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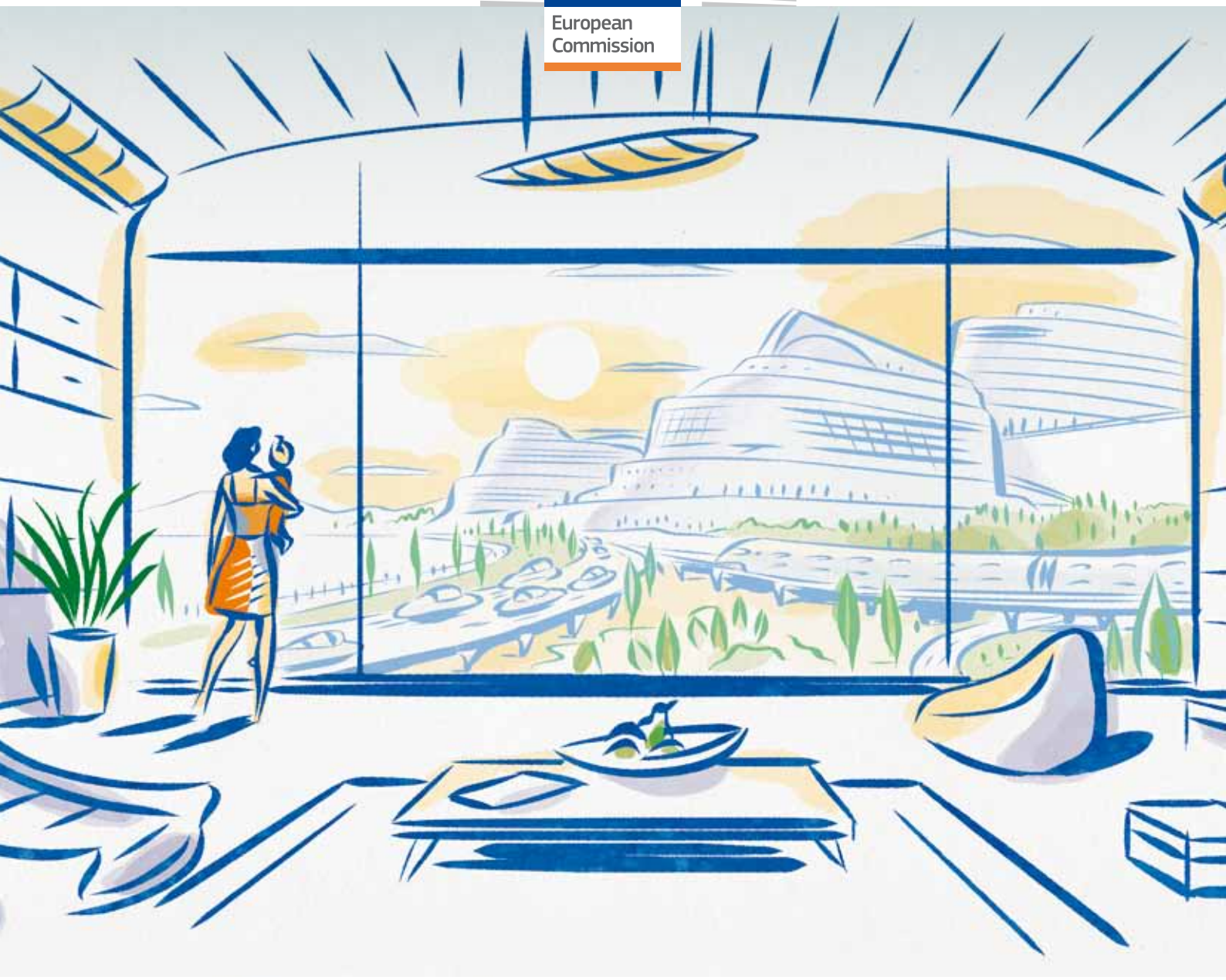

Energy

roadmap 2050

Energy

This illustrated brochure comprises the text of the European Commission's communication 'Energy roadmap 2050' (COM(2011) 885 final of 15 December 2011) and a foreword by Günther H. Oettinger, European Commissioner for Energy.

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Foreword

The EU goal to cut greenhouse gas emissions by 80–95% by 2050 has serious implications for our energy system. We need to be far more energy efficient. About two thirds of our energy should come from renewable sources. Electricity production needs to be almost emission-free, despite higher demand. Our energy system has not yet been designed to deal with such challenges. By 2050, it must be transformed. Only a new energy model will make our system secure, competitive and sustainable in the long-run.

The year 2050 seems a long way off. Today, public deficits, jobs and pensions seem more important than future energy needs. Yet by investing in our energy system, we create jobs, businesses and prosperity. Less energy wastage and lower fossil fuel imports strengthen our economy. Early action saves money later. The roadmap will allow Member States to make the required energy choices and create a stable business climate for private investment, especially until 2030.

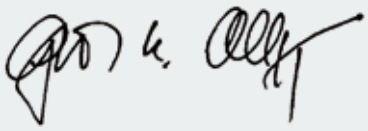
The roadmap confirms that our low-carbon goal is economically feasible. All the scenarios reach it with no major differences in overall costs or security of supply implications.

We can draw three key lessons from the roadmap. First, we need to act quickly. Our energy networks are aging and need billions of euros of investment. The current investment cycle must be the one which transforms Europe's energy system. If not, we will be locked into higher emissions for decades.

Second, EU policies take us in the right direction, but our system is changing too slowly. We need to intensify our efforts beyond 2020 with a new policy framework, including milestones for 2030.

Finally, the costs and disruption will be much less if Europe acts together, in solidarity, in a common energy market. Alongside this energy roadmap, I am publishing the full impact assessment and results of all 2050 scenarios prepared for the Commission.

This is the first time that the Commission has analysed energy trends over such an extended period. The task is full of uncertainties, and the results are not a 'forecast' or 'recipe' for future policies. I offer the roadmap to Member States, Europe's institutions, industry and citizens to feed into the debate on how to put in place the policies, milestones and instruments to deliver our longer term goals: energy security, sustainability and competitiveness.



Günther H. Oettinger

European Commissioner for Energy

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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 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]) focused 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]) and the Energy 2020 strategy are ambitious ([6]). They will continue to deliver beyond 2020 helping to reduce emissions by about 40% by 2050. They will however still be insufficient to achieve the EU's 2050 decarbonisation objective as 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, while keeping a competitive and secure energy sector.

([1]) European Council, October 2009.

([2]) COM(2011) 112 of 8 March 2011.

([3]) COM(2011) 144 of 28 March 2011.

([4]) Extraordinary European Council, 4 February 2011.

([5]) European Council, 8 and 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 and 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.

([6]) See also 'Energy 2020 — A strategy for competitive, sustainable and secure energy' (COM(2010) 639 of 10 November 2010).

Today, there is inadequate direction as to what should follow the 2020 agenda. This creates uncertainty among investors, governments and citizens. Scenarios in the 'Roadmap for moving to a competitive low-carbon economy in 2050' suggest that if investments are postponed, they will cost more from 2011 to 2050 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. The International Energy Agency (IEA) has shown the critical role of governments and underlined the need for urgent action ([7]); with the scenarios of the 'Energy roadmap 2050' different possible pathways for Europe are analysed more in depth.

Forecasting the long-term future is not possible. The scenarios in this 'Energy roadmap 2050' explore routes towards decarbonisation of the energy system. All imply major changes in, for example, carbon prices, technology and networks. A number of scenarios to achieve an 80% reduction in greenhouse gas emissions implying some 85% decline of energy-related CO_2 emissions including from transport, have been examined ([8]). The Commission has also analysed Member States' and stakeholders' scenarios and views ([9]). Naturally, given the long time horizon, there is uncertainty associated to these results, not least because they rely on assumptions which themselves are not certain ([10]). It is impossible to anticipate whether an oil peak will come, since new discoveries have occurred repeatedly; to what extent shale gas in Europe will prove viable; whether and when carbon capture and storage (CCS) will become commercial; what role Member States will seek for nuclear power; and how climate action across the globe will evolve. Social, technological and behavioural changes will also have significant impact on the energy system ([11]).

The scenario analysis undertaken is of an illustrative nature, examining the impacts, challenges and opportunities of possible ways of modernising the energy system. They are not 'either/or' options but focus on the common elements which are emerging and support longer-term approaches to investments.

Uncertainty is a major barrier to investment. The analysis of the projections conducted by the Commission, Member States and stakeholders show a number of clear trends, challenges, opportunities and structural changes to design the policy measures needed to provide the appropriate framework for investors. Based on this analysis, this energy roadmap identifies key conclusions on 'no regrets' options in the European energy system. This makes it also important to achieve a European approach, where all Member States share common understanding of the key features for a transition to a low-carbon energy system, and which provides the certainty and stability which are needed.

The roadmap does not replace national, regional and local efforts to modernise energy supply, but seeks to develop a long-term European technology-neutral framework in which these policies will be more effective. It argues that a European approach to the energy challenge will increase security and solidarity and lower costs compared to parallel national schemes by providing a wider and flexible market for new products and services. For example, some stakeholders show potential cost savings of up to a quarter if there was a more European approach for efficient use of renewable energy.

([7]) IEA (2011), World Energy Outlook 2011.

([8]) The model used for this purpose is the Primes energy system model.

([9]) See annex 'Selected stakeholders' scenarios', including scenarios of the International Energy Agency, Greenpeace/EREC, the European Climate Foundation and Eurelectric. Further studies and reports have been closely analysed, such as the independent report of the Ad hoc Advisory Group on the Energy Roadmap 2050.

([10]) 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.

([11]) European societies might need to rethink the way energy is consumed, e.g. by changing urban planning and consumption patterns. See 'Roadmap to a resource efficient Europe' (COM(2011) 571 of 20 September 2011).

2. A secure, competitive and decarbonised energy system in 2050 is possible

The energy sector 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.

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 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.

OVERVIEW OF SCENARIOS ([12])

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 renewable energy sources (RES) share and greenhouse gas (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, e.g. after the Fukushima events following the natural disasters in Japan, and being proposed as in the Energy 2020 strategy; the scenario also includes proposed actions concerning the 'Energy efficiency plan' and the new 'Energy taxation directive'.

Decarbonisation scenarios (see Graph 1)

- **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 2005–06.

- **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 and storage (CCS).

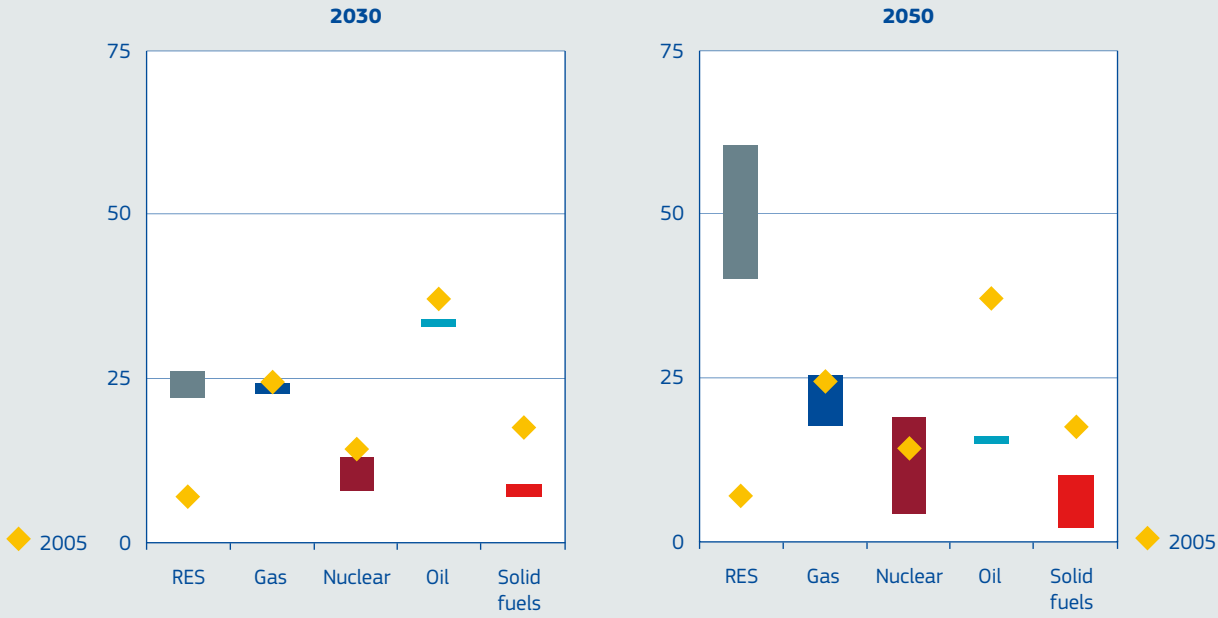
- **High renewable energy sources (RES).** Strong support measures for RES leading to a very high share of RES in gross final energy consumption (75% in 2050) and a share of RES in electricity consumption reaching 97%.

- **Delayed CCS.** Similar to the diversified supply technologies scenario but assuming that CCS is delayed, leading to higher shares for nuclear energy with decarbonisation driven by carbon prices rather than technology push.

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

([12]) For details on the scenarios see the Impact Assessment.

Graph 1: EU decarbonisation scenarios — 2030 and 2050 range of fuel shares in primary energy consumption compared with 2005 outcome (%)



Ten structural changes for energy system transformation

In combination, the scenarios make it possible to extract some conclusions which can help shape decarbonisation strategies today which will deliver their full effects by 2020, 2030 and beyond.

(1) Decarbonisation is possible — and can be less costly than current policies in the long run

The scenarios show that decarbonisation of the energy system is possible. Moreover, the costs of transforming the energy system do **not** differ substantially from the current policy initiatives (CPI) scenario. 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% of European GDP in 2050 in the case of CPI compared to the level of 10.5% in 2005. This reflects a significant shift of the role energy plays in society. 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.

(2) Higher capital expenditure and lower fuel costs

All decarbonisation scenarios show a transition from today's system, with high fuel and operational costs, to an energy system based on higher capital expenditure and lower fuel costs. This is also due to the fact that large shares of current energy supply capacities 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 analysis also shows that cumulative grid investment costs alone could be EUR 1.5 trillion to EUR 2.2 trillion 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 — investments in power plants and grids, in industrial energy equipment, heating and cooling systems (including district heating and cooling), smart meters, insulation material, more efficient and low-carbon vehicles, devices for exploiting local renewable energy sources (solar heat and photovoltaic), durable energy consuming goods, etc. This has a widespread impact on the economy and jobs in manufacturing, services, construction, transport and agricultural sectors. It would create major opportunities for European industry and service providers to satisfy this increasing demand and stresses the importance of research and innovation to develop more cost-competitive technologies.

(3) Electricity plays an increasing role

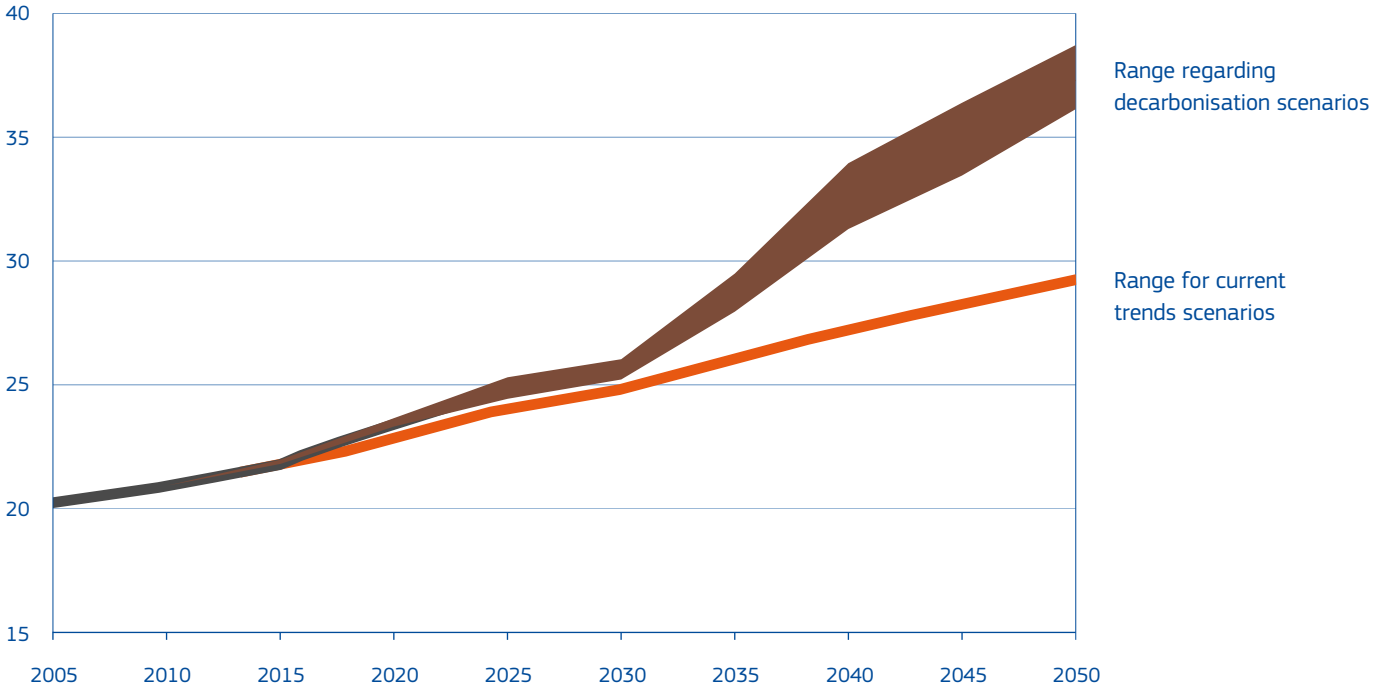
All scenarios show electricity will have to play a much greater role than now (almost doubling its share in final energy demand to 36–39% in 2050) and will have to contribute to the decarbonisation of transport

and heating/cooling (see Graph 2). Electricity could provide around 65% of energy demand by passenger cars and light duty vehicles, as shown 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). This highlights the importance of starting the transition now and providing the signals necessary to minimise investments in carbon intensive assets in the next two decades.

(4) Electricity prices rise until 2030 and then decline

Most scenarios suggest that **electricity prices** will rise until 2030, but fall thereafter. The largest share of these increases is already happening in the reference scenario, and is linked to the replacement in the next 20 years of old, already fully written-off generation capacity. In the high renewables scenario, which implies a 97% share for renewable sources in electricity consumption, the modelled electricity prices continue to rise but

Graph 2: Share of electricity in current trend and decarbonisation scenarios (% of final energy demand)



at a decelerated rate — due to high capital costs and assumptions about high needs for balancing capacity, storage and grid investments in this 'near 100% RES power' scenario. 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. However, 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 provide 60–65% of electricity consumption from RES, up from only 20% at present. In this context, it has to be noted that prices in some Member States are currently artificially low due to price regulations and subsidies.

(5) Household expenditure will increase

In all scenarios, including current trends, expenditure on energy and energy-related products (including for transport) is likely to become a more important element in household expenditure, rising to around 16% in 2030, and decreasing thereafter to above 15% in 2050 ([13]). This trend would also be significant for small and medium-sized enterprises (SMEs). In the long term, the rise in investment costs for

([13]) Energy system costs today and in 2050 are not directly comparable. 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. As vehicle costs covered cannot distinguish between energy-related and other costs, they are upper estimates.

efficient appliances, vehicles and insulation becomes less important than the reduction of expenditure on electricity and fuels. The costs include fuel costs as well as capital costs such as costs of purchasing more efficient vehicles, appliances and refurbishments of housing. However, if regulation, standards or innovative mechanisms are used to accelerate the introduction of energy-efficient products and services, this would reduce costs.

(6) Energy savings throughout the system are crucial

Very significant energy savings (see Graph 3) would need to be achieved in all decarbonisation scenarios. Primary energy demand drops in a range of 16–20 % by 2030 and 32–41 % by 2050 as compared to peaks in 2005–06. Achieving significant energy savings will require a stronger decoupling of economic growth and energy consumption as well as strengthened measures in all Member States and in all economic sectors.

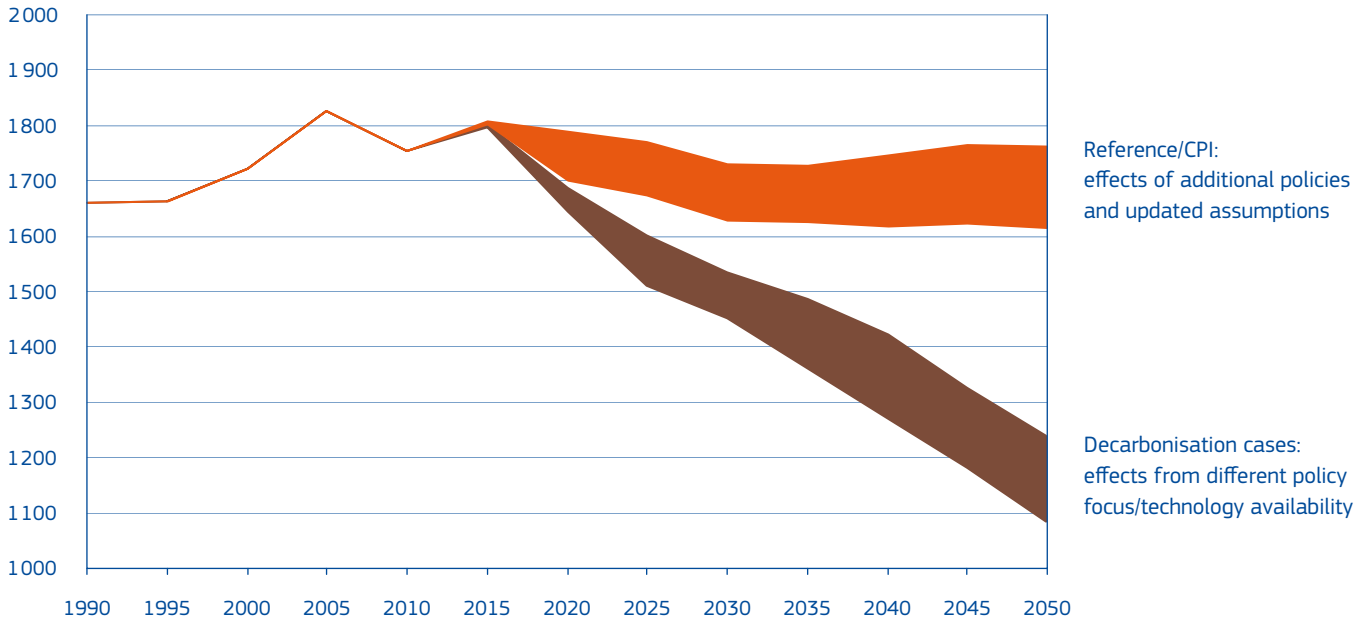
(7) Renewables rise substantially

The share of renewable energy sources (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.

(8) 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 up to 32 % in power generation in the case of constrained nuclear production and shares between 19–24 % in other scenarios, with the exception of the high RES scenario.

Graph 3: Gross energy consumption — range in current trend (REF/CPI) and decarbonisation scenarios (million toe)



(9) 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 pursued. It remains a key source of low carbon electricity generation. The highest penetration of nuclear comes in delayed CCS and diversified supply technologies scenarios (18 % and 15 % in primary energy respectively) which show the lowest total energy costs.

(10) Decentralisation and centralised systems increasingly interact

Decentralisation of the power system and heat generation increases due to more renewable generation. However, as the scenarios show, centralised large-scale systems such as nuclear and gas power plants 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.

Link to global climate action

The scenario results for decarbonisation scenarios all assume that global climate action is taken. First, it is important to note that the EU's energy system needs high levels of investment even in the absence of ambitious decarbonisation efforts. Second, scenarios indicate that modernizing the energy system will bring high levels of investment into the European economy. Third, decarbonisation can be an advantage for Europe as an early mover 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. Fifth, it brings significant air pollution and health co-benefits.

However, in implementing the roadmap, the EU will need to consider progress, and concrete action, in other countries. Its policy should not develop in isolation but take account of international developments, for example relating to carbon leakage and adverse effects on competitiveness. A potential trade-off between climate change policies and competitiveness continues to be a risk for some sectors especially in a perspective of full decarbonisation if Europe was to act alone. Europe cannot alone achieve global decarbonisation. 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 base and needs to strengthen it, the energy system transition should avoid industry distortions and losses especially since energy remains an important cost factor for industry ([14]). Safeguards against carbon leakage will have to be kept under close review in relation to efforts by third countries. As Europe pursues the path towards greater decarbonisation, there will be a growing need for closer integration with neighbouring countries and regions and building energy interconnections and complementarities. The opportunities for trade and cooperation will require a level playing field beyond the European borders.

([14]) For example, it is estimated that electricity prices in Europe are 21 % more expensive than in the United States or 197 % more expensive than in China.

3. Moving from 2020 to 2050 — Challenges and opportunities

3.1. Transforming the energy system

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

The prime focus should remain on energy efficiency. Improving energy efficiency is a priority in all decarbonisation scenarios. Current initiatives need to be implemented swiftly to achieve change. Implementing them in the wider context of overall resource efficiency will bring cost-efficient results even faster.

Higher energy efficiency in new and existing buildings is key. Nearly zero-energy buildings should become the norm. Buildings — including homes — could 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 have more influence on their own consumption patterns. Significant efficiency can be achieved with action on energy use-related resources such as recycling, lean manufacturing and prolonging product lifetime ([15]).

Investments by households and companies will have to play a major role in the energy system transformation. Greater access to capital for consumers and innovative business models are crucial. This also requires incentives to change behaviour, such as taxes, grants or on-site advice by experts, 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 economic activities from, for example, IT systems development to standards for consumer appliances. The role of local organisations and cities will be much greater in the energy systems of the future.

An analysis of more ambitious energy efficiency measures and cost-optimal policy is required. Energy efficiency has to follow its economic potential. This includes questions on to what extent urban and spatial planning can contribute to saving energy in the medium and long term; and 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.

(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 prerequisite for a more sustainable and secure energy system is a higher share of renewable energy beyond 2020. In 2030, all the decarbonisation scenarios suggest growing shares of renewables of around 30% in gross final energy consumption. The challenge for Europe is to enable market actors to drive down the costs of renewable energy through improved research, industrialisation of the supply chain and more efficient policies and support schemes. This could require greater convergence in support schemes and greater responsibilities for system costs among producers, in addition to transmission system operators (TSO).

Renewables will move to the centre of the energy mix in Europe, from technology development to mass production and deployment, from small scale to larger scale, integrating local and more remote sources, from subsidised to competitive. This changing nature of renewables requires changes in policy parallel to their further development.

([15]) For example, more than 5000 petajoules of energy could be saved in the EU (more than three years' consumption of energy in Finland (SEC(2011) 1067 of 20 September 2011).

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 ([16]), on the common principles of cooperation among Member States and with neighbouring countries, and on possible further measures.

Many renewable technologies need further development to bring down costs. There is a need to invest in new renewable technologies, such as ocean energy and concentrated solar power and second and third 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. Storage technologies remain critical. Storage is currently often more expensive than additional transmission capacity, gas backup generation capacity, while conventional storage based on hydro is limited. Greater efficiencies in their use and competitive costs require improved infrastructure for integration across Europe. 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 storage, backup capacity and baseload supply.

In the near future, wind energy from the northern seas and the Atlantic sea basin can supply substantial quantities of electricity with declining costs. By 2050 wind power provides more electricity than any other technology in the high renewables scenario. In the medium term, the contribution of ocean energy can provide an important contribution to electricity supply. Similarly, wind and solar power from the Mediterranean countries could deliver substantial quantities of electricity. The opportunity to import electricity produced from renewable sources from neighbouring regions is already complemented by strategies to use the comparative advantage of Member States such as in Greece where large-scale solar projects are being developed. The EU will continue encouraging and facilitating the development of renewable and low-emission sources of energy in the southern Mediterranean and interconnections with European distribution networks. Further interconnection with Norway and Switzerland will also continue to be critical. Similarly, the EU will look at the potential of renewable sources provided by countries like Russia and Ukraine (notably biomass).

Renewable heating and cooling are vital to decarbonisation. A shift in energy consumption towards low carbon and locally produced energy sources (including heat pumps and storage heaters) and renewable energy (e.g. solar heating, geothermal, biogas, biomass), including through district heating systems, is needed.

([16]) Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

Decarbonisation will require a large quantity of biomass for heat, electricity and transport. In transport, a mix of several alternative fuels will be needed to replace oil, with specific requirements of the different modes. Biofuels will probably be a main option for aviation, long-distance road transport, and rail where it cannot be electrified. Work to ensure sustainability (e.g. on indirect land-use change) is ongoing. The market uptake of new bio energy which reduces demand for land necessary for food production and which increases the net greenhouse gas savings (e.g. biofuels based on waste, algae, forest residues) should continue to be promoted.

As technologies mature, costs will decrease and financial support can be reduced. Trade among Member States and imports from outside the EU could reduce costs in the medium to long run. The existing targets for renewable energy appear to be useful for giving predictability to investors while encouraging a European approach and market integration of renewables.

(c) Gas plays a key role in the transition

Gas will be critical for the transformation of the energy system. Substitution of coal (and oil) with gas in the short to medium term could help to reduce emissions with existing technologies until at least 2030 or 2035. Although gas demand in the residential sector, for example, might drop by a quarter by 2030 due to several energy efficiency measures in the housing sector ([17]), it will stay high in other sectors such as the power sector over a longer period. In the diversified supply technologies scenario for example, gas-fired power generation accounts for roughly 800 TWh in 2050, slightly higher than current levels. With evolving technologies, gas might play an increasing role in the future.

([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 have growth potential in the heating sector in some Member States.

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 pure oil-indexation, will be needed if gas is to remain a competitive fuel for electricity generation.

Global gas markets are changing, notably through the development of shale gas in North America. 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 potential important new sources of supply in or around Europe. Together with internal market integration, 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. 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 rather conservative with respect to the role of gas. The economic advantages of gas today provide reasonable certainty of returns to investors, as well as low risks and therefore 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 generation often setting the wholesale 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 carbon capture and storage (CCS) is available and applied on a large scale, gas may become a low-carbon technology, but without CCS, the long-term role of gas may be limited to a flexible backup and balancing capacity where renewable energy supplies are variable. 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 important 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; it needs to be sufficiently demonstrated on a large scale and investment in the technology ensured in this decade, and then deployed from 2020, in order to be feasible for widespread use by 2030.

(d) Transforming other fossil fuels

Coal in the EU adds to a diversified energy portfolio and contributes to security of supply. With the development of CCS and other emerging clean technologies, coal could continue to play an important role in a sustainable and secure supply in the future.

Oil is likely to remain in the energy mix even in 2050 and will mainly fuel parts of long-distance passenger and freight transport. The challenge for the oil sector is to adapt to changes in oil demand resulting from the switch to renewable and alternative fuels and uncertainties surrounding future supplies and prices. Maintaining a foothold in the global oil market and keeping a European presence in domestic refining — though one that is able to adapt capacity levels to the economic realities of a mature market — is important to the EU economy, to sectors that depend on refined products as feedstocks such as the petrochemical industry, and for security of supply.

(e) Nuclear energy as an important contributor

Nuclear energy is a decarbonisation option providing today most of the low-carbon electricity consumed in the EU. Some Member States consider the risks related to nuclear energy as unacceptable. Since the accident in Fukushima, public policy on nuclear energy has changed in some Member States while others continue to see nuclear energy as a secure, reliable and affordable source of low-carbon electricity generation.

Safety costs ([18]) and the costs for decommissioning existing plants and disposing of waste are likely to increase. New nuclear technologies could help to address waste and safety concerns.

The scenario analysis shows that nuclear energy contributes 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 Commission will continue to further the nuclear safety and security framework, helping to set a level playing field for investments in Member States willing to keep the nuclear option in their energy mix. The highest safety and security standards need to be further ensured in the EU and globally, which can only happen if competence and technology leadership is maintained within the EU. Furthermore, on a 2050 perspective, it will become clearer which role fusion power will be able to play.

(f) Smart technology, storage and alternative fuels

Whichever pathway is considered, the scenarios show that fuel mixes could change significantly over time. Much depends on the acceleration of technological development. It is uncertain which technological options might develop, at what pace, and with what consequences and trade-offs. But new technologies will bring new options in the future. Technology is an essential part of the solution to the decarbonisation challenge. Technological progress can yield significant cost reductions and economic benefits. Establishing energy markets fit for the purpose will require new grid technologies. Support should be given to research and demonstration at industrial scale.

On the European level, the EU should contribute directly to scientific projects and research and demonstration programmes, building on the strategic energy technology plan (SET-Plan) and the next multiannual financial framework, and in particular Horizon 2020, to invest in partnerships with industry and Member States to demonstrate and deploy new, highly efficient energy technologies on a large scale. A 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 increasingly important feature of the required technology shifts is the use of information and communication technologies (ICT) in energy and transport and for smart urban applications. This is leading to the convergence of industrial value chains for smart urban infrastructure and applications which need to be encouraged to secure industrial leadership. The digital infrastructure that will make the grid smart will also require support at EU level by standardisation and research and development in ICT.

Another area of special importance is the shift towards alternative fuels, including electric vehicles. This needs to be supported at European level by regulatory developments, standardisation, infrastructure policy and further research and demonstration efforts, particularly on batteries, fuel cells and hydrogen, which together with smart grids can multiply the benefits of electro-mobility both for decarbonisation of transport and development of renewable energy. The other main options of alternative fuels are biofuels, synthetic fuels, methane and LPG (liquefied petroleum gas).

([18]) Including those resulting from the need to increase the resilience to natural and man-made disasters.

3.2. Rethinking energy markets

(a) New ways to manage electricity

There are national constraints when choosing national energy mix. Our joint responsibility is to ensure that national decisions are mutually supportive and avoid negative spillovers. The cross-border impact on the internal market deserves renewed attention. These create new challenges to power markets in the transition to a low-carbon system providing a high level of energy security and affordable electricity supplies. More than ever should the full scale of the internal market be used. It is the best response to the challenge of decarbonisation.

One challenge is the need for flexible resources in the power system (e.g. flexible generation, storage, demand management) as the contribution of intermittent renewable generation increases. The second is the impact on wholesale market prices of this generation. Electricity from wind and solar has low or zero marginal costs and as their penetration in the system increases, in the wholesale market spot prices could decrease and remain low for longer time periods ([19]). This reduces the revenues for all generators, including those needed to ensure sufficient capacity to meet demand when wind or solar are not available. Unless prices are relatively high at such times, these plants might not be economically viable. This leads to concerns about price volatility and for investors, about their ability to recover capital and fixed operating costs.

Ensuring that market arrangements offer cost-effective solutions to these challenges will become increasingly important. Access to markets needs to be assured for flexible supplies of all types, demand management and storage as well as generation, and that flexibility needs to be rewarded in the market. All types of capacity (variable, baseload, flexible) must expect a reasonable return on investment. It is however important to ensure that policy developments in Member States do not create new barriers to electricity — or gas — market integration ([20]). Whether it concerns energy mix, market arrangements, long-term contracts, support for low-carbon generation, carbon floor prices, etc., the impacts on the internal market, on which all increasingly depend, need to be considered. Now more than ever, coordination is required. Energy policy developments need to take full account of how each national electricity system is affected by decisions in neighbouring countries. Working together will keep costs down and ensure security of supply.

Building on the third 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 incentivised, and that the market arrangements are ready for the challenges decarbonisation will bring. The Commission is examining the effectiveness of different market models for remuneration of capacity and flexibility and how they interact with increasingly integrated wholesale and balancing markets.

(b) Integrating local resources and centralised systems

New, flexible infrastructure development is a 'no regrets' option and could accommodate various pathways.

With electricity trade and renewables' penetration growing under almost any scenario up to 2050, and particularly in the high renewables scenario, adequate infrastructure at distribution, interconnection and long-distance transmission becomes a matter of urgency. By 2020 interconnection capacity needs to expand at least in line with current development plans. An overall increase of interconnection capacity by 40 % up to 2020 will be needed, with further integration after this point. For the successful further integration after 2020, the EU needs to fully eliminate energy islands in the EU by 2015; in addition, networks have to be expanded and come over time to synchronised links between continental Europe and the Baltic region.

([19]) 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.

([20]) Full market integration by 2014, as decided by the European Council on 4 February 2011, supported by infrastructure developments and technical work on framework guidelines and network codes.

The implementation of existing policies in the internal energy market and new policies, such as the energy infrastructure regulation ([21]), can contribute to allow the EU to meet this challenge. The European 10-year planning of infrastructure needs by the ENTSOs ([22]) and ACER already provides a longer-term vision for the investors and lead to stronger regional cooperation. The extension of current planning methods to a fully integrated network planning for transmission (onshore and offshore), distribution, storage and electricity highways for a potentially longer timeframe will be needed. CO_2 infrastructure, that does not currently exist, will be required and planning should be started soon.

To accommodate renewable production locally, the distribution grid needs to become 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 response, there is a greater need for a more integrated view on transmission, distribution and storage. To exploit renewable electricity from the North Sea and the Mediterranean, significant additional infrastructure, notably subsea, will be needed. 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.

To support decarbonisation in power generation and to integrate renewable energies, flexible gas capacities at competitive prices are needed. New gas infrastructures for interconnecting the internal market along the north–south axis and linking Europe to new diversified supplies through the Southern Corridor will be vital to foster the creation of well-functioning gas wholesale markets in the whole EU.

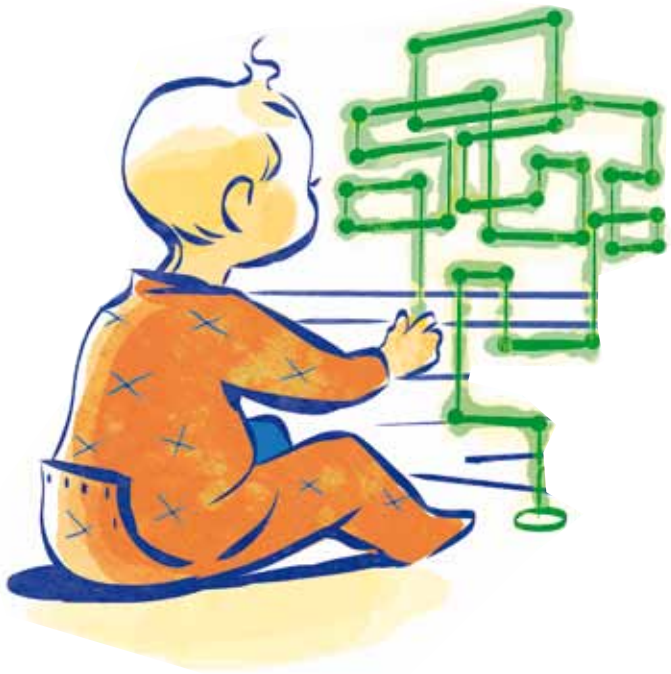
([21]) Proposal for a regulation on guidelines for trans-European energy infrastructure (COM(2011) 658 of 19 October 2011) and proposal for a regulation establishing the 'Connecting Europe facility' (COM(2011) 665 of 19 October 2011).

([22]) European Network of Transmission System Operators.

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

Between now and 2050, there must be wide-scale replacement of infrastructure and capital goods throughout the economy, including consumer goods in people's homes. These are very substantial upfront investments, often with returns over a long period. Early research and innovation efforts are necessary. A unified policy framework that would synchronise all instruments from research and innovation policies to deployment policies would support such efforts.

Massive investments are needed in infrastructures. The increased costs of delay, particularly in the later years, need to be highlighted, recognising that final investment decisions will be influenced by the overall economic and financial climate ([23]). The public sector might have a role as a facilitator for investment in the energy revolution. The current uncertainty in the market increases the cost of capital for low-carbon investment. The EU needs to move today and start improving the conditions for financing in the energy sector.



Carbon pricing can provide an incentive for deployment of efficient, low-carbon technologies across Europe. The ETS is the central pillar of European climate policy. It is designed to be technology neutral, cost-effective and fully compatible with the internal energy market. It will have to play an increased role. The scenarios show that carbon pricing can coexist with instruments designed to achieve particular energy policy objectives, notably research and innovation, promotion of energy efficiency and development of renewables ([24]). More coherence and stability is however needed between EU and national policies for its price signal to function properly.

A higher carbon price creates stronger incentives for investment in low-carbon technologies, but may increase the risk of carbon leakage. Such carbon leakage is in particular a concern for those industry sectors subject to global competition and global price patterns. Depending on efforts of third countries, a well-functioning carbon pricing system should continue to include mechanisms such as incentivising cost-effective emission reductions outside Europe and free allowances based on benchmarks to prevent significant risks of carbon leakage.

Investment risks need to be borne by private investors, unless there are clear reasons for not doing so. Some investments in 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) and the mobilisation of the commercial banking sector in Member States could also help to make the transition work.

Private investors will remain most important in a market-based approach to energy policy. The role of utilities could change substantially in the future, notably as regards investments. While in the past, many generation investments could be done by utilities alone, some argue that this is less likely in the future, given the scale of investment and innovation needs. New long-term investors need to be brought in. Institutional investors could become greater players in the financing of energy investments. Consumers will also play a more important role, which requires access to capital at reasonable cost.

([23]) Scenarios for the low-carbon economy roadmap of March 2011 show the additional costs of delayed action. Also, the IEA World Energy Outlook 2011 argues that on a global level, for every USD 1 of investment avoided in the power sector before 2020 an additional USD 4.3 would need to be spent after 2020 to compensate for the increased emissions.

([24]) The CPI scenario results in a carbon value of some EUR 50 in 2050, the decarbonisation scenarios substantially more.

Support (e.g. energy subsidies) could 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 and supply chains mature and market failures are resolved. Public support schemes in Member States should be clearly targeted, predictable, limited in scope, proportionate and include phase-out provisions. Any support measure has to be implemented in compliance with the internal market and the relevant EU state aid rules. The process of reform must continue to move rapidly to ensure more effective support schemes. In the longer run, high value-added low-carbon technologies, in which Europe has leadership, will positively effect growth and employment.

3.4. Engaging the public is crucial

The social dimension of the energy roadmap is important. The transition will affect employment and jobs, requiring education and training and a more vigorous social dialogue. In order to efficiently manage change, involvement of social partners at all levels will be necessary in line with just transition and decent work principles. Mechanisms that help workers confronted with job transitions to develop their employability are needed.

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, efficient 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. New pricing mechanisms and incentives might be needed but measures should be taken to ensure pricing schemes remain transparent and understandable to final consumers. Citizens need to be informed and engaged in the decision-making process, while technological choices 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 and new forms of energy services 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. A well-functioning internal market and energy efficiency measures are particularly important to consumers. Vulnerable consumers are best protected from energy poverty through a full implementation by Member States of the existing EU energy legislation and use of innovative energy efficiency solutions. As energy poverty is one of the sources of poverty in Europe, the social aspects of energy pricing should be reflected in the energy policy of Member States.

3.5. Driving change at the international level

In the transition to 2050, Europe needs to secure and diversify its supply of fossil fuels while at the same time develop cooperation to 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. The EU should use this opportunity to strengthen its cooperation with its international partners, in line with the new agenda set in September 2011 ([25]). It will be important to manage the transition in close partnership with the EU's energy partners, notably our neighbours, such as Norway, the Russian Federation, Ukraine, Azerbaijan and Turkmenistan, the Maghreb and the Gulf countries while gradually establishing new energy and industrial partnerships. This is for instance the purpose of the 'EU–Russia 2050 energy roadmap'. Energy is also an important contributor to development policy due to its multiplier impact on developing countries' economies; continued work for universal access to energy is needed worldwide ([26]).

The EU needs to expand and diversify links between the European network and neighbouring countries with a particular focus on North Africa (with a view to best harness the solar energy potential of the Sahara).

The EU also needs to address the import of carbon-intensive energy, notably electricity. Enhanced cooperation towards creating a level playing field concerning market and carbon regulation is needed, especially for the power sector, while trade increases and the issue of carbon leakage comes to the fore.

([25]) Communication on security of energy supply and international cooperation (COM(2011) 539 of 7 September 2011).

([26]) 'Increasing the Impact of EU development policy: an agenda for change' (COM(2011) 637 of 13 October 2011).

4. The way forward

The 'Energy roadmap 2050' shows that decarbonisation is feasible. Whichever scenario is chosen, a number of 'no regret' options emerge which can bring down emissions effectively and in an economically viable way.

Transforming the European energy system is imperative for reasons of climate, security and the economy. Decisions being taken today are already shaping the energy system of 2050. To make the necessary transformation of the energy system in time, the EU needs much greater political ambition and a greater sense of urgency. The Commission will discuss with other EU institutions, Member States and stakeholders on the basis of this roadmap. The Commission will update it regularly, reassessing what is necessary in the light of progress and changes, and envisages an iterative process between Member States, through their national policies, and the EU, resulting in timely action to achieve an energy system transformation which delivers decarbonisation, greater security of supply and increased competitiveness for the benefit of all.

The overall system costs of transforming the energy system are similar in all scenarios. A common EU approach can help keep costs down.

Energy prices are rising worldwide. The roadmap demonstrates that while prices will rise until 2030 or so, new energy systems can lead to lower prices after that. Distortions to the internal energy market, including through artificially low regulated prices, should be avoided, since they would send wrong signals to markets, removing incentives for energy savings and other low-carbon investments — this would hold back the transformations which will ultimately bring prices down in the long run. Society needs to be prepared for and adapt to higher energy prices in the coming years. Vulnerable customers and energy-intensive industries may need support in a transitional period. The clear message is that investments will pay off, in terms of growth, employment, greater energy security and lower fuel costs.

The transformation creates a new landscape for European industry and can increase competitiveness.

To achieve this new energy system, 10 conditions must be met.

(1) The immediate priority is to implement fully the EU's Energy 2020 strategy. All existing legislation needs to be applied, and the proposals currently in discussion, notably on energy efficiency, infrastructure, safety and international cooperation, need to be adopted swiftly. The path towards a new energy system also has a social dimension; the Commission will continue to encourage social dialogue and social partners' involvement to help a fair transition and an efficient management of change.

(2) The energy system and society as a whole need to be dramatically more energy efficient. The co-benefits of achieving energy efficiency in a wider resource efficiency agenda should contribute to meeting the goals in a faster and cost-efficient manner.

(3) Particular attention should continue to be given to the development of renewable energy sources. Their rate of development, impact in the market and rapidly growing share in energy demand call for a modernisation of the policy framework. The EU's 20% renewable energy target has so far proven an efficient driver in development of the renewable energy in the EU and timely consideration should be given to options for 2030 milestones.

(4) Higher public and private investments in R & D and technological innovation are crucial in speeding-up the commercialisation of all low-carbon solutions.

(5) The EU is committed to a fully integrated market by 2014. In addition to technical measures already identified, there are regulatory and structural shortcomings which need to be addressed. Well-designed market structure instruments and new ways of cooperation are required for the internal energy market to deliver its full potential as new investments are coming into the energy market and the energy mix is changing.

(6) Energy prices need to better reflect costs, notably of the new investments needed throughout the energy system. The earlier prices reflect costs, the easier the transformation will be in the long run. Special attention should be paid for the most vulnerable groups, for which coping with the energy system transformation will be challenging. Specific measures should be defined at national and local levels to avoid energy poverty.

(7) A new sense of urgency and collective responsibility must be brought to bear on the development of new energy infrastructure and storage capacities across Europe and with neighbours.

(8) There will be no compromise on safety and security for either traditional or new energy sources. The EU must continue to strengthen the safety and security framework and lead international efforts in this field.

(9) A broader and more coordinated EU approach to international energy relations must become the norm, including redoubling work to strengthen international climate action.

(10) Member States and investors need concrete milestones. The 'Low-carbon economy roadmap' has already indicated greenhouse gas emission milestones. The next step is to define the 2030 policy framework, reasonably foreseeable and the focus of most current investors.

On this basis, the Commission will continue to bring forward initiatives, starting with comprehensive proposals on the internal market, renewable energy and nuclear safety next year.

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