution

Nuclear energy will be needed to provide a significant contribution in the energy transformation process in those Member States where it is allowed. It remains a key contributor to CO2 emission reductions. The highest penetration of nuclear comes in Delayed CCS and Diversified supply technologies scenarios which show the lowest total energy costs.

(7) Higher capital expenditure and lower fuel costs will occur

All decarbonisation scenarios show a transition from today's system, mainly based on high fuel and operational costs, **to an energy system based on higher capital expenditure** and low fuel costs. This is also due to the fact that large shares of current energy supply technologies come to an end of their useful life. In all decarbonisation scenarios, the EU bill for fossil fuel imports in 2050 would be substantially lower than today. The IEA also shows a lower EU fossil fuel bill in its decarbonisation scenario until 2035.[9] The analysis also shows that cumulative grid investment costs alone could be 1.5 to 2.2 trillion Euros between 2011 and 2050, with the higher range reflecting greater investment in support of renewable energy.

The average **capital costs of the energy system** will increase significantly. Such costs stem from investments not only in power plants and grids, but also from investments by energy

[9] World Energy Outlook 2010, International Energy Agency (IEA).

users, purchasing industrial energy equipment, heating and cooling systems, smart meters, insulation material, more efficient and low carbon vehicles, as well as devices for self producing renewable energy (solar heat and photovoltaic) or buying durable energy consuming goods such as electric appliances. This would have an impact not just on the energy sector, but also on households, services, construction, transport and agricultural sectors. It would create major opportunities for European industry and service providers to satisfy this increasing demand.

(8) Electricity prices rise until 2030 and then decline

Most scenarios suggest that **electricity prices** will rise to 2030, but fall thereafter. In the High Renewables scenario, which implies a 97% share for renewable sources in electricity consumption, electricity prices continue to rise but at a decelerated rate - due to *high capital* (also for balancing capacity) and *grid investments*. For example, RES power generation capacity in 2050 would be more than twice as high as today's total power generation capacity from all sources. Substantial RES penetration does not necessarily mean high electricity prices. The High Energy Efficiency scenario and also the Diversified Supply Technology scenario have the lowest electricity prices and still provide 60-65% of electricity consumption from RES, up from only 20% at present.

(9) Household expenditure will increase

Expenditure on energy and energy-related products (including for transport uses) is likely to become a more important element in **household expenditure**, rising to as much as 15% of households' income in 2030, and 16% in 2050[10]. The costs include fuel costs as well as capital costs such as costs of purchasing more efficient vehicles, appliances and refurbishments of housing.

(10) Decarbonisation is possible – and can be less costly than current policies in the long-run

The scenarios show that it will be possible to achieve decarbonisation of the energy system. Moreover, the costs of transforming the energy system do *not* differ substantially from the Current Policy Initiatives scenario that is based on a continuation of current policies. The total energy system cost (including fuel, electricity and capital costs, investment in equipment, energy efficient products etc) could represent slightly less than the 14.6% percent of European GDP in 2050 in the case of CPI compared to the current level of 10,5% in 2005. This reflects a significant shift of the role energy plays in our society. System costs will amount to an average of some 2.5 trillion Euros annually from now up to 2050, with some differences among decarbonisation scenarios.[11] Exposure to fossil fuel price volatility would drop in decarbonisation scenarios as import dependency falls to 35-45% in 2050, compared to 58% under current policies.

[10] Energy system costs today and 2050 are not directly comparable as the 2050 costs relate to much more energy efficient appliances that might be better performing, automated house systems that can provide more comfort and refurbished buildings that increase in value, on the one hand, and changes in energy consumption patterns, on the other, that people need to adjust to. While the renovation costs enter fully into the cost accounting, increasing house values relate to assets and capital stock considerations that are not part of the energy analysis.

[11] As substantiated in the Impact Assessment, total energy costs include capital costs (e.g. energy appliances and equipment of energy users including vehicles and investments necessary to reduce energy consumption of the housing sector) and fuel and electricity costs.

Table 1: Selected results of scenario analysis[12]

			Current trends		Decarbonisation scenarios				
		2005	*Reference scenario*	*Current Policy Initiatives*	*High Energy Efficiency*	*Diversified Supply Techno-logies*	*High Renewables*	*Delayed CCS*	*Low nuclear*
Primary energy demand reduction (in % from 2005)[13]	2030 2050		-5.3 -3.5	-10.8 -11.6	-20.5 -40.6	-16 -33.3	-17.3 -37.9	-16.1 -32.2	-18.5 -37.7
Electrification	2030 2050	20.2 -	25.1 29.1	24.5 29.4	25.2 37.3	26.0 38.7	25.4 36.1	26.0 38.7	25.7 38.5
Fuels (in %)									
Renewables in gross final energy	2030 2050	8,6 -	23.9 25.5	24.7 29	27.6 57.3	27.7 54.6	31.2 75.2	28 55.7	28.8 57.5
CCS in power generation	2030 2050	0 -	2.9 17.8	0.8 7.6	0.7 20.5	0.8 24.2	0.6 6.9	0.7 19	2.1 31.9
Nuclear energy in primary energy	2030 2050	14,1 -	14.3 16.7	12.1 13.5	11.1 13.5	13.9 15.3	9.7 3.8	13.2 17.5	8.4 2.6
Fuels in electricity generation (in%)									
RES	2030 2050	14.3 -	40.5 40.3	43.7 48.8	52.9 64.2	51.2 59.1	59.8 86.4	51.7 60.7	54.6 64.8
CCS	2030 2050	0.0 -	2.9 17.8	0.8 7.6	0.7 20.5	0.8 24.2	0.6 6.9	0.7 19.0	2.1 31.9
NUC	2030 2050	30.5 -	24.5 26.4	20.7 20.6	18.6 14.2	21.2 16.1	15.8 3.6	21.5 19.2	13.4 2.5
Average electricity prices (in EUR'08 per MWh, after tax)[14]	2030 2050	109,3 -	154,8 151,1	156,0 156,9	154,4 146,7	159,6 146,2	164,4 198,9	160,4 151,9	168,2 157,2
Annual energy system costs related to GDP (in % 2011 – 2050)		-	14.37	14.58	14.56	14.11	14.42	14.06	14.21
Import dependency (in %)	2030 2050	52,5 -	56.4 57.6	57.5 58.0	56.1 39.7	55.2 39.7	55.3 35.1	54.9 38.8	57.5 45.1

Source: PRIMES modelling

The scenarios all depend on the conclusion of a global climate agreement. If coordinated action on climate among the main global players fails to strengthen in the next few years, the question arises how far the EU should continue with an energy system transition oriented to decarbonisation.

First, it is important to note that the EU's energy system **needs high levels of investment also in the absence of ambitious decarbonisation efforts**. Second, scenarios indicate that modernizing the energy system will bring high levels of sustainable **investment into the European economy**. Third, decarbonisation represents an advantage for Europe as an early

12 For details on the scenarios see Impact Assessment.

13 Results for primary energy consumption should not be confused with the energy saving targets for 2020 which is calculated against the projected consumption for 2020. Relating this savings objective to energy consumption in 2005, similar to the calculations in the scenarios, would be equivalent to a saving target of 14% in 2020.

14 The price projections ensure full recovery of costs associated with electricity supply in order to depict scenarios, in which the investment in production, storage, grids, taxes, etc are fully covered by revenues from selling electricity. In that sense they are not forecasts of future electricity prices, as systems may evolve, in which, *contrary to the overall practice today*, such investments are partly remunerated by other schemes.

mover on energy system transformation in the growing global market for energy-related goods and services. Fourth, it helps in reducing its import dependency and exposure to the volatility of fossil fuel prices.

However, **it has to be seen clearly that there are risks associated to unilateral EU action**, for example relating to carbon leakage and adverse effects on competitiveness. There is a trade-off between climate change policies and competitiveness. Europe cannot act alone in an effort to achieve global decarbonisation. The results of the scenario analysis could be over-optimistic. The overall cost of investment depends strongly on the policy, regulatory and socio-economic framework and the economic situation globally. As Europe has a strong industrial basis, carbon leakage needs to be avoided. If Europe pursues the path towards greater decarbonisation, then there will be a growing need for closer integration with neighbouring countries and regions (e.g. North Africa). The opportunities for trade and cooperation will require a level-playing field beyond the European borders.

3. MOVING FROM 2020 TO 2050 – CHALLENGES AND OPPORTUNITIES

3.1. Transforming the energy system towards decarbonisation

(a) Energy saving and managing demand: a responsibility for all consumers

The **first tool of the EU energy strategy is and should remain energy efficiency**. Improving energy efficiency is a priority in all decarbonisation scenarios. Current initiatives need to be implemented swiftly to achieve change.

Higher energy efficiency in both new and existing buildings is the key driver. Nearly zero energy buildings should become the norm. Buildings – including homes - could also produce more energy than they use. Products and appliances will have to fulfil highest energy efficiency standards. In transport, efficient vehicles and incentives for behavioural change are required. **Consumers will gain with more controllable and predictable** energy bills. With smart meters and smart technologies such as home automation, consumers will get more influence on their own consumption patterns

Investments by **households** will have to play a major role in the energy system transformation. Greater access to capital for consumers and the creation of innovative business models are therefore crucial. This also requires **incentives to change behaviour**, including the monetary incentives provided by energy prices reflecting the external costs. In general, energy efficiency has to be included in a wide range of policy-making from, for example, IT systems development to new consumer appliances.

An analysis of more radical **energy efficiency measures** and cost-optimal policy packages is required. This includes questions on to what extent urban and spatial planning can contribute to saving energy in the medium and long term; how to find the cost-optimal policy choice between insulating buildings to use less heating and cooling and systematically using the waste heat of electricity generation in combined heat and power (CHP) plants. A **stable framework** is likely to require further actions to save energy, especially with a view to 2030.

In this, the role of **local organisations and cities** will be much greater in the energy systems of the future.

(b) Switching to renewable energy sources

The analysis of all scenarios shows that the biggest share of energy supply technologies in 2050 comes from renewables. Thus, the **second major pre-requisite for a more sustainable and secure energy system is a higher share of renewable energy** beyond 2020. This will only happen with an effective combination of policies, enabling and promoting the uptake of renewable energies. Incentives in the future, with increasing shares of renewables, have to become more efficient, create economies of scale, lead to more market integration and as a consequence to a more European approach. This has to build on using the full potential of the existing legislation[15], on the common principles of cooperation among Member States and possible further measures.

However, many renewable technologies need further technological development to bring down costs. There is a need to invest in new renewable technologies, such as wave and concentrated solar power and 2nd and 3rd generation biofuels. There is also a need to improve existing ones, such as by increasing the size of offshore wind turbines and blades to capture more wind and to improve photovoltaic panels to harvest more solar power. All technologies need to improve the efficiency of their resource use and reduce their supply chain and logistics costs. Greater efficiencies in their use requires improved infrastructure for integration across Europe.[16] Technological innovation is needed especially in **storage technologies**. Storage is currently often more expensive than additional transmission capacity, gas backup generation capacity and conventional storage based on hydro is limited. With sufficient interconnection capacity and a smarter grid, managing the variations of wind and solar power in some local areas can be provided also from renewables elsewhere in Europe. This could diminish the need for backup capacity and baseload supply.

In the near future, wind energy supply from the Northern Seas can supply substantial quantities of electricity with declining costs. In the medium term, wind and solar power from the Mediterranean could also be able to deliver substantial quantities of electricity. This opportunity to import electricity from neighbouring regions is already complemented by strategies to use the comparative advantage of Member States e.g. such as in Greece where solar projects are developed that could yield benefits to the whole Union. Countries like Russia and Ukraine also have very large potential for developing renewable energies, including for export, notably biomass.

Renewable heating and cooling are also vital to decarbonisation. There is a need to shift energy consumption towards low carbon and locally produced electricity (including heat pumps and storage heaters) and renewable energy (e.g. solar heating, biogas, biomass), including through district heating systems.

Decarbonisation will require a large quantity of **bio energy** especially in transport where there are few alternatives to oil for long distance haulage of goods, aviation and navigation. The market uptake of sustainable new generations of biofuels (e.g. second and third generation, algae based biofuel) will have to be promoted to reduce demand for land for biofuel

---

15 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

16 Such improvements are especially necessary since renewables energies will compete with technological developments that will make fossil fuels use more efficient and could lead to more utilisation of unconventional sources of fossil fuels, such as natural gas from shale formations, resulting in lower prices in Europe.

production, especially land needed for food production, and increase the net greenhouse gas savings resulting from switching to biofuel from oil.

In 2030, all the decarbonisation scenarios suggest growing shares of renewables of around 30% in gross final energy. In the medium to long term, the political challenge for Europe is therefore to enable market actors develop and drive down the costs of renewable energy technology through **improved research and more efficient policies and support schemes**. This could require greater conformity and consistency in support schemes and greater responsibilities for system costs among producers.

As technologies mature, costs will decrease over time and financial support can be reduced. Trade among Member States and imports from outside the EU could potentially reduce costs in the medium to long-run. Targets for renewable energy appear to be useful for giving predictability to investors while encouraging a European approach and market integration of renewables. The Commission will in 2012 prepare a strategy for increasing the share of renewables in the energy system post 2020.

(c) Transforming conventional sources

Currently, Europe's power system is based mostly on fossil fuels. This has to change.

Coal in the EU adds to a diversified energy portfolio. Coal is relatively cheap and indigenous coal contributes to security of supply. Its future is however tied in with the development of Carbon Capture and Storage. The **use of coal could fall to very low levels**.

Gas, on the other hand, has many competitive advantages. Substitution of coal (and oil) with gas in the short to medium term could help reducing emissions with existing technologies until around 2030 or 2035.

Gas will be critical for the transformation of the energy system. Although gas demand in the residential sector, for example, might drop by a quarter until 2030 due to several energy efficiency measures in the housing sector[17], it will increase in other sectors such as transport and especially in the power sector over a longer period up to 2030-2035. The scenarios show that gas will substantially increase its share in electricity generation and will remain high afterwards. In the Diversified Supply Technologies scenario for example, gas-fired power generation accounts for roughly 800 TWh in 2050, slightly higher than current levels.

The gas market needs more integration, more liquidity, more diversity of supply sources and more storage capacity, for gas to maintain its competitive advantages as a fuel for electricity generation. Long term gas supply contracts may continue to be necessary to underwrite investments in gas production and transmission infrastructures. Greater flexibility in price formula, moving away from oil-indexation, will be needed if gas is to remain a competitive fuel for electricity generation.

Global gas markets are changing. With liquefied natural gas (LNG), markets have become increasingly global since transport has become more independent from pipelines. Shale gas and other **unconventional gas sources** have become possible new sources of supply in or

[17] On the other hand, gas heating may be more energy efficient than electric heating or other forms of fossil fuel heating, implying that gas may also have growth potential in the heating sector in some Member States.

around Europe. Together, these developments could relax concerns on gas import dependency. However, due to the early stage of exploration it is unclear when unconventional resources might become significant and currently no accurate prediction about their contribution is possible. As conventional gas production declines, Europe will have to rely on significant gas imports in addition to domestic natural gas production and potential indigenous shale gas exploitation.

The scenarios are by implication rather conservative with respect to the role of gas. The economic advantages of gas today provide certain returns to investors and therefore **greater incentives to invest in gas-**fired power stations. Gas fired power stations have lower upfront investment costs, are rather quickly built and relatively flexible in use. Investors can also hedge against risks of price developments, with gas fired power stations often setting the market price for electricity. However, operational costs in the future may be higher than for carbon free options and gas fired power stations might run for fewer hours.

If CCS is available and applied at large scale gas may become a low-carbon technology, but without CCS the long term role of gas may be reduced to a flexible back-up and balancing capacity where renewable energy supplies are variable and insufficient in the long-run.

Oil is likely to remain in the energy mix even in 2050, subject to supply security and prices, fuelling parts of long distance passenger and freight transport. The challenge for the oil sector is to adapt to the changes in oil demand resulting from decarbonisation, the switch to renewable and alternative fuels and the uncertainties surrounding future supplies and prices. Maintaining a foot in the global oil market and **keeping domestic refineries**, even when production and consumption is falling at home, is important to the EU economy and security.

For all fossil fuels, **Carbon Capture and Storage will have to be applied from around 2030 onwards** in the power sector in order to reach the decarbonisation targets. CCS is also an option for decarbonisation of several heavy industries and combined with biomass could deliver "carbon negative" values. The future of CCS crucially depends on public acceptance and adequate carbon prices.

(d) Nuclear energy as an important contributor

Nuclear energy is another decarbonisation option providing today most of the low-carbon electricity consumed in the EU. After the accident in Fukushima, public perception on nuclear energy has changed in some Member States while other Member States continue to see nuclear energy as a secure, reliable and affordable source of low-carbon electricity generation. Safety costs are likely to increase, as well as the costs for decommissioning existing plant and disposing of waste.

Significant parts of the European public, however, continue to consider the risks related to nuclear energy as unacceptable and the issue of nuclear waste management as unresolved. New nuclear generation technologies could help to address waste and safety concerns.

The scenario analysis shows that **nuclear energy can contribute to lower system costs and electricity prices**. As a large scale low-carbon option, nuclear energy will remain in the EU power generation mix. The safety and security of nuclear energy will continue to be priorities for the EU, building on a stable, efficient and independent nuclear safety regulatory system. The EU will further need to ensure the highest safety and security standards at its borders and globally, which can only happen if competence and technology leadership is maintained within the EU.

3.2. Rethinking the energy market

(a) New ways to manage electricity

Adequacy of power generation capacity and other resources for flexibility (e.g. storage, demand side management) in the power system are key for the transition to a decarbonised system preserving a high level of **secure and affordable electricity supplies**.

In today's energy market, the impact of high levels of renewable power in the electricity system on lowering electricity wholesale **prices** is an issue of concern. The marginal costs for electricity from wind and solar electricity could be very low. Thus, prices in the wholesale market could decrease and remain low for longer time segments.[18] At other times, they could be relatively high. For consumers, the concern is price volatility. For investors, it is their ability to recover capital and fixed operating costs in such a situation. In addition, wind and solar powered electricity increases supply variability.

Further **electricity market integration** is crucial to making the energy transformation. Full market integration by 2014, as decided by the European Council on February 4th, 2011, and the technical work that is pursued with Framework Guidelines and Network Codes need to be realized. However, while *markets* are slowly merging, *policies* at times seem to be diverging in Member States. Some Member States discuss different policy approaches to move towards decarbonisation, focusing on renewables or nuclear energy. Some are looking at the need for flexible supplies with "**capacity markets**" or capacity payments to ensure enough capacity is available. Others examine specific market-based instruments or other instruments such as carbon price floors. The consequences of Member States' policies create new challenges for the internal market.

Designing markets which are able to offer cost-effective solutions will become increasingly important. For example, a growing need for **flexibility** in the power market for offsetting the changes to wind and solar power generation calls for investment in cost-efficient and flexible technologies and systems. There is a need for flexible supplies to be available and rewarded in the market. The advantages and disadvantages of capacity markets, the prospects of a European balancing market and increased market integration will have to be analysed more broadly.

Allowing the full participation of flexible demand response in the market (e.g. **demand side management**), in particular at a local level, and its interactions with the internal energy market also have to be analysed carefully. Building on the 3rd internal energy market package, the Commission, assisted by the Agency for the Cooperation of Energy Regulators (ACER) will continue to ensure that the regulatory framework stimulates market integration, that enough capacity and flexibility are incentivized, and that the overall **market design** is prepared for the challenges due to decarbonisation.

(b) Integrating local generation and long-distance networks

In a long term perspective, with electricity trade growing in all scenarios, the need for adequate infrastructure grows in importance. Under almost any scenario up to 2050, more

---

18 This situation is not addressed in the scenarios: in the modelling the pricing mechanism is designed so that investors are fully remunerated (full cost recovery via electricity prices) leading to an increase in electricity prices in the long-run.

interconnected networks are needed, with the highest need coming in the case of strong penetration of renewables, both within Member States as well as cross-border. Existing plans for **increased transmission capacity** need to be realised as a matter of urgency. Expansion of **interconnection capacity** is happening too slowly. The European Council recognized this issue already in 2002 and implemented targets for import capacity.[19] The targets have not been achieved yet in all Member States. By 2020 interconnection capacity needs to expand at least in line with current development plans. An increase of interconnection capacity by 40% up to 2020 will be needed, with further integration after this point.

In a European context, **planning of infrastructure needs** well in advance is ongoing (ACER, ENTSO[20]) and should have a positive impact on investment risks. In addition, new policy options could play a role in the future: a common asset base for infrastructures of European importance, the evolution towards regional Transmission System Operators (TSO), the general harmonisation of network charges and the extension of current planning methods to a fully integrated network planning for transmission, distribution and storage in a potentially longer timeframe. Furthermore, CO2 infrastructure, that does not currently exist, will be required and should start to develop soon. **New, flexible infrastructure development is a "no regrets" option** and would allow for accommodating various power generation pathways.[21]

To exploit renewable electricity from the North Sea, the Mediterranean and from North Africa, significant additional infrastructure, notably subsea, will be needed (for the Mediterranean area, an example is the concept "Medgrid"). In the framework of the North Seas Countries' Offshore Grid Initiative, **ENTSO-E is already conducting grid studies for North Western Europe with a 2030 horizon**. This should feed into ENTSO-E's work for a modular development plan of a Pan-European Electricity Highways System up to 2050. Building such highways requires closer cooperation of TSOs across Europe and will induce changes to market structures.

To accommodate renewable production locally, the **distribution grid** also needs to become much smarter to deal with variable generation from many distributed sources such as, in particular, solar photovoltaic, but also increased demand response. With more decentralised generation, smart grids, new network users (e.g. electric vehicles) and demand side management, there is also a greater need for a **more integrated view on transmission, distribution and storage**.

(c) Smart technology, storage and e-transport

Technology is an essential part of the solution to the decarbonisation challenge (for example, to find storage solutions), but it is uncertain how fast **technological change** will occur. The EU should contribute directly to scientific projects and research programmes, building on what is foreseen by the **Strategic Energy Technology Plan** (SET Plan) and the next Multiannual Financial Framework to invest in partnership with industry and Member States to demonstrate and deploy new, highly efficient energy technologies on a large scale. A

---

19 European Council, March 2002, Barcelona.

20 European Network of Transmission System Operators

21 For improved regulation and targeted support see the proposed new infrastructure fund to 2020 ("Connecting Europe Facility") and the Commission's proposal published on 19.10.2011 "Regulation concerning guidelines for the implementation of European energy infrastructure priorities" (COM(2011) XXX).

reinforced SET Plan could lead to cost optimal European research clusters in times of tight budgets in Member States.. The benefits of cooperation are significant, going beyond financial support and building on better coordination in Europe.

An area of special importance is a **shift towards electric vehicles** (battery or fuel cells). Electricity would provide around 65% of energy demand by passenger cars and light duty vehicles in all decarbonisation scenarios. Electro-mobility will need to be supported at European level by regulatory developments, standardisation, infrastructure policy and further research and demonstration efforts in particular on batteries and hydrogen which together with smart grids can multiply the benefits of electro-mobility both for decarbonisation of transport and development of renewable energy.

3.3. Mobilising investors - a unified and effective approach to energy sector incentives

Between now and 2050, there has to be wide-scale replacement of infrastructure and capital goods throughout the economy. This includes consumer goods in people's homes, for leisure and business. These are very substantial upfront investments, often with returns over a long period. Investments are needed early, notably in infrastructures to ensure that changes are possible in sufficient time to meet the 2050 decarbonisation target. The increased costs of delay, particularly in the later years, need to be highlighted, while final investment decisions will be influenced by the overall economic and financial climate[22]. The public sector might have a role as a facilitator for investment in the energy revolution lying ahead. The present uncertainty in the market increases the **cost of capital associated with low-carbon investment**. The EU needs to move today and start improving the conditions for financing in the energy sector.

Carbon pricing (e.g. the EU **Emissions Trading System** and carbon taxes) can provide an incentive for deployment of efficient, low-carbon technologies across Europe. Coherence between EU and national policies and stability are needed for its price signal to function properly. Some stakeholders have concerns about the interplay between the ETS and other measures such as taxes or carbon price floors. The scenarios however show that carbon pricing can coexist with instruments designed to achieve particular energy policy objectives, notably promotion of energy efficiency and development of renewables[23].

While in the long-term, the future carbon price would have to rise well above the current level to create incentives for investment in low-carbon technologies, excessively high carbon prices may harm European competitiveness and lead to carbon leakage in the absence of a global carbon market based on an international agreement. Carbon leakage is in particular a concern for industry sectors subject to global competition and global price patterns. It is important to strengthen **measures to prevent carbon leakage**. A well-functioning carbon pricing system should continue to include mechanisms for cost-effective emission reductions outside Europe and free allowances based on benchmarks in the absence of a comprehensive and fair international climate change agreement. Special treatment, such as tax exemptions or other compensation, for energy intensive industries could also be foreseen. Finally, additional

---

22 Scenarios for the Low Carbon Economy Roadmap of March 2011 show the additional costs of delayed action, notably in the transport and households/tertiary sectors.

23 The CPI scenario results in a carbon value of some 50€ in 2050, the decarbonisation scenarios substantially more.

measures at the border might be brought into play, if consistent with World Trade Organization (WTO) requirements.

Investment risks need to be borne by private investors, unless there are clear reasons for not doing so. Some investments of the energy system have a **public good** character. Thus, some support for early movers may be warranted (e.g. electric cars, clean technologies). A move towards greater and more tailored financing via **public financial institutions**, such as the European Investment Bank (EIB) or the European Bank for Reconstruction and Development (EBRD), "green banks" and the mobilisation of the commercial banking sector in Member States could also help to make the transition work.

Private investors will however remain most important in a market-based approach to energy policy. Yet, the role of **utilities** could change substantially in the future, as regards investments. While in the past, many generation investments could be on balance sheet, this is less likely in the future, given the scale of investment and innovation needs. Long term **investors need to be brought in**. Institutional investors must become greater players in the financing of energy investments.

Energy subsidies will continue to be necessary beyond 2020 to ensure that the **market** encourages the development and deployment of new technologies and will need to be phased out as technologies mature and market failures are resolved. For financing low-carbon technologies, public **support schemes** in Member States should be clearly targeted and limited in scope, decreasing over time and including phase-out provisions. The process of reform must continue to move rapidly to ensure more effective support schemes.

3.4 Improving public acceptance

Public acceptance is crucial for the energy system transformation. New power stations and significantly more renewable installations will have to be built. New storage facilities, including for CCS, more pylons and more transmission lines are needed. Especially for infrastructure, shorter permitting procedures are crucial since it is the precondition for changing supply systems and move towards decarbonisation in time. The current trend, in which nearly every energy technology is disputed and its use or deployment delayed, raises serious problems for investors and puts energy system changes at risk. Energy cannot be supplied without technology and infrastructure. In addition, cleaner energy has a cost. Consumers will have to adapt to new pricing mechanisms and incentives. Citizens need to be persuaded, while technological changes need to take account of the local environment.

The tools to respond to price increases by improving energy efficiency and reducing consumption have to be in place, especially in the medium term, when prices are likely to rise, no matter which policies are followed. While greater control of and reduced energy bills may be an incentive, access to capital at reasonable cost will be crucial. **Vulnerable consumers** in particular might need specific support to enable them to finance necessary investments to reduce energy consumption. This task will increase in importance with the energy transformation being shaped in reality.

3.5 Driving change at the international level

In the transition to 2050, Europe needs to secure its demand for fossil fuels while at the same time develop cooperative methods to increasingly build **international partnerships on a broader basis**.

As Europe's demand develops away from fossil fuels, and energy producers develop more diversified economies, integrated strategies with current suppliers need to **address benefits of cooperation in other areas such as renewable energies, energy efficiency and other low-carbon technologies**. In particular it will be important to manage the transition in close partnership with producer countries, e.g. Russia and Norway, and neighbours in order to valorise at best unused hydrocarbon reserves while gradually establishing new energy and industrial partnerships. This is for instance the purpose of the EU-Russia 2050 Roadmap.

The EU needs to expand and diversify links between the European network and neighbouring countries, for example North Africa or in the Baltic region, where it is necessary to synchronise the Baltic States' networks with the power system of the Union.

The EU also needs to address the import of carbon-intensive energy, notably of electricity, and strike a balance between its international trade obligations and its internal decarbonisation agenda. In the medium term this also requires a level playing field, especially for the power sector, when trade increases and the issue of carbon leakage comes to the fore.

4. THE WAY FORWARD

Transforming the European energy system is absolutely necessary for climate, energy security and economic reasons. Member States have the main responsibility for defining precise strategies and instruments, such as the preferred national energy mix. To make the necessary changes,, common conditions must also be implemented at EU level.

First, the EU **Energy 2020 strategy, the existing rules and the energy targets have to be fully implemented** and full market integration by 2014 has to be achieved.

Second, the policy proposals currently in discussion should be **adopted and complied with** swiftly to ensure that the progress can be made in time as a necessary step in the process towards 2050.

Third, Member States and investors need **more certainty** on the policy framework in 2030. Therefore, the Commission should develop a number of new initiatives and **"no-regret"** options:

- **Milestones** are useful since 2030 is reasonably predictable and significantly more visible than 2050. It is important to know where Europe should be in 2030 with a view to achieving 2050 decarbonisation targets. The scenario analysis has shown how important energy savings and rising shares of renewables are for the transformation to a decarbonised energy system. Further targets for renewables for 2030 could be an option since Europe is currently on the right track to achieve the target for 2020. Further milestones could also be envisioned in other areas, for example to push for CCS by 2030, for the development of infrastructure and for ensuring already existing targets such as the indicative target on electricity interconnection capacity.

- For **energy efficiency**, the Commission will analyse the developments in 2013 and assess whether the 2020 target should be mandatory or not and if on this basis a further target for energy efficiency in 2030, numerical or in other form, will be sensible.

- Further work is also required on the **internal energy market** with respect to the obstacles remaining to achieve full market integration by 2014 and an analysis of the potential consequences of energy system transformation. Proactive development of **infrastructure** is needed continuously.

- The Commission intends to develop a policy **framework for renewable energy for the period after 2020** to ensure the current policy ambition is maintained, technology improvements are triggered, and the right market design to integrate renewable energy into wider European markets is developed.

- The Commission will analyse the **development of Carbon Capture and Storage** including necessary policy changes to push for CCS, the role of funding to take demonstration projects to completion, the needed development of infrastructure and legal issues relating to cross-border transport.

- The Commission will continue to further the **nuclear safety and security** framework at wide EU level, helping to set a level playing field for investments in Member States willing to keep the nuclear option in their energy mix.

- The Commission will work to strengthen and to Europeanize efforts on **research and innovation** for all low-carbon technologies of the future, working together with all involved stakeholders, and in particular with industry.

On the basis of this Roadmap, the Commission will continue discussions with other EU institutions, Member States and stakeholders on the actions which need to be developed to deliver the 2050 goal to transform the energy system. These actions must enable the EU to make the necessary changes in the most efficient, economically sound and socially acceptable way. This Energy Roadmap 2050 focuses on the present moment, but **needs to be updated and reassessed regularly over time**. Member States need to prepare and adapt their strategies. This will result in an iterative process between Member States and the EU to shape a common view on how to achieve an energy system transformation which delivers decarbonisation, greater security of supply and increased competitiveness.