EUROPEAN COMMISSION

Brussels, 15.12.2011
SEC(2011) 1565 final

Part 1/2

COMMISSION STAFF WORKING PAPER

Impact Assessment

Accompanying the document

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

Energy Roadmap 2050

{COM(2011) 885 final}
{SEC(2011) 1566 final}
{SEC(2011) 1569 final}

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1. Section 1: Procedural issues and consultation of interested parties

Identification: Lead DG: DG ENER. Agenda planning/WP reference: 2011/ENER/002

1.1. Organisation and timing

The IA work started early 2009 with the Reference scenario that is being used for all long-term initiatives of the Commission. An Interservice Steering Group was established early 2009 together with DG CLIMA and MOVE. This Group was also used for the Low Carbon Economy Roadmap and Transport White paper. Problem definition, objectives and design of policy options were presented to the Impact Assessment Steering Group in May 2011 and the final draft IA in July 2011.

The following DGs participated in the Impact Assessment Steering Group: AGRI, CLIMA, COMP, ECFIN, EMPL, ENTR, ENV, INFSO, JRC, LS, MARE, MARKT, MOVE, REGIO, RTD, SANCO, SG, TAXUD.

1.2. Consultation and expertise

On 20 December 2010, the Directorate General for Energy launched a public consultation on the Energy Roadmap. The public consultation[1] was based on an online questionnaire with seven questions, some requiring comments and others in the form of multiple choice[2]. The public consultation was open until 7 March 2011. Some 400 contributions, half from organisations and half from individual citizens, were received. Several Member States sent a formal reply to the public consultation. Given the participation from a broad spectrum of organisations as well as citizens, this public consultation offered insights into a large range of stakeholder opinions. All of the Commission's minimum consultation standards were met. The full report presenting results of the public consultation can be downloaded from Europa website[3].

<u>Public consultation questions and summary of replies</u>

Question 1 *How to ensure credibility*: Many contributors emphasised the need for a stable, clear and predictable legislative framework to encourage the necessary investments in the energy sector which generally have a very long lead time. An appropriate analytical framework including transparency on modelling assumptions and results was mentioned by several respondents.

Question 2 *The EU's position in a global policy context:* More than half of all respondents chose "global energy efficiency and demand developments" and "global development of renewable energy" as the most important issues.

Question 3 *Societal challenges and opportunities:* Overall responses were fairly evenly distributed among the different choices. Public acceptance of new infrastructures was seen as important by many.

Question 4 *Policy developments at EU level:* Roughly half of the respondents believe that energy efficiency is among the three most important issues needing more development at the EU level.

1 http://ec.europa.eu/energy/strategies/consultations/20110307_roadmap_2050_en.htm
2 Questions 1, 5 and 7 were open questions and 2, 3, 4 and 6 were multiple choice.
3 http://ec.europa.eu/energy/strategies/consultations/20110307_roadmap_2050_en.htm

Question 5 *Milestones in the transition:* Across all industries and NGOs, intermediate targets, checkpoints and regular updates towards 2050 were recommended. However, the decarbonisation roadmap should be flexible enough to allow the route to be changed along the way.

Question 6 *Key drivers for the future energy mix:* About half of all respondents believe that global fossil fuel prices in relation to costs of domestic energy resources and long term security of supply will be the most likely key drivers of the future European energy mix.

Question 7 *Additional thoughts and contributions:* There was considerable divergence in opinions on the best way to decarbonise the energy sector in terms of market intervention as well as in the selection of a preferred technology option to be pursued.

In addition to the public consultation, representatives from the Directorate General for Energy and Commissioner Oettinger met numerous stakeholders individually and received many reports prepared by stakeholders on this topic. A comparison of stakeholder reports is presented in Annex 2.

An informal Energy Council took place on 2-3 May 2011 where ministers had a full-day discussion on the Energy Roadmap 2050. A meeting of Member State (MS) energy experts on the Roadmap also took place on 25 May 2011. The European Commission (EC) presented the problem definition, objectives and design of policy options of this Impact Assessment (IA) report. An Advisory Group of 15 highly-regarded experts mainly from academia and international institutions was established to support the work on the preparation of the Roadmap A presentation on the Roadmap was also given to the European sectoral social dialogue committee in the electricity sector on 14 December 2010.

The Commission contracted the National Technical University of Athens to model scenarios underpinning the IA analysis. Similarly to previous modelling exercises with the PRIMES model, the Commission discloses a lot of details about the PRIMES modelling system, modelling assumptions and modelling results which can be found in sections 4 and 5 as well as the annex 1 including an extensive section on macroeconomic, energy import prices, technology (capital costs of different technologies in power generation, appliances and transport) and policy assumptions. The PRIMES model was peer-reviewed by a group of recognised modelling experts in September 2011 with the conclusion that the model is suitable for the purpose of complex energy system modelling.

1.3. Opinion of the Impact Assessment Board (IAB)

The IA report was discussed at the IAB hearing on 14 September 2011 and the IAB issued a positive opinion acknowledging the quality of the technical analysis and modelling underpinning the Roadmap and the Impact Assessment. The IAB recommended to improve the report in the following aspects: (1) to bring key findings of the evaluation of on-going policies into the IA report; (2) to consider an alternative policy scenario relying on a more relaxed assumption about the global climate deal; (3) to better describe scenarios and underlying assumptions; (4) to improve assessment of non-energy related impacts (employment, skills and knowledge gaps) and (5) to present stakeholder views in a more transparent way.

As a response to these suggestions, the evaluation part was reinforced; the issue of carbon leakage and external competitiveness was added to the problem definition as well as section 4.1. Methodology, while the part on competitiveness issues was expanded in Annex 1; policy options were described in more detail and the assessment of employment impacts was improved.

2. SECTION 2: PROBLEM DEFINITION

2.1. Context

(i) In the 2nd Strategic Energy Review (November 2008), the Commission undertook to prepare an energy policy roadmap towards a low carbon energy system in 2050. The Europe 2020 strategy includes a general commitment to establish a vision of structural and technological changes required to move to a low carbon, resource efficient and climate resilient economy by 2050.

(ii) The Commission's approach to decarbonisation is firmly grounded in the EU's growth agenda, set out in the Europe 2020 strategy, including the Resource Efficient Europe Flagship Initiative[4]. The Communication "Energy 2020 - A strategy for competitive, sustainable and secure energy" paves the way to 2020 stressing the three pillars of the EU's energy policy: competitiveness, security of supply and sustainability, building on the Climate and Energy package adopted in June 2009.

(iii) The European Council (October 2009) supports an EU objective, in the context of necessary reductions according to the IPCC by developed countries as a group, to reduce GHG emissions by 80-95% by 2050 compared to 1990 levels[5]. The European Parliament similarly endorsed the need to set a long-term GHG emissions reduction target of at least 80% by 2050 for the EU and the other developed countries[6].

(iv) The European Council (February 2011) confirms this emissions reduction commitment and recognises that it will require a revolution in energy systems, which must start now. It requests that due consideration should be given to fixing intermediary stages towards reaching the 2050 objective.

(v) The Roadmap for moving to a competitive low carbon economy in 2050[7] makes the economic case for decarbonisation and shows that the targeted 80-95% GHG emissions reduction by 2050 will have to be met largely domestically. Intermediate milestones for a cost-efficient pathway, e.g. 40% domestic reduction by 2030, and sectoral milestones expressed as ranges of GHG emissions reductions in 2030 and 2050 were put forward.

(vi) The Commission is now preparing sectoral roadmaps exploring the dynamics within the sector and the interplay of decarbonisation[8] and other sectoral objectives. The Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system[9] aims to introduce profound changes in passenger and freight transport patterns,

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4 COM(2011) 21, 26 January

5 European Council, Brussels, 29/30 October 2009, Presidency conclusions. 15265/1/09

6 European Parliament resolution of 4 February 2009 on "2050: The future begins today – Recommendations for the EU's future integrated policy on climate change; resolution of 11 March 2009 on an EU strategy for a comprehensive climate change agreement in Copenhagen and the adequate provision of financing for climate change policy; resolution of 25 November 2009 on the EU strategy for the Copenhagen Conference on Climate Change (COP 15)

7 COM(2011)112, 8 March

8 Both roadmaps provide analysis under global climate action assumption.

9 COM(2011)144, 28 March

resulting in a competitive transport sector which allows increased mobility, cuts CO2 emissions to 60% below 1990 levels by 2050 and breaks the transport system's dependence on oil. A Roadmap to a Resource Efficient Europe, also planned for 2011, builds on and complements other initiatives, focusing on increasing resource productivity and decoupling economic growth from resource use.

This IA is a key part of initiatives to deliver on a resource Efficient Europe, one of the 7 flagships of the Europe 2020 strategy[10]. It aims at further developing the decarbonisation analysis of the energy sector as presented in the Low Carbon Economy Roadmap in March 2011, with particular attention to all three EU energy policy objectives - **energy security, sustainability and competitiveness.**

2.2. What is the problem?

The well-being of people, industry and economy depends on safe, secure, sustainable and affordable energy. Energy is a daily need in a modern world and is mostly taken for granted in Europe. The energy system and its organisation evolved over centuries if not millenaries using different fuels and distribution systems to cover basic needs such as food preparation, protection against winter temperatures and production of tools e.g. via metal melting. Over the last century this has concerned delivering heat and warm water as well as industrial and transport fuels and electricity to consumers. There has been a significant increase in energy production and consumption over the last 100 years providing more comfort and individual freedom but at the same time polluting the environment and (at least partially) depleting existing reserves. Our current energy system and ways of producing, transforming and consuming energy are unsustainable due to:

(1) High GHG emissions of which the great majority is directly or indirectly linked to energy[11] which are not compatible with the EU and global objectives of limiting global climate change to a temperature increase of 2ºC to avoid dangerous impacts[12] (even though the EU contribution to global emissions is low and will decline in particular if other regions make no or little efforts on decarbonisation,[13] industrialised countries should keep their leading role in the fight against climate change);

(2) Security of supply risks, notably those related to:

- high dependence on foreign sources of energy imported from a limited number of suppliers (EU27 currently imports 83.5% of its oil and 64.2% of its gas consumption; overall import dependency is around 54% and is projected to slightly increase by 2050), including supplies from politically unstable regions;

10 COM(2010) 2020, EUROPE 2020 - A strategy for smart, sustainable and inclusive growth

11 Energy related emissions account for almost 80% of the EU’s total greenhouse gas emissions with the energy sector representing 31%; transport 19%; industry 13%; households 9% and others 7 %.

12 Other important issues related to the environmental impacts of our energy system include air pollution, water pollution, wastes and impacts to ecosystems and their services. Indeed, negative trends in land, water (fresh and marine) and air quality depend on how energy is generated and used: combustion processes, especially in the case of small unregulated biomass plants, give rise to gaseous emissions and cause local air quality and regional acidification; fossil and nuclear fuel cycles (as well as geothermal production) emit some radiation and generate waste of different levels of toxicity; intensification of biomass use (and of biomass imports) may lead to forest degradation; bioliquids may lead to GHG emissions and direct and indirect land use driving prices for food up globally; last but not least, large hydropower dams flood land and may cause silting of rivers.

13 International Energy Agency, World Energy Outlook 2010. The EU contribution would decline from 13% of global CO2 at present to 8% in 2035 if all world regions are only pursuing current policies.

- gradual depletion of fossil fuel resources and rising global competition for energy resources;

- increasing electrification from more variable sources (e.g. solar PV and wind) which poses new challenges to the grid to ensure uninterrupted electricity deliveries;

- low resilience to natural or man-made disasters and adverse effects of climate change;

(3) Competitiveness risks related to high energy costs and underinvestment. External competitiveness of the European industry vis-à-vis its international competitors is another crucial aspect determining the design and timing of EU energy and climate action. While it is important to sustain first mover advantage and industrial leadership it should also be assessed whether "early" action comes at a cost of comparatively high carbon, fuel and electricity prices for industry compared to action undertaken in the rest of the world.

It will take decades to steer our energy systems onto a more secure and sustainable path. In addition, there is no silver bullet to achieve it. There is no single energy source that is abundant and that has no drawbacks in terms of its sustainability, security of supply and competitiveness (price). That is why the solution will require trade-offs and why the market alone under the current regulatory environment might fail to deliver. The decisions to set us on the right path are needed urgently as failing to achieve a well-functioning European energy market will only increase the costs for consumers and put Europe's competitiveness at risk. Significant investments will however be needed in the near future to replace energy assets in order to guarantee a similar level of comfort to citizens at affordable prices; assure secure and competitive supplies of energy inputs to businesses and preserve the environment. The energy challenge is thus one of the greatest tests which Europe has to face.

Relying on more low-carbon, domestic (i.e. intra EU) or more diversified sources of energy, produced and consumed in an efficient way, can bring significant benefits not only for the environment, competitiveness and security of energy supply but also in terms of economic growth, employment, regional development and innovation. What are the barriers? Why is the shift to an energy system using low-carbon, more competitive and more diversified sources not, or too slowly happening?

2.3. Underlying drivers of the problem

There are several factors that hamper the shift:

2.3.1. General barriers

1) Energy market prices do not fully reflect all costs to society in terms of pollution, GHG emissions, resource depletion, land use, air quality, waste and geopolitical dependency. Therefore, user and producer choices are made on the basis of inadequate energy prices that do not reflect true costs for society.

2) Inertia of the physical system

The majority of investments in the energy system are long-term assets, sometimes requiring long lead times, and having life times of 30-60 years, leading to significant lock-in effects. Any change to the system materialises only gradually. Current market structure and infrastructures can discourage new technology development, since infrastructure, market design, grid management and development require adaptation and modernisation which represent additional costs which face resistance from industry.

3) Public perception and mindset of the users
General public perception of the risks related to the construction of new power plants (large-scale RES, nuclear, low-carbon fossil) and infrastructure needed to introduce large shares of renewables (which additionally implies new grid lines and large energy storage technologies) or of CO2 storage can be more negative than expert judgements. Public acceptance was also acknowledged as important by many respondents in public consultation. It can also take a long time and require adequate incentives or regulation to persuade people to change the way they heat their houses, transport themselves, etc.

4) Uncertainty concerning technological, demand, prices and market design developments
The energy system is characterised by a large proportion of long-term fixed costs that need to be recovered over several decades. Uncertainty about future technologies, energy demand development, market integration and rules[14], carbon and fuel prices, availability of infrastructures can significantly increase investor risks and costs, and make consumers and businesses reluctant to invest. Private investors can cope well with some categories of risks but policy makers and regulators can contribute to decreasing the uncertainties as regards political and regulatory risks.

5) Imperfect markets
There is weak competition in some Member States where markets are still dominated by incumbents. In particular, the absence or lack of effective non-discriminatory third party access to infrastructure can constitute an entry barrier for new entrants. Another factor is market myopia, i.e. the fact that long-term investments are not necessarily pursued by market actors who are generally drawn towards shorter-term gains.

Regarding new infrastructure investments, it can be difficult to clearly identify the beneficiaries, and therefore efficiently allocate the costs of new investments. In addition, in liberalised markets with various players, interdependencies might impose additional efforts to coordinate some investments (it is unrealistic to expect wind power plants to be constructed in the North Sea if no adequate grid is built).

In some Member States developing markets for energy efficiency services and decentralised RES are faced with a low number of actors on the supply side (lack of qualified labour force) as well as on the demand side (low levels of consumer awareness partly as a consequence of the ongoing rapid technological advances) and the lack of enabling regulatory framework. This has a particularly negative effect on the uptake of energy services companies (ESCOs) that can provide integrated energy saving solutions together with financing schemes. Renewable energy can also suffer from market designs that have been developed alongside the development and optimisation of centralised power generation and trading.

[14] As regards market developments, questions about adequacy and intensification of incentives for investments; future of support schemes for RES and other technologies; support mechanisms/regulations for energy efficiency; etc might arise.

2.3.2. *Sector specific barriers*

Besides these factors and based on **an evaluation of ongoing policies**[15], there are problems specific to energy efficiency, infrastructure, security of supply and low-carbon generation technologies which are discouraging investments.

Energy efficiency

Though a number of initiatives were undertaken at EU level since the mid-1990s, the European Energy Efficiency Action Plan[16] created a framework of legislation, policies and measures with a view to realise the 20% energy efficiency and saving objective. After years of growth, the EU primary energy consumption has stabilized in 2005 and 2006 at around 1,825 Mtoe and decreased in 2007, 2008 and 2009 to reach around 1,700 Mtoe[17]. Energy intensity kept improving. For the first time, the latest business-as-usual scenario projections (PRIMES 2009) show a break in the trend of ever-increasing energy demand in the EU27[18].

However, the EU is far from reaching its 20% objective. The projections indicate that with the rates of implementation of the current energy efficiency policies in Member States only half of the objective might be achieved by 2020[19]. Furthermore, while the economic crisis contributed to this decrease in energy consumption, it has also negatively impacted energy efficiency investment decisions at all levels - public, commercial and private. As a response to this, the Commission has recently adopted two new initiatives - an Energy Efficiency Plan[20] and a Directive on Energy Efficiency - aiming at stepping up efforts towards the 20% target.

In addition to the above mentioned barriers, there are many examples of **split incentives or principal-agent** market failures in the energy sector where the decision maker may be partially detached from the price signals. For example, landlords are often the decision-makers about renovation of buildings, but it is usually tenants that pay the energy bills and benefit from their reduction, giving landlords little reason to invest.

Internal market

The process of opening the EU energy markets to competition started ten years ago. It has allowed EU citizens and industries to benefit in terms of more choice, more competition for a better service and improved security of supply. Since July 2007, all consumers in all EU countries have been free to switch their suppliers of gas and electricity.

Independent national regulatory authorities have been established in each EU country to ensure that suppliers and network companies operate correctly and actually provide the services promised to their customers. An inquiry into the electricity and gas sectors published in January 2007[21] revealed that too many barriers to competition and too many differences across the Member States remain. In 2007 and 2008, a great deal of effort was put into enhancing competition on the wholesale market; significant progress was made through the

[15] SEC(2010) 1346 final, COMMISSION STAFF WORKING DOCUMENT State of play in the EU energy policy

[16] COM(2006) 545.

[17] 2009 Eurostat data are the latest official data.

[18] The scenarios of the "Energy trends 2030" (update 2009) are accessible at the following address: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

[19] COM (2011) 109

[20] Communication Energy Efficiency Plan 2011, SEC(2011) 280 final, SEC(2011) 277 final, SEC(2011) 275 final, SEC(2011) 276 final, SEC(2011) 278 final, SEC(2011) 279 final

[21] COM(2006) 851.

regional initiatives. However, the Benchmarking Report adopted in 2009[22] still showed a mixed picture of the accomplishment of the internal market and revealed in particular that there are still high levels of concentration on the retail and wholesale markets and a lack of liquidity.

To remedy the situation, the Commission came forward with the third internal energy market liberalisation package. It foresees the effective separation of supply and production activities to make the market accessible for all suppliers, the harmonization of powers of national regulators, better cross-border regulation to promote new investments and cross-border trade, effective transparency, as well as assuring that EU and third country companies compete in the EU on an equal footing. For the electricity market, a target model has been agreed in the context of the Florence regulatory forum and for gas markets a target model is under development.

Infrastructure

Tariff regulation - Transmission is a mostly regulated business at national level and cost allocation to final beneficiaries can be difficult for large trans-European infrastructure. Tariff regulation in most Member States has been based on the principle of cost-efficiency, allowing recovery of costs only for projects based on real market needs or cheapest available solutions, but some externalities, such as innovation, security of supply, solidarity aspects or other wider European benefits may not always be fully taken into account. For infrastructure networks that are entirely new, such as electricity highways or CO2 transport infrastructure, it is likely to be of public interest to ensure that the first investments are compatible with later, more efficient network solutions.

In the EU internal energy market, a key tool to promote interconnections is the trans-European energy networks (TEN-E) programme which has positively contributed to the development and operation of the internal energy market and increased security of supply[23]. Despite the progress achieved, the dramatic changes to the EU energy policy framework in recent years call for a review of the TEN-E framework. The programme has responded too slowly to the major energy and climate goals of today, and is poorly equipped to deal with the growing challenges that will arise from the 2020 and 2050 ambitions. In 2009, as the financial crisis unfolded, EU institutions agreed on the European Energy Programme for Recovery (EEPR)[24] which was endowed with a €3,980 million financial envelope in support of gas and electricity interconnection projects, offshore wind projects as well as carbon capture and storage projects.

Security of supply

EU Energy import dependency for all fuels is 54%. More importantly, the EU is vulnerable to the increasing supply of some commodities by global oligopolies which can create internal and external imbalances. EU experiences of gas supply interruptions in early 2006, 2008, 2009 and 2010, as well as the EU's strong dependence on imports of petroleum products and the geopolitical uncertainty in many producer regions led to the adoption of the Regulation concerning measures to safeguard security of gas supply[25].

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22 COM(2010) 84.

23 SEC(2010) 505.

24 Regulation (EC) No 663/2009 of the European Parliament and of the Council of 13 July 2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy.

25 Regulation 994/2010

Since 1968, EU legislation imposes an obligation on Member States to maintain minimum stocks of crude oil and/or petroleum products that can be used in the event of a supply crisis and a new directive[26] adopted in September 2009 aligns stockholding obligations with those of the International Energy Agency.
Electricity blackouts in the EU in November 2006 highlighted the need to define clear operational standards for transmission networks and for correct maintenance and development of the network. Therefore, in order to ensure the functioning of the internal energy market, the EU established obligations for Member States to safeguard security of electricity supply and undertake significant investment in electricity networks[27].

Low-carbon generation technologies

All low carbon technologies are reliant upon a strong carbon price or other regulatory measures. As well as continuous R&D funding, long-term market or regulatory signals to investors are needed.

Renewables

Some renewables are currently at early development stage, insofar as they often have higher costs than alternatives, though they form part of a sector with rapid technological developments and significantly declining production costs resulting from early economies of scale and technology learning.

Renewable energy production has grown rapidly in the last ten years. The Green electricity Directive (2001/77) and the Biofuels Directive (2003/30) aimed to stimulate an increase in the consumption of renewable energy. The former established an overall EU target of 21% and national indicative targets for the RES shares in gross electricity consumption by 2010. The latter required that all Member States should ensure that at least 5.75% of their petrol and diesel for transport comes from renewable fuels. Despite significant growth, the latest EUROSTAT data indicate that 2010 targets will not be met.[28] The Renewable Energy Directive[29] sets out binding targets for all Member State to achieve the 20% renewable energy target for the EU by 2020 as well as a 10% target for the share of renewable energy in transport. It also addresses the problems of administrative barriers to the development of renewables and their integration in the grids and sustainability requirements for biofuels. According to the Communication on "Renewable Energy: Progressing towards the 2020 target", Member States are on track to reach their overall renewable energy target as well as the sub-target for renewable energy in transport.

Table 1: Renewable energy developments and defined targets.

Share of renewable energy in…	**2001**	**Most recent data**	**Target 2010 (indicative)**	**Target 2020 (binding)**
electricity generation	13.4% (36 Mtoe)	16. 6 % (48 Mtoe - 2008)	21%	no
transport	0.3% (1 Mtoe)	3. 5 % (11 Mtoe - 2008)	5.75%[30]	10%[31][3]

26 Council Directive 2009/119/EC of 14 September 2009 imposing an obligation on Member States to maintain minimum stocks of crude oil and / or petroleum products.

27 Directive 2005/89/EC of the EP and of the Council of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructure investment.

28 COM(2009) 192, The renewable energy progress report.

29 2009/28.

30 Relates to share of biofuels and other renewable fuels in petrol and diesel for transport

31 The 2020 target can be fulfilled through the use of renewable energy in all types of transport. Energy use in maritime and air transport counts only for the numerator, not the denominator.

heating[32]	9.1% (52 Mtoe)	12 % (67 Mtoe - 2008)	no target	no
Gross final energy consumption	**7.6% (89 Mtoe)**	**10.6 % (132 Mtoe - 2009)**	**no target**[33]	**20%**
Gross inland consumption	5.8% (101 Mtoe)	9.0% (153 Mtoe)	12%	no

Nuclear

The EU-27 has the largest number of commercial nuclear power stations in the world: some 150 nuclear reactors are in operation, providing around 30% of the EU's electricity and 60% of low carbon electricity. Although nuclear is a proven technology, in some MS it faces uncertainties regarding public acceptance due to risk perception and often also due to lacking implementation of available technical solutions for long term disposal of nuclear waste. The nuclear accident in Japan could further aggravate public acceptance problems in some MS while possible further increased safety requirements might affect the competitiveness of existing nuclear generation capacities in some MS.

Nuclear safety is and will remain one of the absolute priorities of the EU. A Directive establishing the basic framework for nuclear safety[34] adopted in 2009 provides a Community framework in order to maintain and promote the continuous improvement of nuclear safety. When this Directive will be implemented the EU will be the first major regional nuclear player with common binding nuclear safety rules. On 3 November 2010, the European Commission also proposed a Directive which sets safety standards for disposing spent fuel and radioactive waste.

CCS

As a new and developing industry, CCS faces similar challenges to innovative renewable energy technologies. At present, it is in the early commercial-scale demonstration phase, and is ambitiously striving to be commercially viable soon after 2020. But facing a number of problems, its progress is currently challenged by issues that include financing and public perception concerns in some Member States.

The European Council of March 2007 urged to work towards strengthening R&D and developing the necessary technical, economic and regulatory framework to remove existing legal barriers and to bring environmentally safe CCS to deployment. In 2008, the European Council made a commitment to supporting the design, construction and operation of CCS in up to 12 large-scale demonstration plants by 2015. Demonstration of the technology in commercial plants is considered to be an essential step towards commercialisation of CCS to demonstrate the environmental safety and economic viability of the technology, which is also dependent on strong carbon prices. The CCS Directive[35] establishes a comprehensive legal framework to safely manage the environmental aspects of capture, transport and the geological storage of CO2. The revised ETS Directive ensures that safely stored CO2 is not regarded as emitted and provides therefore a financial incentive for CCS. In addition, 300 million allowances from the New Entrants Reserve (NER) shall be available to support

32 "Heating" is a catch-all term for energy consumption that is neither for transport nor in the form of electricity.

33 A 1997 White Paper established an indicative target of 12% of primary energy consumption in 2010, which was used to derive the 21% target for RES in power generation in 2010

34 Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations.

35 Directive 2009/31/EC on the geological storage of carbon dioxide adopted as part of the Climate and Energy Package in 2009

commercial-scale CCS and innovative RES demonstration projects under the NER300 funding programme, thus complementing and going beyond funding already provided by the EEPR. CCS is also an important option for decarbonisation of several heavy industries[36]. Moreover, CCS has the potential to deliver carbon-negative power, if it is combined with biomass combustion or co-firing.

As the Energy Roadmap 2050 is a broad policy document without having the ambition of defining individual policy measures, this IA tries to present a broad picture of the challenges and barriers but will not propose solutions to all of them.

2.4. Business as usual developments

2.4.1. Modelling approach

The Commission has carried out an analysis of possible future developments in a scenario of unchanged policies, the so-called **"Reference scenario"**. The Reference scenario was also used in the IA for the "Low-carbon economy 2050 roadmap" and IA for the "White Paper on Transport". The Reference scenario is a projection, not a forecast, of developments in the absence of new policies beyond those adopted by March 2010. It therefore reflects both achievements and deficiencies of the policies already in place. In order to take into account the most recent developments (higher energy prices and effects of the nuclear accident in Japan) and the latest policies on energy efficiency, energy taxation and infrastructure adopted or planned after March 2010, an additional scenario called **Current Policy Initiatives scenario (CPI)** was modelled.

Both scenarios build on a modelling framework including PRIMES, PROMETHEUS, GAINS and GEM-E3 models. The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand. The model is organized in sub-models (modules), each one representing the behaviour of a specific (or representative) agent, a demander and/or a supplier of energy. GAINS complements PRIMES with consistent estimates of non-CO2 emissions and their contribution to reach the policy targets included in the reference scenario. PROMETHEUS is a stochastic world energy model used for determining fossil fuel import prices, while the results of the GEM-E3 general equilibrium model are used as inputs of macro-economic (e.g. GDP) and sectoral numbers (e.g. sectoral value added) for PRIMES. Several EU scenarios were established at different points in time using a framework contract with National Technical University of Athens (author and owner of the PRIMES model).

2.4.2. Assumptions

The Reference scenario 2050 includes current trends and recent Eurostat and EPC/ECFIN long term projections on population and economic development. It takes into account the upward trend of import fuel prices in a highly volatile world energy price environment. Economic decisions are driven by market forces and technological progress in the framework of concrete national and EU policies and measures implemented by March 2010. The 2020 targets for RES and GHG will be achieved in this scenario, but there is no assumption on targets for later years besides annual reduction of the cap in the ETS directive.

The CPI scenario builds on the same macroeconomic framework and includes policy initiatives adopted after March 2010 or policy initiatives currently being planned as well as updated technology assumptions for nuclear and electric vehicles.

[36] According to recent Technology Roadmap from IEA/ UNIDO, CCS could reduce CO2 emissions by up to 4.0 gigatonnes annually by 2050 in industrial applications, accounting for 9% of the reductions needed to halve energy-related CO2 emissions by 2050.

The main assumptions used for both scenarios are presented in table 2 and all assumptions and more detailed description of results can be found in Annex 1 (part A).

Table 2: Main assumptions in the Reference scenario 2050 and Current Policy Initiatives Scenario

GDP growth rate: 1.7 % pa on average for 2010-2050

Oil price: 106 $/barrel in 2030 and 127 $/barrel in 2050 (in year 2008 dollars)[37]

Main policies included (Reference scenario): Eco-design and Labelling directives adopted by March 2010; Recast of the Energy Performance of Buildings Directive, EU ETS directive; RES directive (20% target); Effort Sharing Decision (non-ETS part of the 20% GHG target); Regulation on CO2 from cars and vans.

Main policies included (Current Policy Initiatives scenario) in addition to those already included in the Reference scenario 2050: Energy efficiency Plan; facilitation policies for infrastructure and updated investments plans based on ENTSO-e Ten Year Network Development Plan; Nuclear Safety Directive; Waste management Directive; revised Energy Taxation Directive

Consequences of the Japanese nuclear accident leading to abandon of nuclear programme in Italy, nuclear phase-out in Germany and in case of nuclear lifetime extension up to 20% higher generation costs reflecting higher safety requirements as well as introduction of a risk premium for new nuclear power plants; revisiting of progress on CCS in demonstration projects and policies and initiatives leading to slightly higher uptake of electric vehicles.

Costs for technologies: Technology parameters are exogenous in the PRIMES modelling and their values are based on current databases, various studies and expert judgement and are regularly compared to other leading institutions. Technologies are assumed to develop over time and to follow learning curves which are exogenously adjusted to reflect the technology assumptions of a scenario. Overall, mature fossil fuel, nuclear as well as large hydroelectric technologies exhibit rather stable technology costs, except for innovative concepts such as 3rd generation nuclear power plants or carbon capture and storage (CCS), where costs decline with further RTD and more technology experience. Similar developments are assumed for new renewable technologies, such as off-shore wind and solar PV as has been witnessed in the past for most energy technologies (e.g. on-shore wind or more recently solar energy).

Drivers: Within these framework conditions market forces drive energy and emission developments. Economic actors optimise their supply and demand behaviour while the simulation of energy markets in the model derives energy prices, which in turn influence the behaviour of energy actors (power generators, various industrial and service consumers, households, transport, etc). The Reference and CPI scenarios do not assume any additional policies. The model provides a simulation of what the interplay of market forces in the current economic, world energy, policy and technology framework would bring about if no new policies would be put in place.

All scenarios are built on assumptions of perfect foresight and "representative" consumer leading to a very high certainty on regulatory framework for investors and rather optimistic deployment of technologies by households and services that will be challenging to ensure in practice.

2.4.3. Energy developments

Energy consumption

Primary energy consumption peaked in 2006, from which point it decreases slightly up to 2050 (-4%). This is despite economic growth leading to a doubling of GDP between 2005 and 2050.

Final energy consumption continues rising until 2020, after which demand stabilises as more efficient technologies have by then reached market maturity and the additional energy

[37] Short-term projections for oil, gas and coal prices were slightly revised according to the latest developments in the Reference scenario as compared to the version used in the low carbon economy roadmap.

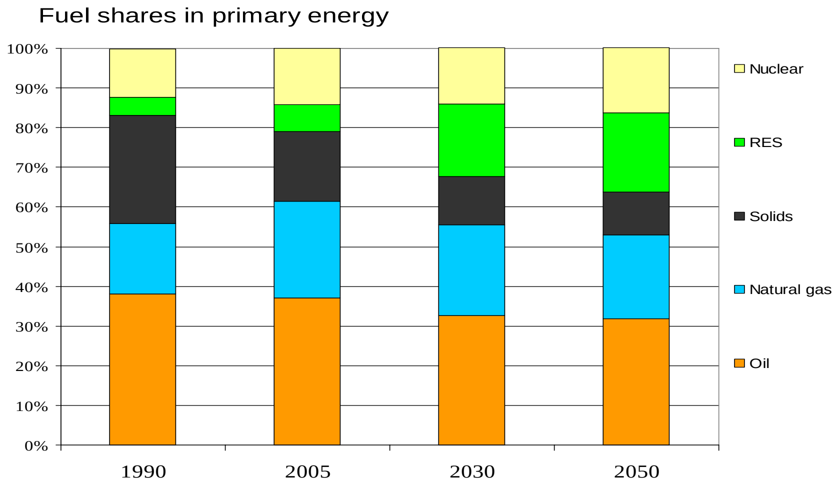
efficiency of the appliances is sufficient to compensate for increased demand. The share of sectors remains broadly stable with transport remaining the biggest single consumer accounting for 32% in 2050; the industrial share increases slightly while that of households declines a bit.

In the CPI scenario, further energy savings are brought about mainly by energy efficiency measures for households and services sector and efficiency improvements in energy transformation in the short to medium term leading to further declines in final energy demand which remains 4-6% below the Reference scenario. There are marked changes also at the level of primary demand in 2020 (-5.0%); 2030 (-5.8%) and 2050 (-8.4%).

The energy intensity of the economy and of different sectors decreases. Increased energy efficiency in the residential sector is due to the use of more efficient energy equipment (appliances, lighting, etc.) and buildings, being driven by the Eco-Design regulations and by better thermal integrity of buildings reflecting the Recast of the Energy Performance of Buildings Directive. Energy consumption in transport is decoupling significantly from underlying transport activity growth due to the use of more energy efficient vehicles; this development is largely driven by more fuel efficient cars, in particular hybrids, following the CO2 performance standards set by the CO2 from cars regulation[38].

There is considerable fuel switching in final and primary energy demand in the Reference scenario. In primary energy, the dominance of fossil fuels diminishes with its share falling from 83% and 79% in 1990 and 2005, respectively, to only 64% in 2050. While non fossil fuels (RES and nuclear) account for 36% of primary energy in 2050, they reach a significantly higher share in the 2050 electricity mix. Energy sources not emitting CO2 supply 66% of electricity output in 2050, with 40% RES and 26% nuclear.

Graph 1: Reference scenario- Fuel shares in primary energy



In the CPI scenario, the share of nuclear is lower due to a change in nuclear assumptions. In this new policy environment gas and RES replace nuclear and thereby increase their share over Reference scenario levels.

Power generation

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38 Regulation on CO2 from cars 2009/443/EC

The demand for electricity continues rising and there is a considerable shift towards RES with a strong increase in wind. Power generation and capacity from solids decrease throughout the projection period due to increasing carbon prices that reduce the competitiveness of this technology; gas power generation capacity increases, also as peak load activated during back-up periods due to the increased amount of RES in the system. As a result of the large increase in RES in power generation the load factor of the system decreases given the more widespread use of technologies that run only a limited number of hours per year. Investment in power generation increases over the projection period, driven by RES and gas.

The carbon intensity of power generation falls by over 75% in 2050 compared to 2010 levels, driven by the decreasing ETS cap and rising carbon prices. CO2 emissions from power generation decline by 2/3rd between 2010 and 2050, while electricity demand still increases. This strong decarbonisation is brought about by fuel switching to RES and nuclear, an increasing share of gas in fossil fuel generation and significant penetration of CCS after 2030. In 2050 18% of electricity is generated through power plants with CCS (solids and gas).

Electricity demand in the CPI scenario falls well below electricity use in the Reference scenario (by 6.5% in 2030 and 4.3% in 2050), reflecting measures in the Energy Efficiency Plan and the revised Energy Taxation Directive. The CPI scenario takes account of the post Fukushima policy change in Member States, notably the abandonment of the nuclear programme in Italy, and new initiatives, such as the nuclear stress tests that will tend to increase costs for new power plants and retrofitting. The CPI scenario has significantly lower CCS penetration primarily as a result of the ETS price being lower in the longer term and also as a consequence of the relatively moderate progress that has been made since 2009 (Reference scenario) towards the EU objective of having up to 12 large-scale CCS demonstration plants operational by 2015 in Europe.

Table 3: Electricity related indicators in CPI scenario and differences from Reference

	Current Policy Intitiatives				Difference from Reference		
	2005	2020	2030	2050	2020	2030	2050
Gross electricity generation (TWh)	3274	3645	3780	4621	-121	-286	-311
Shares in gross electricity generation					in percentage points		
RES share	14,3%	34,5%	43,6%	48,8%	1,2%	3,1%	8,5%
Nuclear share	30,5%	23,9%	20,7%	20,6%	0,8%	-3,8%	-5,8%
Fossil fuel share	55,2%	41,6%	35,7%	30,6%	-2,0%	0,7%	-2,7%
CCS share	0,0%	0,7%	0,8%	7,6%	-0,6%	-2,1%	-10,2%
Prices in €							
ETS (€(08)/t CO2)	0,0	15,0	32,0	51,0	-2,5	-8,0	1,0
Average electricity price (in €(08)/MWh)	110,1	148,5	159,0	159,9	0,0	1,3	6,1

Heating

A strong increase in demand for distributed steam and heat can be observed between 2005 and 2020 following strong CHP promoting policies, as well as commercial opportunities that arise from gas and biomass based CHP technologies. In the longer term further demand for distributed heat in the tertiary and residential sectors slows down as a result of the trend towards electrification (i.e. heat pumps) and higher energy efficiency which limits the overall demand for heating. In industry the increase in demand for distributed steam is projected to continue in the future because the changes of industrial activity are favourable for sectors with high demand for steam such as chemicals, food, tobacco, and engineering.

In the CPI scenario, demand for distributed heat rises compared to current levels but is 1-2% lower than in the Reference scenario, reflecting the effects of more efficient heating systems used in houses.

Transport

Transport accounts today for over 30% of final energy consumption. In a context of growing demand for transport, final energy demand by transport is projected to increase by 5% by 2030 rising further marginally by 2050. Transport growth is driven mainly by aviation and road freight transport. The EU transport system would remain extremely dependent on the use of fossil fuels. Oil products would still represent 88% of EU transport sector needs in 2030 and 2050 in the Reference scenario.

Energy consumption in transport is little affected by current energy policy initiatives (- 1.7% in 2030 and -5.7% in 2050). Changes from the Reference scenario are brought about in particular by the proposed new energy taxation system and through the somewhat more favourable policy environment for electric and plug-in hybrid vehicles.

Policy relevant indicators (and targets)

Emissions - It is estimated that a continuation of current trends and policies (Reference scenario) would result in 40% reduction in energy-related CO2 emissions between 1990 and 2050 and 26% by 2030. All GHG emissions would fall 40% by 2050 (29% by 2030) which represents about half of the domestic efforts needed by a developed economy in the context of limiting climate change to 2°C[39]. Most emissions continue to be energy related emissions. Carbon intensity falls markedly. Producing one unit of GDP in 2050 would lead to only 21% of energy related CO2 emissions that were required in 1990.

In the CPI scenario emission reductions are broadly similar to those in the Reference scenario. CO2 emissions in 2050 are 41% below 1990 values and below those reached in the Reference case due to greater energy intensity improvements brought about by vigorous energy efficiency policies which overcompensates worsening carbon intensity due to lower availability of nuclear and CCS and lower ETS carbon prices. Total GHG emissions in 2050 decrease by 39% below the 1990 level (1 percentage point less than in the Reference scenario) mainly a result of changes of the carbon price over the next decades.

ETS prices under developments in the Reference scenario rise from 40 € (08)/tCO2 in 2030 to 52 € in 2040 and flattens out to 50 € in 2050. The ETS price in the CPI scenario is lower for most of the projection period reflecting efficiency and RES policies (by about 20% in 2025-2035) and ends at 51 € in 2050.[40]

39 This includes also some energy-related non-CO2 emissions, e.g. methane emissions from coal mining and losses in gas distribution networks and F-Gas emissions related to air conditioning and refrigeration. While the former are estimated to decrease under current trends, the latter are projected to increase considerably. For a more detailed analysis of the overall GHG reduction efforts needed and of trends in non-CO2 emissions see the Impact Assessment of the Roadmap for moving to a competitive low carbon economy in 2050 (SEC(2011)288).

40 Correspondingly, a higher amount of banking of ETS allowances beyond 2020 takes place in the CPI scenario compared to the Reference scenario, rising from around 2000 Mt to 2700 Mt in 2020 and reducing more slowly in the post-2020 period. For a detailed interplay of ETS, other policies, carbon prices and ETS allowance banking see SEC(2010)650 part 2.

RES target - The Reference scenario assumes that the RES target is reached in 2020; the RES share continues rising in the Reference scenario to reach 24% in 2030 and over 25% in 2050. Further penetration of RES progresses more slowly due to the assumed phasing out of operational aid to mature RES technologies. RES in transport contribute 10% in 2020 to comply with the RES directive; this share increases to 13 % by 2050. However, the pace of electrification in the transport sector is projected to remain slow in the Reference scenario: electric propulsion in road transport does not make significant inroads by 2050[41]. The CPI scenario has higher RES shares, e.g. 25% RES in final energy in 2030 and 29% in 2050.

The indicative 20% energy savings objective for 2020 would not be achieved under current policies - not even by 2050. The Reference scenario would deliver 10% less energy consumed in 2020 compared to the 2007 projections. The CPI scenario delivers significantly more. Energy consumption in 2020 is 14% below the 2007 projections further decreasing significantly up to 2050.[42]

Import dependency - Total energy imports increase by 6% from 2005 to 2050. The increase is rather limited despite decreasing indigenous production, as rising gas (+28% from 2005 to 2050) and biomass imports are compensated by a marked decline in coal imports while oil imports remain broadly stable. Import dependency rises above the present level (54%), reaching 58% in 2020 and flattening out to 2050 thanks to more RES and nuclear. It remains broadly unchanged in the CPI scenario.

Average electricity prices rise up to 2030 and stabilise thereafter. The price increase up to 2030 is due to three main elements: RES supporting policies, ETS carbon price and high fuel prices due to the world recovery after the economic crisis. Thereafter electricity prices remain stable because of the techno-economic improvements of various power generation technologies that limit the effects of higher input fuel prices and CO2 prices. In the CPI scenario, electricity prices are slightly higher (1% in 2030 and 4% in 2050) reflecting the lower share of nuclear as well as higher lifetime extension costs post Fukushima and high investments for new electricity generation capacity, especially RES.

Total costs of energy (including capital costs, energy purchases and direct efficiency investment costs) are rising fast over the projection period but are not equally distributed across sectors. Energy related expenditures in households rise strongly while the growth of energy related costs for services and industry is more moderate. Energy costs are rising faster than GDP and represent around 15.1% of GDP in 2030 (up from 10.5% in 2005) and 14.3% in 2050. The faster rate of growth relative to GDP reflects significant investments needs in energy production, transmission and distribution as well as demand based energy efficiency measures. Under the CPI scenario, system costs are slightly higher amounting to 15.3% and 14.6% in relation to GDP in 2030 and 2050, respectively, reflecting in particular greater investment requirements.

41 The Reference scenario does not cover the European Commission CARS 21 (Competitive Automotive Regulatory System for the 21st century) initiative and the recent initiatives of car manufacturers as regards electric vehicles.

42 The results diverge slightly from the assessment done for the Energy Efficiency Directive. In fact, measures of the Energy Efficiency Directive were taken but they are expected to produce effects over a longer period of time. Also the stringency of energy efficiency measures is assumed to be slightly lower. However, a more vigorous implementation of the Energy Efficiency Directive is assumed in decarbonisation scenarios which all surpass the indicative 20% target in the decade 2020-2030.

2.4.4. Sensitivity analysis

Considering the high degree of uncertainty surrounding projections over such a long time horizon, a sensitivity analysis has been carried out with respect to two key parameters - energy imports prices and GDP. A high and a low case has been analysed for both variables.

<u>GDP</u>

The two economic growth variants explore a High GDP case where GDP per capita is 0.4 percentage points (pp) higher than in the Reference scenario throughout the projection period (+15% increase in GDP level in 2050) and a Low GDP case with GDP per capita 0.4 pp lower (-14.7% in GDP level in 2050). GDP and economic activity have a significant influence on energy consumption in particular in industry and services.

The model based analysis shows that policy relevant indicators are rather insensitive against variations in GDP assumption, which is a significant result given the great uncertainty in making GDP projections for the next few years let alone the next four decades.

CO2 reduction becomes only slightly more difficult to achieve under significantly higher economic growth. Higher economic growth brings more opportunities for innovation and investment leading to improvements in both energy and carbon intensity. In a similar manner, low economic growth entails lower economic activity but fewer investments in low carbon and energy efficient technologies. There is thus only limited further emission reductions brought about by considerably lower GDP levels. RES shares in gross final energy consumption are pretty robust with respect to GDP levels with variation spanning just 1 percentage point in 2050. Import dependency is also unaffected by such significant changes in GDP levels. Policy relevant indicators regarding competitiveness are pretty much unaffected by economic growth; while ETS prices differ to some extent, the effects on electricity prices are marginal.

<u>Energy prices</u>

Two energy price sensitivities were modelled – a High energy price case with the world oil price 28% higher in 2050 and a Low energy price case with the world oil price 34% below the Reference scenario in 2050. In the low price case, fossil fuel import prices remain broadly at the 2010 level; coal prices are stable, oil has a small peak around 2030, whereas gas prices remain weak over the next few years but recover to the 2010 level in the long run.[43]

High world energy prices reduce CO2 and GHG emissions, while low prices exert the opposite influence. However, there are several other effects via the fuel mix, electricity generation, ETS price adaptations with a given cap and CCS incentives that modify the overall effect. In total, differences in world energy prices exert only a minor influence on total GHG emissions in the EU given the existence of the EU ETS with a decreasing cap that is independent from GDP or world energy price developments.

High fossil fuel prices limit business opportunities for energy exporters given that EU imports would decrease, especially for natural gas. Conversely, with lower fossil fuel prices, significantly higher gas deliveries to the EU can be assumed. Import dependency increases with low world energy prices, whereas it stays below the Reference scenario in the High price case. Electricity prices are significantly lower in the Low price case, whereas they are significantly higher in the High energy price case. High energy import prices increase the

[43] Global developments as regards shale gas are taken into account when projecting global gas prices.

EU's external fuel bill substantially. On the contrary, lower fossil fuel prices give a boost to the EU economy improving its competitiveness, also through lower costs and inflation.

2.4.5. Conclusion

The Reference scenario and CPI assume the overall GHG target, ETS cap and non-ETS national targets to be achieved by 2020 but thereafter GHG reductions fall short of what is required to mitigate climate change with a view to reaching the 2 °C objective. Import dependency, in particular for gas, increases over the projection period and electricity prices and energy costs are rising. So despite efforts over recent years, the long term effects of our current and planned policies are not sufficient to achieve the ambitious decarbonisation objective and to improve both security of supply and competitiveness. These conclusions are broadly consistent with other major stakeholder work such as the IEA World Energy Outlook 2010 (Current Policies scenario), the European Climate Foundation (baseline scenario); Power Choices (baseline scenario) and Greenpeace (baseline scenario). A more thorough comparison of stakeholder work is provided in Annex 2.

2.5. The EU's right to act and EU added-value

The EU's competence in the area of energy is set out in the Treaty on the Functioning of the European Union, in Article 194[44]. EU competences related to combating climate change, including GHG emission reductions in energy and other sectors, are enshrined in Art. 191-193. The EU's role needs to respect the principles of subsidiarity and proportionality.

From an economic perspective, as is the case with the European carbon market, many energy system developments can best be achieved on an EU-wide basis, encompassing both EU and Member State action while respecting their respective competences. An EU wide European market can facilitate the balancing of the electricity system, reduce the need for back-up capacities and encourage RES production where it economically makes most sense. Large scale investments require big markets which also justify one EU wide approach. A bigger market can also better encourage the development of innovative products and systems mainly in the area of energy efficiency and renewables.

2.6. Who is affected?

Everybody is affected. Energy consumers will be affected by higher energy costs (a combination of energy prices and amount of energy used) as well as by extra non-energy investment needed such as more efficient appliances, new types of vehicles, house renovations, etc. The energy industry will be directly concerned as it needs to heavily invest in the next two decades. Public authorities will also need to engage in discussions about the pros, cons and trade-offs of different options as each generation source has its drawbacks (solar and wind generation will require significant infrastructure investments; supply of sustainable biomass might be limited; nuclear faces public acceptance and waste problems

[44] Article 194:
1. In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to:
(a) ensure the functioning of the energy market;
(b) ensure security of energy supply in the Union;
(c) promote energy efficiency and energy saving and the development of new and renewable forms of energy;
(d) promote the interconnection of energy networks.

and CCS still requires large-scale experience to be able to reduce costs and sufficiently decrease financial risks for private investors). Changes in the EU energy sector will also have a strong influence on third countries, notably fuel suppliers.

3. SECTION 3: OBJECTIVES

3.1. General objective

The general objective is to shape a vision and strategy of how the EU energy system can be decarbonised by 2050 while taking into account the security of supply and competitiveness objectives.

3.2. Specific objectives

To achieve the general objective, more specific objectives are being proposed:

– Assist political decision making for providing more certainty to investors as regards possible future policy orientations at the EU level by showing different decarbonisation pathways to 2050 as well as their main economic, social and environmental impacts;
– Show trade-offs among policy objectives as well as among different decarbonisation pathways and identify common elements in all decarbonisation pathways;
– Help policy makers set milestones after 2020.

The Roadmap 2050 should be based on the current key objectives of EU energy policy – sustainability, security of supply and competitiveness. Not all three objectives can be specified and quantified in the same manner. While the decarbonisation objective can be relatively easily defined and quantified, the other two are more complex. The goal of sustainability is linked in particular to the achievement of 80% domestic GHG reduction below 1990 in 2050, which implies a reduction of energy related CO2 emissions by 85%, consistent with the required contribution of developed countries as a group to limit global climate change to a temperature increase of 2ºC compared to pre-industrial levels. The goal of security of supply entails not only decreasing import dependency but also increasing supply diversity and continued stability of electricity grid. The competitiveness objective implies assuring a competitive energy sector, encouraging investments and achieving affordable energy costs for consumers as well as developing new technologies and ensuring a competitive clean technology manufacturing sector.

In general the objectives of energy policy are complementary and mutually reinforcing. For example, increased energy efficiency reduces GHG emissions, increases energy security and contributes towards achieving a competitive energy sector. A significant part of low carbon energy supply can be produced in the EU, thus also increasing energy security of supply. However, there are also some possible **trade-offs**. Some of them are presented below for illustration:

– Renewables do not require fuels to be imported and emit less or no GHG emissions, but may need public support (if necessary and proportionate) to be competitive; this increases costs to consumers. The merit order effect however reduces wholesale electricity prices.
– Although nuclear is a large provider of low carbon electricity in the EU, it faces in some MS acceptance and financing problems.

– CCS prevents CO2 emissions, but is comparatively resource inefficient in relation to unabated fossil fuel combustion. Up to 25% additional energy input may be needed for capture, transport and storage of CO2.
– Gas is the fossil fuel with the lowest carbon content but poses a challenge to security of supply especially for countries with undiversified supplies.
– The current tariff-setting for transmission and distribution networks is cost-based and should assure the lowest short term prices to consumers but is not yet supportive enough to new technologies enabling integration of RES and energy efficiency that have longer term benefits.

3.3. Consistency with other European policies

The Energy Roadmap 2050 subscribes into the overall framework of decarbonisation as designed by the flagship initiative Resource efficient Europe and the Roadmap for moving to a competitive low carbon economy in 2050. All objectives are coherent with the objectives of the medium term strategy as described in the Communication Europe 2020 and Energy 2020 as well as with energy policy objectives as described in the Lisbon Treaty.

4. SECTION 4: POLICY OPTIONS

4.1. Methodology

This is not a typical impact assessment in that it does not list policy options to meet certain policy objectives and then assesses impacts of these policy options to determine a preferable one. It rather examines a set of possible alternative future developments to get more robust information on how the energy system could achieve 85% reduction of energy related CO2 emissions compared to 1990 without selecting one of them as the preferred option. Nor does it seek to justify the decarbonisation target as this was the focus of the Low Carbon Economy Roadmap[45] . It is mainly concerned with analysing possible energy related pathways to reach decarbonisation in a "global climate action" world. **Lower import fossil fuel prices are introduced to reflect significant impacts on global fossil fuels prices in policy scenarios** while fossil fuel prices are higher in the Reference scenario and CPI scenarios which project current trends and policies[46].

The Energy Roadmap assumes the implementation of the European Council's decarbonisation objective that includes similar efforts by industrialised countries as a group. The analysis presented focuses on energy consequences. A more comprehensive analysis of different global paths to decarbonisation was presented in the Low Carbon Economy Roadmap 2050[47], exploring the impacts of three global climate situations: a) business as usual; b) global climate action and c) fragmented action. Fragmented action assumes strong EU climate action that is however followed globally only by the low end of the Copenhagen pledges up to 2020 and afterwards the ambition level of the pledges is assumed to stay constant. It analyses impacts on energy intensive industries (EII) both in a global macroeconomic modelling framework to address carbon leakage issues and by means of energy system modelling to address the effects of fragmented action, including electricity costs for companies. Electricity costs are, in fact, higher in the fragmented action scenarios as compared to the global action scenarios due to

45 COM (2011)112
46 Please see IA on Low carbon economy Roadmap for the analysis of impacts of decarbonisation on energy import prices SEC(2011)288·
47 Impact assessment report SEC(2011)288 final, section 5)

higher energy import prices. On the other hand, carbon prices are lower under fragmented action.

A "fragmented" action scenario including measures against carbon leakage was not analysed in this IA report as the challenges for the energy sector arising from decarbonisation are the biggest under the "global climate action" assumption, given that fragmented action with measures against carbon leakage will deliver lower GHG reductions by 2050. Decarbonisation scenarios that accommodate action against carbon leakage under fragmented action could either go for lower ambitions in terms of GHG reduction for sectors with relevant leakage risks or could have measures included that compensate efforts for energy intensive industries. With action on carbon leakage the challenge for the transition in the energy system could be smaller given lower efforts in parts of the system. Such results are however modified through countervailing effects from lower world fossil fuel prices under global action that encourage somewhat higher energy consumption and emissions. In any case, the implementation of measures will be crucial. The real difference for industrial and thereby climate policy might come from the concrete design of policy instruments that is not discussed in this the Energy Roadmap Impact Assessment (e.g. special provisions on ETS for EII).

Section 5 provides an assessment of the environmental, economic and social impacts that is proportionate to the nature of the document proposed. The assessment is supported by modelling results and/or by academic research where possible. It is important to underline that modelling results are tentative and present impacts as illustrations rather than as conclusive evidence. A 40-year outlook is naturally steeped in uncertainty. Whereas some parameters such as population growth can be projected with a reasonable degree of confidence, the projection of other key factors such as economic growth, energy prices or technological developments over such a long time span incorporates a great deal of uncertainty.

The modelling framework used for decarbonisation scenarios is the same as for the Reference scenario (see section 2.4 and annex 1). A quantitative methodology is the core of this assessment. However, not all aspects could be modelled. For instance, significant environmental impacts that go beyond GHG emissions, such as impacts on biodiversity and air pollution, were not assessed quantitatively. For GDP and employment impacts, analysis done for the Communication on moving beyond 20% GHG reductions[48] and several recent studies were used. It was neither possible to assess impacts on different household income levels, nor distributional impacts at Member State level.

The methodology factors in uncertainties but ensures for a coherent approach based on proven technologies, applying the following limitations:

– Taking into account existing physical and capital infrastructure and limitations regarding physical and capital stock turn-over.
– Technological progress over time is assumed as typical in long term modelling. Potential break-through technologies depending on unforeseeable structural change have not been taken into account. Similarly, major lifestyle changes, beyond demand side effects of carbon pricing on behaviour, have not been taken into account in

48 European Commission: Communication 'Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage' (COM(2010) 265 final). Background information and analysis, Part II (SEC(2010) 650).; http://ec.europa.eu/clima/documentation/international/docs/26-05-2010working_doc2_en.pdf

quantitative terms, as this goes beyond the capabilities of the quantitative modelling tools.[49]

– The modelling also could not take into account effects of the changing climate itself on the energy system. Effects can go in different directions and will depend on how climate changes in different parts of the EU (e.g. more demand for cooling, less demand for heating, impact on water availability for power plant cooling or hydroelectricity production).

Only by comparing results from different decarbonisation scenarios is it possible to extract more robust conclusions, how key parameters influence the results and how various parts interact with each other. By requiring similar levels of cumulative GHG emissions across scenarios, this analysis ensures comparability, as regards the objective of decarbonisation, given that emission mitigation aims at preventing dangerous levels of atmospheric GHG concentrations that is a matter of cumulative emissions. An identification of common features to all scenarios will be an important part of the analysis. The Commission's own scenario analysis will be complemented by MS and other stakeholders' work. An in-depth impact assessment report examining impacts of concrete policy measures will be submitted for any legislative proposal following this roadmap.

4.2. Policy options

Several useful scenarios could be proposed for a decarbonisation analysis of the energy system. The design of scenarios was extensively discussed with various stakeholders. Stakeholders and the European Commission identified four main decarbonisation routes for the energy sector – energy efficiency impacting mostly on the demand side and RES, nuclear and CCS predominantly on the supply side (lowering the carbon intensity of supply). This finding is in line with the decarbonisation scenarios of a number of stakeholders, such as Eurelectric Power Choices, the Energy Roadmap of the European Climate Foundation and the work done at national level by some MS (such as the UK, DE and DK). The policy options (scenarios) proposed explore five different combinations of the four decarbonisation routes. Decarbonisation routes are never explored in isolation as the interaction of different elements will necessarily be included in any scenario that evaluates the entire energy system.

All decarbonisation scenarios achieve close to 85% energy related CO2 emissions by 2050 and it is carefully assessed what effect each policy option has in terms of security of supply, competitiveness of the energy sector and affordability of energy costs. All scenarios use the same assumptions about GDP developments as the Reference scenario. The scenarios achieving the European Council's GHG objective have lower fossil fuel prices 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). In addition, most technology assumptions are the same as in the Reference scenario, although there are additional features and mechanisms to stimulate decarbonisation and technology penetration. For details please see Annex 1, pages 56-60.

Table 4: Policy options/Scenarios

	Option/scenario	Short description
1	**Business as usual (Reference**	The Reference scenario includes current trends and long-term projections on economic development (GDP growth 1.7% pa). It takes into account rising fossil

[49] For details and the implications on the cost and benefit quantifications please refer to Annex 1, part A, point 1.4 and part B, points 1.4 and 2.7.

	scenario[50]**)**	fuel prices and includes policies implemented by March 2010. The 2020 targets for GHG reductions and RES shares will be achieved but no further policies and targets after 2020 (besides the ETS directive) are modelled. See also section 2.4 Sensitivities: a) a case with higher GDP growth rates, b) a case with lower GDP growth rates, c) a case with higher energy import prices, d) a case with lower energy import prices.
1bis	**Current Policy Initiatives – CPI scenario (updated Reference scenario)**	The Reference scenario includes only adopted policies by March 2010. Since then, several new initiatives were adopted or are being proposed by the EC. The EC outlined its future work programme on energy mainly until 2020 in the Communication "Energy 2020 - A strategy for competitive, sustainable and secure energy". This policy option analyses the extent to which measures adopted and proposed will achieve the energy policy objectives.[51] It includes additional measures in the area of energy efficiency, infrastructure, internal market, nuclear, energy taxation and transport. Technology assumptions for nuclear were revised reflecting the impact of Fukushima and the latest information on the state of play of CCS projects and policies were included. See also section 2.4.
	Decarbonisation scenarios	All decarbonisation scenarios build on Current Policy Initiatives (reflecting measures up to 2020) and are driven by carbon pricing to reach some 85% energy related CO2 reductions by 2050 (40% by 2030) which is consistent with the 80% reduction of GHG emissions. Transport measures (energy efficiency standards, low carbon fuels, infrastructure, pricing and transport planning) as reflected in the Transport White Paper are included in all scenarios. All scenarios will reflect significant development of electrical storage and interconnections (with the highest requirements in the High RES scenario). Different fuels can compete on a market basis besides constraints for nuclear investment in scenario 6.
2	**High Energy Efficiency**	This scenario is driven by a political commitment of very high primary energy savings by 2050 and includes a very stringent implementation of the Energy Efficiency plan. It includes further and more stringent minimum requirements for appliances and new buildings; energy generation, transmission and distribution; high renovation rates for existing buildings; the establishment of energy savings obligations on energy utilities; the full roll-out of smart grids, smart metering and significant and highly decentralised RES generation to build on synergies with energy efficiency.
3	**Diversified supply technologies**[52]	This scenario shows a decarbonisation pathway where all energy sources can compete on a market basis with no specific support measures for energy efficiency and renewables and assumes acceptance of nuclear and CCS as well as solution of the nuclear waste issue. It displays significant penetration of CCS and nuclear as they necessitate large scale investments and does not include additional targeted measures besides carbon prices.
4	**High RES**	The High RES scenario aims at achieving a higher overall RES share and very high RES penetration in power generation, mainly relying on domestic supply[53].
5	**Delayed CCS**	This scenario follows a similar approach to the Diversified supply technologies scenario but assumes difficulties for CCS regarding storage sites and transport while having the same conditions for nuclear as scenario 3. It displays considerable penetration of nuclear.
6	**Low nuclear**	This scenario follows a similar approach to the Diversified supply technologies scenario but assumes that public perception of nuclear safety remains low and that implementation of technical solutions to waste management remains unsolved leading to a lack of public acceptance. Same conditions for CCS as scenario 3. It displays considerable penetration of CCS.

[50] Used also in the Low Carbon Economy Roadmap and Transport White Paper.

[51] This analysis does not prejudge the final outcome of the legislation process on these policies and will not be able to deliver a quantitative assessment of the consequences of the Energy 2020 strategy.

[52] Scenario 3 reproduces "Effective and Widely Accepted Technologies" scenario used in Low Carbon Economy roadmap and Transport White Paper on the basis of scenario 1bis.

[53] Global climate action requires that each region uses its RES potential. Moreover, geopolitical and security of supply risks can justify the reliance on domestic energy sources.

A more detailed presentation of assumptions for all scenarios can be found in Annex 1.

5. SECTION 5: ANALYSIS OF IMPACTS

5.1. Environmental impacts

Energy consumption and use of renewable energy

Primary energy consumption is significantly lower in all decarbonisation scenarios as compared to the Reference scenario. The biggest decline of primary energy consumption comes in the High Energy Efficiency scenario (-16% in 2030 and -38% in 2050) showing the effects of stringent energy efficiency policies and smart grid deployment. The decrease in energy consumption compared with the Reference scenario for all decarbonisation scenarios spans a range from 11-16% in 2030 and 30-38% in 2050. Compared with primary energy consumption in 2005 there is a very significant decrease of 32-41%. It is important to note that these levels of reduced primary energy demand do not come from reduced GDP or sectoral production levels (which remain the same in all scenarios). Instead they are mainly the result of technological changes on the demand and supply side, coming from more efficient buildings, appliances, heating systems and vehicles and from electrification in transport and heating. All decarbonisation scenarios over-achieve the 20% energy saving objective in the decade 2020-2030[54]. This result is consistent with other stakeholder work.

Not only the amount, but also the composition of energy mix would differ significantly in a decarbonised energy system. Low carbon energy sources are strongly encouraged but can follow various decarbonisation routes shown by rather wide ranges for shares of energy sources in primary energy while all satisfying the decarbonisation requirement by 2050. Moreover, all decarbonisation routes achieve the same cumulative GHG emissions in 2011-2050.

Table 5: Fuel shares in primary energy consumption

		Reference/CPI		**Decarbonisation scenarios**	
	2005	2030	2050	2030	2050
RES	6,8%	18,4%-19,3%	19,9% - 23,3%	21,9% - 25,6%	40,8% - 59,6%
Nuclear	14,1%	12.1% - 14,3%	13,5% - 16,7%	8.4% - 13,2%	2,6% - 17,5%
Gas	24,4%	22,2% - 22,7%	20,4% - 21,9%	23,4% - 25,2%	18,6% - 25,9%
Oil	37,1%	32,8% - 34,1%	31,8% - 32,0%	33,4% - 34,4%	14,1% - 15,5%
Solid fuels	17,5%	12,0% -12,4%	9,4% - 11,4%	7,2% - 9,1%	2,1% - 10,2%

54 The scenarios are based on model assumptions, which are consistent with the input for the 2050 Low Carbon Economy Roadmap. Recognising the magnitude of the decarbonisation challenge, which implies a reversal of a secular trend towards ever increasing energy consumption, this Energy Roadmap has adopted a rather conservative approach as regards the effectiveness of policy instruments in terms of behavioural change. However, the Roadmap results should not be read as implying that the 20% energy efficiency target for 2020 cannot be reached effectively. Greater effects of the Energy Efficiency Plan are possible if the Energy Efficiency Directive is adopted swiftly and completely, followed up by vigorous implementation and marked change in the energy consumption decision making of individuals and companies. In modelling terms this means a significant lowering of the discount rate used in energy consumption decision making of hundreds of millions of consumers.

Renewables increase their share in primary energy substantially in all decarbonisation scenarios to reach at least 22% by 2030 and at least 41% by 2050. The RES share in primary energy is the highest in the High RES scenario (60% in 2050). The RES share is higher when calculated in terms of gross final energy consumption[55]- it represents at least 28% (2030) and 55% (2050) in all decarbonisation scenarios and rises up to 75% in 2050 in the High RES scenario. The share of renewables in power generation stands at 86% in 2050 in the High RES scenario and the share in power *consumption* is even higher at 97% in 2050.[56] RES share in power generation can be further increased by allowing for imports of renewable electricity from North Africa.

Nuclear developments have been affected by the policy reaction in some Member States after the nuclear accident in Fukushima. The share of nuclear varies depending on policy assumptions. In the Low nuclear scenario the nuclear share declines gradually to 3% by 2050. In the most ambitious nuclear scenario (Delayed CCS scenario), the share rises to 18%.

The share of gas is higher in the Current Policy Initiatives scenario compared to the Reference scenario, partly replacing nuclear. It increases slightly by 2050 in the Low nuclear scenario where the CCS share in power generation is around 32%. The oil share declines only slightly until 2030 due to the high dependency of transport on oil. However, the decline is significant in the last decade (2040-2050) when oil in transport is to a large extent replaced by biofuels and electricity. The share of solid fuels shrinks further to reach only 2-6% in all decarbonisation scenarios except in the Low nuclear scenario (10% in 2050).

Final energy demand declines similarly to primary energy demand. In the High Energy Efficiency scenario the reduction compared to the Reference scenario is -14% in 2030 and -40% in 2050. The decrease in the decarbonisation scenarios is at least -8% in 2030 and -34% in 2050. Sectors showing higher reductions than the average are residential, tertiary and generally also transport. There is a lot of structural change in the fuel composition of final energy demand. Given that it is highly efficient and emission free at use, electricity makes major inroads already under Current Policy Initiatives (increase by 9 pp in 2005-2050). The electricity share soars further in the decarbonisation scenarios reaching 36% - 39% in 2050 (almost doubling from current levels and becoming the most import final energy source), reflecting also its important role in decarbonising heating and transport. The crucial issue for any decarbonisation strategy is therefore the full decarbonisation of power generation.

Energy intensity reduces by at least 67% in the Delayed CCS scenario (2005-2050). It reduces by 70% in the High RES and Low nuclear scenarios and by 71% in the Energy Efficiency scenario in 2005-2050 (against a 53% improvement in the Reference scenario).

Emissions

All decarbonisation scenarios achieve 80% GHG reduction and close to 85% energy related CO2 reductions in 2050 compared to 1990 as well as equal cumulative emissions over the projection period. In 2030, energy-related CO2 emissions are between 38-41% lower, and total GHG emissions reductions are lower by 40-42%.

55 As specified in the RES directive for the calculation of the 20% target by 2020.

56 With much more variable supply and demand some electricity produced needs to be stored. Losses, linked to storage, lead to lower consumption than production of electricity. When calculating the RES-E share in line with the RES directive (focussing on gross final energy consumption i.e. excluding energy losses to pumped storage and hydrogen storage), the RES share in electricity consumption amounts to 97%.

Impacts on biodiversity, air pollution and other environmental impacts
The ranking of the different policy options as regards impacts on biodiversity, air pollution, water use and other environmental impacts depends on the implementation of different energy mixes. Some overall trends are presented below while some impacts are analysed in the Resource Efficiency Roadmap 2050 but with much less focus on energy.

In most scenarios, air pollution can be expected to decrease significantly, as this often goes hand in hand with GHG emissions. However, in some cases (especially if the energy mix leads to the development of small unregulated biomass plants), particulate matter (PM) and gaseous emissions could rise, causing local air pollution and regional acidification issues, although the overall effects can be expected to remain positive[57].

All options will impact land use and consequently biodiversity and other land-related ecosystem services. Indeed, any new infrastructure, be it in terms of grid development, power plant installations (nuclear, CCS, fossil), renewable infrastructure (sitting of wind mills, hydropower dams) will lead to land use changes and fragmentation, with potential negative impacts on biodiversity and on the services we receive from ecosystems. However, if the infrastructure development follows well established environmental rules, these potentially negative consequences can be limited[58]. Therefore, the pathways as such do not necessarily lead to land use and biodiversity problems, as this will depend on implementation. Consequences of mostly domestic RES are presented in terms of needs for domestic biomass[59] giving details for each scenario on the total use of biomass and biofuels in transport). The maximum amount of biofuels in 2050 would reach 300 Mtoe for use within the EU and 20 Mtoe for bunkers. The other decarbonisation scenarios have around 270 Mtoe including bunkers.[60] Still, there are also impacts of CO2 emissions related to land use, land use change and forestry due to increased bioenergy use.[61] As the biomass needed for energy will not only come from forests/forest-based industries, biowaste and residues, this will require considerable additional amounts of agricultural land.

In terms of water use, the consequences will depend on the energy mix. New hydropower projects (including pumped storage), the cultivation of some energy crops, and increased demand for water for cooling in the nuclear energy sector might exacerbate existing water shortages, increasing potential impacts on river morphology and groundwater availability, all this in a context of increasing EU temperatures and reduced water availability.

5.2. Economic impacts

Economic growth
The current report is part of a joint Commission analysis related to the transition to a low-carbon economy by 2050. Previous assessment by the Commission shows that the costs by

57 For a detailed analysis see SEC(2011)288, section 5.2.14.
58 For example by making sure that rich habitats are not fragmented, ensuring the integrity of Natura 2000 sites and the coherence and connectivity of its network. Green Infrastructure developments can lead to win-win situations, where negative environmental impacts of energy-related infrastructure can be mitigated while adaptation to climate change is enhanced, as well as public acceptance of alternative energy projects.
59 Annex 1, table 37, pages 83
60 The European Environment Agency assessed the amount of biomass that could be used in an environmental sustainable way in EU-25 by 2030 at 295 Mtoe.
61 For a detailed analysis of these interactions see SEC(2011)288, sections 5.1.4, 5.2.7 and 5.2.10.

2020 of putting the EU economy on a path that meets the long-term requirements for limiting climate change to 2°C would be limited compared to business-as usual, at around 0.2%-0.5% of GDP[62], with access to international carbon credits. Using the additional revenues from auctioning CO2 emissions allowances in EU ETS sectors and tax revenues from the non-ETS sectors to decrease labour costs would improve overall macroeconomic results leading to 0.4%-0.6% increase in GDP by 2020.

As regards the differentiated impact of policy options on economic growth, the long-term perspective implies that it is very difficult to go beyond a qualitative assessment. The Reference and CPI scenarios have higher fuel costs which do not generate much economic growth but require fewer investments in new technologies. On the contrary, the decarbonisation scenarios entail much higher investment in equipment and energy efficiency while lowering expenditure on fuels. These investments can generate further GDP growth and technologies may be exported worldwide if the EU keeps its front-runner position. Thus, policy scenarios which drive forward energy efficiency measures and investments in renewable energy technology have the potential to generate new industries, jobs and substantial economic growth. Although it is difficult to assess in details, such investments could also protect the EU economy against external energy price shocks[63].

An assessment of the macro-economic impact of the European decarbonisation objectives towards 2050 was performed in the European Climate Foundation's 2050 Roadmap[64]. It shows an annual GDP growth of 0.1% below the baseline scenario until 2015 but a reversal of the trend afterwards resulting in GDP being 2% above the baseline in 2050. Marginally positive effects remain under different sensitivity cases.

Energy system costs

The **total energy system costs** are costs for the entire energy system including capital cost, (for energy using equipment, appliances and vehicles), fuel and electricity costs, and direct efficiency investment costs (house insulation, control systems, energy management, etc) [65]. They exclude disutility costs[66] and auction payments[67].

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62 SEC(2010) 650, Commission Staff Working Document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage: Background information and analysis.

63 For further analysis of the role of energy price shocks see SEC(2011)288.

64 "Roadmap 2050: a practical guide to a prosperous, low-carbon Europe; Volume 1 – Technical and Economic Analysis" (European Climate Foundation, 2009)

65 As discussed in Annex 1, this represents a cautious approach. Whereas investment costs are displayed at their actual maximum levels, future benefits are priced in at a lower level.

66 Disutility costs are a concept that captures losses in utility from adaptations of individuals to policy impulses or other influences through changing behaviour and energy consumption patterns that might bring them on a lower level in their utility function. The PRIMES model has a micro-economic foundation which allows it to deal with utility maximisation and to calculate such perceived utility losses via the concept of compensating variations. While these costs capture relevant short term transition costs, their relevance and appropriate calculation over a long time horizon is challenging. This concept has to assume that preferences and values remain the same, even over 40 years, and it compares utility with a hypothetical state of no policy or no change in framework conditions. Examples of such decreases in utility are lowering thermostat in space heating, reducing cooling services in offices, switching lights off, staying at home instead of travelling, using a bicycle instead of a car, etc.

67 Auction payments are expenditures for individual sectors, and are not considered as costs for the economy as a whole, since the auctioning revenues are assumed to be recycled back into the economy in a neutral way. However, one could also have taken account of the shadow costs in making public

Table 6: Average annual total energy system cost (without auctioning and disutility)

Average annual total energy system costs 2011-2050

Bln. EUR'08	**Ref**	**CPI**	**High Energy effic.**	**Div. supply techn.**	**High RES**	**Delayed CCS**	**Low nuclear**
Capital cost	955	995	1115	1100	1089	1094	1104
Energy purchases	1622	1611	1220	1295	1355	1297	1311
Direct efficiency inv. costs	28	36	295	160	164	161	161
Total cost for final consumers excl. all auction payments and disutility	2582	2619	2615	2535	2590	2525	2552

Absolute Difference to Reference

Bln. EUR'08	**High Energy effic.**	**Div. supply techn.**	**High RES**	**Delayed CCS**	**Low nuclear**
Δ Capital cost	160	145	134	139	149
Δ Energy purchases	-402	-327	-267	-325	-312
Δ Direct efficiency inv. costs	267	132	135	133	133
Δ Total cost for final consumers excl. all auction payments and disutility	33	-47	8	-57	-29

Depending on the decarbonisation scenario, there are no or little additional average annual energy system costs due to the pursuit of major decarbonisation as part of a global effort compared with the Reference and CPI scenarios. Diversified supply technologies and Delayed CCS scenarios have the lowest level of average annual energy system costs, representing even a cost saving of around 90 bn €(08) compared with CPI (around 50bn € compared to the Reference scenario) mainly due to large fossil fuel import savings. Those two scenarios have the highest nuclear share[68].

The modelling results suggest that the highest total energy system costs will occur in the High Energy Efficiency scenario. Unlike the majority of other scenarios, the modelling of the High Energy Efficiency scenario does not rely entirely on economic optimisation in determining the level of energy consumption, but rather projects the impact of a set of energy efficiency measures (building retrofit etc.). In addition, the scenario pushes the limits of what the chosen measures can achieve (by assuming that the whole European building stock is fully refurbished; by making use of distributed renewable energy solutions as one of the more expensive renewable energy solutions; by amortising long-lived measures over a short time). Furthermore, it has to be taken into account that all policy scenarios already include considerable energy efficiency improvements and the cost difference merely indicates an

transfers and it is not guaranteed that this transfer would be purely neutral for the economy, as shown by the discussions on the optimal reallocation of auction revenues (see above).

68 When taking a macroeconomic view, i.e. by excluding auctioning revenue that are recycled to the economy, and excluding disutility costs, the Delayed CCS scenario has lower costs than the Diversified supply technologies scenario. However, when the economic actors' perspective is taken, i.e. auctioning and disutility costs are included, the lowest system costs materialise in the Diversified supply technology scenario (for details see Annex 1, part B, point 2.7).

increasing marginal cost for moving from a high to a very high level of energy efficiency (see Annex 1, part B for details). Finally, the modelling reflects significant transaction costs for energy efficiency investments in the form of relatively high weighted average costs of capital.

Cumulative auction payments are lowest in the High Energy Efficiency scenario due to the reduced energy consumption, decreasing emissions and therefore the necessity to buy ETS permits. The scenario with the highest auction revenues is Delayed CCS where the delay in the use of CCS leads to high carbon prices to ensure the achievement of the decarbonisation target in later years, which is made more challenging by the fact that CCS has not been able to move down the cost curve earlier. The auction revenues represent an equivalent of around 1% of total cumulative energy system costs.

All scenarios show higher annual costs in the last two decades 2031-2050 reflecting mainly increased investments in transport equipment as the major transition to electric and plug in hybrids vehicles is projected after 2030. In the High RES scenario costs are also linked to significant expansion of RES based power generation capacity.

The **ratio of energy system costs to GDP** is similar across the scenarios: ranging from around 14.1% to 14.6%, the costs of the Diversified supply technologies and delayed CCS scenarios being at the lower end of the range.

Table 7: Cumulative system costs related to GDP 2011-2050

	Cumulative system costs related to GDP
Reference	14.37%
CPI	14.58%
High Energy Efficiency	14.56%
Diversified supply technologies	14.11%
High RES	14.42%
Delayed CCS	14.06%
Low nuclear	14.21%

The **external fuel bill** arising from the net imports of fossil fuels decreases below 2005 levels in all decarbonisation scenarios by 2050. This result stems from the pursuit of major decarbonisation as part of a global climate effort with fossil fuel import prices expected to be much lower. The actual imports of fossil fuel due to energy efficiency and penetration of RES will be much lower too. These combined effects reduce the expenditure for each fossil fuel and thereby the total external fuel bill of the EU. The decrease of the fuel bill from 2005 in the decarbonisation scenarios is smallest in the Low nuclear scenario at 31% and highest in the High RES scenario at 43% with RES replacing most fossil fuels. Compared with the current level, all decarbonisation scenarios increase their fuel bill in 2030, but to much lower levels than the Reference and CPI scenarios. Savings in the external fuel bill are most striking in 2050. Compared with the CPI scenario, the EU economy could save in 2050 between 518 and 550 bn € (08) by taking this strong decarbonisation route under global climate action.

Impacts on competitiveness

Average prices of electricity are rising compared to 2005 in all scenarios including Reference and CPI scenarios (by a range of 41% in the High Energy Efficiency scenario to 54% in the Low nuclear scenario in 2030 and by 34% in the Diversified supply technologies to 82% in the High RES scenarios in 2050). Electricity prices are calculated in such a way that total costs of power generation, balancing, transmission and distribution are recovered, ensuring that investments can be financed. The residential sector has the highest user price and industry the lowest as is currently the case. Decarbonisation scenarios have lower fuel costs but tend to have higher capital investment costs that offer more business opportunities for domestic investments instead of fuel imports.

Due to depressed demand for electricity, the High Energy Efficiency scenario shows the lowest prices in 2030 for all sectors – even slightly lower than in the Reference scenario (which however exhibits a significant price increase from today's level). In 2050, electricity prices are lowest in the Diversified supply technologies scenario for all sectors, except industry, which faces slightly higher prices compared with the Reference and Current Policy Initiatives. In 2050, average electricity costs are highest in the High RES scenario while the Low nuclear scenario has the highest prices in 2030.

In this exercise, potential macroeconomic benefits from the development of "green technology" manufacturing and services sectors have not been quantified for the various policy scenarios.

Energy related costs for companies

Electricity prices for industry are the lowest among all sectors. The lowest increase occurs in the Diversified supply and Delayed CCS scenarios and the highest increase, similarly to average prices developments, in the High RES scenario. As the whole analysis is performed under the hypothesis of "global climate action", the whole world would decarbonise and would have to bear carbon prices, so the question of industrial competitiveness would not arise. More information on electricity costs is provided in Annex 1 (part B, point 2.7). If no global climate deal is reached and the EU is reducing emissions significantly more than other countries, certain industries supplying low carbon technologies will benefit from improved competitiveness due to higher internal demand and first mover advantage. However, for energy intensive industries it would be difficult to realise the prescribed GHG reductions without affecting their international competitiveness through higher carbon, fuel and electricity prices. This might be even more pronounced if reductions need to be achieved with CCS, which is a technology that has no other benefits than reducing GHG emissions.

Energy related costs in relation to sectoral value added rise from 5.8% in 2005 to 7.8% in 2030 in the Reference/CPI cases and to around 7.5% in the decarbonisation scenarios. In 2050, under current policies, this indicator declines to 7.5% and even more so in the decarbonisation scenarios falling to less than 7%.

Energy intensive industries face particularly high energy costs for their highly energy consuming production processes. Energy related costs in relation to sectoral value added for five industrial sectors (iron and steel, non-ferrous metals, non metallic mineral products, chemicals, paper and pulp industries) would rise under current trends, but would be markedly lower under global decarbonisation. Following lower world energy prices and due to energy efficiency improvements, the ratio of energy costs to value added would return to the 2005 level by 2050 in most decarbonisation scenarios, except for the Energy Efficiency scenario, which exhibits an even lower ratio.

ETS carbon prices

The ETS allowance price rises moderately from the current level until 2030 and significantly in the last two decades providing support to all low carbon technologies and energy efficiency. After 2020, the same carbon value applies also to non- ETS sectors assuring cost-efficient emissions abatement in the whole economy post 2020. Concrete policy measures such as those pushing energy efficiency and/or those enabling penetration of renewables depress demand for ETS allowances which subsequently lead to lower carbon prices. Carbon prices are the lowest in the High Energy Efficiency scenario with lowest energy demand followed by the High RES scenario (in 2030 and 2040) and Diversified supply technologies[69] (in 2050). Delay in penetration of technologies (CCS) or unavailability of one decarbonisation option (nuclear) put an upwards pressure on demand for allowances and ETS prices.

Table 8: ETS prices in €'08/t CO2

	2020	2030	2040	2050
Reference	18	40	52	50
CPI	15	32	49	51
High Energy Efficiency	15	25	87	234
Diversified supply technologies	25	52	95	265
High RES	25	35	92	285
Delayed CCS	25	55	190	270
Low nuclear	20	63	100	310

Impacts on infrastructure

Infrastructure[70] requirements differ between scenarios. Decarbonisation scenarios require increasingly more sophisticated infrastructures (mainly electricity lines, smart grids and storage) than Reference and CPI scenarios. The High RES scenario necessitates additional DC lines mainly to transport wind electricity from the North Sea to the centre of Europe and more storage.

Table 9: Grid investment costs (investments in transmission grid including interconnectors and investments in distribution grid including smart components).

(Bln Euro '05)	2011-2020	2021-2030	2031-2050	2011-2050
Reference	292	316	662	1269
CPI	293	291	774	1357
High Energy Efficiency	305	352	861	1518
Diversified supply technologies	337	416	959	1712
High RES	336	536	1323	2195
Delayed CCS	336	420	961	1717
Low nuclear	339	425	1029	1793

69 The difference in ETS prices compared to Effective and Widely accepted technologies presented in the Low Carbon Economy Roadmap is due to additional energy efficiency measures, the revised Energy Taxation Directive and changed assumptions for nuclear after Fukushima. The share of nuclear is considerably lower than in decarbonisation scenarios presented in the Low Carbon Economy Roadmap. Current Policy Initiatives and all policy scenarios in this exercise are based on revised assumptions on nuclear (abandonment of the nuclear programme in Italy, change of nuclear policy in Germany, no new nuclear plants in Belgium and upwards revision of costs for nuclear power plants). Moreover, electricity demand is lower due to stringent energy efficiency measures. In addition, assumptions on the potential of electricity in transport were revised, following more closely the scenarios developed in the White Paper on Transport leading to lower utilisation rate of nuclear power plants than in the Low Carbon Economy Roadmap Scenarios. Electric vehicles flatten electricity demand and thus incentivise baseload power generation.

70 A dedicated infrastructure modelling was performed with the PRIMES model and the main results are presented in Annex 1.

The model assumes that grid investments, that are prerequisites to the decarbonisation scenarios in this analysis, are undertaken and that costs are fully recovered in electricity prices. Reality might differ in the sense that the current regulatory regime might be more short to medium term cost minimisation oriented and might not provide sufficient incentives for long-term and innovative investments. There might also be less perfect foresight and lower coordination of investments in generation, transmission and distribution as the model assumes.

Impacts on internal market and competition

Electricity markets might change substantially with an increasing share of generation with close to zero marginal costs. A competitive market would in this situation lead to almost zero prices which would be insufficient to pay for upfront capital investments[71]. A different market design might be needed. While a specific regime for RES (e.g. feed-in tariffs) may be justified in certain situations (e.g. for new RES which are not yet competitive), every effort is needed to ensure that RES is integrated into the energy market, through support, regulatory and infrastructure policies. This is even more the case when RES becomes a significant share of overall energy production (especially in the high RES scenario).

Innovation and R&D

A goal of the Europe 2020 strategy[72] (underpinned by the Communication on the Innovation Union[73]) is to increase innovation in Europe and focus R&D and innovation policies on tackling major societal challenges such as climate change. The EU27 is already a world leader in some segments of low-carbon and energy efficient technologies (nuclear power plants, wind turbines, some energy efficient appliances, etc). All policy scenarios involve significant improvement in efficiency and cost parameters of new technologies as compared to the Reference scenario due to more economies of scale and faster learning rates. The deployment of CCS and some RES in the decarbonisation scenarios, for instance, implies a rate of capacity growth and innovation that is at least as great as that seen for energy technologies in the 20th century[74]. As a consequence all policy options are expected to further boost research and innovation, thereby also improving competitiveness. However, the magnitude of innovation between different policy options might differ. Moreover, impacts expected on innovations can hardly be grasped by current models.

Impacts on third countries

Impacts on third countries, mainly oil and gas importing countries would be significant. Imports in decarbonisation scenarios decrease sharply (besides gas imports in the Low nuclear scenario). In addition, global decarbonisation efforts lead to lower fossil fuel prices. So, under these particular circumstances the export revenues from European customers are 31 to 43% lower in 2050 than in 2005. In the mid-term, in 2030 all decarbonisation scenarios have a higher fuel bill compared to 2005 by at least 35%, but to much lower levels than the

[71] The modelling does not show this situation arising because the model assumes full cost recovery of capital investments in all scenarios

[72] Europe 2020 COM(2010) 2020

[73] EU 2020 Flagship Initiative Innovation Union SEC(2010) 1161

[74] The fastest previous scale-up was for electricity generation from nuclear power, which expanded at a rate of approximately 25-30% per year between 1960 and 1980 globally. The decarbonisation scenarios almost all envisage a major roll-out of CCS starting after 2030 and reaching average rates of up to 36% per year in 2030-2040 (20% pa in 2030-2050); similarly but closer to now, certain RES technologies could be soaring, especially from 2010 to 2030 at average annual rates of up to 20% and 15% per year for off-shore wind and solar electricity, respectively.

Reference and Current Policy Initiative scenarios[75]. (See also section on Energy system costs).

There is no major impact on electricity trade, which remains marginal with third countries. The increased global use of biomass for energy purposes might have impacts on food prices and input costs of other biomass-using industries.

Impacts on prices for biomass and land prices
Bioenergy is expected to be an important part of any low-carbon energy strategy. This might have impacts on prices for biomass from agriculture and forest-based industries either directly through increased demand for energy use, or through increased demand for land and thus higher land prices. As most of the biomass used for energy has competing uses (food and feed, renewable raw materials), food prices and input costs of other biomass-using industries are likely to increase.

5.3. Social impacts

Impacts on employment
The social dimension of decarbonisation is crucial as transition to a low carbon economy will require an in depth change in several sectors, affecting companies, employment and working conditions. Education and training need to be addressed at an early stage in order to avoid unemployment in some sectors and labour shortages in others. More knowledge should be gathered about the social implications of deep and long-term decarbonisation as no studies are available yet. Consultations, also in the context of the social dialogue, could improve the follow-up work on the decarbonisation roadmaps[76], including decarbonisation of the energy sector.

Employment effects of decarbonisation policies up to 2020 are generally ambiguous and difficult to assess. A direct positive effect of relative growth in the "green" technology sector is that some subsectors like energy efficiency in buildings are usually assumed to have a relatively high labour intensity. Indirect positive effects for employment may include increased innovation resulting from stricter environmental policy, increased export potential for green technologies, as well as less fossil fuel imports. Negative effects may include transition costs, such as inflexibilities in the labour market to respond to changes in skill demand. There is uncertainty as to whether positive or negative effects would dominate.

However, most studies that evaluate the net employment effects of the EU's 20-20-20 targets record impacts of typically ±1%[77]. A recent extensive macroeconomic study suggests that net employment effects for meeting the EU's targets for 2020 will be small and positive, leading to an average increase in employment demand of up to 0.3%[78]. The two scenarios with the

[75] No further analysis has been done as regards the impact of increased revenues of oil and gas exporting countries on imports from the EU.

[76] The social dimension might be better tackled in a decarbonisation roadmap treating all the interdependencies among sectors such as energy, transport, industry and agriculture than in a sectoral roadmap dealing with energy only.

[77] See literature review section in the report "Studies on Sustainability Issues- Green Jobs; Trade and Labour" (2011) commissioned by the European Commission, DG Employment.

[78] "Studies on Sustainability Issues- Green Jobs; Trade and Labour" (2011) commissioned by the European Commission. The leading objective has been to analyse the employment consequences of the implementation of policies to achieve the key EU environmental targets of a 20% cut in emissions of GHG by 2020 compared to 1990 levels (increasing to 30% if other countries make similar

most ambitious targets (30% GHG emission reductions by 2020, achieving the 20% energy efficiency target) have the highest net effects on employment. Similarly, a 2009 study[79] finds modestly positive net employment effects of up to 0.1% for supporting policies to meet the 2020 RES targets. An assessment of net employment effects of the European decarbonisation objectives towards 2050 was performed in the European Climate Foundation's 2050 Roadmap[80]. It expects net employment to initially be marginally negative and turn positive at a later stage: employment in the decarbonisation scenario is 0.06% below the baseline by 2020 and 1.5% higher than the baseline in 2050. An estimate of net employment effects until 2030 and some quantitative examples of job creation in certain sectors are provided in the IA report on Low Carbon Economy Roadmap[81].The net impact on jobs can be an increase by 0.7% compared to the Reference scenario, corresponding to 1.5 million jobs by 2020.

The overall effects of the increased investment in green technologies on the labour market are thus expected to be fairly modest relative to the effects of other developments such as globalisation, technical progress and demographic change. On a sectoral level, a small increase in jobs in the engineering and construction sectors and a decrease in the energy supplying sectors might arise. The effects on the energy-intensive sectors are ambiguous. Higher energy prices may lead to losses in competitiveness on the one hand while there would also be increased demand for goods from the sector (such as steel and concrete) on the other. However, by focussing on sectoral gains and losses, potentially significant impacts at a more micro level may not be captured in these studies. Also, regional differences may be significant.

As the whole analysis was done in a global climate effort context, there are no job losses due to carbon leakage. However the decision by companies to relocate production away from the EU may be related to other factors such as access to markets or raw materials or secure access to energy sources with long-term price guarantees.

Quality of jobs

The more investments are made in new technologies – many of which are likely to be energy saving or related to new forms of energy generation – the more demand there will be for people in higher skilled jobs (especially professional and associate professional ones). In this way, the greening of the economy can stimulate the demand for highly skilled (and high waged) workers, although the extent to which this will occur even under the most optimistic of scenarios is relatively modest when compared to the business as usual scenario.

Affordability

Affordability of energy services as regards costs for fuel and electricity as well as for equipment, appliances, insulation and transport services is one of the essential elements of the analysis. The sector most concerned is households. All decarbonisation scenarios show significant fuel savings compared to the Reference and CPI scenarios but also higher costs for energy appliances and insulation.

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commitments), a 20% increase in the share of renewable energy, and the objective of a 20% cut in energy consumption (the 20-20-20 targets).

79 "EmployRES: The impact of renewable energy policy on economic growth and employment in the European Union" (2009), commissioned by the European Commission, DG Transport and Energy

80 "Roadmap 2050: a practical guide to a prosperous, low-carbon Europe; Volume 1 – Technical and Economic Analysis" (European Climate Foundation, 2009)

81 SEC(2011) 288 final page 44 and 90-91

Energy related expenditures of households for heating, cooling, lighting, cooking, appliances i.e. excluding transport services, almost double from around 2000 EUR'08 today to 3800-3900 EUR'08 in 2050 in the Reference and CPI scenarios reflecting rising fuel and electricity prices and increasing direct household investments in energy efficiency. Expenditures per household amount to around 4500 EUR'08 in most decarbonisation scenarios in 2050, with expenditure per household reaching some 4800 €(08) and almost 4900 €(08) in the Energy Efficiency and High RES scenarios respectively. It is important to note that per capita income in 2050 will also almost double from today's level, but also that households will be composed of fewer members reflecting aging and changing lifestyles. Energy costs for stationary uses per household exceed the Reference/CPI case level by 16-17% in 2050 in most decarbonisation scenarios. They are 25-27% higher in the Energy Efficiency and High RES scenarios, as these scenarios are particularly investment intensive.
However, energy expenditures including expenses for transport services as a percentage of household expenditure show a different picture. They rise over time in all scenarios from 10% in 2005 to around 16% in 2030, stabilising thereafter to around 15-16% by 2050. Among the decarbonisation scenarios, the costs of the Delayed CCS and the Diversified Supply Technology scenarios, similar to the Reference and CPI scenarios, are at the lower end of this range, whereas the High RES and Energy efficiency scenarios show 2050 costs at the upper end. To the extent that vulnerable consumers would incur similar expenditure increases, in particular the necessary upfront investment to realise later savings may pose an affordability challenge for them.

Security of supply
Import dependency, one of the indicators of security of supply, does not change substantially in 2030 in decarbonisation scenarios compared to the Reference scenario and Current Policy Initiatives scenario due to declining gross inland consumption and imports. There is however a substantial decrease in 2050, driven by increased use of domestic resources, mainly renewables. Import dependency is only 35% in the High RES scenario[82] (compared to 58% in the Reference and CPI scenarios) and 39-40% in the other decarbonisation scenarios besides the Low nuclear scenario (45% due to significant use of fossil fuels with CCS). Decarbonisation will significantly reduce fossil fuel security risks.

Large scale electrification combined with more decentralised power generation from variable sources brings other challenges to high quality energy service at any time. However, there are no standardised indicators for the time being. Moreover, adequate stability of the grid is a precondition for modelling, which is why differences in indicators on the stability of the grid are rather small across scenarios[83].

Safety and public acceptance
Safety concerns might be raised against some power generation technologies as well as against infrastructure and exploration of energy fuels. The public in general perceives technological risks as more important than expert judgement would suggest. Across Europe, public acceptance of different generation technologies and infrastructures differs, but none of them is 100% accepted by local communities where they are (going to be) located. A better and more targeted communication with the concerned public and stakeholders might be needed in the future to assure the EU's energy needs.

Table 10: Selected results of scenario analysis

[82] High RES scenario relies mainly on domestic sources of renewable energy.
[83] Please see more specialised indicators in Annex 1, part B, section 2.5.

			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)[84]	2030		-5.3	-10.8	-20.5	-16	-17.3	-16.1	-18.5
	2050		-3.5	-11.6	-40.6	-33.3	-37.9	-32.2	-37.7
Electrification	2030	20.2	25.1	24.5	25.2	26.0	25.4	26.0	25.7
	2050	-	29.1	29.4	37.3	38.7	36.1	38.7	38.5
Fuels (in %)									
Renewables in gross final energy	2030	8,6	23.9	24.7	27.6	27.7	31.2	28	28.8
	2050	-	25.5	29	57.3	54.6	75.2	55.7	57.5
CCS in power generation	2030	0	2.9	0.8	0.7	0.8	0.6	0.7	2.1
	2050	-	17.8	7.6	20.5	24.2	6.9	19	31.9
Nuclear energy in primary energy	2030	14,1	14.3	12.1	11.1	13.9	9.7	13.2	8.4
	2050	-	16.7	13.5	13.5	15.3	3.8	17.5	2.6
Fuels in electricity generation (in%)	2030	14.3	40.5	43.7	52.9	51.2	59.8	51.7	54.6
RES	2050	-	40.3	48.8	64.2	59.1	86.4	60.7	64.8
	2030	0.0	2.9	0.8	0.7	0.8	0.6	0.7	2.1
CCS	2050	-	17.8	7.6	20.5	24.2	6.9	19.0	31.9
	2030	30.5	24.5	20.7	18.6	21.2	15.8	21.5	13.4
NUC	2050	-	26.4	20.6	14.2	16.1	3.6	19.2	2.5
Average electricity prices (in EUR'08 per MWh, after tax)[85]	2030	109,3	154,8	156,0	154,4	159,6	164,4	160,4	168,2
	2050	-	151,1	156,9	146,7	146,2	198,9	151,9	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	52,5	56.4	57.5	56.1	55.2	55.3	54.9	57.5
	2050	-	57.6	58.0	39.7	39.7	35.1	38.8	45.1

Source: PRIMES modelling

Table 11: Summary of impacts

	1 Reference scenario	1bis Current Policy Initiatives	2 High Energy Efficiency	3 Diversified supply technologies	4 High RES	5 Delayed CCS	6 Low nuclear
Environmental impacts							
Energy consumption/Energy intensity			+ + +	+	+ +	+	+ +
RES share		+	+ +	+ +	+ + +	+ +	+ +
Energy related CO2 emissions		=	+ + +	+ + +	+ + +	+ + +	+ + +
Economic impacts							
Economic growth		=	=	=	=	=	=
Competitiveness		=	+	+	+	+	+

[84] 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.

[85] 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.

Energy security (import dependency and imports from third countries)		=	+ +	+ +	+ + +	+ +	+
Social impacts							
Employment		=	+ +	+	+ +	+	+
Quality of jobs		=	+ +	+ +	+ +	+ +	+ +
Affordability		=	-	=	-	=	=

Legend:
= equivalent to Reference scenario
+ to +++ improvement compared to Reference scenario
- to - - - worsening compared to Reference scenario

5.5 Sensitivity analysis

It is clear that the robustness of modelling results is affected by the assumptions underlying the modelling scenarios. As outlined in section 2.4, sensitivity analysis has been carried out for the Reference scenario by varying two key parameters – GDP and energy import prices. The conclusions on GDP analysis are quite robust showing that key policy indicators do not vary significantly with GDP given feedback mechanisms and the architecture of EU energy and climate policies (ETS). Following this pattern, a similar outcome might be expected for policy scenarios even though it has not been demonstrated by current analysis. This holds also for variations in energy import prices, although the results are somewhat less stable regarding certain indicators, such as import dependency. Impacts of additional variations in import price assumptions in decarbonisation scenarios (very high oil price and oil shock scenarios) were analysed in the Low Carbon Economy Roadmap.

Constant climate conditions were assumed over time. This simplification may be justified given that all decarbonisation scenarios assume that the climate targets are met. However, even when temperature changes are limited to 2 degree Celsius, some climate impacts will occur.[86] In addition, changes in temperature will lead to changes in energy demand patterns for heating and cooling. It can hence be expected that decarbonisation leads to further positive economic impacts with regard to energy security and competitiveness by avoiding parts of the expected damage and adaptation costs in the energy system due to climate change impacts.

Other assumptions are embedded in the design of policy scenarios. Policy scenarios assume different costs and timing of technology (delay of CCS, faster penetration of RES) and can therefore be interpreted as sensitivity analysis on R&D and learning curves for main technologies. Changes in other sectors such as a higher uptake of electricity in transport, were implicitly studied in this report by assuming that the main thrust of the policies included in the

86 A literature review on climate change impacts in the European energy supply sector as part of the European Commission contract "Climate proofing EU policies" has identified the following main impacts:

- Cooling water constraints for thermal power generation (especially during heat waves), with nuclear appearing to be the most vulnerable technology
- Damage to offshore or coastal production facilities due to sea level rise and storm surges
- Damage to transmission and distribution lines due to storm events, flooding
- Unpredictable hydropower potential
- Affected yield in renewable energy sector (hydropower in Southern Europe, possibly biofuels due to vector diseases and forest fires)
- Melting permafrost affecting energy production and distribution in cold climates
- Damages and output constraints in wind energy due to storms and increased average wind speed

2011 White Paper on Transport is also pursued in these decarbonisation scenarios. No additional transport related policies were examined.

6. SECTION 6: COMPARING THE OPTIONS

This section provides an assessment of how the policy options will contribute to the realisation of the policy objectives, as set in Section 3, in light of the following evaluation criteria:

– **effectiveness** – the extent to which options achieve the objectives of EU energy policy[87];
– **efficiency** – the extent to which objectives can be achieved at least cost;
– **coherence** – the extent to which policy options are likely to limit trade-offs across the economic, social, and environmental domains.

Effectiveness

As regards effectiveness, the three objectives of energy policy – sustainability, security of supply and competitiveness - were taken into account. All policy scenarios were designed to reach 85% reduction of energy related CO2 emissions in 2050, so all are effective in that sense. It should be noted that some scenarios are highly dependent on success of new technologies that are still under demonstration or only partly proven commercially (CCS, off-shore wind, 3rd generation nuclear etc). For the other two objectives the question of most suitable indicators arises. As regards security of supply, all policy scenarios improve import dependency, the best being the High RES scenario with 35% import dependency in 2050 and the least effective the Low nuclear scenario with 45% in 2050 (as compared to 58% in the Reference scenario). However, in a more electrified world, stability of the grid might be of much higher concern with major challenges ahead that can be met as demonstrated by the modelling of the scenarios. As regards competitiveness, some scenarios show a small decrease in electricity prices as compared to the Reference and CPI scenarios (High Energy Efficiency, Diversified supply technologies) while some others show increases (High RES and to a lesser extent Low nuclear). ETS prices are significantly higher than in the Reference and CPI scenarios with the highest values in Delayed CCS scenario and lowest in High Energy Efficiency scenarios where decarbonisation is triggered also by specialised measures. The model triggers adequate investments which are driven by specific policies or carbon prices and investment decisions are based on perfect foresight assumption. All decarbonisation scenarios foster innovation and R&D.

Efficiency

In terms of efficiency, the analysis demonstrates that the costs of decarbonisation of the energy system are not substantially higher compared to the Reference scenario and most decarbonisation scenarios even show a lower annual average cost than the CPI scenario. The least costly scenarios are Delayed CCS and Diversified Supply Technologies scenarios with significant penetration of nuclear.

Coherence

All policy scenarios are coherent with other EU long term objectives (on climate, transport, etc). There is no clear winner among policy options scoring the best in all criteria and several trade-offs will need to be taken into account. The role of this analysis is not to select one

[87] It has been considered more useful to check scenarios against objectives of the EU energy policy than against those of the Roadmap that focus on instruments and processes to deliver more certainty to investors.

preferred pathway but rather to identify the pros and cons of different options and identify common elements from all of them.

Table 12: Comparison of policy scenarios to the Reference scenario

	1bis. Current Policy Initiatives	2. High Energy Efficiency	3. Diversified supply technologies	4. High RES	5. Delayed CCS	6. Low nuclear
Effectiveness						
Sustainability	=	+ + +	+ + +	+ + +	+ + +	+ + +
Security of supply	=	+ +	+ +	+ + +	+ +	+
Competitiveness	=	+	+	+	+	+
Efficiency						
Additional annual average total costs relative to Reference scenario in bn EUR'08	37	33	-47	8	-57	-29
Additional annual average total costs as % of GDP	0.21%	0. 19%	-0.26%	0.05%	-0.31%	-0.16%
Coherence						
Trade-offs between economic, social and environmental impacts		Scenario reducing the most energy consumption and significantly improving import dependency but rather costly for households and difficult to implement when it comes to behavioural changes	Scenario with lowest cost from the economic actors' point of view, significant energy efficiency gains and renewables shares but depending on success (technological progress of CCS and some RES as well as public acceptance of nuclear and CCS)	Scenario showing the highest penetration of RES; highest decrease in import dependency and second strongest reduction of energy consumption pushing innovation in new technologies, but rather costly and leading to highest electricity prices	Scenario with lowest costs scoring well on security of supply, RES penetration and competitiveness but the least effective in terms of energy efficiency; rather strong reliance on nuclear being contingent on absence of further public acceptance problems	Scenario scoring well on costs, RES shares and energy efficiency but still with high consumption of fossil fuels and dependency on their imports. Heavily dependent on technological progress and acceptance of CCS

Legend:
= equivalent to Reference scenario
+ to +++ improvement compared to Reference scenario
- to - - - worsening compared to Reference scenario

Conclusions

The Commission services conducted a model-based analysis of decarbonisation scenarios exploring energy consequences of the European Council's objective to reach 80% GHG reductions by 2050 (as compared to 1990), provided that industrialised countries as a group undertake similar efforts. These scenarios explore also the energy security and competitiveness dimension of such energy developments. Businesses as usual projections show only half the GHG emission reductions needed; increased import dependency, in particular for gas; and rising electricity prices and energy costs. Several decarbonisation scenarios highlighting the implications of pursuing each of the four main decarbonisation routes for the energy sector – energy efficiency, renewables, nuclear and CCS - were examined by modelling a high and low end for each of them. The model relies on a series of input assumptions and internal mechanisms to provide the outputs.

The most relevant assumptions and mechanisms of the model

- All scenarios were conducted under the hypothesis that the whole world is acting on climate change which leads to lower demand for fossil fuel prices and subsequently lower prices.
- The model assumes perfect foresight regarding policy thrust, energy prices and technology developments which assures a very low level of uncertainty for investors, enabling them to make particular cost-effective investment choices without stranded investments. There is also no problem with uncertainty on whether all the infrastructure and other interrelated investment needed to make a particular investment work will be in place in time.
- Regulatory framework in model allows for investments to be built and costs fully recovered.
- The model assumes a "representative" or average household or consumer while in reality there is a more diversified picture of investors and consumers.
- The model assumes continuous improvements of technologies.

The model-based analysis has shown that decarbonisation of the energy sector is feasible; that it can be achieved through various combinations of energy efficiency, renewables, nuclear and CCS contributions; and that the costs are affordable. The aim of the analysis was not to pick preferred options, a choice that would be surrounded with great uncertainty, but to show some prototype of pathways to decarbonise the energy system while improving energy security and competitiveness and identify common features from scenario analysis.

Common elements to scenario analysis

- There is a need for an integrated approach, e.g. decarbonisation of heating and transport relies heavily on the availability of decarbonised electricity supply, which in turn depends on very low carbon investments in generation capacity as well as significant grid expansions and smartening.
- Electricity (given its high efficiency and emission free nature at use) makes major inroads in decarbonisation scenarios reaching a 36-39% share in 2050 (almost doubling from the current level and becoming the most important final energy source). Decarbonisation in 2050 will require an almost carbon free electricity sector in the EU, and around 60% CO2 reductions by 2030.
- Significant energy efficiency improvements happen in all decarbonisation scenarios. One unit of GDP in 2050 requires around 70% less energy input compared with 2005. The average annual improvement in energy intensity amounts to around 2.5% pa.
- The share of renewables rises substantially in all scenarios, achieving at least 55% in gross final energy consumption in 2050, up 45 percentage points from the current level (a high RES case explores the consequences of raising this share to 75%).
- The increased use of renewable energy as well as energy efficiency improvements require modern, reliable and smart infrastructure including electrical storage.
- Nuclear has a significant role in decarbonisation in Member States where it is accepted in all scenarios (besides Low nuclear and High RES), with the highest penetration in case of CCS delay.
- CCS contributes significantly towards decarbonisation in most scenarios, with the highest penetration in case of problems with nuclear investment and deployment. Developing CCS can be also seen as an insurance against energy efficiency, RES and nuclear (in some Member States) delivering less or not that quickly.
- All scenarios show a transition from high fuel/operational expenditures to high capital expenditure.
- Substantial changes in the period up to 2030 will be crucial for a cost-efficient long term transition to a decarbonised world[88]. Economic costs are manageable if action starts early so that the

[88] Scenarios for the Low Carbon Economy Roadmap of March 2011 show the additional costs of delayed action.

restructuring of the energy system goes in parallel with investment cycles thereby avoiding stranded investment as well as costly lock-ins of medium carbon intensive technology.

- The costs of such deep decarbonisation are low in all scenarios given lower fuel procurement costs with cost savings shown mainly in scenarios relying on all four main decarbonisation options.
- Costs are unequally distributed across sectors, with households shouldering the greatest cost increase due to higher costs of direct energy efficiency expenditures in appliances, vehicles and insulation.
- The external EU energy bill for importing oil, gas and coal will be substantially lower under decarbonisation due to a substantial reduction in import quantities and prices dependent on global climate action lowering world fossil fuel demand substantially.

Some policy relevant conclusions can be drawn based both on the results of the scenario analysis as well as on a comparison of the hypothetical situation of ideal market and technological conditions needed for modelling purposes and what is found in the much more complex reality.

Implications for future policy making

- Successful decarbonisation while preserving competitiveness of the EU economy is possible. Without global climate action, carbon leakage might be an issue and appropriate instruments could be needed to preserve the competitiveness of energy intensive industries.
- Predictability and stability of policy and regulatory framework creates a favourable environment for low carbon investments. While the regulatory framework to 2020 is mainly given, discussions about policies for 2020-2030 should start now leading to firm decisions that provide certainty for long-term low-carbon investments. Uncertainty can lead to a sub-optimal situation where only investment with low initial capital costs is realised.
- A well functioning internal market is necessary to encourage investment where it is most cost-effective. However, the process of decarbonisation brings new challenges in the context, for example, of electricity price determination in power exchanges: deep decarbonisation increases substantially the bids based on zero marginal costs leading in many instances to prices rather close to zero, not allowing cost recovery in power generation. Similarly, the necessary expansion and innovation of grids for decarbonisation may be hampered if regulated transmission and distribution focuses on cost minimisation alone. Building of adequate infrastructure needs to be assured and supported either by adequate regulation and/or public funding (e.g. financed by auctioning revenues).
- Energy efficiency tends to show better results in a model than in reality. Energy efficiency improvements are often hampered by split incentives, cash problems of some group of customers; imperfect knowledge and foresight leading to lock-in of some outdated technologies, etc. There is thus a strong need for targeted support policies and public funding supporting more energy efficient consumer choices.
- Strong support should be given to R&D in order to bring costs of low-carbon technologies down and to minimize potential negative environmental and social side-effects.
- Due attention should be given to public acceptance of all low carbon technologies and infrastructure as well willingness of consumers to undertake implied changes and bear higher costs. This will require the engagement of both the public and private sectors early in the process.
- Social policies might need to be considered early in the process given that households shoulder large parts of the costs. While these costs might be affordable by an average household, vulnerable consumers might need specific support to cope with increased expenditures. In addition, transition to a decarbonised economy may involve shifts to more highly skilled jobs, with a possibly difficult adaptation period.
- Flexibility. The future is uncertain and nobody can predict it. That is why preserving flexibility is important for a cost efficient approach, but certain decisions are needed already at this stage in order to start the process that needs innovation and investment, for which investors require a reasonable degree of certainty from reduced policy and regulatory risk.

- External dimension, in particular relations with energy suppliers, should be dealt with pro-actively and at an early stage given the implications of global decarbonisation on fossil fuel export revenues and the necessary production and energy transport investments during the transition phase to decarbonisation; new areas for co-operation could include renewable energy supplies and technology development.

7. MONITORING AND EVALUATION

The Roadmap is not a one-off exercise and will be regularly updated taking into account the most recent developments. In addition, the Commission will constantly monitor a set of core indicators which are already available and are being currently used. Other indicators might be added at a later stage.

Table 12: Key indicators and their relevance

KEY INDICATORS	2009	RELEVANCE
Share of RES in gross final energy consumption	10.3% (2008)	Increase in RES use in the economy
Share of renewable energy in transport	3.5% (2008)	Increase in RES use in the transport
Energy intensity	165.48 (toe/M€ '00)	Increase in energy efficiency
Gross inland consumption (by fuel)	1703 Mtoe http://ec.europa.eu/energy/publications/statistics/doc/2011-2009-country-factsheets.pdf	Changes in the overall demand and composition of energy mix over time; existing indicative energy saving objective for 2020
Energy per capita	3403 kgoe/cap	Evolution of energy consumption relative to population growth
Final energy consumption (by fuel and by sector)	1114 Mtoe http://ec.europa.eu/energy/publications/statistics/doc/2011-2009-country-factsheets.pdf	Decrease in absolute energy consumption and effectiveness of energy efficiency policies as well as sectoral developments
Electricity generation	3210 TWh	Electrification of the economy
Energy related CO2 emissions	4055 MT CO2	Trends in the emissions from the energy sector; lion's share in total GHG emissions
Import dependency for all fuels	54%	Vulnerability to imports from third countries
Electricity prices	http://ec.europa.eu/energy/observatory/electricity/electricity_en.htm http://ec.europa.eu/energy/observatory/reports/EnergyDailyPricesReport-EUROPA.pdf	Competitiveness of European industry and affordability for households
Diesel and petrol prices in different MS	http://ec.europa.eu/energy/observatory/oil/bulletin_en.htm	Evolution in prices of transport fuels and their convergence across the EU 27
Total GHG emissions compared to 1990	-17.4% http://ec.europa.eu/clima/policies/g-gas/docs/com_2011_624_en.pdf	Meeting climate targets

8. ANNEXES

Annex 1 Scenarios - assumptions and results

Annex 2 Report on Stakeholders scenarios

Annex 1 Scenarios – assumptions and results

This document describes in detail the assumptions and results of the Reference scenario 2050 and its sensitivities, Current Policy Initiatives scenario and decarbonisation scenarios developed for the purposes of the Energy Roadmap 2050.

The Commission contracted the National Technical University of Athens to model scenarios underpinning the Impact Assessment analysis. Similar to previous modelling exercises with the PRIMES model, the Commission discloses a lot of details about the PRIMES modelling system, modelling assumptions and modelling results. In this tradition, the Commission services, based on the modelling results and analysis on specific topics from NTUA, have drafted the following comprehensive overview of the macroeconomic, world energy price, policy, technology and other assumptions as well as the detailed results of the current trend scenarios including sensitivities (Part A) and the various decarbonisation scenarios (Part B). This is complemented with the attachments to this document giving further details.

The PRIMES model was peer-reviewed by a group of recognised modelling experts in September 2011 with the conclusion that the model is suitable for the purpose of complex energy system analysis.

Reference scenario is based on the scenarios up to 2030 published in the report "Energy Trends to 2030: update 2009", but extends the projection period to 2050. It includes current trends on population and economic development and takes into account the highly volatile energy import price environment. Economic decisions are driven by market forces and technology progress in the framework of concrete national and EU policies and measures implemented until March 2010. These assumptions together with the current statistical situation derived from the Eurostat energy balances represent the starting point for projections which are presented from 2010 onwards in 5 year steps until 2050. The 2020 targets on RES and GHG will be achieved, but there is no assumption on targets for later years. Sensitivities on higher/lower economic growth and higher/lower energy import prices were undertaken in order to assess the robustness of policy relevant indicators with respect to these framework conditions for EU energy policy.

The overall policy context has developed since the Reference scenario was established in 2010. Therefore an additional trend scenario has been modelled including policies that are being prepared with a view to the 2020 Energy Strategy. The **Current Policy Initiatives scenario** includes the same macroeconomic and demographic assumptions as the Reference scenario, slightly updated energy import prices (only for 2010 with repercussions on 2015), revised cost-assumptions for nuclear following post Fukushima reactions and policies either adopted after March 2010 or being currently proposed by the Commission.

In addition to their role as a trend projection, the Reference and the Current Policy Initiatives scenarios are benchmarks for energy scenarios achieving the European Council's objective to reduce GHG by 80-95% below the 1990 level as part of industrialised countries as a group undertaking such a reduction effort. Comparisons of other scenarios with the Reference scenario concern questions related to the additional policies with respect to those already implemented in the Member States. Distinct from this, comparisons of the Current Policy Initiatives scenario with decarbonisation scenarios address further policies that might be envisaged in addition to those being proposed in the context of the 2020 Energy Strategy. Such comparisons on the basis of the Current Policy Initiatives scenario deal with new policies that might be debated under a 2030 horizon, which is an important milestone year on the decarbonisation pathways to 2050.

Decarbonisation scenarios in the Energy Roadmap 2050 have been designed to provide more detail on the analysis of the energy sector that was presented in the Low Carbon Economy Roadmap. Scenarios showing different energy related decarbonisation pathways reach the 85% domestic energy related CO2 emission reductions by 2050 as compared to 1990 which is consistent with the required contribution of developed countries as a group to limit global climate change to a temperature increase of 2ºC compared to pre-industrial levels. All decarbonisation scenarios developed for the Low carbon Economy Roadmap show around 85% reductions of energy related CO2 emissions.

The scenarios modelled for the 2050 Energy Roadmap investigate in great depth the main strategic directions (energy efficiency, RES, CCS and nuclear) towards a decarbonised European energy system. In doing so, they reflect for each of these directions or main ways of decarbonisation a low and a high end option. This underlines the fact that there are many different pathways for reaching the same level of decarbonisation in the EU.

All numbers included in this report, except otherwise stated, refer to European Union of 27 Member States.

PART A: REFERENCE SCENARIO AND ITS SENSITIVITIES AND CURRENT POLICY INITIATIVES SCENARIO

1. ASSUMPTIONS

1.1 Macroeconomic and demographic assumptions

The population projections draw on the EUROPOP2008 convergence scenario (EUROpean POPulation Projections, base year 2008) from Eurostat, which is also the basis for the 2009 Ageing Report (European Economy, April 2009)[89]. The key drivers for demographic change are: higher life expectancy, low fertility and inward migration.

The macro-economic projections reflect the recent economic downturn, followed by sustained economic growth resuming after 2010. The medium and long term growth projections follow the "baseline" scenario of the 2009 Ageing Report (European Economy, April 2009), which derives GDP growth per country on the basis of variables such as population, participation rates in the labour market and labour productivity.[90] Based on the Ageing Report the Commission services developed a common Reference scenario, the macroeconomic part of which is referred to below. Further details relating notably to the sectoral value added can be found in the report "EU Energy Trends to 2030".[91] The same macroeconomic assumptions were already used for the "Roadmap for moving to a competitive low-carbon economy in 2050" of March 2011.[92]

The Reference scenario assumes that the recent economic crisis has long lasting effects, leading to a permanent loss in GDP. The recovery from the crisis is not expected to be so vigorous that the GDP losses during the crisis are fully compensated. In this scenario, growth prospects for 2011 and 2012 are subdued. However, economic recovery enables higher productivity gains, leading to somewhat faster growth from 2013 to 2015. After 2015, GDP growth rates mirror those of the 2009 Ageing Report. Hence the pattern of the Reference scenario is consistent with the intermediate scenario 2 "sluggish recovery" presented in the Europe 2020 strategy[93].

The average growth rate for EU-27 is only 1.2% per year for 2000-2010, while the projected rate for 2010-2020 is recovering to 2.2%, similar to the historical average growth rate between 1990 and 2000. GDP increases in line with the Ageing Report developments, depicting declining growth rates over time as well as great variation among Member States. Recovering from the crisis (reflected by only 0.6% pa GDP growth in 2005-2010), EU-27

[89] European Commission, DG Economic and Financial Affairs: 2009 Ageing Report: Economic and budgetary projections for the EU-27 Member States (2008-2060). EUROPEAN ECONOMY 2|2009, http://ec.europa.eu/economy_finance/publications/publication14992_en.pdf. The "baseline" scenario of this report has been established by the DG Economic and Financial Affairs, the Economic Policy Committee, with the support of Member States experts, and has been endorsed by the ECOFIN Council.

[90] European Commission, DG Economic and Financial Affairs: 2009 Ageing Report: Economic and budgetary projections for the EU-27 Member States (2008-2060). EUROPEAN ECONOMY 2|2009, http://ec.europa.eu/economy_finance/publications/publication14992_en.pdf

[91] EU energy trends to 2030, Directorate General for Energy in collaboration with Climate Action DG and Transport DG, 2010

[92] COM(2011)112, 8 March 2011

[93] Communication from the Commission: Europe 2020. A strategy for smart, sustainable and inclusive growth. COM(2010)2020, Brussels, 3.3.2010.

GDP is expected to rise 1.7% per annum (pa) from 2010 to 2050, and more specifically by 2.0% up to 2030 and only 1.5% pa after 2030. EU-12 growth is considerably higher in 2010-2030 (2.7% pa) but significantly smaller post 2030 due to shrinking and ageing population (0.9% pa).

The recent economic crisis has added sustainability problems to the public finances. Overall, as an effect of both economic crisis and the ageing of the population, without fiscal consolidation the gross debt-to-GDP ratio for the EU as a whole could reach 100 percent as early as 2014 and 140 percent by 2020[94,95]. The recent economic crisis might therefore limit the public funding available for low carbon investments.

Sensitivities – Higher and Lower GDP cases

Considering the high degree of uncertainty surrounding projections over such a long time horizon, a sensitivity analysis has been carried out with respect to GDP developments. A high and a low case have been analysed. The GEM-E3 model was deployed to simulate higher and lower expansion paths for GDP growth, while all other assumptions, including world fossil fuel prices, have remained the same.

Table 1: EU-27 GDP in real terms in the high and low economic growth variants, compared to the Reference scenario GDP

	2010	2020	2030	2040	2050
Reference (M€05)	11386	14164	16825	19528	22560
High economic growth (M€05)	11386	14488	17889	21596	25953
	0.0%	*2.3%*	*6.3%*	*10.6%*	*15.0%*
Low economic growth (M€05)	11386	13605	15527	17322	19239
	0.0%	*-3.9%*	*-7.7%*	*-11.3%*	*-14.7%*

Table 2: Average annual growth rate for the EU-27

	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Reference	0.58	2.29	2.13	1.82	1.65	1.54	1.47	1.47	1.44
High economic growth	0.58	2.37	2.51	2.22	2.05	1.93	1.87	1.87	1.84
Low economic growth	0.58	1.89	1.70	1.41	1.25	1.13	1.07	1.07	1.04

The two economic growth variants are designed to provide insights into the energy system developments stemming from alternative outcomes on economic drivers of energy consumption. In the high growth variant, GDP per capita is 0.4 percentage points higher than in the Reference case throughout the projection period, whereas it would be 0.4 pp lower in the low growth case. These variants examine the energy consequences of alternative economic developments broken down by economic sector in particular with regard to activities of energy intensive sectors versus less intensive ones.

Higher GDP growth would be driven mainly by enhanced activities of the services sector, with particular high value added growth in market services and trade, as these sectors are not

94 European Commission, DG Economic and Financial Affairs: Sustainability Report 2009. EUROPEAN ECONOMY 9|2009, http://ec.europa.eu/economy_finance/publications/publication15998_en.pdf.

95 European Commission, DG Economic and Financial Affairs: Public Finances in EMU 2010. EUROPEAN ECONOMY 4|2010, http://ec.europa.eu/economy_finance/publications/european_economy/2010/pdf/ee-2010-4_en.pdf.

very energy intensive. By comparison, industrial value added would exhibit less additional growth with expansion rates lower than that of GDP Both energy intensive and less energy intensive industrial sectors would however still show healthy additional growth.

In the low economic growth variant, all economic sectors would suffer to a similar extent with value added in most cases being 14-15% lower in 2050 than in the Reference case. One exception would be agriculture where the decrease in output with respect to the Reference case would be smaller.

1.2 Energy import prices

The energy projections are based on a relatively high oil price environment compared with previous projections and are similar to reference projections from other sources[96]. The baseline price assumptions for the EU27 are the result of world energy modelling (using the PROMETHEUS stochastic world energy model) that derives price trajectories for oil, gas and coal under a conventional wisdom view of the development of the world energy system.

International fuel prices are projected to grow over the projection period with oil prices reaching 88$’08/bbl in 2020, 106$’08/bbl in 2030 and 127 $08/barrel in 2050 with 2% inflation (ECB target) this corresponds to some 300 $ in 2050 in nominal terms.

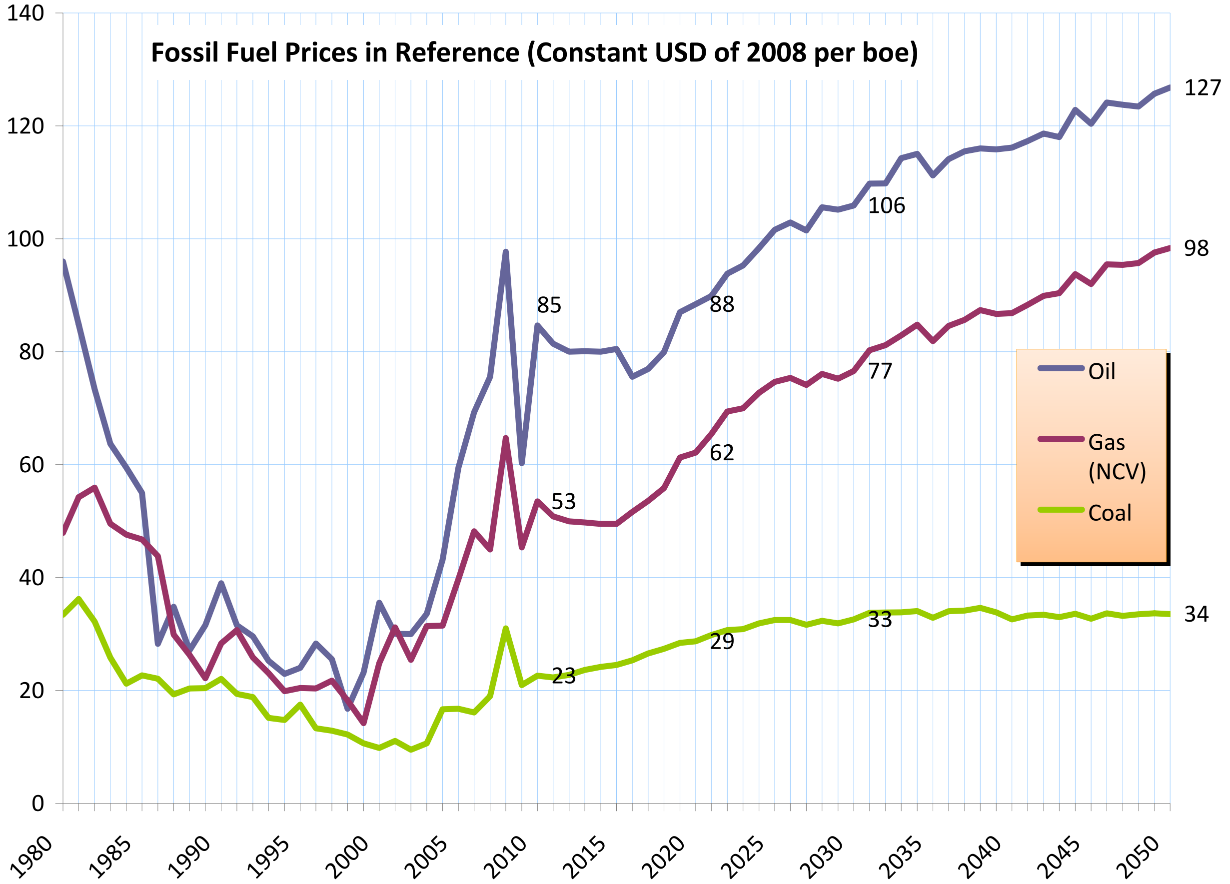
Gas prices follow a trajectory similar to oil prices reaching 62$’08/boe in 2020, 77$’08/boe in 2030 and 98 $(08)/boe in 2050 while coal prices increase during the economic recovery period to reach almost 26$’08/boe in 2020 and stabilize at around 30$’08/boe.[97]

The price development to 2050 is expected to take place in a context of economic recovery and resuming GDP growth without decisive climate action in any world region. Prices were derived with world energy modelling that shows largely parallel developments of oil and gas prices whereas coal prices remain at much lower levels.

[96] This refers to energy projections from the US Energy Information Administration (EIA) and the International Energy Agency (IEA). The EIA International Energy Outlook 2009 assumed 130 $/barrel in 2007 prices for 2030, equivalent to 134 $/barrel in 2008 prices. The IEA World Energy Outlook 2009 assumed 115 $/barrel in 2008 prices for 2030.

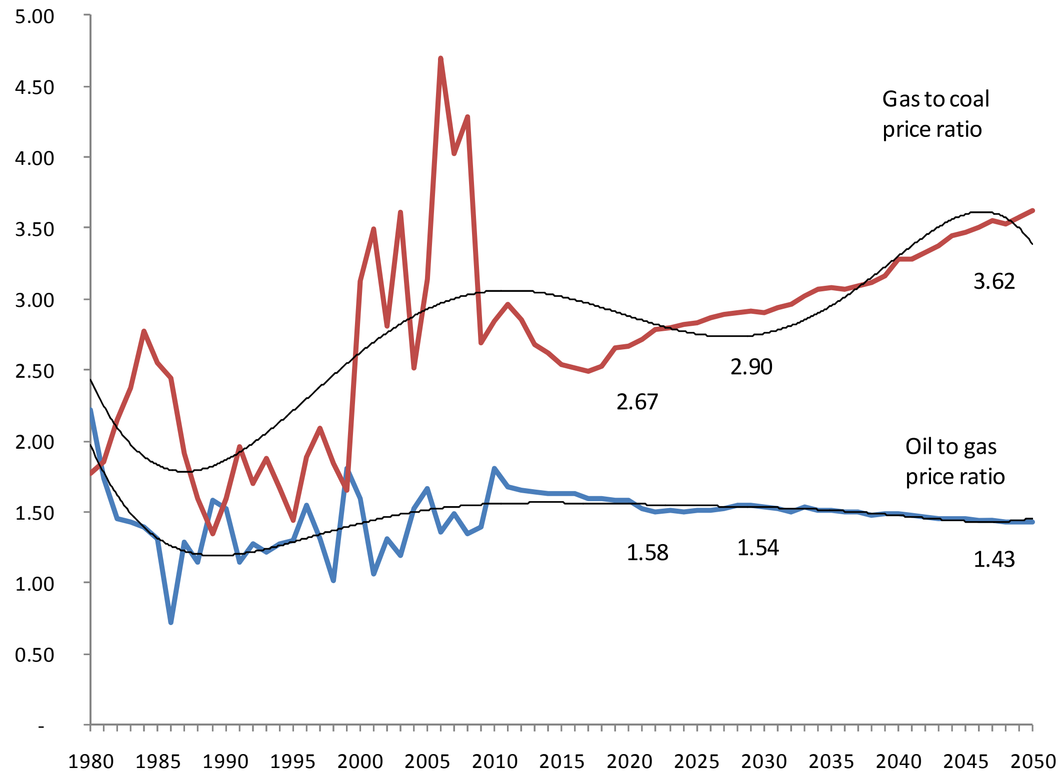
[97] As the model operates in constant euros, for which the exchange rate is assumed to depreciate from the currently high levels of around 1.4 $/€, there will be a somewhat faster increase in energy prices in euros than in dollar.

Figure 1: Reference scenario fossil fuel price assumptions



The evolution of the ratio of gas and coal prices can to a great extent influence the investment choices taken by investors in the power sector. A relatively low gas to coal price ratio up to the year 2000, together with the emergence of the gas turbine combined cycle technology, led to massive investments in gas fired power plants. The investments decreased afterwards due to significant gas price increases. The ratio between gas and oil prices remains stable over time as gas prices continue to follow oil prices. The gas to coal price ratio is projected to rise steadily over time as the coal prices in the world modelling results do not follow oil prices but remain around 30$’08/boe from 2030 onwards. While this ratio will increase over time, investment decisions will also be highly dependent on the expectations about future carbon prices.

Figure 2: Ratios of fossil fuel prices



Sensitivities: Higher and lower energy import prices

Considering the high degree of uncertainty surrounding projections over such a long time horizon, a sensitivity analysis has been carried out with respect to developments in energy imports prices. A high and a low case have been analysed. When undertaking the price sensitivities in 2011, the energy price figures for 2010 were updated from the estimates made in early 2009 for the Baseline/Reference scenario (in the same way as in the Reference case).[98] Global developments as regards shale gas are taken into account in this analysis.

The world energy model PROMETHEUS was deployed to derive the alternative prices trajectories. This stochastic model is particularly well suited given the great uncertainty regarding future world economic developments and the extent of recoverable resources of fossil fuels. Two different world energy price developments have been examined. The high world fossil fuel price development is driven by somewhat higher global GDP growth than under reference developments, especially in China, giving rise to higher energy consumption. Moreover, there are somewhat less optimistic assumptions on reserves regarding unconventional oil, which has the highest marginal costs. This favours stronger market power of key exporting countries and thereby higher prices. On the contrary, the low world energy

98 The price sensitivities presented in this IA complement those made in the Impact Assessment for the Low Carbon Economy Roadmap, which included an oil shock case in 2030 with oil prices suddenly rising to 212 $(08)/barrel, representing a doubling from Reference case in that year. In the following years, the genuine oil shock case depicts some oil demand reaction and a subsequent gradual decline of oil prices towards Reference case levels without reaching those, not even in 2050 (still being 18% higher). On the contrary, an alternative development was also examined, in which the oil prices would stay at the high 212 $/barrel level throughout the rest of the projection period. In the latter case, the 2050 oil price exceeds the Reference case level still by two thirds. (Results can be found in the above mentioned Impact Assessment and are not repeated here).

prices derive from markedly more subdued world economic growth combined with higher fossil fuel reserves and consequently less market power of key export players.

The sensitivities below are more symmetrical around the Reference case, including a High Price case with oil prices exceeding the Reference case level by 28% in 2050 and a Low Price case, in which the oil price in 2050 is 34 % lower than in the Reference case.

The price trajectories for oil, gas and coal shown in table 3 for the high energy price scenario stem from the following developments mirrored in the world modelling analysis:

- There is sustained economic growth in many Asian economies (notably China) following their reaction to the recent crisis, which has been to support domestic market expansion as a counterweight. The result has been that economic growth in the large Asian economies like China and India has barely been affected by the world economic slowdown. Since these are large consumers of coal the effect of this economic activity revision is particularly pronounced on short to medium term coal prices.
- There appears to be pronounced delays in oil productive capacity expansion with many plans being constantly revised. In addition, the recent accident in the Gulf of Mexico has resulted in a moratorium on deep water development in that area and is likely to result in delays in other parts of the world as well, in response to increased environmental concerns.
- There is increased concern that oil reserves and prospects for undiscovered resources are overstated. This may be particularly the case in OPEC countries where resource endowment is used as a criterion for production quota allocations.
- In view of the oligopolistic nature of world oil markets the tighter supply conditions usually translate into disproportionate increases in resource rents. Likewise such conditions imply greater vulnerability to short term supply disruptions leading to price spikes and resulting in higher average prices.
- The higher oil prices result in substitution of oil for gas in markets where the two fuels compete. The reduction in oil discoveries also implies a reduction in future reserves of associated gas. On the other hand gas price increases are moderated by an increasing share of unconventional gas from shales, as technology improves and the interest in its potential spreads beyond North America.

The low energy price scenario has been based on the following hypothetical background:

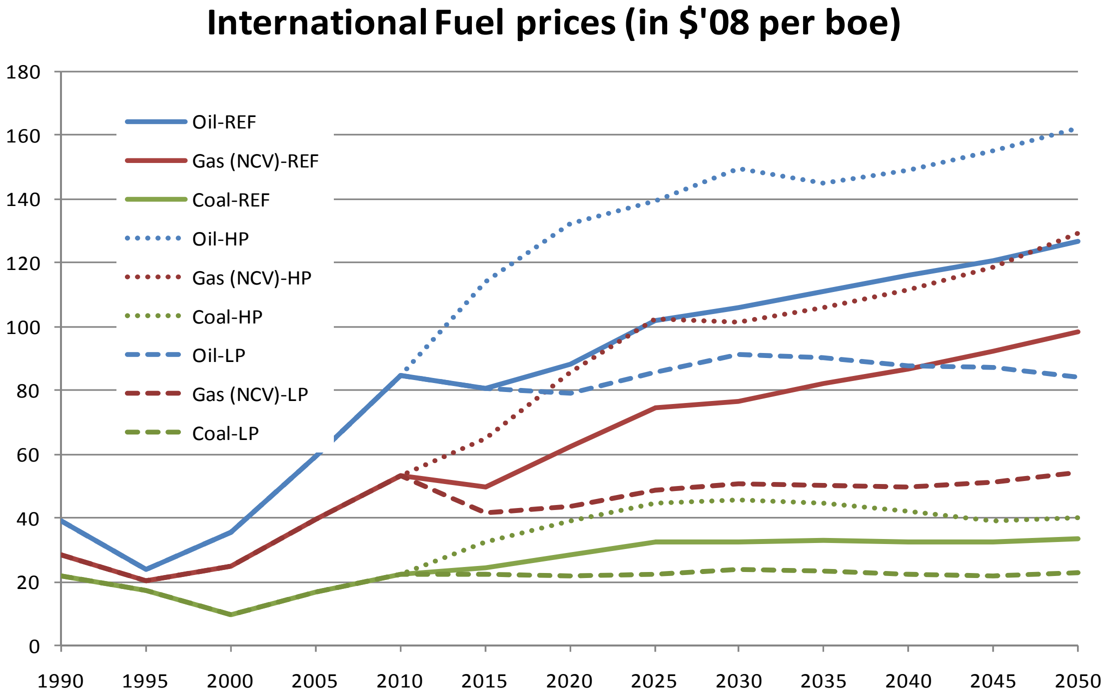
- There is currently great uncertainty on economic development including regarding excessive debts. It cannot be excluded that the recovery observed in 2009 and 2010 could prove to be relatively short lived, potentially leading to a "W shaped recession”).Whereas the reference scenario assumes a strong recovery of the world economy in the 2011-2014 period predicated on a rapid absorption of excess productive capacity (both capital and labour) and a strong resumption of investment in anticipation of fast growth in demand, developments could be less favourable. In particular, credit expansion could be hampered by the persistence of creditor exposure to uncertainty and increasing concern over the scope and timing of adjustments aimed at addressing imbalances (including sovereign debt). Consequently the investment boom may fail to materialize leading to some permanent loss of potential GDP (in the longer term world GDP is 7% lower in the modelled environment, which explains particularly low world fossil fuel prices).

- There is also uncertainty about energy resources and a more optimistic view could be adopted on this world energy price driver. In the low price variant, undiscovered conventional oil resources are set at their upper ten percentile value following USGS and PROMETHEUS assessments (in the reference scenario median values were used).
- In addition, the low price variant also assumes an increase in exploration activity outside the Gulf region as a response to security of supply concerns. This results in a more rapid translation of the resource basis into larger quantities of exploitable reserves. The main impact of this assumption is to bring forward the market easing emanating from greater resource abundance.
- The variant assumes rapid improvements in the knowledge and technologies associated with unconventional (shale) gas extraction. These in turn lead to enhanced interest in shale gas resources beyond North America leading to their more rapid incorporation into the exploitable resource base of some regions of the world. The assumptions concerning shale gas are the key driver for the high oil to gas price ratio that characterizes the low price variant.

Table 3: Energy import prices in the Reference scenario and low and high price variants

	2010	2020	2030	2040	2050
OIL					
Reference	84.6	88.4	105.9	116.2	126.8
High prices	84.6	132.2	149.3	148.8	162.3
%difference to Reference	*0.0%*	*49.5%*	*41.0%*	*28.1%*	*28.0%*
Low prices	84.6	78.8	91.5	87.9	83.9
%difference to Reference	*0.0%*	*-10.8%*	*-13.6%*	*-24.3%*	*-33.8%*
GAS					
Reference	53.5	62.1	76.6	86.8	98.4
High prices	53.5	85.5	101.5	111.6	129.0
%difference to Reference	*0.0%*	*37.7%*	*32.5%*	*28.5%*	*31.1%*
Low prices	53.5	43.7	50.9	49.9	54.1
%difference to Reference	*0.0%*	*-29.7%*	*-33.6%*	*-42.6%*	*-45.0%*
COAL					
Reference	22.6	28.7	32.6	32.6	33.5
High prices	22.6	39.3	45.7	42.0	40.0
%difference to Reference	*0.0%*	*37.0%*	*40.2%*	*28.9%*	*19.5%*
Low prices	22.6	21.9	23.8	22.2	23.1
%difference to Reference	*0.0%*	*-23.8%*	*-27.1%*	*-31.8%*	*-31.1%*

Figure 3: Sensitivity for international fuel prices



Similarly, to these sensitivities, the Current Policy Initiatives Scenario is based on slightly higher short term energy import prices reflecting 2010 developments.

1.3 Policy assumptions

Policy measures included in the Reference scenario are resumed in the following table:

	Measure		**How the measure is reflected in PRIMES**
Regulatory measures			
	Energy efficiency		
1	Ecodesign Framework Directive	Directive 2005/32/EC	Adaptation of modelling parameters for different product groups for Ecodesign and decrease of perceived costs by consumers for labelling (which reflects transparency and the effectiveness of price signals for consumer decisions). As requirements and labelling concern only new products, the effect will be gradual (marginal in 2010; rather small in 2015 up to full effect by 2030). The potential envisaged in the Ecodesign supporting studies and the relationship between cost and efficiency improvements in the model's database were cross-checked.
2	Stand-by regulation	Regulation No 1275/2008	
3	Simple Set-to boxes regulation	Regulation No 107/2009	
4	Office/street lighting regulation	Regulation No 245/2009	
5	Household lighting regulation	Regulation No 244/2009	
6	External power supplies regulation	Regulation No 278/2009	
7	TVs regulation (+labelling)	Regulation No 642/2009	
8	Electric motors regulation	Regulation No 640/2009	
9	Circulators[99] regulation	Regulation No 641/2009	
10	Freezers/refrigerators regulation (+labelling)	Regulation No 643/2009	
11	Labelling Directive	Directive 2003/66/EC	Enhancing the price mechanism mirrored in the model

[99] Circulator is an impeller pump designed for use in heating and cooling systems. Glandless standalone circulators and glandless circulators integrated in products are covered by this regulation.

12	Labelling for tyres	Regulation No 1222/2009	Decrease of perceived costs by consumers for labelling (which reflects transparency and the effectiveness of price signals for consumer decisions)
13	Energy Star Program (voluntary labelling program)		Enhancing the price mechanism mirrored in the model
14	Directive on end-use energy efficiency and energy services	Directive 2006/32/EC	National implementation measures are reflected
15	Buildings Directive	Directive 2002/91/EC	National measures e.g. on strengthening of building codes and integration of RES are reflected
16	Recast of the EPBD	Directive 2010/31/EU	New building requirements are reflected in technical parameters of the model, in particular through better thermal integrity of buildings and requirements for new buildings after 2020
17	Cogeneration Directive	Directive 2004/8/EC	National measures supporting cogeneration are reflected
	Energy markets		
18	Completion of the internal energy market (including provisions of the 3rd package)	http://ec.europa.eu/energy/gas_electricity/third_legislative_package_en.htm	The model reflects the full implementation of the Second Internal market Package by 2010 and Third Internal Market Package by 2015. It simulates liberalised market regime for electricity and gas (decrease of mark-ups of power generation operators; third party access; regulated tariffs for infrastructure use; producers and suppliers are considered as separate companies) with optimal use of interconnectors.
19	EU ETS directive	Directive 2003/87/EC as amended by Directive 2008/101/EC and Directive 2009/29/EC	The ETS carbon price is modelled so that cumulative cap for GHGs is respected[100]. The permissible total CDM amount over 2008-2020 is conservatively estimated at 1600 Mt. Banking of allowances is reflected The ETS cap is assumed to continue declining beyond 2020 as stipulated in legislation, however with an effective domestic emission decrease lower than the linear decrease rate of 1.74%) to result in a 50% cumulative decrease of actual emissions instead of 70% which could stem from the Directive as a maximum reduction of EU emissions if no use of international credits would be allowed beyond 2030[101]; currently no provision for the use of international credits post 2020 have been fixed and in the reference scenario world without global action, the higher ETS price might trigger

[100] For the allocation regime for allowances in 2010, the current system based on National Allocation Plans and essentially cost-free allowances is assumed, with price effects stemming from different investment and dispatch patterns triggered by need to submit allowances. For the further time periods, in the power sector there will be a gradual introduction of full auctioning, which will be fully applicable from 2020 onwards, in line with the specifications of the amended ETS directive.
For the other sectors (aviation and industry), the baseline follows a conservative approach which reflects the specifications in the directive on the evolution of auctioning shares and the provisions for free allocation for energy intensive sectors based on benchmarking.

[101] Compared with the Reference scenario to 2030, in the Reference scenario to 2050, the expectation of high ETS allowance prices in future and the possibility to bank allowances leads to higher prices in 2025 and 2030 than in the Reference scenario up to 2030.

			greater use of such credits, which would also be in greater supply with higher ETS prices. ETS prices are derived endogenously on the basis of allowances, international credits, emissions reflecting developments of energy consumption while taking account of banking.
20	RES directive	Directive 2009/28/EC	Legally binding national targets for RES share in gross final energy consumption are achieved in 2020; 10% target for RES in transport is achieved for EU27 as biofuels can be easily traded among Member States; sustainability criteria for biomass and biofuels are respected using the full detail of the biomass model linked to the PRIMES energy system model; cooperation mechanisms according to the RES directive are allowed and respect Member states indications on their "seller" or "buyer" positions. RES subsidies decline after 2020 starting with the phasing out of operational aid to new onshore wind by 2025; other RES aids decline to zero by 2050 at different rates according to technology. Increasing use of RES co-operation mechanisms is assumed and should help to reduce RES costs. Policies on facilitating RES penetration will continue.
21	GHG Effort Sharing Decision	Decision 406/2009/EC	National targets for non-ETS sectors are achieved in 2020, taking full account of the flexibility provisions such as transfers between Member States. After 2020, stability of the provided policy impulse but no strengthening of targets is assumed.
22	Energy Taxation Directive	Directive 2003/96/EC	Tax rates (EU minimal rates or higher national ones) are kept constant in real term. The modelling reflects the practice of MS to increase tax rates above the minimum rate due to i.a. inflation.
23	Large Combustion Plant directive	Directive 2001/80/EC	Emission limit values laid down in part A of Annexes III to VII in respect of sulphur dioxide; nitrogen oxides and dust are respected. Some existing power plants had a derogation which provided them with 2 options to comply with the Directive: either to operate only a limited number of hours or to be upgraded. The model selected between the two options on a case by case basis. The upgrading is reflected through higher capital costs.
24	IPPC Directive	Directive 2008/1/EC	Costs of filters and other devices necessary for compliance are reflected in the parameters of the model
25	Directive on the geological storage of CO2	Directive 2009/31/EC	Legal framework regulating the geological storage of CO2 allowing together with EEPR and NER300 CCS demonstration support (see below) economic modelling to determine CCS penetration
26	Directive on national emissions' ceilings for certain pollutants	Directive 2001/81/EC	PRIMES model takes into account results of RAINS/GAINS modelling regarding classical pollutants (SO2, NOx). Emission limitations are taken into account bearing in mind that full compliance can also be achieved via additional technical measures in individual MS.

27	Water Framework Directive	Directive 2000/60/EC	Hydro power plants in PRIMES respect the European framework for the protection of all water bodies as defined by the Directive, which limits the potential deployment of hydropower and might impact on generation costs.
28	Landfill Directive	Directive 99/31/EC	Provisions on waste treatment and energy recovery are reflected
	Transport		
29	Regulation on CO2 from cars	Regulation No 443/2009	Limits on emissions from new cars: 135 gCO2/km in 2015, 115 in 2020, 95 in 2025 – in test cycle. The 2015 target should be achieved gradually with a compliance of 65% of the fleet in 2012, 75% in 2013, 80% in 2014 and finally 100% in 2015. Penalties for non-compliance are dependent on the number of grams until 2018; starting in 2019 the maximum penalty is charged from the first gram.
30	Regulation EURO 5 and 6	Regulation No 715/2007	Emissions limits introduced for new cars and light commercial vehicles
31	Fuel Quality Directive	Directive 2009/30/EC	Modelling parameters reflect the Directive, taking into account the uncertainty related to the scope of the Directive addressing also parts of the energy chain outside the area of PRIMES modelling (e.g. oil production outside EU).
32	Biofuels directive	Directive 2003/30/EC	Support to biofuels such as tax exemptions and obligation to blend fuels is reflected in the model The requirement of 5.75% of all transportation fuels to be replaced with biofuels by 2010 has not been imposed as the target is indicative. Support to biofuels is assumed to continue. The biofuel blend is assumed to be available on the supply side.
33	Implementation of MARPOL Convention ANNEX VI	2008 amendments - revised Annex VI	Amendment of Annex VI of the MARPOL Convention reduce sulphur content in marine fuels which is reflected in the model by a change in refineries output
34	Regulation Euro VI for heavy duty vehicles	Regulation (EC) No 595/2009	Emissions limits introduced for new heavy duty vehicles.
35	Regulation on CO2 from vans[102]	Part of the Integrated Approach to reduce CO2 emissions from cars and light commercial vehicles.	Limits on emissions from new LDV: 181 gCO2/km in 2012, 175 in 2016, 135 in 2025 – in test cycle
Financial support			
36	TEN-E guidelines	Decision No 1364/2006/EC	The model takes into account all TEN-E realised infrastructure projects
37	EEPR (European Energy Programme for Recovery) and NER 300 (New entrance reserve) funding programme	For EEPR: Regulation No 663/2009; For NER300: EU Emissions Trading Directive 2009/29/EC	Financial support to CCS demonstration plants; off-shore wind and gas, innovative renewables and electricity interconnections is reflected in the model. For CCS, - the following envisaged

102 On 28 October 2009 the European Commission adopted a new legislative proposal to reduce CO2 emissions from light commercial vehicles (vans). The draft legislation is closely modelled on the legislation on the CO2 emissions from passenger cars (Regulation 443/2009) and it is part of the Integrated Approach taken by the Commission in its revised strategy to reduce CO2 emissions from cars and light commercial vehicles (COM(2007) 19 final). Not including this proposal in the 2050 Reference scenario could lead to an increased bias towards vans, which is not justified given the likelihood of its adoption towards the end of 2010/beginning of 2011.

		Article 10a(8), further developed through Commission Decision 2010/670/EU[103]	demonstration plants are taken into account for commissioning in 2020: Germany 950 MW (450MW coal post-combustion, 200MW lignite post-combustion and 300MW lignite oxy-fuel), Italy 660 MW (coal post-combustion), Netherlands 1460 MW (800MW coal post-combustion, 660MW coal integrated gasification pre-combustion), Spain 500 MW (coal oxy-fuel), UK 3400 MW (1600MW coal post-combustion, 1800MW coal integrated gasification pre-combustion), Poland 896 MW (306MW coal post-combustion, 590MW lignite post-combustion); investment in further plants depends on carbon prices
38	RTD support (7th framework programme- theme 6)	energy research under FP7	Financial support to R&D for innovative technologies such as CCS, RES, nuclear and energy efficiency is reflected by technology learning and economies of scale leading to cost reductions of these technologies
39	State aid Guidelines for Environmental Protection and 2008 Block Exemption Regulation	Community guidelines on state aid for environmental protection	Financial support to R&D for innovative technologies such as CCS, RES, nuclear and energy efficiency is reflected by technology learning and economies of scale leading to cost reductions of these technologies
40	Cohesion Policy – ERDF, ESF and Cohesion Fund		Financial support to national policies on energy efficiency and renewables is reflected by facilitating and speeding up the uptake of energy efficiency and renewables technologies.
41	Rural development policy - EAFRD	Council Regulation (EC) No. 1698/2005	Financial support for supply and use of renewable energy to farmers and other actors in rural areas, financial support to investments increasing energy efficiency of farms
National measures			
42	Strong national RES policies		National policies on e.g. feed-in tariffs, quota systems, green certificates, subsidies and other cost incentives are reflected
43	Nuclear		Nuclear, including the replacement of plants due for retirement, is modelled on its economic merit and in competition with other energy sources for power generation except for MS with legislative provisions on nuclear phase out. Several constraints are put on the model such as decisions of Member States not to use nuclear at all (Austria, Cyprus, Denmark, Estonia, Greece, Ireland, Latvia, Luxembourg, Malta and Portugal) and closure of existing plants in some new Member States according to agreed schedules (Bulgaria 1760 MW, Lithuania 2600 MW and Slovakia 940 MW). The nuclear phase-out in Belgium and Germany is respected while lifetime of nuclear power plants was extended to 60 years in Sweden. Nuclear investments are possible in Bulgaria, the Czech Republic, France, Finland, Hungary, Lithuania, Romania, Slovakia, Slovenia, Spain and UK

[103] NER covers 300 million allowances set aside in the new entrants reserve of the EU ETS for the co-financing of commercial demonstration projects of environmentally safe CCS as well as innovative RES technologies

			For the modelling the following plans on new nuclear plants were taken into account: Bulgaria (1000 MW by 2020 and 1000 MW by 2025), Finland (1600 MW by 2015), France (1600 MW by 2015 and 1600 MW by 2020), Lithuania (800 MW by 2020 and 800 MW by 2025), Romania (706 MW by 2010, 776 MW by 2020 and 776 MW by 2025), Slovakia (880 MW by 2015). Member States experts were invited to provide information on new nuclear investments/programmes in spring 2009 and commented on the PRIMES baselines results in summer 2009, which had a significant impact on the modelling results for nuclear capacity.

In addition to these measures, the Current Policy Initiatives Scenario includes the following policies and measures:

Area	Measure	How it is reflected in the model
Internal market		
1	Effective transposition and implementation of third package, including the development of pan-European rules for the operation of systems and management of networks in the long run	The modelling approach mirrors completion of the internal market, but has to account for existing interconnector limitations. Better market integration is reflected by having higher net transfer capacities in the near future and additional interconnectors in the longer term which lead to higher price convergence in multi-country market coupling in both electricity and gas markets (for details see below). In the gas market, more diversification (see also point 1) and higher degree of competition lead to lower oligopoly mark-ups and lower prices.
2	Regulation on security of gas supply (N-1 rule, necessity for diversification)	Compliance with N-1 rule and the necessity for diversification induce higher costs in the model for gas companies.
3	Regulation on Energy market integrity and transparency (REMIT)	The model simulates well functioning energy markets
Infrastructure		
4	Facilitation policies (faster permitting; one stop shop)	All these policies induce shorter lead times and slightly lower costs allowing faster infrastructure deployment.
5	Infrastructure instrument	More funding available from the EU budget
6	Updated investments plans based on ENTSO-e Ten Year Network Development Plan	Interconnection capacity reflects projects in the TYNDP by 2020.
7	Smartening of grids and metering	Smart grids and meters will lead to higher costs mainly for distribution but will allow for more energy efficiency in the system and decentralised RES
Energy efficiency	measures proposed in the Energy efficiency Plan – implementation compared to scenario 3[104] less vigorously and at a more moderate	

[104] All measures included in the scenario underpinning the IA for the Energy efficiency Directive are included. Energy (saving) results can differ given different framework conditions flowing from all the additional assumptions above. Moreover, it should be considered that scenario 3 Energy Efficiency should show contrasted results in terms of energy consumption so that a significant individual contribution of energy

	rate	
8	Obligation for public authorities to procure energy efficient goods and services	Cost perception parameters for non market service sector adapted accordingly
9	Planned Ecodesign measures (boilers, water heaters, air-conditioning, etc)	Adaptation of modelling parameters for different product groups. As requirements concern only new products, the effect will be gradual (rather small in 2015 and up to full effect by 2030/2035 as e.g. boilers can have a very long lifetime)
10	High renovation rates for existing buildings due to better/more financing and planned obligations for public buildings	Change of drivers (ESCOs, energy utilities obligation in point 13, energy audits point 14) influence stock – flow parameters in the model reflecting higher renovation rates, with account being taken of tougher requirements for public sector through specific treatment of the non-market services sector
11	Passive houses standards after 2020 (already in the Reference scenario)	Higher penetration of passive houses standards compared to the Reference scenario (around 30-50 KWh/m2 depending on a country which might to a large extent be of renewable origin)
12	Greater role of Energy Service Companies	Enabling role of ESCOs is reflected via altered economic parameters leading to more energy efficient choices (see also point 10)
13	Obligation of utilities to achieve energy savings in their customers' energy use of 1.5% per year (until 2020)	Induce more energy efficiency mainly in residential and tertiary sectors by imposing an efficiency value for grid bound energy sources (electricity, gas, heat)
14	Mandatory energy audits for companies	Induce more energy efficiency in industry (see also point 10)
15	Obligation that, where there is a sufficient demand authorisation for new thermal power generation is granted on condition that the new capacity is provided with CHP; Obligation for electricity DSOs to provide priority access for electricity from CHP; Reinforcing obligations on TSOs concerning access and dispatching of electricity from CHP	To a large extent already reflected in the Reference scenario 2050 Further facilitation of CHP penetration in the model
16	Obligation that all new energy generation capacity reflects the efficiency ratio of the best available technology (BAT), as defined in the Industrial Emissions Directive	High energy efficiency to a large extent already reflected in the Reference scenario 2050 as a response to ETS carbon prices; energy efficiency improves furthermore in power generation along with new investment from more efficient vintages
17	Other measures (better information for consumers, public awareness, training, SMEs targeted actions)	Induce faster energy efficiency improvements
Nuclear		
19	Nuclear Safety Directive	Harmonisation with international standards
20	Waste Management Directive	Cost for waste management reflected in generation costs
21	Consequences of Japan nuclear accident	Stress tests and other safety measures reflected through higher costs for retrofitting (up to 20% higher generation costs after lifetime extension compared with Reference scenario) and introduction of risk premium for new nuclear power plants. Nuclear determined on economic grounds, subject

efficiency towards decarbonisation can be identified. Scenario 1bis includes some adjustments to reflect somewhat less optimistic expectations for penetration of energy efficiency products/renovation of buildings.

		to non nuclear countries (except for Poland) remaining non-nuclear
CCS		
22	Slower progress on demonstration plants	Downward revision of planning for some CCS demonstration plants compared to the Reference case; some plants might be commissioned later depending on carbon prices. Change regarding potential storage sites in BE and NL.
Oil and gas		
23	Offshore oil and gas platform safety standards	Standards slightly increase production costs for oil and gas in the EU
Taxation		
24	Energy taxation Directive (revision 2011)	Changes to minimum tax rates for heating and transport sectors reflect the switch from volume-based to energy content-based taxation and the inclusion of a CO_2 tax component. Where Member States tax above the minimum level, the current rates are assumed to be kept unchanged. For motor fuels, the relationships between minimum rates are assumed to be mirrored at national level even if the existing rates are higher than the minimum rates. Tax rates are kept constant in real terms.
Transport		
25	A revised test cycle to measure CO_2 emissions under real-world driving conditions (to be proposed at the latest by 2013) [105]	Implementation of CO_2 standards for passenger cars (95 g CO_2/km) by 2020. Starting with 2020 assume autonomous efficiency improvements as in the Reference scenario.
26	Update of the CO_2 standards for vans according to the adopted regulation[106]	Implementation of CO_2 standards for vans (175 g of CO_2 per kilometre by 2017, phasing in the reduction from 2014, and to reach 147g CO_2/km by 2020).
Other parameters		
Energy import prices		Short-term increase to reflect the evolution of prices up to 2010
Technology assumptions	Higher penetration of EVs reflecting developments in 2009-2010 national support measures and the intensification of previous action programmes and incentives, such as funding research and technology demonstration (RTD) projects to promote alternative fuels.	Slightly higher penetration of EVs Assumed specific battery costs per unit kWh in the long run: 390-420 €/kWh for plug-in hybrids and 315-370 €/kWh for electric vehicles, depending on range and size, and other assumptions on critical technological components[107].

[105] In Europe, the New European Driving Cycle is the official driving cycle used for vehicle type approval. According to a study carried out for the Commission in 2009, there is some discrepancy (typically 10-20%) between the fuel consumption as measured on the NEDC and that in real world driving. Source: Sharpe, R.B.A. (2009) Technical options for fossil fuel based road transport, Paper produced as part of contract ENV.C.3/SER/2008/0053 between European Commission Directorate-General Environment and AEA Technology plc; http://eutransportghg2050.eu/cms/assets/EU-Transport-GHG-2050-Paper-1-Technical-options-for-f-fuel-road-transport-11-02-10.pdf, p.9

[106] Regulation (EU) No 510/2011 of the European Parliament and of the Council of 11 May 2011, setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO2 emissions from light-duty vehicles

[107] International Energy Agency (2009), Transport, Energy and CO2: Moving Towards Sustainability.

1.4 Assumptions about energy infrastructure development

Regarding **infrastructure** representation, the scope of the modelling was increased by undertaking the determination of electricity interconnectors in a two stages approach. The aim is to represent market integration cost-effectively given many different scenarios modelled. The purpose of stage 1 is to determine electricity trade in the internal market based on a simpler version of PRIMES determining the equilibrium with all countries linked through endogenous trade, which due to its great technology detail on power generation requires very long computing times for each run. Stage 2 concerns the fully detailed modelling on the basis of the outcome of stage 1. The very long computing times for each model run under endogenous trade require a cost-effective approach, given that many iterations need to be performed between demand and supply and for meeting carbon targets. Running all countries in parallel in stage 2, involving many iterations, ensures delivery of modelling results in time.

Data about NTCs and interconnection capacities were taken from ENTSOe databases. Information on new constructions was taken from the latest “Ten-year network development plan 2010-2020”, complemented, where necessary, with information from the Nordic Pool TSOs and the Energy Community (for South East Europe). Some of the planned new constructions would justify increase of NTCs values until 2020, as mentioned in the ENTSOe’s TYNDP document. Other mentioned new constructions regard directly the building of new interconnection lines which are introduced as such in the model database.

Market integration leads to more electricity trade, which in turn needs infrastructure that is also dealt with in the modelling. Several test modelling runs were undertaken. It turned out that for the Reference and Current Policy Initiatives scenarios, the 2020 interconnection capacity would allow for most intra-EU electricity trade up to 2050 provided that a few identified bottlenecks would be dealt with. Such areas are the southern and eastern connections of Germany, the area linking Italy, Austria and Slovenia, the linkages of Balkans with northern neighbours and the linkages within Balkans. Some NTC additions should be also made for the linkages Denmark-Sweden and Latvia-Estonia. With lower electricity demand due to the assumed strong energy efficiency policies, these results also hold for the Current Policy Initiatives scenario.

Other infrastructure is dealt with in a less sophisticated way given that this is not so much in the focus of the energy system model at the European level. For CCS infrastructure (CO2 storage and transport) as well as for the sites of power plants, e.g. nuclear or RES installations (the sites - not the generation as such, see below) non-linear cost supply curves have been applied that take account of increasing costs, leading to higher costs once the most suitable and cheapest sites have been used.

Details on the modelling approach taken can be found in the Attachment 2 on interconnections.

1.5 Technology assumptions

Technology parameters are exogenous in the PRIMES modelling and their values are based on current databases, various studies[108] and expert judgement and are regularly compared to other leading institutions. Technologies are assumed to develop over time and to follow learning curves which are exogenously adjusted to reflect the technology assumptions of a scenario. For some technologies, in particular, for off-shore wind and nuclear, the database of

[108] NEMS database and reports, IEA studies, industry surveys, EU project reports, etc.

realised projects is very limited which can lead to significant differences depending on how many projects and what projects were included and where projects are being built.

The energy efficiency and other characteristics of the existing stock for a technology in a given period depend on previous investments. This ensures that as in real life changes in the characteristics of the technology stock happen only gradually depending on the type and magnitude of new investment as well as the rate of retirement of obsolete equipment. The market acceptance of a technology is also modelled and depends on the maturity of a technology; the more mature a technology the higher its market acceptance. Nuclear is however a special case driven mainly by political considerations at government levels and acceptance by citizens.

In order to ensuring comparability across scenarios, technology assumptions regarding capital and operational costs as well as technology performance over time have to remain the same across scenarios, except for cases, in which there were specific policies on technology progress (e.g. targeted support to one specific technology). In addition to these genuine technology parameters, the uptake of technologies is also influenced by other modelling parameters reflecting policy intensity, such as carbon and renewables values; these are discussed in later chapters. Current trend and decarbonisation scenarios differ regarding enabling policies, impacting also on technology uptake, as well as economies of scale in technology deployment, bringing lower energy costs. Technology specific parameters as such remain the same across scenarios.

The modelling cycle ending with the Energy Roadmap started in 2009 with the update of the Baseline, meaning that capital costs assumptions for 2010 and their evolution up to 2050 are based on information available in 2009/2010.. The Low Carbon Economy Roadmap and the Transport White Paper of spring 2011 were based on the same technology assumptions. It is clear that markets and technology costs as well as performance parameters evolve over time. Therefore, such assumptions need periodical update, which will be done again for the next modelling cycle starting in 2012.

Power generation

Power generation technologies are characterised by capital costs, variable and fixed operation costs and by efficiencies. These characteristics are assumed to change over time due to technological improvements (impacting predominantly on capital costs). The assumptions for the Reference scenario for 2010 have been compared to other studies (e.g. IEA[109] and US DOE[110]), where possible[111]; all costs have been transformed into EUR[112].

As can be seen in Figure 4 the capital costs in PRIMES are within the range of other studies.

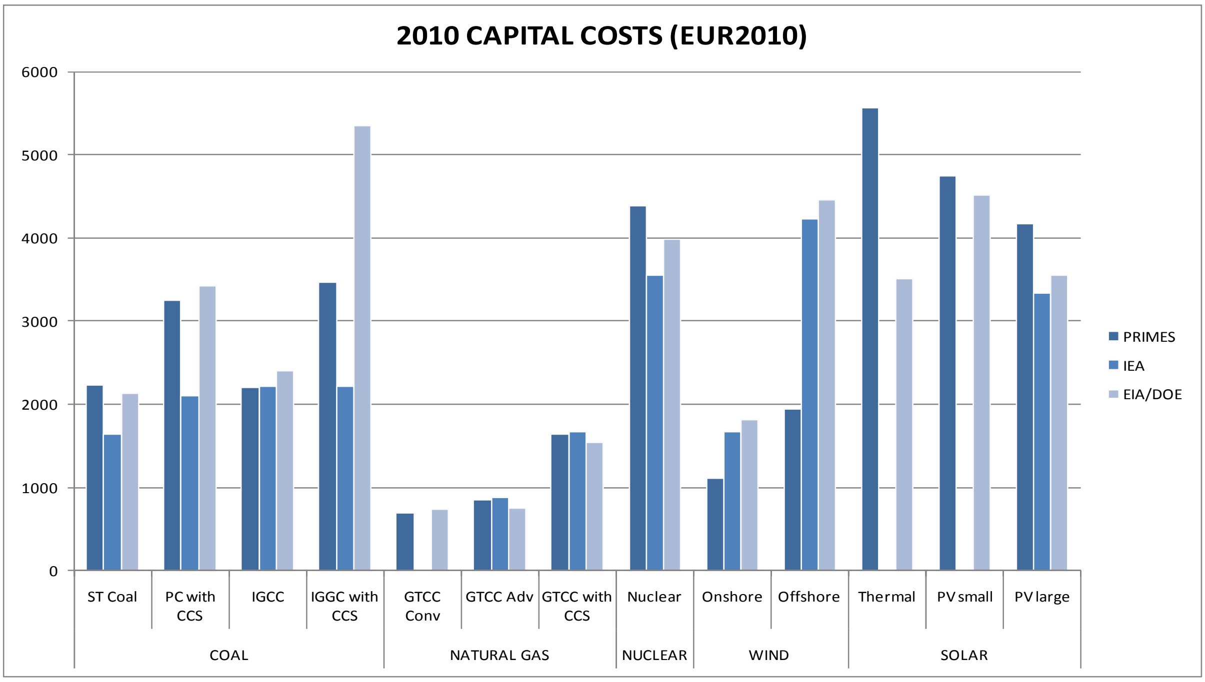
109 IEA (2010), Projected Costs of Generating Electricity, 2010 Edition. IEA, NEA, OECD, Paris

110 Energy Information Administration, Annual Energy Outlook 2010, December 2009, DOE/EIA-0383 (2009)

111 Definitions in the studies may not totally overlap, in particular for fixed and variable costs.

112 The exchange rates used are: 1.34USD/EUR (USD2010 to EUR2010).

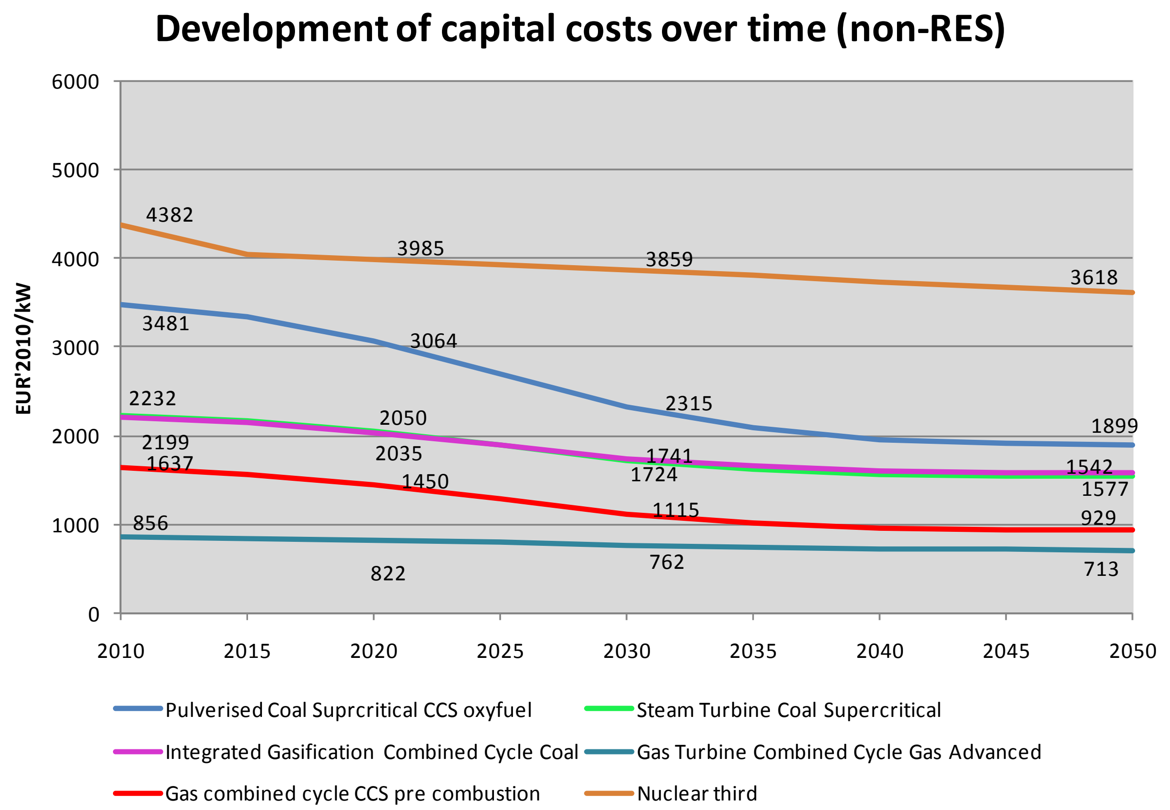
Figure 4: Capital costs in EUR/kWh in 2010[113]

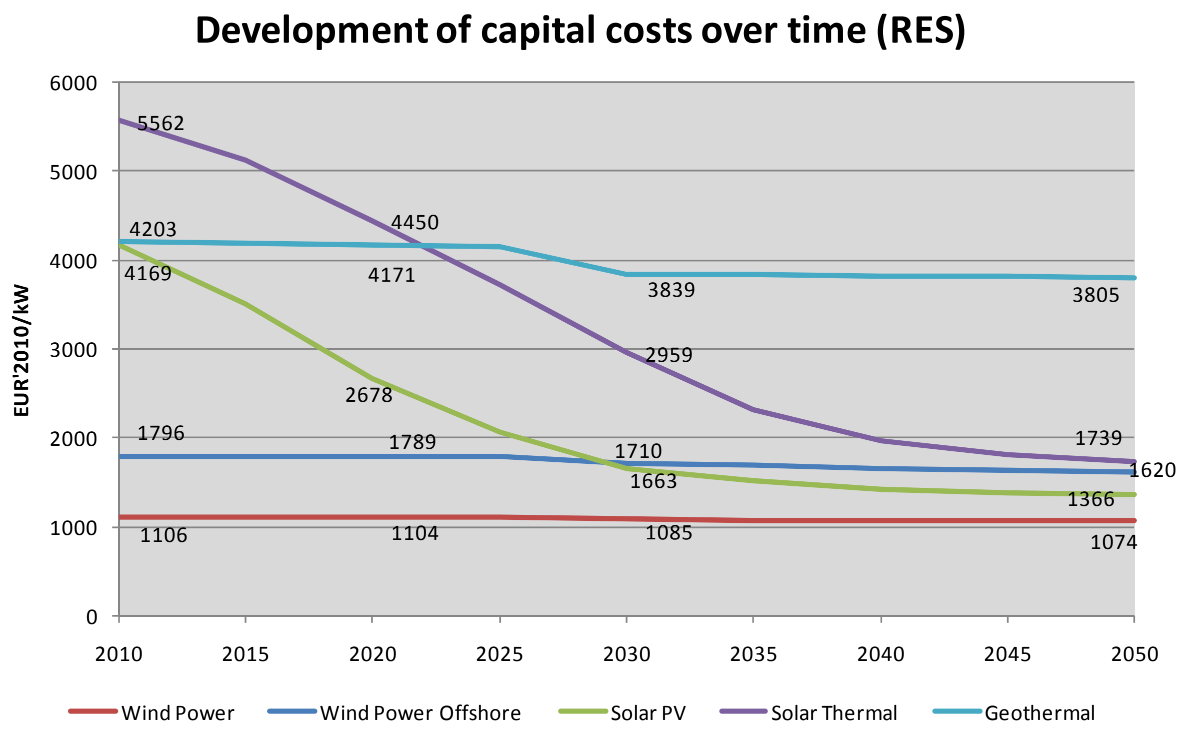


The costs of technologies evolve over time in the Reference scenario reflecting learning curves and economies of scale. There are ample possibilities for solar technologies, both thermal and PV, to see costs decreasing over time, which is also the case for CCS technologies. These are not yet mature technologies and can therefore still follow steep learning curves. By comparison, the possibilities of wind onshore to further decrease its costs are rather limited with some potential still existing for small wind turbines., Figure 5 shows cost developments for mainstream onshore wind at medium size. As can also be seen in that figure, capital costs for off-shore wind can be expected to decrease significantly over time.

[113] Abbreviations in the figure: ST Coal: Steam Turbine Coal; CCS: Carbone Capture and Storage; PC with CCS: pulverised coal with CCS; IGCC: Integrated Gasification Combine Cycle; GTCC: Gas Turbine Combined Cycle; PV: photovoltaic.

Figure 5: Development of capital costs over time in the Reference scenario





The effective cost of a technology depends also on subsidies that may be paid by governments for environmental reasons to encourage specific innovative technologies that may require state aids for some time. In the case of renewables, Member States have support schemes that encourage the uptake of renewables technologies depending often on cost differences with conventional power generation technologies. This implies dependence of such aids on the progress in the cost reduction for renewables technologies, which are becoming increasingly cost competitive over time.

The Roadmap modelling assumes that such existing operational aid to RES for power generation is being phased out according to the maturity of the individual technology subgroups. In the longer term, only innovative and still costly RES technologies, such as solar PV, wave, tidal and off-shore wind at difficult sites, would receive aids. While for the more mature technologies (onshore wind) such aid is assumed to have been phased out rather early in the modelling (by 2025), the phasing-out of operational aid is completed by 2050 for other technologies. As RES technology costs come down, sometimes ahead of expectations, governments curtail the aid they grant.

In any case, the operational aids modelled only foster the uptake of RES technologies that are not yet fully commercial. Renewables support is modelled via support to capital costs. This support is relevant only for the investment decision but does not reduce electricity costs, given that the full costs of RES deployment are paid for by electricity consumers. In a large number of Member States this is currently done via feed-in tariffs, the salient features of which (all electricity consumers pay for the support to specific technologies) are captured by the electricity modelling undertaken in these scenarios. It is important to note that the current trend and decarbonisation scenarios have the same levels of operational aids that decrease over time.[114]

Distributed Heat and Steam

Distributed heat in PRIMES can come either from CHP or district heating boilers. There are several technologies to produce steam, but distribution technologies are rather standard. For CHP there are ten different technologies that are applicable to different power generation technologies; the CHP technologies relate to the different technical options to extract the steam e.g. extraction, back-pressure or condensing technologies. The CHP technologies are considered mature, therefore no new learning effects are assumed. The higher penetration of CHP technologies in the different scenarios is based on policy drivers.

Demand side technologies

Demand side technologies are mainly related to buildings, appliances, industrial equipment and transport vehicles. The penetration of new technologies can have important effects on energy efficiency improvement as well as on fuel switching. Technology parameters are exogenous with assumptions being based on results of various studies. The PRIMES data is compared regularly to other sources. For electric appliances PRIMES technologies were compared to the EuP Preparatory studies set out in directive 2005/32/EC and to the IEA Energy Technology Perspectives 2008, as well as the “Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries Final Report”[115]. The comparison proved that the assumptions taken in the PRIMES model are comparable to the developments of BAT and BNAT available from the EuP preparatory studies.

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114 Greater deployment of RES or other low carbon technologies in decarbonisation scenarios is due to carbon prices/values as well as other specific changes (including higher RES values) depending on the scenario, but does not involve greater operational aid.

115 Eichhammer et al. (2009), Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries Final Report, Fraunhofer ISI and ENERDATA and ISIS and Technical University Vienna and WI, March 2009.

There is a very large number of different energy uses and technologies to provide the energy services (heating and cooling, light, motion, communication, etc) that consumers want when purchasing equipment and energy carriers.

In the PRIMES modelling, consumers always have the possibility of choosing between several vintages of the same technology, which are characterised by different prices and efficiencies. Throughout the projection period technologies become more mature and their market acceptance may grow, due to increased market maturity and policies.

Figure 6: Examples of developments of electric appliances in PRIMES compared to other literature sources[116]

Appliance	Source	Base Case	Improved	BAT	BNAT
Washing machine	EuP and IEA	0.998kWh/cycle 443EUR		-10% (+25% cost)	Technical performance limit might soon be reached
	PRIMES	1.57kWh/cycle 582EUR	40% improvement,	-50% (+32% cost)	further -5%, at 25% cost increase
Lighting	EuP			Residential: - Services: -70% Street: -30%	LEDs and OLEDs
	PRIMES		-26% at 30% cost	-80% (+250% cost)	further -2% at 35% cost
Entertainment /office equipment	EuP			TVs: -20% Computers: -65 to -75%	TVs:-30 to -50% compared to current Computers: software and consumer behaviour
	PRIMES	815EUR	-10% at 32% cost	further -10% (+32% cost)	further -5%, at 25% cost increase
Boilers (Water heating)	EuP (Gas?)		30-40%	60%	
	Primes (Gas)	500-1500EUR	21%	42% (add. Inv. Cost 100%)	47%
Boilers (Central heating)	EuP (Gas?)			30%-40%	
	Primes (Gas)	1000-3000EUR	9%	23% (add. Inv. Cost. 49%)	30%
Air conditionining	EuP			-57%	
	Primes (Elec)	500-1500EUR		-47% (add. Inv. Cost 61%)	

The technologies in the above table only show a small variety of the technologies available in the model; further technologies and fuels for the technologies are available both for the services and residential demand as well as for industry and agriculture. The data has been

[116] Due to the variety of appliances available (in particular for boilers) the values here are chosen as examples and due to lack of data it is possible that the typical appliances of the different sources do not correspond entirely to the PRIMES technology.

compiled and updated over the years based on numerous sources including data from NEMS, the MURE database, industrial surveys, EU project reports and IEA studies.

For households PRIMES includes five different dwelling types, differentiated according to the main energy pattern[117] which each have energy services provided to them such as: space heating, water heating, cooking, cooling, lighting and other needs. Because of the very large variety of housing types both within and between countries, PRIMES uses curves for the possibilities of changes in thermal integrity of buildings relating marginal costs with energy efficiency improvements. Specific numbers for a typical household/dwelling type can therefore not be provided explicitly.

Transport

For transport vehicles the same mechanisms apply as for appliances; a consumer can choose different vintages of the same kind of vehicle at different costs and efficiency. Also for transport, a comparison with a variety of literature sources was carried out, which proves that the estimates of PRIMES are in line with other estimates.

[117] Please refer to the PRIMES model description available at : http://www.e3mlab.ntua.gr/e3mlab/PRIMES%20Manual/The_PRIMES_MODEL_2010.pdf

Table 4: Comparison of costs and efficiencies from different literature sources with PRIMES[118]

Vehicle type	Source		Base case technology	Improved technology	Advanced technology	More advanced technology
ICE gasoline	McKinsey 2009	efficiency [l/100km]			6.1	
		cost [EUR]			22252	
	IEA 2009	efficiency [l/100km]	7.0	5.6	4.3	
		cost [EUR]		21336	22169	
	PRIMES	efficiency [l/100km]	*10.0*	8.0	6.3	5.7
		cost [EUR]	*19252*	22461	26739	30750
	DOE 2010	efficiency [l/100km]	*8.99*		5.6	
		cost [EUR]				
	EPA 2005	efficiency [l/100km]		7.2	5.3	
		cost [EUR]		19964	20570	
ICE diesel	McKinsey 2009	efficiency [l/100km]			4.5	
		cost [EUR]			23461	
	IEA 2009	efficiency [l/100km]	7.0			3.9
		cost [EUR]			24295	25961
	PRIMES	efficiency [l/100km]	9.7	7.5	5.9	5.4
		cost [EUR]	21795	27927	32714	37239
	EPA 2005	efficiency [l/100km]			5.8	
	FEV/EPA	cost [EUR]			23786	
		efficiency [l/100km]			6.5	
	ORNL	cost [EUR]			24344	
	WBSCD 2004	efficiency [l/100km]		8.0		
HEV gasoline	McKinsey 2009	efficiency	7.0	3.92		
		cost [EUR]		22586		
	IEA 2009	efficiency	6.7	5.5	5.0	3.2
		cost [EUR]	21336	21752	23002	26452
	PRIMES	efficiency	6.3	5.0	3.9	3.6
		cost [EUR]	27167	30563	35037	38742
	EPA 2005	efficiency		4.9		
	EPRI	cost [EUR]		21752		
		efficiency		6.0		
	ORNL	cost [EUR]		21935		
	WBCSD 2004	efficiency		7.5	6.3	
HEV diesel	McKinsey 2009	efficiency [l/100km]	7.0	5.6		
		cost [EUR]		22586		
	IEA 2009	efficiency [l/100km]	6.0	5.5	4.7	2.7
		cost [EUR]	21752	23419	24252	26752
	PRIMES	efficiency [l/100km]	6.3	5.0	3.9	3.6
		cost [EUR]	26953	30322	34761	38438
	EPA 2005	efficiency [l/100km]			2.9	
		cost [EUR]			23375	
	WBCSD 2004	efficiency [l/100km]	7.6	6.4		
EV	McKinsey 2009	efficiency [l/100km]			3.0	1.5
		cost [EUR]			49252	24086
	IEA 2009	efficiency [l/100km]			2.8	2.8
		cost [EUR]			29669	33836
	PRIMES	efficiency [l/100km]	3.7	3.5	3.2	2.9
		cost [EUR]	32292	36329	41647	46052
	WBCSD 2004	efficiency				2.0

The amounts of biofuels in the fuel mix of the Reference scenario are determined by the relative costs of the fuels taking account of tax differentials and biofuel quotas. The PRIMES model currently does not distinguish between dedicated biofuel vehicles and vehicles that allow only for blending; the fuel and vehicle stock mix simulate the inclusion of dedicated vehicles implicitly.

118 Note: for EV 1l/100km is approximately 8.5kWh/100km; an exchange rate USD to EUR of 1.2USD/EUR has been used.

The Current Policy Initiatives Scenario relies on the same technology assumptions besides nuclear in power generation which has been revised upwards reflecting the follow-up to the Japanese nuclear accident.

1.6 Other assumptions

Discount Rates

The PRIMES model is based on individual decision making of agents demanding or supplying energy and on price-driven interactions in markets. The modelling approach is not taking the perspective of a social planner and does not follow an overall least cost optimization of the energy system. Therefore, social discount rates play no role in determining model solutions. However, social discount rates can be used for ex post cost evaluations.

Discount rates pertaining to individual agents play an important role in their decision behaviour. Agents' decisions about capital budgeting involve the concept of cost of capital, which is depending on the sector - weighted average cost of capital (for firms) or subjective discount rate (for individuals). In both cases, the rate used to discount future costs and revenues involves a risk premium which reflects business practices, various risk factors or even the perceived cost of lending. The discount rate for individuals also reflects an element of risk averseness.

Table 5: Discount rates for the different actors[119]

Discount rates	
Industry	12%
Private individuals	17.5%
Tertiary	12%
Public transport	8%
Power generation sector	9%

Degree days against the background of climate change

The heating degree days, reflecting climate conditions, are kept constant at the 2000 level, which is higher than the long term average without assuming any trend towards further warming. The degree days in 2000 were fairly similar to the ones in 2005. This simplification allows comparison of recent statistics with the projection figures, without the need for climate correction.

There are also other energy related impacts from climate. However, future climate change depends on future emissions worldwide, atmospheric concentration and the sensitivity of the climate system to such concentration increases. Future developments in these areas are surrounded by substantial uncertainty. Given this uncertainty and the focus of this impact assessment on the various energy system impacts this quantitative analysis has assumed constant climate conditions over time. This simplification should be borne in mind when considering the following detailed results under constant climate, which is likely to change more, the more pronounced the global emission increase. All the decarbonisation scenarios in Part B assume meeting the climate targets, which are expected to prevent dangerous climate change. However, even when temperature changes are limited to 2 degrees Celsius, some

[119] The discount rate for private individuals includes risk aversion; risk premiums are added for other actors and are technology specific.

climate impacts will occur. A literature review on climate change impacts in the European energy supply sector[120] has identified the following main impacts:

- Cooling water constraints for thermal power generation (especially during heat waves), with nuclear appearing to be particularly strongly affected[121]
- Damage to offshore or coastal production facilities due to sea level rise and storm surges
- Damage to transmission and distribution lines due to storm events, flooding
- Lower predictability of hydropower availability
- Affected yield in renewable energy sector (hydropower in Southern Europe, possibly biofuels due to diseases and forest fires, possibly faster biomass plant growth in certain areas)
- Melting permafrost affecting energy production and distribution in cold climates
- Damages and output constraints in wind energy due to storms and increased average wind speed

In addition, changes in temperature might lead to changes in energy demand patterns for heating and cooling.

It can hence be expected that decarbonisation has also positive economic impacts with regard to energy security and competitiveness by avoiding parts of the damage and adaptation costs in the energy system due to climate change.

In any case, given our lack of knowledge – perhaps for a considerable time to come - about how the EU 2050 GHG emission objective will be met and how global GHG emission will develop over time and therefore lacking information on future atmospheric concentrations and their impacts on temperatures in the Member States, the simplifying assumption has been made in this analysis that heating degree days remain constant.

Exchange rates

All monetary values are expressed in constant, 2005, terms (without inflation). The economic modelling in PRIMES is based on euros. The dollar exchange rate for current money changes over time; it starts at the value of 1.45$/€ in 2009 and is assumed to decrease to 1.25 $/€ by 2020 and to remain at that level for the remaining period.

[120] As part of the European Commission contract "Climate proofing EU policies".

[121] Interim results of the FP7 project "European RESPONSES to climate change"

2. RESULTS

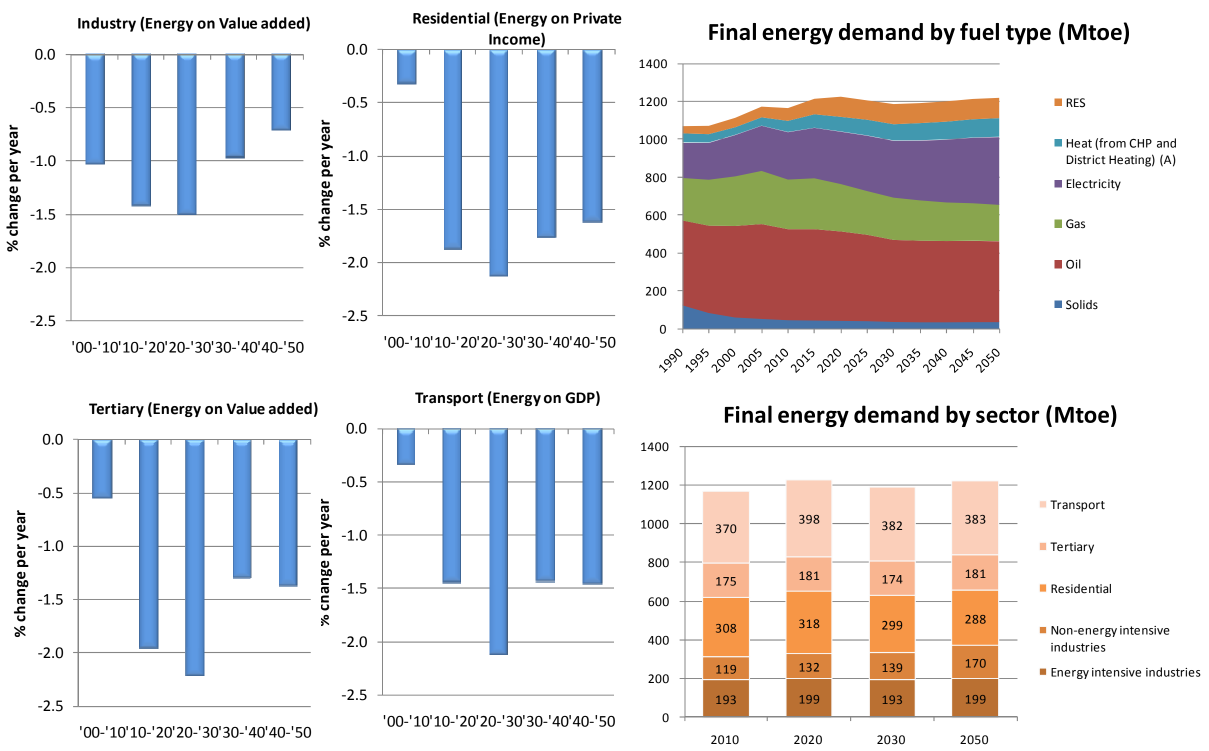
2.1 Reference scenario

Energy consumption and supply

Primary energy consumption peaked in 2006 at a level only marginally different from the year before. Given that 2005 numbers in the PRIMES output have been fully calibrated to 2005 Eurostat energy statistics, the following comparisons start from 2005, being virtually the peak year of energy consumption so far[122]. With ongoing energy efficiency policies – even in the absence of any further policy intensification as depicted in the Reference case- total energy demand decreases slightly up to 2050 (-4% from 2005). This is despite post-crisis economic growth leading to a doubling of GDP between 2005 and 2050 (on an EU-27 average of 1.6 % per year). Therefore, energy intensity drops considerably with one unit of GDP in 2050 requiring only less than half the energy needed in 2005.

Final energy consumption continues rising until 2030, after which demand stabilises as more efficient technologies have by then reached market maturity and the additional energy efficiency of the appliances is sufficient to compensate for increased demand for energy services (heat, light, motion, etc). The share of sectors remains broadly stable with transport staying the biggest single consumer accounting for 32% in 2050; the industrial share increases slightly while that of households declines a bit.

Figure 7: Final energy demand indicators

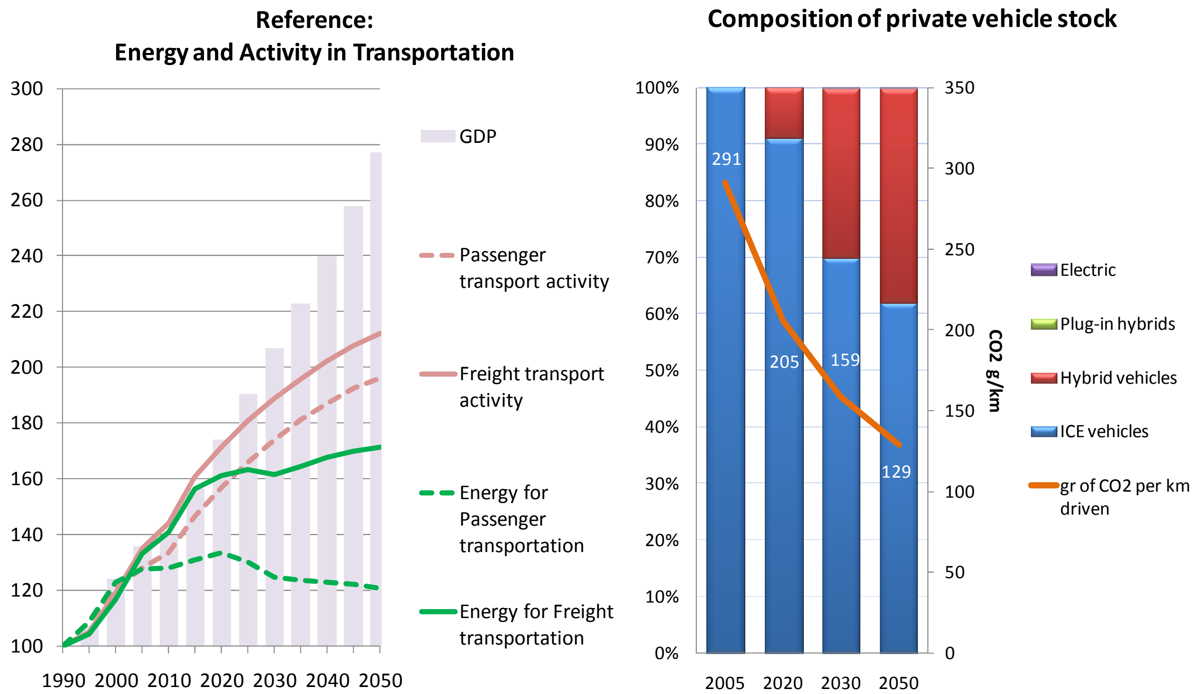


122 … and perhaps ever – except for much higher economic growth materialising (see below under sensitivities)

The energy intensity of different sectors decreases, as does the overall energy intensity of the economy. Increased energy efficiency in the residential sector is due to the use of more efficient energy equipment (appliances, lighting, etc.) and buildings as well as behavioural changes. The strong improvement in the energy efficiency of energy equipment is driven by the Eco-Design regulations and by better thermal integrity of buildings reflecting the Recast of the Energy Performance of Buildings Directive. While these improvements are sufficient to ensure a decrease in final energy demand over the projection period in the residential sector, the increased efficiency is not sufficient to compensate for higher needs in the tertiary sector.

In the transport sector, the correlation between GDP growth and transport activity is found to decouple somewhat when using satellite transport modelling tools. Energy consumption is decoupling much more significantly due to the use of more energy efficient vehicles, in particular hybrids. The CO2 from cars regulation is instrumental for this development. This scenario takes a conservative view regarding the development of alternative energy carriers such as electric and fuel cell cars; it does not assume strong policies leading to a shift towards electric mobility or plug-in hybrid vehicles in addition to the existing CO2 from cars regulation. The CO_2 emissions per kilometre driven decrease rapidly up to 2020 but as the regulation is not strengthened after 2020 in this scenario, improvements thereafter are due to stock renewal and some autonomous efficiency improvements brought about by markets as has been the case in the past. The penetration of biofuels in the Reference scenario is limited to road transportation; overall biofuels in liquid fuels achieve a share of 10% by 2050. The amount of RES in transport meets the 10% target in 2020 to comply with the RES directive and increases to 13.3% by 2050.

Figure 8: Energy and Activity in transport; composition of private vehicle stock[123]



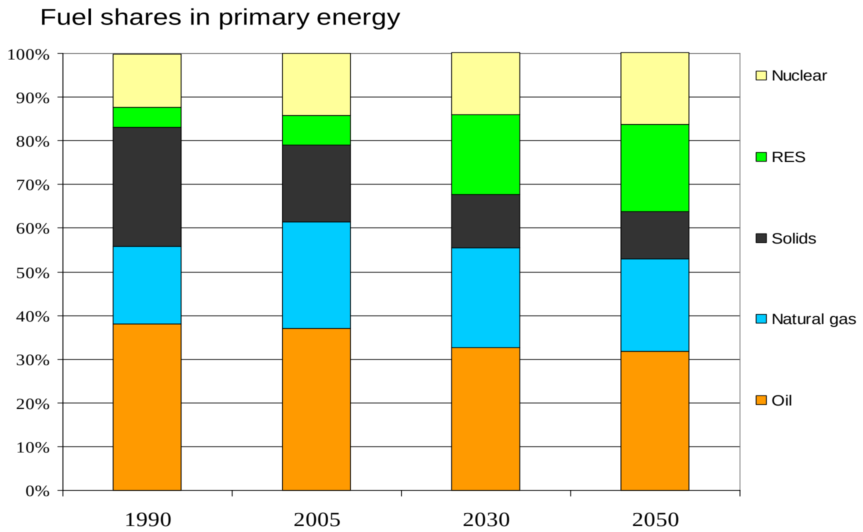
There is considerable fuel switching in final energy demand, especially in the residential and tertiary sectors where the use of fossil fuels (solids, petroleum products and gas) decreases

123 Freight transport does not include international maritime.

while there is a strong tendency towards electrification. The share of RES in final energy consumption increases markedly, reflecting the RES Directive. RES penetration continues with ongoing enabling policies (priority access, streamlined authorisation) whereas operation aid to mature RES technology is progressively reduced in this Reference case.

Also on the primary energy level, there is significant restructuring. This can be seen from the pronounced shifts in the shares of individual fuels up to 2050 (in terms of **primary energy**):

Figure 9: Fuel mix development



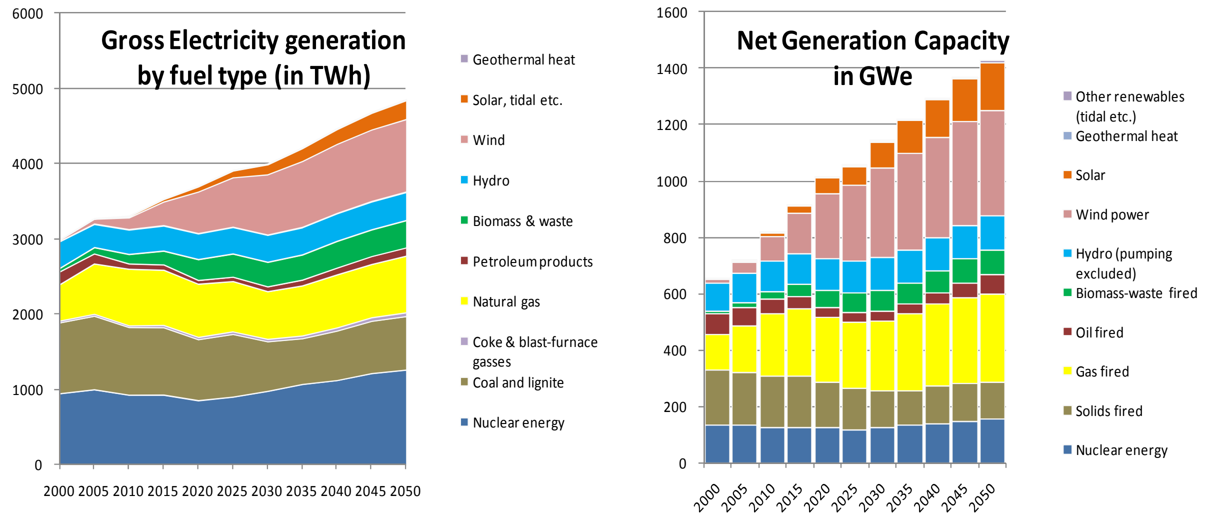
- RES gain 13 percentage points (pp) from 2005 (15 pp from 1990); making it the third most important primary energy source (after oil and gas) in 2050 (when it reaches 20% of primary energy consumption);
- Nuclear increases 2 pp from 2005 (4 pp from 1990), becoming more important than solid fuels (16% share in 2050);
- Oil loses 5 pp (6 pp on 1990); oil share in 2050 amounts to only 32%;
- Solids lose 7 pp from 2005 (16 pp from 1990) reaching just 11% by 2050;
- Gas declines least of all fossil fuels (-3 pp from 2005 to 2050); the gas share in 2050 is still higher than in 1990 (3 pp) because of the significant inroads made up to now; gas will represent more than a fifth of the primary EU energy mix in 2050 (21%);
- The dominance of fossil fuels diminishes with their share falling from 83% and 79% in 1990 and 2005, respectively to only 64% in 2050.

While non fossil fuels (RES and nuclear) account for 36% of primary energy in 2050, they reach a significantly higher share in the 2050 electricity mix. Energy sources not emitting CO2 supply 66% of electricity output, with 40% RES and 26% nuclear. In addition, 18% of electricity would come from CCS plants, which do however still emit some CO2.

Power generation changes substantially in the projection period; the demand for electricity continues rising and there is a considerable shift towards RES. As can be seen in Figure 10 installation of capacity and generation from wind increase steadily throughout the period. The incentives due to the RES target until 2020 are sufficient to make wind power generation competitive with other technologies. Power generation and capacity from solids decrease throughout the scenario due to the carbon prices that reduce the competitiveness of this technology; gas power generation capacity increases, also as peak load activated during back-up periods due to the increased amount of RES in the system. As a result of the large increase in RES in power generation the load factor of the system decreases due to the more widespread use of technologies that run only a limited number of hours per year, such as wind.

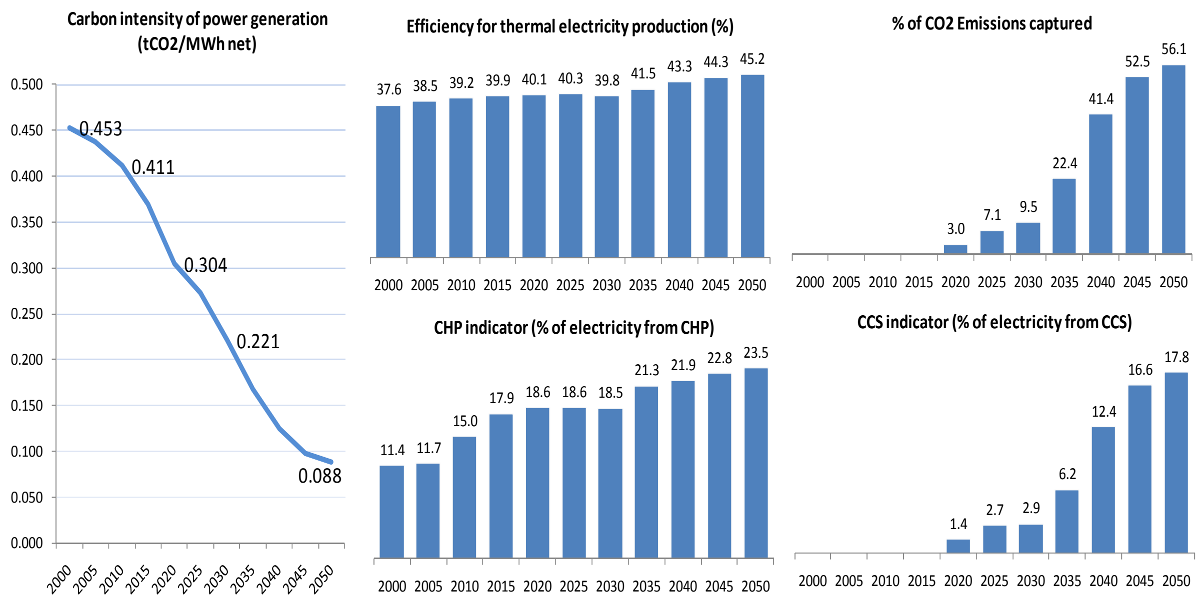
Investment in power generation increases over the projection period, driven by new investments in RES and gas.

Figure 10: Electricity generation and net generation capacity



The carbon intensity of power generation reduces by over 75% in 2050 compared to 2010 levels, driven by the decreasing ETS cap and the rising carbon prices (see Figure 11). In 2050 17.8% of electricity is generated through power plants equipped with CCS. This corresponds to a CCS share in fossil fuel power generation of over 50%. More than 50% of the potential emissions from the power generation sector are captured. The efficiency of thermal electricity production rises throughout the projection period due to the renewal of the power plants, in particular investment in gas and in spite of CCS being widely used in power generation. CHP plants are assumed to be integrated into the competitive electricity markets, facilitated by the CHP Directive and their share in electricity generation will rise. Incentives for CHP focus on electricity, which implies that an increase in electricity production from CHP power plants does not necessarily imply an increase in CHP capacity, given that there is some flexibility in the power to heat ratio.

Figure 11: Power generation indicators [124]

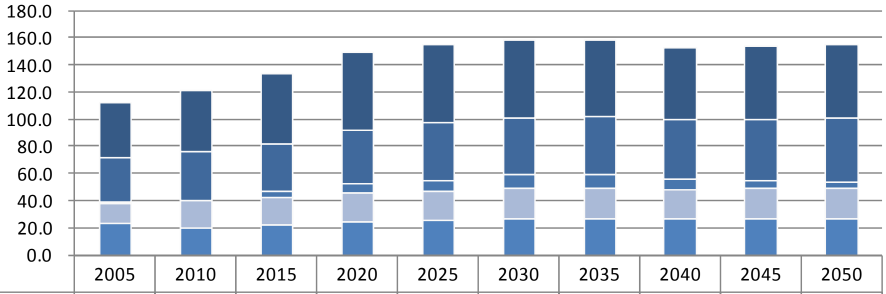


The price of electricity peaks in 2030 and decreases slightly thereafter. The price increase up to 2030 is due to three main elements: the policies inducing investment in RES, the ETS carbon price and the high fuel prices due to the world recovery after the economic crisis. Thereafter electricity prices do not increase further, indeed decline slightly, because of the technical improvements of technologies that limit the effects of higher input fuel prices. Moreover, taxes on fuels and ETS auction payments sink beyond 2030. This is due to the declining cap and the introduction of CCS in particular, which limits emission quantities and therefore auction revenues from the ETS despite rising ETS prices. Whereas the CO2 price increases, the average levy on electricity production, including the carbon free and decarbonised parts, declines in the long term. Moreover, there is a continued decrease in the use of diesel oil in power generation, which Member States may tax for environmental reasons.

124 The percentage of emissions captured is calculated as the ratio between the total emissions captured and the potential emissions of thermal power plants, which are the remaining emissions plus the emissions captured.

Figure 12: Cost components of average electricity price

Cost components of electricity generation (Euro'10 per MWhe)



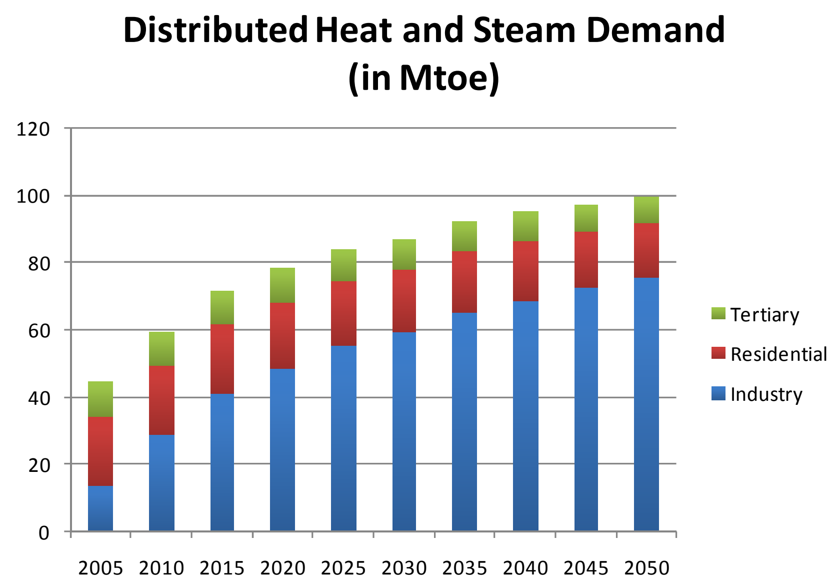
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Fixed Costs	40.5	45.2	51.0	57.1	56.9	58.0	55.9	53.1	54.1	53.6
Variable and Fuel	32.7	35.8	34.7	39.6	42.9	41.6	43.2	44.2	45.3	47.2
Tax on fuels and ETS auction payments	1.0	0.6	5.4	6.3	7.6	10.2	9.9	7.4	5.7	5.1
Excise tax and VAT on electricity	14.2	19.3	20.1	21.2	21.7	22.1	22.2	22.0	22.1	22.2
Grid and sales costs	23.1	20.1	21.7	24.6	25.5	26.5	26.7	26.0	26.2	26.4
Average price of electricity (pre-tax)	97.3	101.6	112.8	127.7	132.8	136.2	135.7	130.8	131.4	132.4
Average price of electricity (after tax)	111.5	121.0	132.9	148.9	154.5	158.3	157.9	152.8	153.4	154.5

Distributed Heat

Demand for distributed heat demand rises in the Reference scenario throughout the projection period; a strong increase can be observed between 2005 and 2020 reflecting the strong CHP promoting policies in all Member States, as well as commercial opportunities that arise from gas based and biomass based CHP technologies. It is assumed that the same policies continue at least until 2020 as part of the implementation of the 20-20-20 policy package. Among the CHP promoting drivers worth mentioning are: the CHP directive (facilitating absorption of CHP-electricity by wholesale markets), national policies including feed-in tariffs and the ETS-carbon prices. CHP growth is limited by the geographic possibilities of the distribution system. District heating powered by boilers is a less attractive option, except in cases exploiting local resources e.g. biomass, and existing distribution networks.

In the longer term further demand for distributed heat in the tertiary and residential sectors seem to slow down as a result of the trend towards electrification (i.e. heat pumps) and higher energy efficiency which limits the overall demand for heating. In industry the increase in demand for distributed steam is projected to continue in the future because the changes of industrial activity are favourable for sectors with high demand for steam such as chemicals, food, drink, tobacco, engineering and other industries. Furthermore the development of the market for distributed steam and the possibilities of selling electricity to the wholesale market favours the construction of CHP units of different sizes and technologies in these industrial sectors

Figure 13: Heat demand by sector



Transport

Transport accounts today for over 30% of final energy consumption. In a context of growing demand for transport, final energy demand by transport is projected to increase by 5% by 2030 to represent 32% of total final energy consumption. This development is driven mainly by aviation and road freight transport. At the same time, however, the energy use of passenger cars would drop by 11% between 2005 and 2030 due to the implementation of the Regulation setting CO2 emission performance standards for new passenger cars[125]. After 2030 transport energy demand would increase only marginally up to 2050.

The EU transport system would remain extremely dependent on the use of fossil fuels. Oil products would still represent 88% of the EU transport sector needs in 2030 and in 2050 in the Reference scenario.

Energy Imports/ Security of Supply

Total energy imports increase 6% from 2005 to 2050. The increase is rather limited despite decreasing indigenous production, as rising gas and biomass imports are compensated by a marked decline in coal imports while oil imports remain broadly stable.

Gas imports continue to rise (28% from 2005 to 2050) due to declining production and despite decreasing consumption.

Import dependency rises only slightly above the present level (54%), reaching 58% in 2020 and flattening out to 2050 thanks to more RES and nuclear.

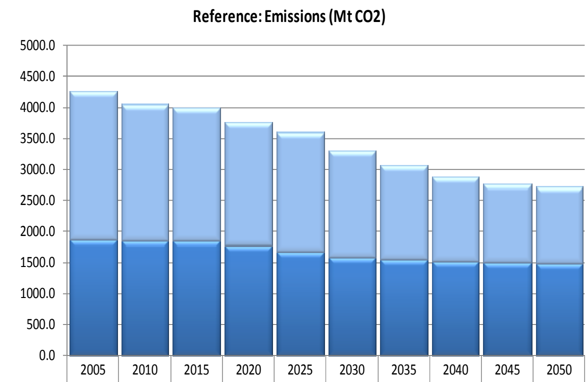
[125] Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles, OJ L 140, 5.6.2009, p. 1–15.

Emissions

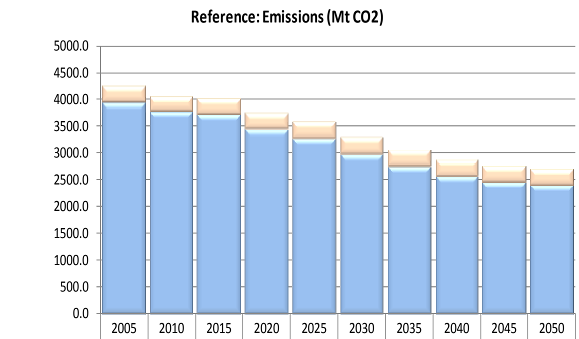
Energy related CO2 emissions decline much faster than energy consumption, giving rise to some decarbonisation of the energy system because of fuel switching to RES and nuclear at the expense of solid fuels and oil:

- Carbon intensity falls markedly. Producing one unit of GDP in 2050 would lead to only 30% of energy related CO2 emissions that were required per unit of GDP in 2005 and to just one fifth of what the CO2/GDP indicator was in 1990.
- Energy related CO2 emissions sink 40% below the 1990 level in 2050; thus the reference scenario represents about half of the efforts needed by a developed economy if a global deal to limit climate warming to 2°C will be achieved.
- CO2 emissions from electricity and heat generation fall almost 70% between 1990 and 2050 when they will make up 14 % of all GHG emissions (down from 27 % in both 1990 and 2005);
- Total GHG emissions decrease slightly less (39%) by 2050 from 1990. Whereas non-CO2 emissions fall somewhat more, the total emission decline is hampered by the very moderate decrease of CO2 from industrial processes (CO2 not related to fuel combustion).

Figure 14: CO2 emissions [126]



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ETS	2379.4	2198.4	2147.9	1982.1	1916.9	1716.9	1522.2	1358.5	1258.8	1226.8
Non-ETS	1871.6	1852.2	1860.4	1771.0	1675.3	1584.3	1548.0	1521.3	1506.1	1484.6
Total CO2	4251.0	4050.6	4008.3	3753.1	3592.2	3301.2	3070.2	2879.8	2764.8	2711.3



	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Process related CO2 Emissions	304.5	279.0	294.8	311.1	318.7	318.4	314.7	314.3	313.5	310.9
Energy related CO2 Emissions	3946.6	3771.6	3713.4	3442.0	3273.4	2982.8	2755.5	2565.5	2451.4	2400.4
Total CO2	4251.0	4050.6	4008.3	3753.1	3592.2	3301.2	3070.2	2879.8	2764.8	2711.3

The contribution to the emission reductions is driven by the ETS sectors which decrease emissions by 48% between 2005 and 2050; on the contrary the non-ETS sectors reduce by 21% compared to 2005. The share therefore shifts from 56% of emissions in ETS sectors in 2005 to 46% in 2050. Most emissions continue to be energy related emissions; energy related CO2 emissions decrease by 39% in the time period from 2005 to 2050 whereas non-energy related CO2 emissions increase by 3%.

Policy relevant indicators (and targets)

The indicative 20% energy savings objective for 2020 would not be achieved under current policies - not even by 2050. The reference case would deliver **10% less energy consumed in 2020 compared to the 2007 projections**.

---

126 The split between ETS and non-ETS emissions reflects over the whole period the ETS scope as valid from 2013 onwards.

The reference case assumes that the RES target is reached in 2020; the RES share (as defined in the RES directive: as a percentage of gross final energy consumption) continues rising to reach 24% in 2030 and **25% in 2050**; further penetration of RES is limited due to the assumed phasing out of operational aid to mature RES technologies (see below). On the basis of final energy, the RES share gains nevertheless 17 pp between 2005 and 2050 (13 pp on the basis of primary energy).

The ETS carbon price rises from 40 € (08)/tCO2 in 2030 to 52 € in 2040 and flattens out to 50 € in 2050 (after having triggered some emission reducing restructuring in ETS sectors to comply with the dynamic requirements of the Directive).

These CO2 prices seem high enough to trigger significant CCS investment from 2040 onwards; whereas the CCS share in gross power generation reaches only 2% in 2030, it rises to 12% in 2040 and 18% in 2050 (this percentage is 15% in net power terms). CCS is mainly applied on solid fuel power generation, but also to gas power plants towards the end of the projection period; by 2050 half of solid fuel power capacities are equipped with CCS and 17% of gas power plants. Generation by solid fuel CCS plants represents 10% of net total power generation in 2050; the share of gas based CCS is 5% in 2050.

The reference case assumes the overall GHG target, ETS cap and non-ETS national targets to be achieved by 2020 but thereafter GHG reductions fall short of what is required to mitigate climate change with a view to reaching the 2 °C aim. While the reference case development lead to only 40% less GHG emissions from 1990, more than twice as much might be needed, i.e. minus 80-95% by developed economies.

2.2 Economic growth sensitivities

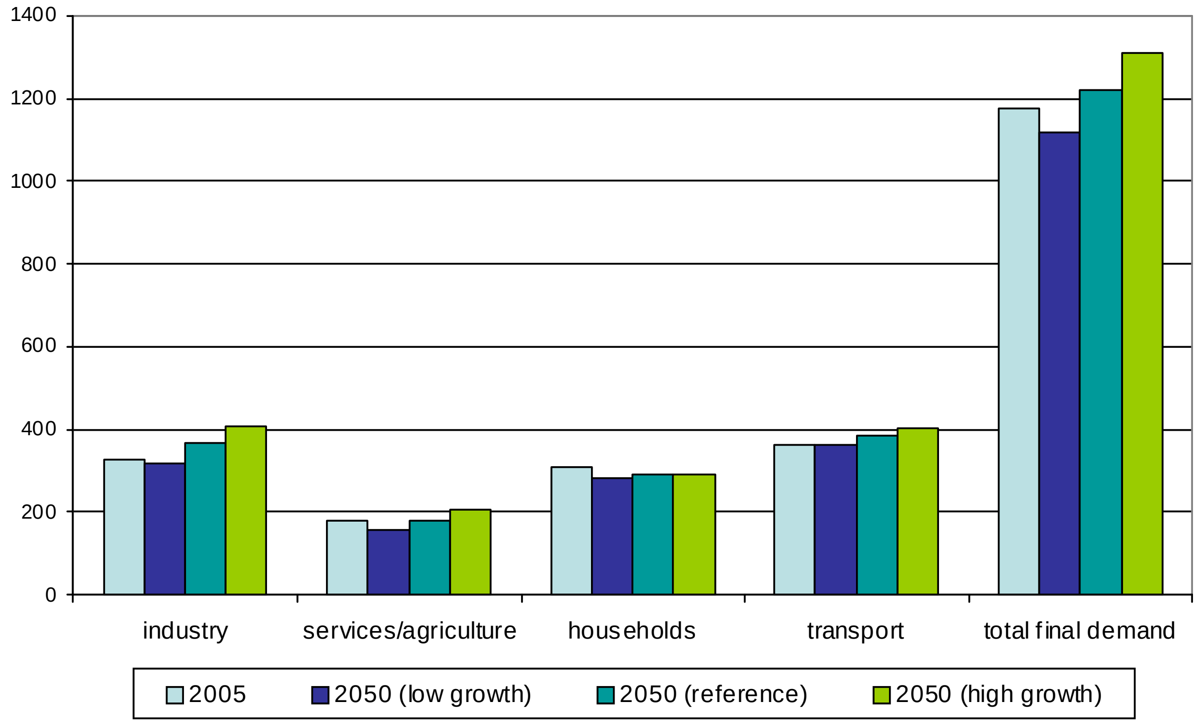
Economic activity is a key driver of energy consumption and therefore emissions. It can be expected that higher GDP growth rates will lead to higher energy consumption and CO2 emissions and vice versa in the case of lower economic growth.

Final energy demand

In fact, final energy consumption in the high economic growth case is 7.3% higher in 2050 than in the Reference case. This increase is however much lower than the increase in GDP (+15.0%) due to important energy intensity improvements. These improvements are linked in particular to the structure of the additional economic activity, which takes place mainly in less energy intensive sectors, such as market services and trade. Moreover, higher economic growth allows faster capital turnover so that more energy efficient equipment enters the capital stock sooner. Better capacity utilisation in case of high economic growth can also add to this improvement in energy intensity. Higher household income also allows for faster replacement with new, more energy efficient, appliances and cars, although the overall demand of energy services would increase via more purchase of higher performing items.

CO2 emissions from final energy demand rise slightly less than energy consumption thanks to some fuel switching to zero carbon (electricity and heat) or low carbon fuels (gas). In 2050, CO2 emissions in final demand are 6.9% higher than in the Reference case (while energy demand and GDP are 7.3% and 15% higher, respectively).

Figure 15: Final energy consumption broken down by sector in different economic growth cases (in Mtoe)



Additional energy consumption is most pronounced in the services/agriculture sector where demand in 2050 is 14.9% higher than in the Reference case. Again, CO2 emissions rise less than energy consumption thanks to fuel switching connected especially with more use of electricity[127]. In 2050, CO2 emissions from this sector exceed the Reference level by 12.6%, falling nevertheless well below current levels (see table 6).

With less pronounced expansion of economic activities in industry there is lower, but still considerable, growth in final energy demand. Increased industrial activities require more energy inputs so that industrial energy demand exceeds Reference case levels in 2050 by 9.9%. Energy consumption growth in industry is fossil fuel intensive with higher demand for carbon rich coal in certain branches, which – under constant CO2 policies via the EU ETS - leads to higher CO2 emissions, which exceed the Reference case level in 2050 by 12.0%. It is however worth noting that even with such high economic growth, industrial CO2 emissions in 2050 remain below today's level.

Table 6: CO2 emissions from final energy demand sectors in different economic growth cases (in Million tonne CO2)

	1990	2005	2050 low growth	2050 Reference	2050 high growth
Industry	781	582	361	425	476
Services/agriculture	301	262	136	158	178
Households	499	487	292	297	303
Transport	813	1053	951	1007	1061
Total final demand	2394	2384	1740	1888	2018

Energy consumption of households rises much less in comparison to the Reference case (by 1.9% in 2050) because many energy services, such as heating and cooking are very income inelastic once certain comfort levels have been reached. Moreover, increased purchases of appliances in the context of higher incomes concern items with lower specific energy consumption compared with the existing stock, a process that is being made more pronounced with eco-design Regulations. Household CO2 emissions in 2050 are just 2% higher than in the Reference case, but still a third lower than today.

Transport energy demand exceeds Reference case levels by only 5.5% in 2050. The reason is similar to that for households. Except for holiday trips, passenger transport activity tends to grow slower than private incomes. On the contrary, freight transport activity is much more influenced by the level of economic activity. In the absence of major possibilities for fuel switching under current trends and policies, higher transport energy demand translates directly into higher CO2 emission (5.3% higher than Reference in 2050), keeping emissions at current levels in 2050.

[127] However, it should be noted that such higher electricity demand could lead to higher CO2 emissions, depending on the fuel input structure, which are accounted for under power generation (see below)

The improvement of carbon intensity in final energy demand under high economic growth (lower CO_2 growth than growth of final energy demand) is mainly due to fuel switching towards electricity, which has been an ongoing trend with higher incomes and structural change in the economy (e.g. more ICT based services). Higher economic growth would lead to 8.8% higher electricity consumption (compared with Reference) in 2050 with CO_2 consequences for power generation.

Higher GDP growth leads to higher demand for heat (+ 7% in 2050) in line with overall increase of final energy demand but significantly lower than increase in GDP (+15%). The growth comes mainly from industry and tertiary sectors reflecting higher economic activity in these two sectors. Residential demand is rather stable (+1%) as heat is an essential need and not very elastic to changes in household income. Supply increases from both CHP and district heating units.

Lower economic growth entails lower energy consumption and emissions in all sectors. With GDP in 2050 remaining 14.7% below the Reference case level, there would be a reduction of final energy demand by only 8.4%. Consequently, energy intensity (of final demand) would deteriorate compared with the Reference case (and even more so in the high growth case). Slower capital turnover in case of sluggish economic growth is one reason for this as well as a lot of energy uses being rather income inelastic, such as home heating and cooking. CO_2 emission would decline to a somewhat smaller extent than energy consumption (only by 7.8% in 2050 compared with Reference). Low carbon content fuels reduce somewhat more than the more carbon intensive ones, leading also to a slight worsening of carbon intensity of final energy demand.

Energy demand in services/agriculture would fall almost as much as GDP in 2050 compared with the Reference case (-14.3%). The decline in CO_2 emissions would be similar (-13.8%). Industrial energy consumption and emission decrease also markedly with lower economic growth; they are down on the Reference case in 2050 by 13.6% and 15.1%, respectively. CO_2 emissions reduce somewhat more than energy consumption, as fossil fuel demand drops slightly more than demand for electricity and steam that are carbon free at use.

By comparison, households and transport reaction to lower GDP is much less pronounced. Household energy consumption and CO_2 emissions are both down 2% on the Reference case 2050 level (i.e. substantially less than the decline in GDP: almost -15%). Given that freight transport reacts rather strongly to lower economic activity while passenger transport decreases comparatively little with lower income, transport energy consumption falls 5.7% below the 2050 reference case. CO_2 emissions sink by almost the same percentage (-5.5%), as possibilities for fuel switching are limited in a Reference case environment without intensified climate or renewables policies.

Lower economic growth leads to a rather strong reduction of electricity demand, which remains 9.7% below the Reference case level in 2050, still exhibiting healthy growth from current levels.

Demand for distributed heat decreases by 10% in 2050 compared to the Reference scenario mainly due to sharp decreases in tertiary (-14%) and industry (-12%) sectors reflecting lower economic activity. Residential demand reacts much less (-3%) as heat is an essential need and not very elastic to changes in household income. There is a shift from CHP production (-11% in 2050 following lower electricity demand) to higher district heating units production (+10%).

Electricity generation

Electricity demand is particularly sensitive to variations in economic activity. With limited possibilities for electricity imports this translates into a similar requirement on the generation of electricity in the EU. In the high economic growth case with 15% higher GDP in 2050, gross electricity generation exceeds the 2050 reference case level by 9.2%. Similarly, 14.7% lower economic activity in 2050 entails 10.2% less electricity generation in 2050.

Whereas the level of electricity generation strongly depends on the magnitude of economic growth, its structure changes much less with lower or higher GDP in 2030 and 2050. In 2030, the RES share in electricity varies within a margin of 1 percentage point around 40.5% in the Reference case (see table 7 on fuel shares in generation). This range becomes somewhat larger in 2050 (around 2 percentage points). With unchanged support for RES, higher economic growth encourages in particular nuclear and fossil fuel generation, leading to a somewhat lower RES share in power generation; it should be noted that the absolute level of RES based electricity generation is significantly higher with high economic growth (+5.3% in 2050 compared with Reference).

Table 7: Electricity related indicators under different economic growth assumptions

	High economic growth		Low economic growth		Reference case	
	2030	2050	2030	2050	2030	2050
Gross electricity generation (TWh)	4229	5386	3848	4422	4067	4931
Shares in gross electricity generation						
RES share	39,8%	38,8%	41,5%	42,5%	40,5%	40,3%
Nuclear share	25,1%	27,4%	23,2%	25,3%	24,5%	26,4%
Fossil fuel share	35,1%	33,8%	35,3%	32,2%	35,0%	33,3%
CCS share	4,2%	20,3%	1,6%	12,1%	2,9%	17,8%
Prices in €						
ETS (€(08)/t CO2)	50,0	52,5	32,0	41,5	40,0	50,0
Average electricity price (in €(08)/MWh)	159,7	153,9	157,0	153,5	157,7	153,8

High economic growth brings about higher ETS prices (see table 7), which in turn encourage CCS deployment. Combined with a higher share of fossil fuel based power generation, this leads to CCS shares in power generation that are higher than Reference in 2030. The increase is particularly pronounced in 2050, when 20% of total power generation would be equipped with CCS. On the contrary, with low economic growth leading to low ETS prices as well as lower fossil shares in power generation, CCS amounts to only 12% in 2050.

Electricity prices are rather insensitive with respect to variations in economic growth. Higher economic growth increases the 2030 average electricity price slightly by 1.2%, while lower economic growth would lead to an electricity price that is 0.4% below the Reference case price. These electricity price modifications relate to the significant changes in ETS prices brought about by variations in allowances demand due to growth of energy demand and changing fossil fuel inputs to power. In 2050, when the variation in ETS prices from the Reference case is pretty small, the variations in electricity prices become marginal or even undetectable (electricity prices: minus 0.2% with low GDP growth and 0.0% with high growth). Consequently, different economic growth patterns do not alter the Reference case result that shows strongly rising electricity prices up to 2030 in the context of higher fixed costs following the restructuring of the power generation system for reaching the RES and GHG targets, with a stabilisation of prices in the following two decades.

Primary energy consumption and energy intensity

As was discussed in the part on final energy demand, certain parts of energy consumption react only to a limited extent to variations in economic growth; this concerns in particular the household sector and also passenger transport. Combined with more favourable conditions for improving energy efficiency under high economic growth (bringing about, together with structural change in economic activity, 5.8% better energy intensity), this leads to primary energy demand rising much less than GDP. Compared with the Reference case, primary energy demand increases 3.4% in 2030 while GDP is 6.3% higher, in 2050 primary energy exceeds the Reference case by 8.4% with the economy being 15.0% larger in terms of GDP.

Also in the case of lower economic growth, the effects on primary energy consumption are moderated by the less income elastic consumption sectors (households, where heating needs remain largely the same, as well as passenger transport having rather unchanged needs for commuting, shopping and similar travelling). Moreover, lower capital turnover with lower economic growth limits the opportunities for investing in energy efficient items. As a result, energy intensity worsens by 6.4% in 2050. Consequently, energy consumption sinks significantly less than GDP. With 7.7% lower GDP in 2030 compared with the Reference case, primary energy is down 5.0%; in 2050 with 14.7% lower GDP compared with Reference there is a decline of primary energy by just 9.3%.

These energy intensity effects (the improvement of 5.8% compared with Reference in 2050 under high economic growth and the 6.4% deterioration under sluggish GDP growth) limit the impacts of alternative developments of GDP on CO2 emissions. Another countervailing (or reinforcing) factor could come from changes in the fuel mix. Different economic growth patterns exert somewhat different influences on individual fuels.

Fuel mix and carbon intensity

Under high economic growth, oil and gas consumption grow less than overall energy consumption. Nuclear reacts in a more pronounced way (above average) given its exclusive use in power generation, which in turn is more sensitive to variations of GDP. Also the reaction, to higher economic growth, of solids being mostly used in power generation is fairly marked in 2050, given the absence of strong CO2 limitation policies. On the assumption of unchanged RES support schemes, RES are not particularly encouraged by higher economic growth.

On the other hand, RES are not particularly discouraged by lower economic growth. The negative effects of such GDP losses on nuclear and solids are much stronger, exceeding the percentage changes of total energy consumption. Oil and gas sink largely in line with the reduction in total energy demand.

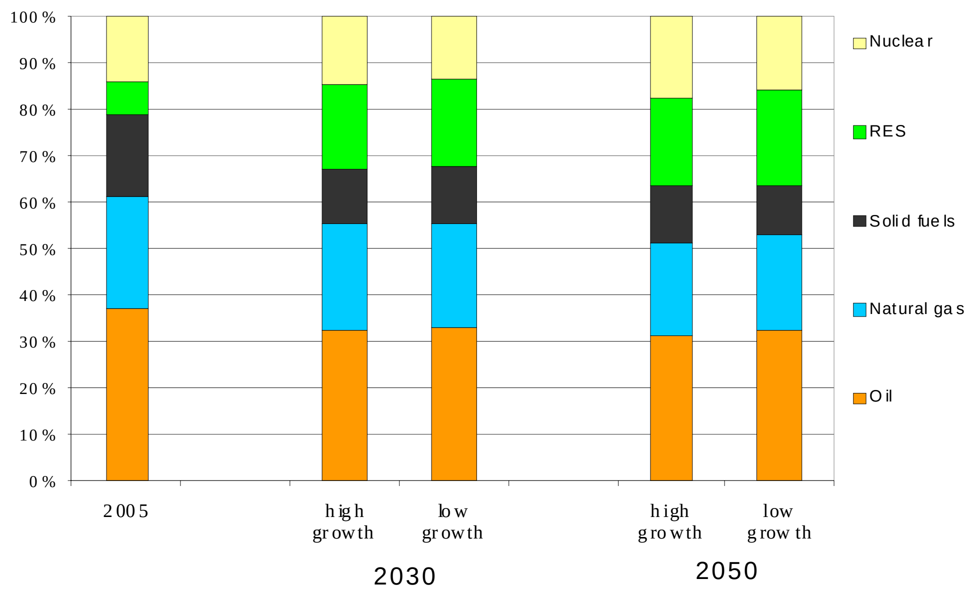
This leads to the following fuel shares in 2050:

- Oil reaches shares between 31% and 32.5% under high and low economic growth, respectively;
- The gas share amounts to 20% in both growth cases;
- Solids account for 12% under high and 10.5% under low economic growth;
- The nuclear share reaches 17.5% under high and 16% under low economic growth
- RES increase their share to 19.5% with high GDP and even 21% with lower economic expansion;

When evaluated in terms of gross final energy consumption (definition in the RES Directive), the RES shares amount to 25% under high and to 26% under low economic growth, which represents increases from the 2005 level of between 16 and 18 pp in the high and low GDP case, respectively. The RES share in transport is also pretty robust across economic growth cases amounting to 13% in 2050 under the different GDP assumptions, up half a percentage point from its level in 2030.

While there are only limited changes of fuel shares across economic growth cases, the evolution of fuel shares over time, especially regarding RES, is pretty dynamic. Fossil fuels in total lose around 16 percentage points between 2005 and 2050, with somewhat higher losses for solids and oil. RES gain between 12.5 and 14 percentage points under high and low growth, respectively, while nuclear accounts for the remaining gain.

Figure 16: Development of the fuel mix under high and low economic growth



The overall result of these changes in the fuel mix is that the carbon intensity improves with higher economic growth, i.e. one unit of energy consumed results in slightly less CO2 emissions under high growth (1.32 t CO2/toe in 2050) than in the Reference case (1.36 t CO2/toe for the same year). The opposite effect on carbon intensity comes about under lower economic growth, in which case one tonne of oil equivalent energy consumption is associated with CO_2 emissions of 1.45 tonnes, which equates to a 6.4% worsening.

Total CO2 emissions

These effects on energy and carbon intensity and the existence of the ETS with a given emission cap mean that GDP-induced changes in CO_2 emissions are much less significant than underlying changes in GDP. With 15% higher GDP in 2050, CO_2 emissions are only 5.3% higher (both on Reference in 2050). Similarly, a GDP drop of 14.7% leads to CO_2 emissions that are only 3.3% lower in 2050. For 2030, a GDP rise on Reference by 6.3% is associated with a 1.2% increase of CO_2 emissions, while a GDP loss of 7.7% entails 2.3% lower CO_2 emissions (compared with Reference case).

It can be concluded that emission results are pretty robust with respect to variations of GDP. This reduces greatly one possible uncertainty regarding policy objectives on emissions, as there are mechanisms (ETS, effects on energy intensity) that limit the effects of variations in GDP levels on energy consumption and on CO_2 emissions. This is important given the great uncertainty in projecting economic activity for the coming years, let alone over the next four decades.

While there are such energy and carbon intensity effects, limiting the impact of economic activity on CO_2 emissions, alternative economic developments would still alter the expected decline in CO_2 emissions up to 2050. Such a decline of emissions materialises under Reference case policies and is also brought about by Current Policy Initiatives and even more so in decarbonisation scenarios.

Emissions reduce somewhat more over time with lower economic growth and somewhat less with higher economic growth. Variations in CO_2 reductions from 1990 levels are however marginal in 2030 (around 1 percentage point more or less CO_2 reduction from Reference case level in 2030 with higher or lower growth), while GDP varies 6-8 percentage points. In 2050 variations in the policy relevant indicator: CO_2 reductions from 1990 around what would materialise in the reference case are still rather small (plus/minus 2-3 percentage points) - with GDP varying 15 percentage points around the reference case level.

Table 8: CO2 reduction below 1990 (index 1990 =100) and major drivers

1990 = 100	2030			2050		
	High growth	Reference	Low growth	High growth	Reference	Low growth
GDP	220	207	191	319	277	236
Energy consumption	108	104	99	115	106	96
CO2 emissions	75	74	72	63	60	58

Again, the possibilities for technically achieving GHG gas targets are not overly dependent on the level of economic growth. In any case, it needs to be borne in mind that GHG reduction requires innovation and investment, which is harder to finance in a low economic growth environment. Overall, emission reduction may be rather facilitated with sustained economic growth.

Finally, regarding the GHG emission reductions in ETS and non-ETS sectors, there is as to be expected with a given emission cap particularly little variation across economic growth cases for ETS sectors, whereas the GDP growth cases are somewhat more contrasted regarding non-ETS emissions.

Non-ETS GHG emissions reduce comparatively little up to 2030 under high economic growth and stay almost flat thereafter, whereas there is still a slight decrease in the reference case. Nevertheless, these changes are much lower than the underlying changes in GDP. In case of sluggish economic development, non-ETS emissions would continue declining through 2050. However, the reduction from Reference in 2050 is much lower than the decline of GDP.

Energy imports and external dependency

Total net energy imports increase 16% from 2005 to 2050 under high economic growth, whereas they decline 4% with low GDP (Reference case: 7% increase). Increasing imports of both gas and biomass contribute to the import rise in both economic growth cases, whereas imports of solid fuels decline both under high and low GDP assumptions; oil imports increase with higher economic growth and decline under low economic growth.

Despite different developments of energy imports in quantitative terms, import dependency as a percentage of total supply stays constant at 58% in 2050 in the different economic growth cases, marginally up from 57% in all cases in 2030 and an estimated 54% in 2010.

Conclusions on economic growth variants

The model based analysis shows that policy relevant indicators are pretty robust against variations in economic growth assumption, which is a significant result, given the great uncertainty in making GDP projections for the next few years let alone the next four decades.

- CO2 reduction becomes only slightly more difficult in technical terms under significantly higher economic growth. Moreover, it is important to note in this context that higher economic growth brings also more opportunities for innovation and investment in low carbon technologies, thus facilitating climate change mitigation and dealing with the competitiveness and energy security aspects. This result stems from improvements in both energy and carbon intensity facilitated by the ETS emission cap in place.

- In a similar manner, the countervailing effects through energy and carbon intensity are also present in the case of low economic growth so that there is only limited further emission reduction brought about by considerably lower GDP levels.

- RES shares are pretty robust with respect to GDP levels with variation spanning just 1 percentage point in 2050 for the RES share in gross final energy demand (overall indicator of the RES Directive). Similar results hold for the RES share transport and to a slightly lesser extent for the RES-E share.

- High economic growth gives rise to more energy intensity improvements, but would render absolute energy saving objectives with respect to e.g. a statistical year more difficult to achieve (with opposite conclusions under low economic growth). Energy saving objectives, such as the current one for 2020, are measured in absolute terms (without reference to GDP). However, energy consumption reacts to economic growth; it rises with higher GDP and declines in the opposite case.

- Policy relevant indicators regarding competitiveness are pretty much unaffected by economic growth; while ETS prices differ to some extent the effects on electricity prices are marginal.

- Exposure to external dependency measured as share of energy imports in energy supplies is also unaffected by such significant changes in GDP levels.

2.3 Energy import price sensitivities

Two such sensitivities were modelled spanning a fairly wide range around the Reference case price trajectories (see assumptions part above for details). The world oil price in 2050 is assumed to be 28% higher than the Reference scenario in the high price case, whereas it stays 34% below Reference in the low price case. In the low price case, fossil fuel import prices remain broadly at the 2010 level; coal prices are stable, oil has a small peak around 2030, whereas gas prices remain weak over the next few years but recover to the 2010 level in the long run.

Higher import prices bring about higher end-user prices discouraging energy use in the various sectors and vice versa. Moreover, such developments change the competitive position of individual fuels and technologies given all the other cost elements in addition to fuel input costs in the formation of end-user prices (e.g. capital costs and taxes). Effects are therefore differentiated according to fuel and sector. For example, electricity prices are less affected than end user prices of e.g. gas. Similarly, the percentage increase of end user prices following higher import prices is much more pronounced in e.g. industry compared with transport where existing high excise taxes moderate the increase in percentage terms.

Energy consumption

Under **higher energy import prices** (oil price up 28% on Reference in 2050), final energy consumption decreases by just 2.3% in 2050 from the Reference case. The decline spans from 1.1% in transport to 4.7% in services/agriculture where more electricity use, encouraged by higher prices of competing fuels, improves the energy intensity of the sector (electricity at use having a very high efficiency). Total electricity use in final energy consumption rises 1.0% compared with Reference in 2050.

Primary energy demand decreases 2.0% in 2050 compared with Reference, mirroring also the price induced effects in the energy transformation sectors notably in power generation as well as price inelastic parts, such as energy use as feedstock in the petrochemical industry.

Whereas higher energy prices exert only a limited effect on the level of energy consumption, the influence on the fuel mix is important. Gas demand reacts most strongly to rising prices given its use as a major input fuel for power generation where it competes with coal, RES and nuclear, which are either not affected (RES, nuclear) or less affected by rising fossil fuel import prices (see assumption part above). Gas demand in 2050 would fall by 14.7% in 2050 compared with Reference. Oil demand would also decline by 3.3% in 2050. The limited reaction is due to the concentration of oil use on petrochemicals and transport, where price reactions are small due to lack of substitutes and high existing tax levels in transport.

The use of solid fuels is encouraged despite higher import prices as gas competitiveness suffers in particular as a result of the more pronounced price increases (this is also linked to the cost structure in power generation where fuel costs are relatively more important for gas given its lower capital costs than for coal plants). Solid fuel use would increase 2.2% over Reference in 2050. Nuclear benefits also from higher fossil fuel import prices gaining 4.4% on Reference in 2050. Renewables win most, reaching 5.4% higher use compared with Reference in 2050.

In the case of **low energy import prices** (-34% in 2050 from Reference), final energy demand would increase by only 4.2% above Reference in 2050. The increase would be particularly high in services/agriculture where higher gas and oil use would be encouraged to the detriment of electricity. As electricity loses competitiveness, it contributes less to overall energy intensity improvements. Similar effects occur in households, while demand rises in the other sectors stay well below average. Electricity demand under low prices sinks 2.2% in 2050 compared with Reference.

Lower fossil fuel energy import prices entail 5% decrease in heat and steam demand, mainly due to decrease in industry (-9%). There is also a shift from CHP generation that looses 5% in 2050 to district heating units (+14%).

Primary energy consumption increases 2.8% in 2050 compared with Reference. The lower increase than for final energy is linked to lower electricity demand, which entail somewhat lower electricity generation and therefore transformation losses.

Again, with limited effects on overall energy consumption there are considerable changes in the fuels mix. Gas consumption increases 23.0% over Reference in 2050, while oil demand rises 4.8%. Solids, RES and nuclear, having all power generation as major areas of use, are discouraged, also because their prices do not fall (RES, nuclear) or to a lesser extent (solids). Solids use drops 7.3% below Reference, nuclear declines by 7.6%, while RES reduce least below Reference in 2050 (-6.6%).

Fuel mix

Consequently, the fuel mix would be somewhat altered both in the high and in the low energy import price cases.

Table 9: Shares of energy sources in primary energy consumption (in %)

	2005	2030			2050		
		High price	Ref.	Low price	High price	Ref.	Low price
Oil	37.1	32.0	32.8	32.4	31.3	31.8	32.4
Gas	24.4	20.3	22.2	25.4	17.7	20.4	24.4
Solids	17.5	13.0	12.4	11.7	11.8	11.4	10.2
Nuclear	14.1	15.4	14.3	13.2	17.8	16.7	15.0
RES	6.8	19.5	18.4	17.5	21.4	19.9	18.1

The marked variations in the import prices give rise to rather limited changes in the fuel share trends. Fossil fuels, especially solids, lose importance under both high and low prices, while RES make substantial inroads und nuclear progresses in the long term under high prices.

Variations across scenarios regarding the fuel shares are most important for gas, for which high import prices could lead to a considerable decline in its contribution (falling to only 17.7% in 2050 whereas low import prices could help maintain its current share in 2050 and even increase it somewhat in 2030 to over a quarter).

Power generation

Fossil fuel import prices render direct use of fuels more expensive. They result in lower percentage price increases for electricity given the rather small part of fuel input costs in total electricity costs. Under high fossil fuel prices, electricity production is encouraged, whereas it falls below Reference case under low import prices.

RES and nuclear benefit from high fossil fuel import prices. Low fossil fuel prices affect in particular nuclear penetration. The RES share remains stable due to rather unchanged production still benefiting from RES support and sinking overall electricity generation (compared with Reference). The fossil fuel share in power generation would go down to only 30% in 2050 under high energy import prices, down from 55% in 2005.

CCS penetration would be somewhat encouraged by lower fossil fuel prices and corresponding higher ETS carbon prices to ensure meeting the emission cap, leading to almost 4 percentage points more deployment in 2050. On the contrary high fossil fuel prices would delay its introduction so that the CCS share would be about 3.5 percentage points lower in 2050 compared with Reference.

Table 10: Electricity related indicators in different energy import price cases

	High import prices		Low import prices		Reference case	
	2030	2050	2030	2050	2030	2050
Gross electricity generation (TWh)	4103	4952	4003	4841	4067	4931
Shares in gross electricity generation						
RES share	40,6%	42,1%	40,6%	40,6%	40,5%	40,3%
Nuclear share	25,4%	27,4%	23,4%	24,9%	24,5%	26,4%
Fossil fuel share	34,0%	30,4%	36,0%	34,5%	35,0%	33,3%
CCS share	1,5%	14,4%	3,1%	21,5%	2,9%	17,8%
Prices in €						
ETS (€(08)/t CO2)	37,1	46,2	41,0	52,5	40,0	50,0
Average electricity price (in €(08)/MWh)	165,1	159,5	149,8	140,8	157,7	153,8

Electricity prices are lower than Reference with low import and therefore power generation input prices, while the opposite is the case with high import prices. The time profile of prices remains the same as under Reference case developments (see above).

CO2 emissions

The changes in the fuel mix and CCS penetration have important effects on CO_2 emissions and ETS prices. With significantly more zero carbon power generation under high fossil fuel prices, ETS prices in the high import price case are somewhat below Reference, despite lower CCS penetration and somewhat higher electricity generation, given that with a constant ETS cap there is less demand for allowances. Under low import prices the opposite trends materialise and ETS prices are higher. In total, significant changes in the level of world energy prices exert only a small influence on ETS prices, as long as the coal to gas price ratio does not change significantly.

In the high fossil fuel price case, larger use of zero carbon fuels, moderated by effects on coal and lignite consumption as well as lower CCS deployment and slightly lower ETS prices bring about a marginal improvement in carbon intensity of primary energy consumption (1.35 t CO_2/toe instead of 1.36 t CO_2/toe in 2050 in Reference). Combined with the 2.0% improvement of energy intensity under high import prices, this leads to a 2.7% reduction of CO_2 emissions below Reference in 2050.

In the low fossil fuel price case, in which oil and gas prices remain virtually flat at 2010 level through 2050 rather than increasing as in the Reference case, there is a more marked increase of CO_2 emissions from Reference in 2050 (6.6%), in particular due to increases of non-ETS emissions with lower fuel prices. This is due to energy intensity deteriorating 2.8% compared with Reference in 2050 combined with a worsening of carbon intensity by 3.7%. Carbon intensity rises to 1.45 t CO_2/toe in 2050 as a result of delayed CCS and higher shares of gas and of oil in the long run.

It can therefore be concluded that important further rises in oil and gas import prices, under a given emission cap for power and energy intensive industries, lead to only minor changes in CO_2 emissions via limited effects on energy intensity and marginal effects through changes in fuel mix and technology deployment. The CO_2 effects of lower fossil fuel prices (virtual stabilisation of fossil fuel import prices) appear to be proportionately more pronounced in the long term than those from further price increases above Reference case levels.

Table 11: CO_2 reduction below 1990 (index 1990 =100) and major drivers

1990 = 100	2030			2050		
	High prices	Reference	Low prices	High prices	Reference	Low prices
Oil ($(08) / barrel)	149	106	91	162	127	84
Energy consumption	102	104	105	104	106	109
CO2 emissions	71.7	74.0	76.1	57.9	59.6	63.5

Higher world energy prices bring lower CO_2 emissions including in the sectors subject to ETS, which in turn reduces both demand for allowances and their price, given the fixed cap. Conversely, lower fossil fuel prices increase emissions and therefore demand for allowances, leading to higher ETS prices.

In total, differences in world energy prices exert only a minor influence on total CO2 emissions in the EU. There are feedback mechanisms via ETS carbon prices. High fossil fuel prices reduce demand and CO2 emissions and thereby carbon prices. With low fossil fuel prices there is upward pressure on CO2 emissions and carbon prices increase under ETS.

Energy imports

Net energy imports fall 6.9% below Reference in 2050 under high import prices. Gas imports are particularly sensitive to variations in price levels (-15.7% on Reference in 2050) given the competitive environment in power generation and most final demand sectors, where ample substitution possibilities exist. Oil use is less flexible (transport, petrochemicals) so that oil imports decline by only 3.4% in 2050. Solid fuel imports are even less affected (-2.0%), while imports of biomass increase (4.9%) given higher demand.

Low energy prices encourage significantly higher net energy imports, which in 2050 exceed the Reference level by 11.0%. Gas is the main driver for this increase, with imports being 25.2% higher than Reference in 2050. Again, oil and coal imports react more moderately, rising 5.0% and 6.5%, respectively. With lower RES consumption, biomass imports would fall 11.5% below Reference in 2050.

Import dependency in the high price case would stay at the current level throughout the projection period reaching 54% in 2030 and 55%. Under low energy prices import dependency would increase slightly reaching 58% in 2030 and 62% in 2050 (up over 4 percentage points from Reference).

Energy costs

Higher and lower fossil fuel import prices impact strongly on the EU's external energy bill. With fossil fuel prices exceeding significantly the Reference level (e.g. oil by 41% and 28% in 2030 and 2050, respectively), the EU has additional costs over Reference for fossil fuel imports of 158 bn € (08) in 2030 and of 148 bn € (08) in 2050. The average annual extra fuel bill over the next 40 years amounts to 131 bn (08); it is worth noting that this is per year and in real terms.

In the low fossil fuel import price sensitivity, i.e. in case energy import prices remain essentially at the 2010 level, there are considerable external fuel bill savings. The costs for importing oil, gas and coal would decrease by 88 bn € (08) in 2030 and by 230 bn € (08) in 2050 with respect to Reference developments, in which fossil fuel prices rise considerably. The average annual import cost saving in 2011-2050 would amount to 108 bn € (08).

Total energy system costs, i.e. the amount that the rest of the economy has to pay to the energy system for the provision of energy, including capital, fuel and other costs, amounts to 2582 bn € (08) on average in each year from 2011 to 2050. This amount does not include auctioning payments, as these expenditures for individual sectors are not costs for the economy as a whole, since the auctioning revenues are recycled back to the economy. Moreover, this cost concept excludes so called disutility costs.[128]

[128] Disutility costs are a concept that tries to capture losses in utility from adaptations of individuals to policy impulses or other influences through changing behaviour and energy consumption patterns that might bring them on a lower level in their utility function. The PRIMES model, having a micro-economic foundation, deals with utility maximisation and can calculate such perceived utility losses via the concept of compensating variations (amount of additional income that would bring the individual on the same level of

With higher energy import prices, total energy system costs are 187 bn € (08) per year larger throughout the period 2011 to 2050. Under the hypothesis of low world fossil fuel prices, average annual energy system costs would decrease by 155 bn € (08) per year over the same period.

Conclusions on import price sensitivities

High world energy prices reduce CO2 and GHG emissions, while low prices exert the opposite influence. However, there are several other effects via fuel mix, electricity generation, ETS prices (given the same ETS cap across scenarios) and CCS incentives that modify the overall effect while working in different directions.

High fossil fuel prices lead to slightly higher electricity demand given the small reaction of electricity prices to increasing fuel input prices in the presence of large unrelated cost blocks such as capital costs, levies and taxes. Combined with a significant increase in the share of zero carbon (non-fossil) fuels there is lower demand for ETS allowances and therefore the ETS price decreases somewhat.

Lower fossil fuel prices give rise to the opposite effects. Energy consumption and CO2 emissions rise, however moderated by lower competitiveness of non-fossil, carbon free fuels. As an overall result, the effect of this fuel shift outweighs the effects through lower electricity production and lower CCS share, bringing about higher demand for allowances and slightly higher ETS prices.

The sensitivity cases show that significant changes in world energy prices exert only a small influence on ETS prices as long as the gas to coal price ratio does not change significantly.

This conclusion on rather limited effects of significant changes in world energy prices on EU GHG emission can also be derived by considering the above results on energy and carbon intensities. Important further rises in oil and gas import prices lead to only minor changes in CO2 emissions via limited effects on energy intensity and marginal effects through changes in fuel mix and technology deployment (carbon intensity). The CO2 effects of lower fossil fuel prices (virtual stabilisation of fossil fuel import prices) appear to be proportionately more pronounced in the long term than those from further price increases above Reference case levels. Regarding total GHG emission, the CO2 effects from changes in fossil fuel prices would be limited through countervailing effects of high fossil fuels prices through reduced carbon prices.

High fossil fuel prices limit business opportunities for energy exporters given that EU imports would decrease, most so for natural gas. Conversely, with lower fossil fuel prices, significantly higher gas deliveries to the EU can be assured. Import dependency increases with low world energy prices, whereas it stays below Reference at the current level throughout the projection period.

Electricity prices are significantly lower than Reference under low fossil fuel import prices, whereas they are significantly higher in the case that high energy import prices prevail.

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utility as experienced before the change). However, this concept has to assume that preferences and values remain the same, even over 40 years, and has to compare utility with a hypothetical state of no policy or no change in the framework conditions. Numbers in particular in the longer term are uncertain. The numbers shown above relate to costs that reflect actual payments.

Moreover, high energy import prices increase the EU's external fuel bill substantially, thereby weakening the competitiveness of the EU economy. Income that would have been used to buy domestically produced goods and services would be diverted to energy exporters with only a small part being recycled into higher EU exports into these countries. On the contrary, lower fossil fuel prices give a boost to the EU economy improving its competitiveness, also through lower costs and inflation.

The external energy bill of the EU becomes significantly larger with high world energy prices (+132 bn € (08) per year over the next 40 years), whereas this bill was reduced by 109 bn € (08) annually in the case that fossil fuel prices remained broadly at the level seen in 2010. Similarly, total energy system costs would be significantly larger with high fossil fuel prices, whereas the rest of the economy would need to pay to the energy system a significantly lower amount in case of low world energy prices.

2.4 Current Policy Initiatives scenario

This scenario reflects the Current Policy Initiatives (CPI) that are being discussed or undertaken in the EU context with a view to the 2020 Energy Strategy. This scenario does not attempt to give a full appreciation of all the results that might be expected from the Energy Strategy, nor does it mirror in detail the – future – policy adoption and implementation; it reflects the measures being proposed and discussed (for details see above under assumptions). While the measures focus on the medium term, the CPI scenario modelling evaluates also the long term consequences up to 2050 and provides thereby another benchmark for comparison with decarbonisation scenarios.

Energy demand

Primary energy consumption under CPI declines pretty strongly between 2005 and 2020 (-6.9%) and continues to do so through 2030 when it will have fallen well below the 1990 level. There is a further decline up to 2050 (-11.6% from 2005), in which year energy consumption would be 8.4% lower than in the Reference case. There are also marked changes from Reference in 2020 (-5.0%) and 2030 (-5.8%).

These energy savings from 2005 levels are brought about by a decline in final energy demand, especially in the households and services/agriculture sectors, and by efficiency improvements in energy transformation resulting from the implementation of measures in the Energy Efficiency Plan. Bottom up energy efficiency measures reverse the trend of ever increasing final consumer demand witnessed so far in statistics and many trend scenarios, including the Reference scenario in the period up to 2020.

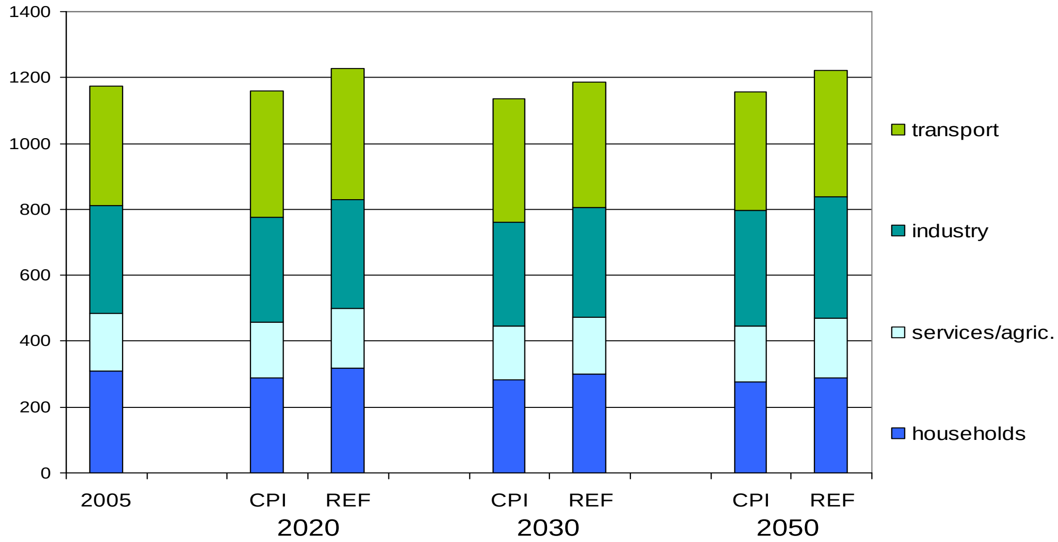
Total ***final energy demand*** reduces 1.3% from 2005 by 2020. Reductions by 2030 amount to 3.2%; thereafter final demand starts growing again slightly through 2050. Nevertheless, in 2050, CPI final demand stays 5.3% below Reference (even 5.6% for 2020 as CPI includes many energy efficiency policies to be implemented over the next few years).

Households show the greatest decrease below 2005 levels: by 6.1% up to 2020 as well as by 8.5% and 10.0% until 2030 and 2050, respectively. In 2020 household energy consumption is 8.9% below the Reference case, while this decline in 2050 amounts to 3.8%. This decline compared with Reference in 2050 is smaller given that large parts of the energy efficiency potential captured in CPI in the earlier years is taken up the Reference case in later years. Energy efficiency measures linked especially to Eco-design regulations and savings obligations on energy providers with respect to their customers are instrumental for this pronounced decline in CPI. Moreover, the effects on final consumer prices stemming from the proposed Energy taxation directive contribute towards reducing energy consumption.

Energy demand in services and agriculture also decreases significantly by 5.5% and 6.7% in 2005-2020 and 2005-2030, respectively. After 2030, final energy demand in this sector would resume its rising trend reflecting growing economic activity. In any case, demand in services/agriculture falls well below Reference case levels through 2050, with demand being 7.0% lower in 2050 and even 7.8 % lower in 2020. Eco-design measures, faster renovation rates for existing - especially public - buildings, promotion of energy service companies as well as energy savings obligations are key policy measures to bring about such savings. The new energy taxation directive also contributes to this decline.

Energy consumption in industry also declines from 2005 levels: by 2.3% up to 2020 and by 3.7% up to 2030. Thereafter, industrial energy demand starts growing slightly without reaching again the current level. Industrial energy demand stays below Reference scenario levels: by 5.5% in 2030 and 5.1% in 2050. Energy service companies, eco-design and energy savings obligations are among the drivers for bringing about such savings, which are somewhat moderated by healthy production growth and by the feedbacks through lower ETS prices regarding certain industrial branches. Such feedbacks stem from energy/electricity savings that reduce the demand for ETS allowances and therefore ETS prices (see below).

Figure 17: Final Energy Consumption by sector in Current Policy Initiatives and Reference Scenarios (in Mtoe)



Transport energy consumption is comparatively little affected by current energy policy initiatives. Energy consumption continues to increase, exceeding the 2005 level by 5.6% in 2020. After 2025, transport energy consumption starts declining slowly, returning the 2005 level by 2050. Compared with Reference, consumption remains below the levels reached throughout the projection period (by 1.7% in 2030 and 5.7% in 2050). Changes from Reference are brought about in particular by the proposed new energy taxation system and through the somewhat more favourable policy environment for electric and plug-in hybrid vehicles, while CO2 standards exert only a limited influence given that the CO2 from cars regulation is already included in the Reference case.

While final energy demand for oil, gas and coal would continuously decline up to 2050, demand for electricity, heat and RES would increase. Most important in absolute terms is the increase in electricity demand, which rises 43% between 2005 and 2050. Nevertheless, electricity demand in CPI falls well below electricity use in Reference, reflecting measures in the Energy Efficiency Plan and revised Energy taxation Directive. CPI electricity consumption is down on Reference by 6.5% in 2030 and 4.3% in 2050.

Demand for distributed heat is rising compared to current level but is 1-2% lower than in the Reference scenario reflecting effects of measures in the Energy Efficiency Plan, in particular more efficient heating systems in houses. Heat demand in residential sector is 7% lower in 2020 compared to the Reference scenario. The difference is much lower towards the end of the projection period (1-2%) as the measures included in the Energy Efficiency Plan target short to medium term.

Power generation

Rising electricity demand over time will require a similar increase in power generation and a lot of new investment in power generation and grids. Even though energy efficiency measures bring about lower electricity demand and production compared with Reference (see table 12) gross electricity production is expected to increase 41% by 2050 under CPI. Electricity based on RES is expected to make major inroads reaching a share in power generation of close to 50% in 2050.

Table 12: Electricity related indicators in CPI scenario and differences from Reference

	Current Policy Intitiatives				Difference from Reference		
	2005	2020	2030	2050	2020	2030	2050
Gross electricity generation (TWh)	3274	3645	3780	4621	-121	-286	-311
Shares in gross electricity generation					in percentage points		
RES share	14,3%	34,5%	43,6%	48,8%	1,2%	3,1%	8,5%
Nuclear share	30,5%	23,9%	20,7%	20,6%	0,8%	-3,8%	-5,8%
Fossil fuel share	55,2%	41,6%	35,7%	30,6%	-2,0%	0,7%	-2,7%
CCS share	0,0%	0,7%	0,8%	7,6%	-0,6%	-2,1%	-10,2%
Prices in €							
ETS (€(08)/t CO2)	0,0	15,0	32,0	51,0	-2,5	-8,0	1,0
Average electricity price (in €(08)/MWh)	110,1	148,5	159,0	159,9	0,0	1,3	6,1

The CPI scenario takes account of the post Fukushima policy change in Member States, notably the abandoning of the nuclear programme in Italy and the new nuclear approach in Germany modifying somewhat the previously decided nuclear phase-out Moreover, it includes other changes and new initiatives, such as the nuclear stress tests that tend to increase costs for new power plants and retrofitting.[129]

[129] There are slightly higher risk premiums for new nuclear investment in this scenario, considering that investors might factor into their decisions the possibility that the policy reaction to any hypothetical further nuclear accident may affect the nuclear plants under investment consideration, even though such an accident could happen rather far away geographically. Requiring thereby a slightly higher return on investment to cover this political risk has also certain effects on new nuclear investment. As a result of these changes in the policy

The slightly higher nuclear share in 2020 reflects lower total electricity production and the modification in the nuclear phase-out provisions between the German nuclear law before the extension of nuclear plant lifetimes in autumn 2010 (mirrored in the Reference case) and the new schedule. The new phase-out schedule includes faster closure of nuclear plants in the next few years, compensated by slightly higher capacity around 2020, keeping cumulative allowed nuclear generation (in TWh) at the same level.

Fossil fuel based power generation falls significantly throughout the projection period; its share diminishes from 55% to just over 30% in 2050. Solid fuels lose most, with losses for gas based power generation remaining rather limited.

The CPI scenario has significantly lower CCS penetration in 2020 compared to the quite optimistic national plans as envisaged in 2009 (Reference scenario) and rather moderate recent progress in demonstration plants. This concerns also potential storage sites. In medium term, lower ETS price in the CPI scenario, reflecting lower energy demand due to additional energy efficiency measures, affects commercial viability of CCS. In the long term, lower numbers compared with Reference are also a result of the strong decline in solid fuels and gas based power generation.

ETS prices are lower in CPI compared with Reference in the medium to long term. The CCS incentive through carbon prices is reduced by 20% from 40 €/tCO2 to 32€/t CO2 in 2030. Consequently, the CCS share in CPI in 2030 amounts to 1% and rises thereafter significantly with high ETS prices to reach 8% in 2050. The energy efficiency measures in CPI cut electricity and fuel demand and the need for allowances, which in a context of an unchanged ETS cap leads to lower ETS prices. This limits - as a side effect - also the incentives for CCS.

Average electricity prices are slightly higher than Reference over the projection period (0.8% in 2030 and 4.0% in 2050) reflecting the lower share of nuclear post Fukushima and high investments for new electricity generation capacity, especially RES.

Fuel mix

These changes in the demand side and in power generation have significant impacts on primary energy consumption and the fuel mix. Primary energy demand declines 200 Mtoe up to 2050, when it remains 150 Mtoe below the Reference case level.

In the long term to 2050, both fossil fuels and, to a limited extent, nuclear reduce their importance in the fuel mix, with solids undergoing the greatest decline (minus 8 percentage points in 2005-2050). The share of nuclear is lower also in comparison to the Reference scenario due to changes in nuclear assumptions. RES are the clear winner of this structural change, making them in 2050 the second most important fuel after oil. RES gain 16 percentage points from today's level in terms of primary energy and about 20 percentage points when accounted for in terms of gross final energy demand.

Oil remains the most important fuel throughout the projection period as the fuel mix in transport remains largely unchanged. Nevertheless oil loses 5 percentage points by 2050.With primary energy demand declining, the fuels used most in sectors that are least affected by

environment, the nuclear share is somewhat lower than Reference in the long term, for which the Italian withdrawal from nuclear is particularly important. Moreover, lower ETS prices in CPI reduce the economic advantages connected to nuclear investments.

current energy policies, such as oil in transport, are able to score a slightly higher share in the fuel mix compared with Reference.

Post Fukushima changes in nuclear (discussed above) reduce the role on nuclear compared with Reference. In this new policy environment gas and RES replace nuclear and thereby increase their share over Reference scenario levels.

These changes towards a significantly greater RES contribution bring about an important decline in carbon intensity over time (by a third between 2005 and 2050). However, with respect to Reference, there is a certain increase in carbon intensity, given that CPI relies less on nuclear and that CCS penetrates more slowly. Carbon intensity in 2050 exceeds the Reference case level by 7.7%.

Table 13: Fuel mix of primary energy consumption in CPI and Reference

	Current Policy Intitiatives				CPI: difference	Difference from Reference		
	2005	2020	2030	2050	2005-2050	2020	2030	2050
Primary energy consumption (Mtoe)	1826	1700	1629	1615	-211	-90	-99	-148
Shares in primary energy					in percentage points			
Oil	37,1%	34,7%	34,1%	32,0%	-5,1%	0,3%	1,2%	0,3%
Natural gas	24,4%	22,4%	22,7%	21,9%	-2,5%	-0,6%	0,5%	1,6%
Solid fuels	17,5%	14,0%	12,0%	9,4%	-8,1%	-0,7%	-0,5%	-1,9%
Nuclear	14,1%	13,2%	12,1%	13,5%	-0,5%	0,7%	-2,2%	-3,2%
RES	6,8%	15,8%	19,3%	23,3%	16,4%	0,3%	0,9%	3,3%
share in final energy	8,6%	20,6%	24,6%	29,0%	20,3%	0,5%	0,8%	3,5%

CO2 and GHG emissions

In spite of this deterioration of carbon intensity there is a somewhat greater CO2 reduction in CPI than in Reference; CO2 emissions in 2050 are slightly lower than in the Reference scenario. This development is due to greater energy intensity improvements brought about by vigorous energy efficiency policies, which overcompensates the worsening of carbon intensity due especially to lower use of nuclear and CCS.

This energy intensity effect on CO2 emissions is somewhat moderated by the effect of energy efficiency on carbon intensity via ETS prices. Declining ETS prices, triggered to some extent by lower energy demand, give rise to lower incentives for investing in e.g. CCS and nuclear, thereby giving rise to somewhat higher carbon intensity.

Table 14: CO2 emissions and drivers in CPI and Reference scenarios

	Current Policy Initiatives scenario			Reference
	2005-2030	2030-2050	2005-2050	2005-2050
	average annual change (% pa)			
GDP	1,7%	1,5%	1,6%	1,6%
Energy intensity	-2,1%	-1,5%	-1,8%	-1,6%
Carbon intensity	-0,8%	-1,0%	-0,9%	-1,0%
CO2 emissions	-1,2%	-1,0%	-1,1%	-1,1%
Total CO2 reduction (%)	-26,4%	-18,5%	-40,0%	-39,2%

Energy intensity improvements are particularly pronounced in the earlier years of the projection period thanks to vigorous new energy saving measures targeting in particular the short and medium term. In total CO2 emissions reduce 40% between 2005 and 2050, up one percentage point from what would be achieved under reference case developments. With respect to 1990 CO2 emissions in CPI decline by 41.3% up to 2050. The Reference scenario has a decrease of 40.4%.

Total GHG emissions in 2050 decrease 38.6% below the 1990 level, which is slightly less than in the Reference case (-39.7%), given the significantly lower carbon price until just before 2050, reflecting especially successful energy efficiency policies. This means, on the other hand, that total GHG emissions reduce faster in CPI than in Reference in the time horizon to 2020 and also to 2030.

Energy imports / security of supply

Lower energy demand and the changes in the political environment after the Japanese nuclear accident of March 2011 give rise to significant changes in EU energy production, which is down on Reference by 9.0% in 2050. Nuclear production sinks 25.8% compared with Reference in 2050, while RES production is 7.8% higher. Also gas production is seen in a more favourable light (+4.0%).

Despite lower indigenous production, energy imports are 7.5% lower in 2050 than in the Reference scenario due to the policy measures, notably on energy efficiency, included in CPI. Nevertheless, net energy imports are expected to broadly stabilise throughout the projection period (peaking in 2015, when they exceed the 2005 level by 6.4%, before declining 7.5% up to 2050).

Biomass and natural gas imports increase significantly, whereas oil imports decline moderately and solids see their imports sink considerably. Gas imports in 2050 are expected to be 26% higher than they were in 2005. Oil imports decrease 6% over this period, while solid fuel imports plummet 56%.

Import dependency remains broadly unchanged from Reference case and also current levels. Up to 2020, this indicator rises from 54% at present to reach 56%. This is one percentage point less than in Reference, reflecting the impact of efficiency measures mainly on imported fuels. In 2030, import dependency reaches 57.5%, up one percentage point on Reference, which is largely a result of lower nuclear availability. In 2050, this indicator amounts to 58% in both CPI and Reference.

Conclusions on Current Policy Initiatives scenario

As a result of current policy initiatives, energy consumption is expected to be reduced significantly. The decline in both final and primary energy consumption is most pronounced in the medium term, for which most of the measures have been designed. The implementation of the Energy Efficiency Plan brings important reductions in final energy demand, especially in the household and services/agriculture sectors.

In terms of primary energy, consumption sinks throughout the projection period, falling below the 1990 level by 2030 with a continuing decline thereafter. In 2050, energy demand decreases 12% below the 2005 level. As a result, energy intensity improves 1.8% pa, which is 0.2 percentage points up from the number in the Reference case.

This decline in energy consumption is connected with significant changes in the fuel mix, which are also linked, among other things, to post Fukushima changes in the policy environment for nuclear energy in several Member States. Compared with Reference, the contribution of nuclear and solid fuels declines, while oil, gas and in particular RES account for higher shares in primary energy consumption in 2050.

In a comparison over time, fossil fuels lose as much as 16 percentage points from 2005 to 2050, of which solid fuels account for 8 percentage points, oil for 5 and gas for 3 percentage points. Renewables are the clear winner, benefiting from several policies not even directly targeting RES and of course those measures included in the 2008 Energy and climate package. The RES share in primary energy rises 16 percentage points, while the nuclear share remains almost constant (only a slight decrease post Fukushima).

The RES share in gross final energy consumption increases 20 percentage points from 2005 by 2050 when it reaches 29%. Also the RES shares in transport and power generation rise considerably reaching 49% and 20% in 2050, respectively. Taking a 2030 perspective, the overall RES share in final demand grows 16 percentage points to reach 25% in 2030 under current policy initiatives. RES in transport account for 13%. RES contribute 44% to power generation.

Electricity generation also falls compared with Reference, given successfully implemented energy efficiency policies, but would exceed the 2005 level by 41% in 2050. Again, there are significant changes in the generation mix, which also explain to a large extent the fuel mix changes at the primary energy level. Almost half of power generation in 2050 would be based on RES, up from just 14% in 2005. Nuclear loses around 10 percentage points share in power generation in 2005-2050 given strongly rising electricity production and the recent changes in the policy environment for nuclear. The share of fossil fuel based electricity generation diminishes from 55% in 2050 to just over 30% in 2050 mainly due to reductions in solid fired power generation.

These changes in power generation towards lower solid fuel contribution compared with Reference entail lower demand for ETS allowances giving rise to lower ETS prices thus also providing fewer incentives for CCS. As an overall result of these simultaneous changes, the

ETS price falls 20% below the Reference level in 2030. In 2030 almost 1% of gross power generation undergoes CCS, while this share rises to 8% in 2050.

Developments of the fuel mix and the CCS penetration bring about a 0.9% pa decline in carbon intensity from 2005 to 2050. This decline in carbon intensity is marginally smaller than the one under Reference developments, reflecting in particular post Fukushima changes for nuclear and lower medium term ETS prices following strong energy efficiency measures, which, as an indirect effect, limit CCS penetration.

Nevertheless, energy related CO2 emissions reduce slightly more than under Reference developments. CO2 emissions in CPI sink 41.3% while the decline amounts to 40.4%. Total GHG emissions in CPI reduce 38.6% below 1990 by 2050.

Total energy imports broadly stabilise throughout the projection period, despite significant increases in biomass and natural gas imports. Oil and notably solid fuels import decline. Import dependency remains broadly unchanged from Reference case and also current levels.

The CPI scenario involves higher system costs stemming notably from the additional investment triggered through additional energy efficiency requirements and the restructuring of the energy and transport systems including the lower nuclear contribution due to upward revised costs and more Member States renouncing the nuclear option. Moreover the inclusion of the Energy taxation directive adds to these additional costs. Taking into account the fuel savings from energy efficiency measures as well as the taxation induced savings, energy system costs in the period 2011 to 2050 increase by an annual amount of bn 37 €(08). These cost estimates do not consider possible changes in the utility levels of consumers regarding the behavioural changes induced that are, in any case, not directly measurable and can only be captured in the modelling indirectly via the concept of compensating variations.

Average electricity prices rise at only a slightly faster pace compared with Reference developments. In 2030, the average electricity price exceeds Reference by only 1%; this price increase becomes 4% in 2050.