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ELECTRICITY FOR EUROPE

Power Choices

Pathways to Carbon-Neutral Electricity in Europe by 2050

Full Report

The **Union of the Electricity Industry – EURELECTRIC** is the sector association representing the Electricity Industry at pan-European level, plus its affiliates and associates on several other continents.

EURELECTRIC's mission is to contribute to the development and competitiveness of the Electricity Industry and to promote the role of electricity in the advancement of society.

As a centre of strategic expertise, EURELECTRIC identifies the common interests of its Members and, through research into the marketplace, technologies, legislation, etc., assists them in formulating common solutions to be implemented and in coordinating and carrying out the necessary action. It also acts in liaison with other international associations and organisations, recognising their specific missions and responsibilities.

In the European Union, EURELECTRIC represents the Electricity Industry in public affairs, in particular in relation to the EU legislative institutions, in order to promote the interests of its Members at political level.

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In addition to this Full report, the Executive summary is also available online at the project website
www.eurelectric.org/powerchoices2050

EURELECTRIC pursues in all its activities the application of the following sustainable development values:

- **Economic Development**
  Growth, added-value, efficiency
- **Environmental Leadership**
  Commitment, innovation, pro-activeness
- **Social Responsibility**
  Transparency, ethics, accountability

Foreword

Climate change has emerged as the most serious environmental challenge of our time. Reducing greenhouses gas emissions is essential in tackling it. These issues are high on the political agenda and constitute a crucial element of the business one.

In the current economic context, maintaining the competitiveness of Europe's economy and ensuring security of supply are also vital.

Electricity Industry plays a central role in the development of a low carbon economy not only because it can significantly reduce it own carbon emissions, but also offer the possibility to decarbonise the rest of energy use in society by replacing other fuel sources.

In March 2009, Chief Executives of power companies representing over 70% of EU electricity production have already signed a declaration in which they committed to become carbon neutral by 2050. Building on that commitment, the EURELECTRIC *Power Choices* study was set up to examine how this vision can be made a reality. I am proud to share with you EURELECTRIC's vision of a cost-effective and secure pathway to a carbon-neutral power supply by 2050. The study shows that the Electricity sector, while complying with existing legislation, will implement deep cuts in carbon emissions from 2025 onwards.

As an extension of the 2007 study *Role of Electricity*, *Power Choices* charts the technological developments that will be needed in the coming decades and analyses the policy options that will be required to attain deep cuts in carbon emissions by mid-century.

The EURELECTRIC *Power Choices* should be seen as compass to indicate the way to carbon-neutral electricity in Europe by 2050. The European Electricity Industry is fully committed to this goal. To achieve it, it must be supported by policymakers and stakeholders and be translated into strong, coherent and urgent action.

Lars G. JOSEFSSON
President
Union of the Electricity Industry – EURELECTRIC

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Executive Summary

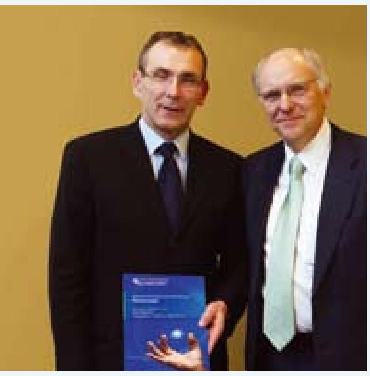
Background

Carbon Reduction Actions and the Power Choices Study

EURELECTRIC's 2007 *Role of Electricity* project showed that, under the most favourable scenario using all available energy options to meet a 50% reduction target for carbon dioxide emissions in the EU 25 by 2050, the specific CO_2 emissions for the European power sector would fall from the current 0.45 tonnes CO_2 per MWh to 0.10 t CO_2/ MWh – equivalent to some 500 million tonnes of CO_2 per annum.

Meanwhile the 4th Assessment Report of the International Panel on Climate Change (IPCC) indicated that, in order to stabilise atmospheric CO_2 emissions within the threshold of 440ppm, and thus hold the global temperature rise to an average of 2°C over the pre-industrial level, emissions would have to fall by 50% on current levels and that the OECD countries would have to reduce their emissions by 60-80%. This implies that the OECD power sector would have to be virtually carbon-free by 2050.

Recognising the responsibility of the power sector as a major emitter of greenhouse gas, sixty one Chief Executives of electricity companies representing well over 70% of total EU power generation signed a Declaration in March 2009, committing to action to achieve carbon-neutrality by mid-century. The Declaration, which also draws attention to the need for a properly-functioning electricity market in Europe, the desirability of an international carbon emissions market and the role of efficient electric technologies in the overall drive for energy efficiency and carbon reductions, was handed to the EU Energy Commissioner by EURELECTRIC President Lars G. Josefsson.



Carbon-neutrality means:

- *Calculating emissions accurately in a transparent manner*
- *Reducing emissions to the fullest extent feasible within the sector*
- *Offsetting residual emissions through actions to reduce greenhouse gases elsewhere – via technology transfer, afforestation, etc – such that net carbon emissions are equivalent to zero*

The EURELECTRIC *Power Choices* study was set up to examine how this vision can be made reality. Setting a reduction goal of 75% – mid-way on the IPCC's 60-80% scale – *Power Choices* looks into the technological developments that will be needed in the coming decades and examines some of the policy options that will have to be put in place within the EU to attain a deep cut in carbon emissions by mid-century.

Confirming that a carbon neutral power supply, in combination with a paradigm shift on the demand side, is the key to achieving this deep cut in overall EU emissions, the Power Choices scenario delivers carbon-neutral power in Europe by 2050:

- via low-carbon technologies such as renewable energies (RES), carbon capture & storage (CCS) technologies and nuclear power
- through intelligent and efficient electricity generation, transmission and use
- with intelligent electricity use as the driver for a secure, low-carbon energy future
- by promoting the roll-out of electric road vehicles
- through a drive for widespread energy efficiency in our economy and society
- at a lower long-term total energy cost than under the *Baseline* scenario

For more information go to the project website at: www.eurelectric.org/PowerChoices2050

The Study

Modelling for an Optimum Energy Portfolio

EURELECTRIC's *Power Choices* study uses the PRIMES energy model developed and run by Athens Technical University by a team under Professor Pantelis Capros – also used by the European Commission for its energy scenario work – to examine scenarios to 2050. For this project, the model has been updated as regards macroeconomic and power-sector data and assumptions. Data on power plant technology and costs were provided by our partner organisation VGB PowerTech.

The scenario calculations break the 2050 timeframe into three periods: 1) recession 2008-2014; 2) recovery 2015-2022; and 3) low but stable growth 2023-2050. These macroeconomic assumptions are consistent with those employed by the EU legislative bodies for economic analysis. They are a key factor in the model, as the level of economic activity and growth drives future energy demand. Fuel prices are derived from the Prometheus world energy model and are employed consistently throughout.

The study develops two alternative scenarios for the EU-27 countries during the 1990-2050 period: *Baseline*, assuming all existing policies are pursued; and *Power Choices*, which sets a 75% reduction target for greenhouse gases across the entire EU economy.

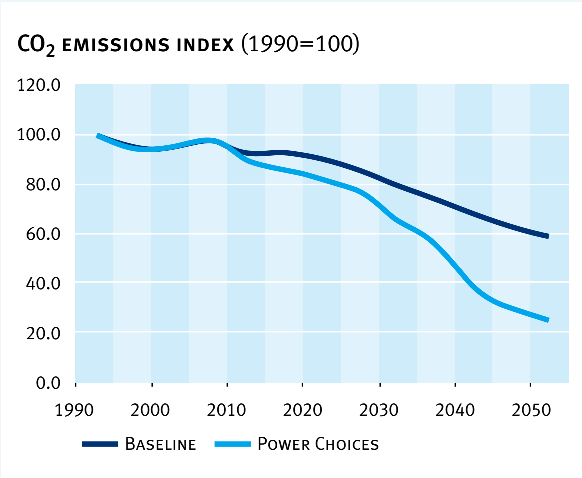
The *Baseline* scenario assumes that:

- Full auctioning of emissions allowances under the EU Emissions Trading System (ETS) applies as of 2015
- Renewable energies (RES) reach their highest level of deployment via existing national support mechanisms
- Announced projects for building new lines or extending the capacity of existing lines are realised
- The EU maintains beyond 2020 the linear CO_2 reduction set by the ETS
- CO_2 prices are applied only in sectors covered by the ETS
- Announced pilot projects for carbon capture and storage are in operation by 2020
- The nuclear phase-out envisaged in Germany and Belgium remains in place
- Energy efficiency policies are enacted, driving energy savings and cutting demand
- Electricity does not become a major fuel in the road transport sector

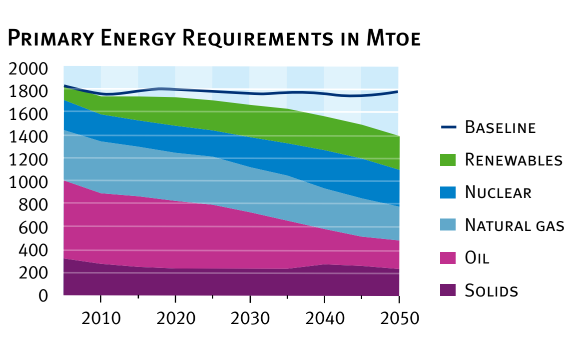
The *Power Choices* scenario aims for an optimal portfolio of power generation based on an integrated energy market. The PRIMES model calculates the market-optimum, taking into account the technology assumptions developed by the industry. The scenario assumes that:

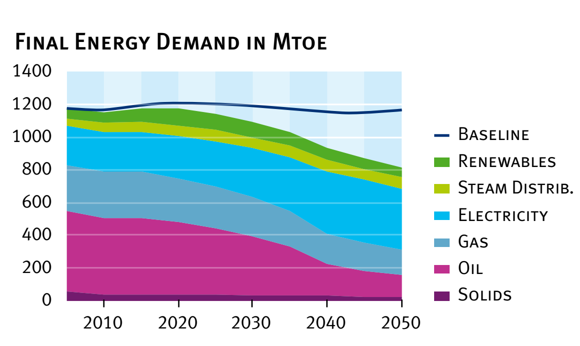
- Climate action becomes a priority and the EU sets and reaches a target of cutting via domestic action 75% of its CO_2 emissions from the whole economy versus 1990 levels
- Electricity becomes a major transport fuel as plug-in electric and hybrid cars develop
- All power generation options remain available, including nuclear power in those countries that currently produce it, but envisaged national phase-out policies remain
- No binding RES-targets are set after 2020; RES support mechanisms remain fully in place until 2020 and are then gradually phased out during 2020-2030
- Energy efficiency is pushed by specific policies and standards on the demand-side during the entire projection period, which will result in slower demand growth
- The price of CO_2 ('carbon-value') applies uniformly to all economic sectors, not just those within the ETS, so that all major emitting sectors pay for their emissions
- After 2020, an international carbon market defines the price per tonne of CO_2; after 2030 the CO_2 price is the only driver for deployment of low-carbon technologies
- CCS technology is commercially available from 2025

CO_2 emissions under *Baseline* and *Power Choices* work out as shown in the graph:



Energy in the Wider Economy





Power Choices results in savings in primary energy consumption versus Baseline

The *Power Choices* scenario shows primary energy consumption to 2050 falling from 1758 Mtoe to 1408 Mtoe, a reduction of 20% on *Baseline*.

The major part of this reduction is accounted for by considerably lower demand in the transport and residential sectors, much of this trend being due to substitution by electricity of relatively inefficient uses of oil and gas in road transport and household heating. A significant role is also played by much improved building insulation, plus efficiency advances in existing electrical applications.

***Power Choices* scenario delivers a major reduction in import dependency.**

We observe a reduction of 40% in net energy imports under the *Power Choices* scenario compared to *Baseline*. In addition to the greatly reduced use of oil and gas in end-user applications, the scenario also indicates a slightly lower use of gas for generating electricity than in the *Baseline* scenario.

A change in the structure of final energy demand – a shift to electricity.

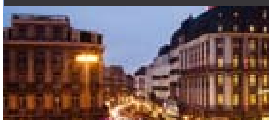
This reduction in primary energy demand translates to an even steeper decrease in final energy consumption, from 1174 Mtoe to 826 Mtoe, a saving of 30% on *Baseline*.

The *Power Choices* scenario delivers a significant part of the reduction in final energy consumption through a shift towards electric applications.

The scenario indicates very strong reduction in end use of gas and oil – down from 52% of final energy demand under *Baseline* to only 34% under *Power Choices*. This is mirrored by a consequent increase in the proportion of electricity in end-use applications – up from 20% to 45.5%. We see a small increase in the proportion of renewable energy in end use – from 7.3% to 7.8% – a figure which includes applications such as solar thermal and biomass-based heating. However the overall RES share in energy demand is much higher, as RES-power assumes much greater importance in electricity generation.

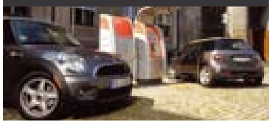
A paradigm shift on the demand side: oil and gas replaced by efficient electric technologies

RESIDENTIAL



Under *Power Choices*, the residential sector shows final energy consumption of 175Mtoe in 2050, down from 308Mtoe in 2005. A major part of this cut is accountable to heating and cooling, in which final energy demand falls by over half from 275Mtoe to 135Mtoe, due to major progress in insulation and a shift in heating technology away from oil and gas towards efficient heat pumps, which sees both gas and oil demand in the sector cut by over 60% by 2050. Residential energy demand is also reduced by major advances in the efficiency of electrical appliances and lighting technology, where the *Power Choices* scenario results in 40% lower energy demand in 2050 compared to *Baseline*.

TRANSPORT



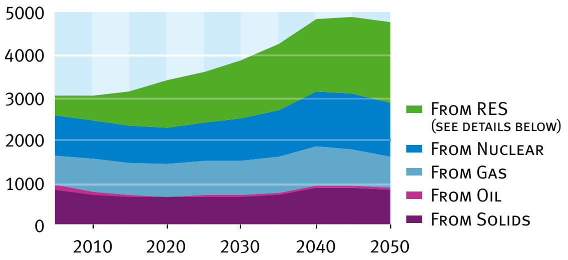
Under the *Power Choices* scenario, final energy consumption in the transport sector is cut by almost 40%, from 362Mtoe in 2005 to 226Mtoe in 2050. Meanwhile electricity consumption increases from 6Mtoe in 2005 to 140Mtoe in 2050, accounting for 62% of total final energy demand in the sector. This transition is particularly remarkable given a predicted rise of over 45% in distance travelled per citizen over the period – from 12,750km per year in 2005 to 18,250km in 2050. The key here is the wholesale electrification of road transport, with over 90% of passenger cars powered by electricity by 2050. This reduces both oil consumption and carbon emissions in the sector by over 75%.

Electricity Generation

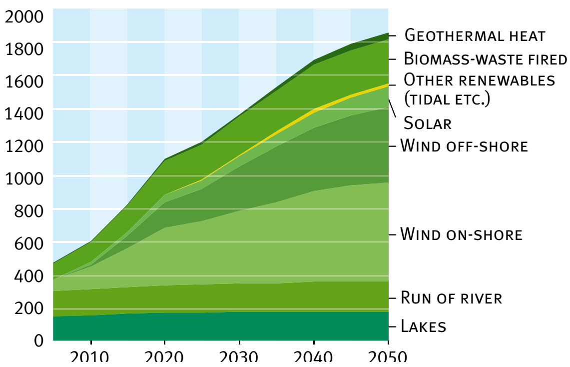
RES Take Off, Broad Fuel Mix Maintained

Although the *Power Choices* scenario sees electricity claim a greater share of total energy consumption, as the energy-efficiency drive squeezes out less efficient vectors, total EU net power generation reaches a level not much greater than under *Baseline*, rising from some 3,100 TWh in 2005 to around 4,800 TWh in 2050.

Power Choices - Power Generation (TWh net)



Power Choices - Power Generation from RES in TWh



Among the various sources of power generation, RES-power production increases dramatically, reaching 1,900 TWh in 2050 and becoming – despite the phase-out of support schemes by 2030 – at 40% of total EU generation the greatest single source of power. This compares with just 15% in 2005. Among RES technologies, windpower takes the lead, with onshore wind providing 35% of the RES contribution and off-shore wind 27%. Hydropower remains stable throughout the period, accounting for 23% of the RES total. Biomass-fired electricity also sees a substantial increase, although in relative terms its share of RES power slightly decreases, while solar power also comes into the picture with a 13% share.

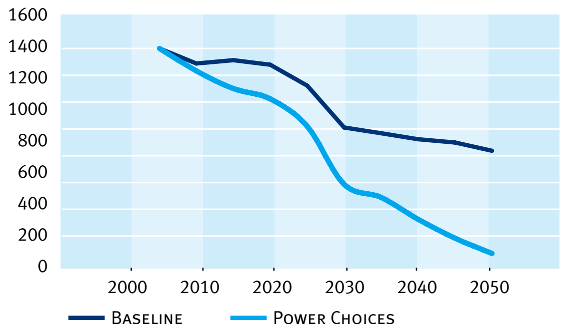
While nuclear power generation increases somewhat under *Power Choices* – from around 950TWh in 2005 to 1300TWh in 2050 – its share of electricity actually falls from 31% to 28%. Most new nuclear capacity is completed after 2025. Electricity from solid fuels decreases until 2025, when the implementation of CCS facilitates a revival. However, the level of solid fuel-fired generation in 2050, at 770TWh, still remains significantly lower than the 2005 figure of 900TWh and its share actually falls from about 29% to 16% over the period. Gas-fired power reaches its peak in 2025, followed by a slight decline as gas and carbon prices rise and CCS also becomes necessary for gas-fired plants, stabilising at 660 TWh in 2050, 14% of total EU electricity compared to 21% in 2005. Oil-fired plants have only a marginal role, with production progressively reducing over time to reach just 1% of total power generation in 2050.

Meanwhile total power capacity increases 60% from 800GW in 2010 to over 1300GW in 2050. This net increase is almost solely attributable to RES-technologies, which by 2050 take a 54% share of EU installed power capacity, while thermal (32%) and nuclear (13%) capacity increase slightly over the period.

Carbon Intensity Falls Dramatically

Carbon dioxide emissions from the EU power sector decrease substantially under both *Baseline* and *Power Choices* scenarios. *Baseline* policy action reduces sector CO_2 emissions by 66%, still leaving 750 Mt CO_2 emitted in 2050.

CO_2 emissions (in Mt CO_2)
Thermal power plants

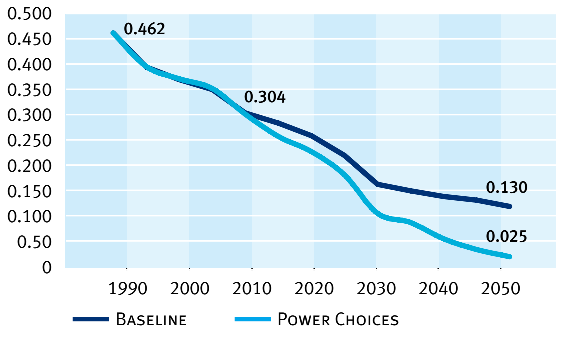


Power Choices sees CO_2 emissions plummet by 90% versus the 2005 level, from 1423 Mt to just 150 Mt in 2050.

> What does '150 Mt CO_2 emitted by 2050' really mean?
> *Taking as an example a typical large-sized lignite-fired plant of 1,250 MW capacity, with average emissions of 0.955 tonnes of CO_2 per MWh electricity produced, and assuming an average base-load operation of 7,500 hours per year, the entire European power sector would emit in 2050 the equivalent 2009 emissions of roughly only one single power plant for every two EU member states*

Under the *Baseline* scenario, the power sector would still emit 134Kg/MWh in 2050, thus delivering a reduction of less than 65% on the 2005 level. Under *Power Choices*, the carbon intensity of power generation falls by almost 95%, from roughly 360kg/MWhin 2005 to 26kg/MWh in 2050.

CARBON INTENSITY OF THE POWER SECTOR (IN T CO_2/MWH NET)



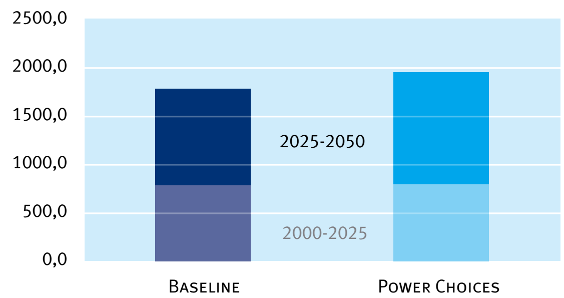
Until 2025, the main drivers for carbon reductions are energy efficiency improvements and a fuel switch from oil and coal to gas, while the increasing deployment of renewable energy sources also plays an important role. As from 2025, CO_2 emissions decline quite rapidly, primarily due to the deployment of CCS technologies, first applied to coal-fired plants and then also to gas- and oil-fired plants. The two other main drivers for reducing CO_2 emissions are, once again, the higher penetration rate of RES, plus new installed nuclear power capacity.

INVESTMENT AND COST

INVESTMENTS RISING FROM 2025

Total cumulative investment in power generation amounts to some €2 trillion in 2005 money by 2050. During the 2000-2025 period, *Power Choices* investments total €855 billion, quite comparable with the €836 billion under the *Baseline* scenario. In the subsequent 25 years, from 2025 to 2050, the required investments are much higher, totalling €1,141 billion, €162 billion more than *Baseline*.

POWER GENERATION INVESTMENT (BILLION €)

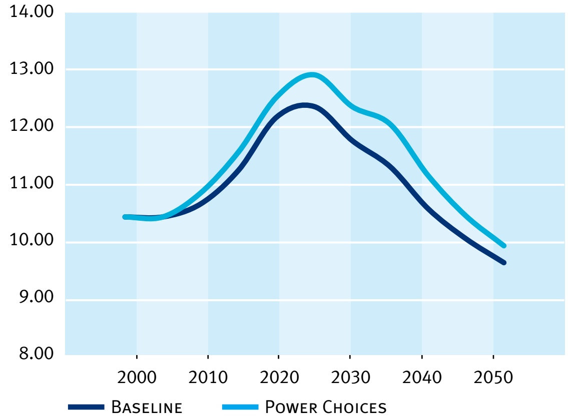


OVERALL ENERGY COST IN THE ECONOMY DECREASES LONG TERM

The *Power Choices* scenario sees the overall cost of energy in relation to GDP increasing from 10.5% in 2010 to 13% by 2025, up to 0.6% higher than in *Baseline*. However, in the long term, the cost of energy under *Power Choices* falls back to 10% at 2050, just 0.3% higher than under *Baseline*, despite the less ambitious GHG emissions reduction target in that scenario.

The initial rise in the cost of energy is due to high capital outlay, in line with the carbon-neutrality goal, and one-off investments in energy efficiency – for example in insulation equipment, which will also contribute to the rise in energy costs.

TOTAL COST OF ENERGY AS % OF GDP



Over time, return on investments in energy efficiency, the growing role of electricity, particularly in transport, combined with demand-side management programmes, will allow optimisation of the system by smoothing out more expensive peaking electricity production and reducing average costs. The rapid decrease in energy cost as a percentage of GDP after 2025 also reflects the overall decrease in primary energy use.

ENERGY EFFICIENCY

Q: How significant is the impact of energy efficiency?

A: Reducing EU greenhouse gas emissions by 75% by 2050, without the strong investment drive in energy efficiency seen under the *Power Choices* scenario would push the total cost of energy up by an additional 2% of GDP.

Power Choices policy framework...

The *Power Choices* main scenario assumes that all power generation options will be used in a market environment, taking full account of today's political realities, including planned nuclear phase-outs in Germany and Belgium. In addition, we have assumed that CCS technologies would be demonstrated by 2020, allowing full-scale commercial deployment to commence in 2025. The main scenario also places no limitations on the building of onshore windpower installations.

... but what if?

WHAT IF countries such as Germany and Belgium decide to overturn their previously envisaged nuclear phase-out policies? What impact would that have on how Europe reduces its CO_2 emissions?

WHAT IF CCS technologies are delayed by ten years and available for commercial, full-scale deployment only after 2035? What would happen to Europe's CO_2 emissions?

WHAT IF future onshore windpower capacity is dramatically curtailed due to unfavourable planning and authorisation procedures? What if a third of planned onshore wind simply does not get built?

We ran these scenarios through the model to see how *Power Choices* outcomes might change.

WHAT IF... countries envisaging a phase-out of nuclear power decide to reverse this policy? What impact might that have on Europe's CO_2 emission reductions?

If the envisaged nuclear phase-out policies are overturned, nuclear energy could see its share of the EU power generation mix increase to 33%. Some 30GW of additional nuclear capacity could be installed compared with the *Power Choices* main scenario, bringing EU installed nuclear capacity up to 192GW. This would also have an impact on the way the EU reduces its CO_2 emissions. With more nuclear energy in the system, the power industry would be able to smooth out its CO_2 reduction curve, especially in the 2015-2035 period.

WHAT IF... CCS technology is seriously delayed and does not become available before 2035?

Should CCS not become commercially available from 2025, but only after 2035, this would have a significant impact on the way the EU reduces its CO_2 emissions. Reduction of power-related CO_2 emissions would happen much more slowly during the 2020-2035 period, after which a sharp reduction would be seen. This would slow down emissions reductions from the EU economy as a whole, as no other technology would be deployed rapidly enough to replace CCS.

WHAT IF... deployment of new onshore windpower between 2010 and 2050 is reduced by a third due to obstruction to development through planning rules and local public opposition?

The shortfall in onshore wind generation reaches 92TWh by 2050 compared to the *Power Choices* main scenario. This is compensated for by a combination of nuclear power (an extra 18TWh), and CCS-equipped coal- and gas-fired generation (an extra 45TWh). However, notably very little additional offshore wind (only an extra 15TWh) is constructed under this sub-scenario as it remains relatively expensive. The compensatory role of biomass generation is also very small, with only an additional 2TWh over the *Power Choices* main scenario.

Key Outcomes

- Carbon-neutral power in Europe by 2050 is achievable
- The major CO_2 reduction in the power sector occurs during 2025 to 2040
- All power generation options, plus robust electricity and carbon markets and policies to foster energy efficiency, are all needed simultaneously
- A paradigm-shift is needed on the demand side: intelligent electricity systems should replace direct use of fossil fuels
- The *Power Choices* scenario minimises energy import dependency

A carbon-neutral power sector will have a growing role to play in decarbonising society. Reaching the global objective of a -75% reduction in GHG for the EU by 2050, will imply both:

- An increased degree of electrification of final energy usage
- Decarbonise power generation

To achieve this objective, strong and immediate political action is required to:

Technology Choices

- ➢ Enable the use of all low-carbon technologies and ensure investments in transmission and distribution lines
- ➢ Encourage public acceptance of modern energy infrastructure commitments.

Carbon and Electricity Markets

- ➢ Support well functioning carbon and electricity markets so as to deliver carbon reductions at least cost
- ➢ Ensure that all sectors internalise the cost of greenhouse gas emissions
- ➢ Actively promote an international agreement on climate change

Energy Efficiency

- ➢ Facilitate the electrification of road transport and efficient electro-technologies for heating and cooling
- ➢ Ensure that public authorities take a leading role in energy efficiency, adopting standards and incentives to help consumers choose energy-efficient technologies

Costs

- ➢ European and national budgets should radically refocus towards supporting a new intelligent energy economy
- ➢ Recognise that the cost of technology deployment differs substantially across the EU Member States and distribution effects will vary

Project Features

EURELECTRIC worked in close cooperation with a number of partners whose expertise and close involvement made the project possible.

Project Management Team

- Project Leader: William S Kyte OBE
- Deputy Project Leaders: Juho Lipponen, John Scowcroft
- Project Coordinator: Nicola Rega
- Project Advisors: Sam Cross (Modelling), Gunnar Lorenz and Pierre Schlosser (Networks), Hélène Lavray (Environment), Olga Mikhailova (Electricity Markets)
- Report Editor: Karine Milheiro. A big thank you goes also to the communication team of the Electricity Supply Board for their support in finalising the report.

Modelling

The project has used PRIMES 2009 energy model, developed and run by E3MLab of the National Technical University of Athens, led by Prof. Pantelis Capros with Dr. Leonidas Mantzos, Nikos Tasios and Nikos Kouvaritakis.

Technology on the supply side

VGB PowerTech, led by Dr. F. Bauer, has provided the technical and economic characteristics of power generation technologies assumed for the modelling.

Steering Committee

The project was carried out under the strategic direction of a Steering group composed of experts in the electricity sector throughout the whole value-chain.

Chair:

- Giuseppe Montesano, Enel S.p.A., Vice-Chair of EURELECTRIC Environment & Sustainable Development Policy Committee.

Members:

- Franz Bauer, VGB PowerTech e.V.
- Jean-Guy Bartaire, Electricité de France, Chair of EURELECTRIC Environmental Protection Working Group
- Peter Birkner, RWE AG, Chair of EURELECTRIC Networks Committee
- Jean-Yves Caneill, Electricité de France
- Tomas Chmelik, CEZ a.s., Chair of EURELECTRIC Climate Change Working Group
- Gwyn Dolben, Association of Electricity Producers, Chair of EURELECTRIC Energy Policy Working Group
- Reinhold O. Elsen, RWE Technology GmbH
- Per-Olof Granstrom, Vattenfall AB
- Per Hallberg, Vattenfall AB, Chair of EURELECTRIC Smart Grids / Networks of the Future Working Group
- Ignacio Martinez Del Barrio, Asociacion Espanola de la Industria Electrica
- John McElroy, RWE Npower, Chair of EURELECTRIC Flexibility Mechanisms Sub-Group
- Tomas Müller, Verband der Elektrizitätsunternehmen Österreichs, Chair of EURELECTRIC Perspective Working Group
- Claude Nahon, Electricité de France, Chair of EURELECTRIC Energy Efficiency Working Group
- Pedro Neves Ferreira, EDP – Energias de Portugal
- Charles Nielsen, DONG Energy A/S, Chair of EURELECTRIC Renewables and Distributed Generation Working Group
- Andy Papageorgi, Electricity Authority of Cyprus, Chair of EURELECTRIC Statistics & Prospects Network of Experts
- Heiko Rottmann, Bundesverband der Energie- und Wasserwirtschaft e.V
- Walter Ruijgrok, EnergieNed, Chair of EURELECTRIC Environmental Management & Economics Working Group
- Stanislav Tokarski, Tauron Polska Energia SA
- Oluf Ulseth, Statkraft AS, Vice-Chair of EURELECTRIC Energy Policy & Generation Committee
- Eric van Vliet, EnergieNed, Vice-Chair of EURELECTRIC Markets Committee
- Owen Wilson, Electricity Supply Board, Chair of EURELECTRIC Environment & Sustainable Development Policy Committee

External experts and stakeholders

EURELECTRIC would like to thank all those organisations, governments officials, academics, NGOs and companies for their feedback provided during the preparation of the report:

European Commission, International Energy Agency, Nuclear Energy Agency, Foratom, Government of Poland, Government of Sweden, Centre for European Policy Studies, European Energy Institute, European Climate Foundation, World Wildlife Fund, European Wind Energy Association, Confederation of European Paper Industries, ABB, Alstom, Areva, Arkema, Pöyry Forest Industry Consulting, Siemens, Vestas.

They have all provided important feedbacks that helped EURELECTRIC in advancing the study. However, this consultation exercise should be in no way understood as an implicit agreement, from any of the above mentioned, on the assumptions or conclusions made in the report. In this context, it must be clearly stressed that EURELECTRIC is solely responsible for the content of Power Choices.

We thank all partners, associations and individual experts for their contribution.

1 Introduction

The 4th Assessment Report of the International Panel on Climate Change (IPCC) indicated that in order to stabilise atmospheric greenhouse gas (GHG) concentrations within the threshold of 450ppm, thus holding the risk of global temperature rise to an average of 2°C over the pre-industrial level, GHG emissions would have to fall by 50% in 2050, relative to 2005 levels. Taking into account emission trends by world region and development dynamics, it becomes evident that the OECD economies will have to reduce their emissions by 70-80% in 2050, relative to 2005. This implies that the OECD power sector will have to become virtually carbon-free by 2050. Given that the GHG concentration matters for temperature rise, emission cuts have to be continuous and sustained throughout the time period, from today until 2050.

It is thus imperative for the electricity sector to plan for a carbon-constrained future. Power generation, as a major emitter of carbon dioxide, needs to transform at a sustained pace towards carbon neutrality. Electricity as an energy carrier can then become an opportunity for other sectors, such as transportation, the second larger emitter, to decarbonise. More generally, the intelligent use of electricity can drive higher energy efficiency where energy saving potential exists and substitute for fossil fuels, wherever possible. Transformations thus concern the whole energy system, both demand and supply in all sectors, and will require deployment of a diverse set of new and existing technologies, none of which alone deliver the required emission cuts. A diverse set of policy supports, regulations and common infrastructures are also required.

In 2007 EURELECTRIC's "Role of Electricity" study showed that, under the most favourable scenario using all available energy options to meet a 50% reduction target for carbon dioxide emissions in the EU 25 by 2050, the specific CO_2 emissions for the European power sector would fall from the current 0.45 tonnes CO_2 per MWh to 0.10 t CO_2/ MWh – equivalent to some 500 million tonnes of CO_2 per annum.

In March 2009, recognising the responsibility of the power sector as a major emitter of greenhouse gas, sixty one Chief Executives of electricity companies representing well over 70% of total EU27 power generation signed a Declaration, committing to action to achieve carbon-neutrality by mid-century. The Declaration, which also draws attention to the need for a properly-functioning electricity market in Europe, the desirability of an international carbon emissions market and the role of efficient electric technologies in the overall drive for energy efficiency and carbon reductions, was handed to the EU Energy Commissioner by EURELECTRIC President Lars G. Josefsson.

The EURELECTRIC Power Choices study was set up to examine how this vision can become reality. Setting a EU economy-wide reduction goal of 75% (mid-way on the IPCC's 70-80% scale)[1] Power Choices looks into the technological developments that will be needed in the coming decades, examines some of the policy options that will have to be put in place within the EU and quantifies a road map for energy system changes that help to attain a deep cut in carbon emissions by mid-century.

Carbon-neutrality means:

- Calculating emissions accurately in a transparent manner
- Reducing emissions to the fullest extent feasible within the sector
- Offsetting residual emissions through actions to reduce greenhouse gases elsewhere – via technology transfer, afforestation, etc – such that net carbon emissions are equivalent to zero

EURELECTRIC's Power Choices study uses the PRIMES energy model developed and run by E3MLab of the National Technical University of Athens, to quantify energy system scenarios for the EU up to 2050. For this study, the model has been fully updated as regards macroeconomics, energy data and assumptions. The Baseline scenario builds upon the recent (end 2009) baseline scenario developed for DG TREN. The policy scenarios include a Reference case, the ***Power Choices*** case and a series of sensitivity analyses which examine cases with different assumptions regarding the targets or the availability of emission cutting options. The model-based analysis covers in detail all the EU Member-States.[2]

1 The 75% reduction objective refers only to the EU; additional emissions reductions could be achieved through international carbon offsets. In this respect, this objective is in line with the more recent EU objective of reaching 80 to 95% emission re-ductions by 2050.

2 Non-EU countries (Switzerland and Norway, as well as all Balkan countries and Turkey) are fully considered in the PRIMES model regarding exchanges of electricity and the operation of the interconnected system. However, for the purpose of this study, those countries are only assessed in terms of EU import-export projection.

2 GHG MISSION REDUCTION: GLOBAL OUTLOOK

Holding the rise in global mean tem-perature below 2°C compared to the pre-industrial level is an aim on which agreement was reached at the 2009 COP15 in Copenhagen. Continuing current trends in emissions would lead to an atmospheric concentration of GHGs in excess of 1000ppm, which corresponds to a risk of a temperature rise greater than 6°C. Stabilising the concentration at 450ppm, as required to avoid a temperature rise beyond 2°C, calls upon drastic emission cuts relative to current trends: cumulative emissions of GHGs must not exceed roughly 1000 Gt at a global scale within the period 2005 to 2050. This means that the World will have to halve cumulative emissions from current trends during the same period of time.

Distributing the required emission cuts among sectors, countries and over time is obviously a complex task. However, there is actually wide agreement in the literature about the following: a) the required emission reduction is so ample that all countries and sectors have to participate in the mitigation effort; b) even if the OECD countries reduce emissions close to zero, eventual non participation of developing countries will lead to unacceptable concentration levels at a global scale; c) the time profile of emission reduction pathways is important: inaction in the early phases would either imply deviating from the desired concentration or would lead to unacceptably high mitigation costs in later phases.

In order to define an emission reduction target for the EU which is consistent with global action aiming at stabilising the concentration at 450ppm, the Power Choices study has used the Prometheus world energy model, developed and run by E3MLab. The model projects energy-related CO_2 emissions which count for roughly 75% of total GHGs.

By using the Prometheus model, the study initially developed a world energy outlook for a reference case, which does not involve significant climate action.

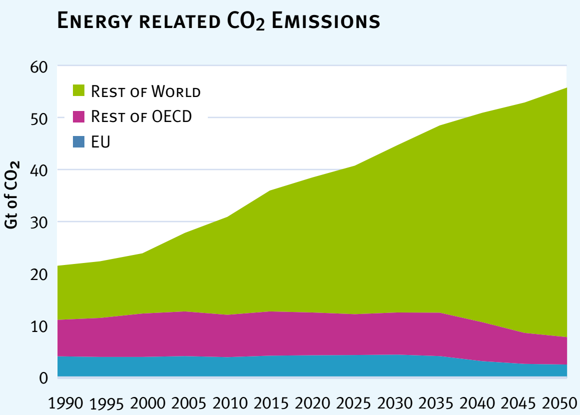


Figure 1: Reference Case Emissions

The Prometheus projections for the Reference case *(see Figure 1)* show that world emissions are likely to double between the present and 2050. Global CO_2 emissions are found rising from 27.1 Gt in 2005 to 44.3 Gt in 2030 and 55.2 Gt in 2050. The scenario incorporates policies implemented in the OECD countries up to early 2009 including RES support mechanisms, some energy efficiency regulations and the emissions trading scheme of the EU (ETS). Regarding the latter it is assumed that moderate emission reduction targets will apply in the future in the context of the refer-ence case. The driving macroeconomic trends take into account the effects of the financial crisis of 2008 and its longer term implications. Recovery of the world economy is projected to take place between 2012 and 2020, followed by lower but sustained economic growth until 2050.

Non-OECD countries overwhelmingly dominate the rise in emissions, exhibiting increasing trends, as opposed to OECD emissions which are slightly lower in 2030 than in 2005 and decrease further by 2050. Non-OECD countries' CO_2 emissions grow to double the OECD's emissions by 2020.

WORLD	2005	2020	2035	2050
CO_2 Emissions (Gt CO_2)	27.1	38.3	48.1	55.2
By sector				
Indusrty	5.1	7.2	8.4	8.1
Transport	6.3	8.0	10.9	15.9
Residential/Commercial	3.4	4.0	4.5	4.7
Electricity production	9.9	15.5	19.7	21.1
Other (including bunkers)	2.4	3.7	4.6	5.3
By fuel				
Coal	11.5	16.7	22.2	25.7
Gas	5.5	8.4	9.9	9.4
Oil	10.1	13.1	15.9	20.2

***Table 1:** Reference Case Emissions by Sector*

According to the model results *(see Table 1)*, power generation dominates and will, according to projections, continue to dominate world CO_2 emissions. The transport sector is also of significant and increasing importance. Unlike the power generation sector, where multiple options for emission reduction exist and can be activated by appropriate price signals, transport and especially road transport demands a specific policy focus if a transition to a low carbon system is to be attained. Solid fuels remain the largest single source of electricity in the reference case, followed by gas and nuclear. Renewables make remarkable inroads with their usage quadrupling in 2050 relative to 2005. The Carbon intensity of power generation is projected to decrease, reaching 0.343 tCO_2/MWh in 2050, significantly below the 0.559 tCO_2/MWh in 2005.

The 450ppm case quantified using the Prometheus model meets the requirement of limiting energy-related cumulative emissions in the period 2005-2050 to a maximum of one trillion tons of CO_2. The scale of emission cuts relative to the reference case justifies taking advantage of emission reduction potentials in all world regions. The model assumes that beyond a certain transition period all countries and sectors will operate in an ideal market for carbon allowances clearing at a single carbon price. Regarding the transition period it is assumed that developing countries start participating after 2015 with gradually increasing commitments and achieve a similar participation after 2025.

Harmonization of carbon policies between the EU and the rest of OECD are assumed to be completed by 2015. A common target and therefore common effective carbon prices apply within the OECD thereafter.

In order to overcome non-market barriers some sectors are ssumed to be subject to additional policy interventions especially in the early stages. These include renewable energy supports differentiated according to the maturity of the different technologies, as well as measures promoting efficiency improvements and structural change in demand sectors. A particular focus is placed on road transport in the scenario via the provision of power distribution infrastructure and additional R&D on batteries and hybrid electric vehicles.

The model determines an "optimal" time profile of emissions reduction which is consistent with the concentration objective. Global emissions are found to be reduced by 50% in 2050 relative to 2005 and by 20% in 2030, after an increase of 10% in 2020 *(see Figure 2)*.

In this context the OECD countries undertake larger emission cuts, which range between 75-83% in 2050, 40-60% in 2030 and 26-44% in 2020, depending on the OECD region. As expected, developing countries' participation is imperative: they should take commitments to cut emissions by 25% in 2050 relative to 2005, a substantial reduction since it represents a 75% drop in 2050 relative to the reference case in 2050 (the same drop is 50% for 2030). As far as the EU is concerned, setting a reduction objective of 75% for 2050 relative to 2005 is consistent with the global mitigation effort. The emission reduction effort needs to be continuous, starting from today, and should deliver at least 40% by 2030 (relative to 2005) and 26% by 2020.

The model-based simulations provide evidence that very low carbon energy systems consistent with climate stabilisation are feasible without implying a radical deviation from economic growth patterns.

A wide range of options enabling the provision of energy services while drastically reducing carbon emissions is available or is in the pipeline, which can enable a drastic decoupling of CO_2 emissions from GDP growth *(see Figure 3)*.

Early deployment can be assisted by additional R&D and a focus on infrastructure development.

However, early climate policy determination and concerted commitment is required to ensure a smooth and cost effective transition. This is particularly so when ambitious global emission targets are set and emission controls must neutralise growth pressures emanating from developing economies.

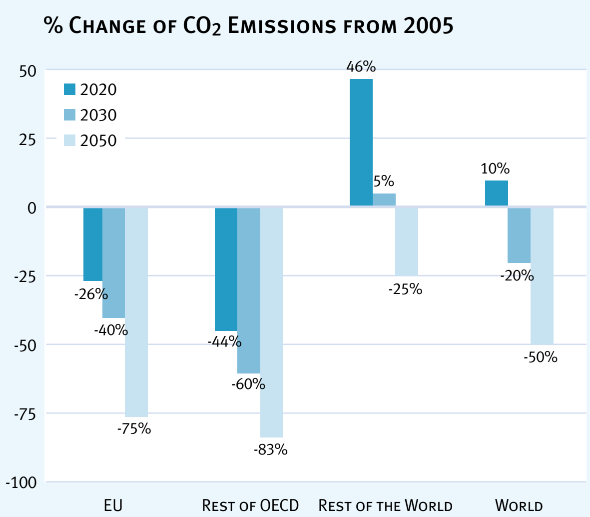


Figure 2: *Emission Cuts in the 450ppm Case*

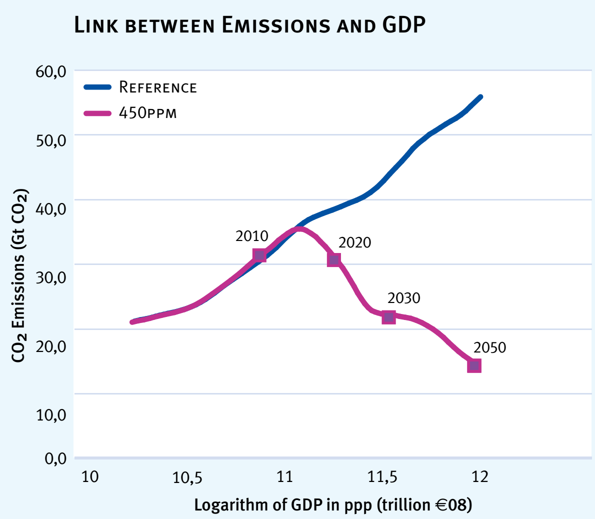


Figure 3: *Emissions and GDP for World in the 450ppm Case*

Under the conditions examined electricity plays a pivotal role in achieving the requisite emission reductions: firstly by making de-carbonisation of power generation possible through phasing in a wide range of zero or very low carbon production options; secondly by deep penetration in energy demand sectors, such as electric processes replacing thermal applications in industry, large scale penetration of heat pumps and direct electric heating, and especially by making massive in-roads in the hitherto intractable road transport energy market. This explains why electricity demand remains closely linked with GDP, while total final energy decouples from GDP growth *(see Figure 4)*.

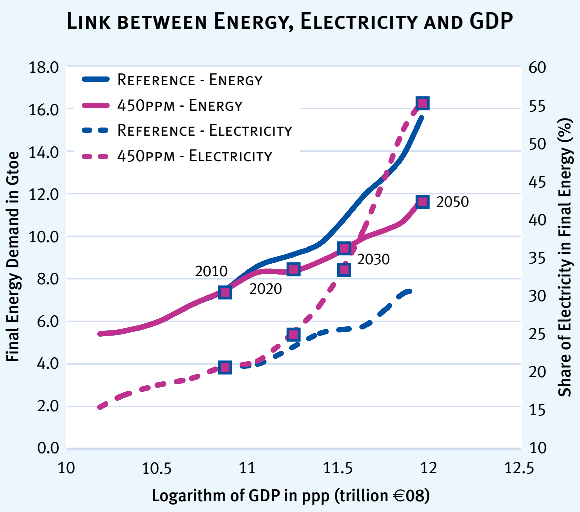


***Figure 4:** Final Energy and Electricity World in the 450ppm Case*

De-carbonisation of power generation *(see Figure 5)* broadly follows this pattern: a) Large scale expansion of renewable forms until supply constraints start partially offsetting technological improvements, b) Rapid introduction of carbon sequestration options with an increasing shift from post- to pre- combustion, c) Reversal of Nuclear share decline as third and fourth generation designs mature, d) Emerging role for more "exotic" options such as hydrogen, biomass gasification with sequestration.

Carbon intensity of power generation gets as low as 0.017 tCO_2/MWh in 2050 (0.097 in 2030).

CCS technologies dominate new coal power developments and capture 57% of potential emissions from power generation at a global scale in 2050 (25% in 2030). Renewables including biomass double their share in power generation by 2030, relative to 2005, and maintain a share of 40% in 2050. In the longer term, intermittent renewables contribute roughly 15% to power generation.

Road transport transformation to low carbon structures follows a pattern marked by the acceleration of conventional hybrid penetration in the early stages, early introduction of plug-in hybrids and steady expansion in line with infrastructure expansion (stunting conventional hybrid take-up), and in later stages the introduction of pure electric vehicles benefitting from improvements in batteries and the development of large scale infrastructure *(see Figure 6)*. Transformation partially spills over to the rest of World even in cases where the climate abatement effort is limited to OECD countries. Conventional vehicles do retain a small share (more pronounced among heavy duty commercial vehicles).

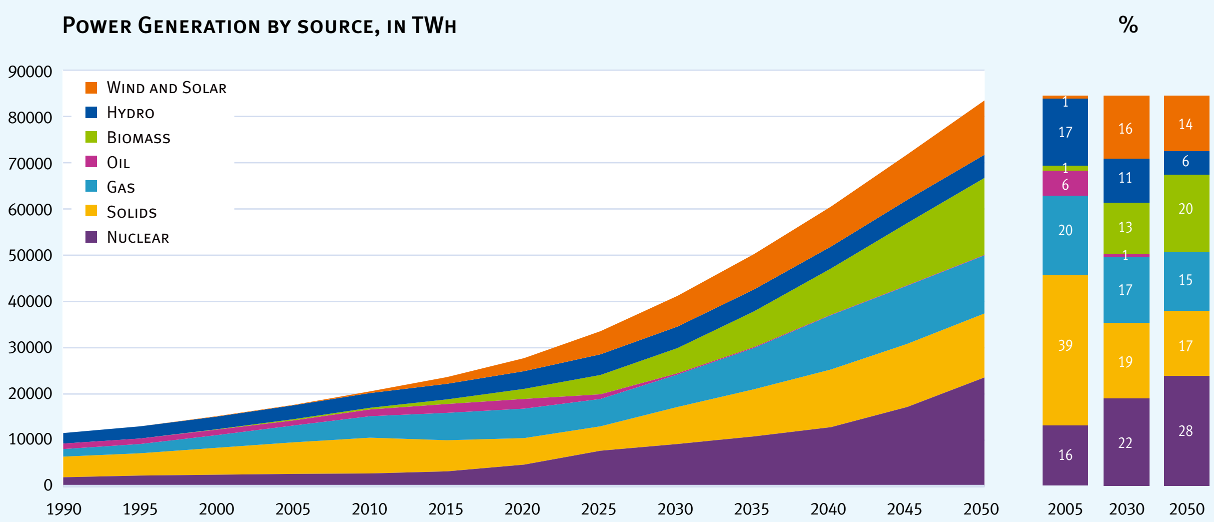


***Figure 5:** Power Generation for World in the 450ppm Case*

The acceleration of energy efficiency improvement in final energy demand is an important ingredient in the transformation pathway towards low carbon. It is particularly important in the early stages of the process, as it proves to be cost effective; however, the improvement pace differs between OECD and developing countries, being much slower in the latter. In the context of the 450ppm case, electricity's role in final energy demand is not only to enable lower carbon by substituting for fossil fuels but also to bring about higher energy efficiency contributing to energy savings. The share of electricity gets as high as 55% by 2050 (33.5% in 2030); this compares to 31% in the reference case for 2050 (25% in 2030).

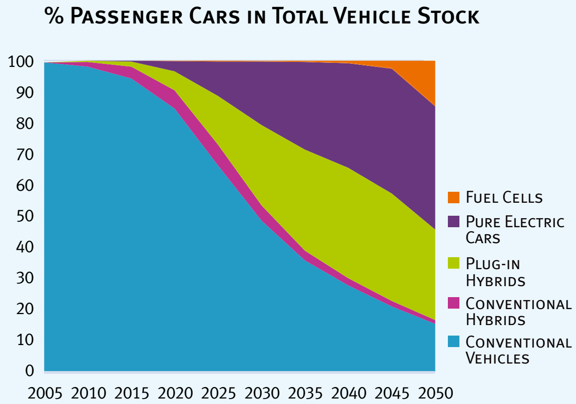


Figure 6: *Vehicle Technologies for World in the 450ppm Case*

Increasing energy efficiency in energy demand combined with de-carbonisation of the energy system could lead to a relative oversupply of fossil fuels at World level. If that is the case, oil prices would collapse to values close to their historical lows when the World acts in unison. Gas prices would also tend to hold in the medium term but tend to be lower in the longer term. Similarly, coal prices would fall significantly in the 450ppm case. Such effects on prices may imply additional abatement effort in the global reduction scenario and raise questions on committing major energy producers to the global effort. However, evolution of fossil fuel prices might be impacted also by several other events which could result in a less optimistic scenario. For these reasons, the study did not further explore these world energy price issues and it has retained energy price projections unchanged from the reference case for the EU scenarios.

The case of OECD countries alone performing drastic emission cuts (up to 80% by 2050 relative to 2005) was also explored using the Prometheus model. The rest of the World does not participate but nevertheless gets favourable spill over effects from technologies deployed in the OECD. As expected, that unilateral action has little effect on global emissions: cumulative emissions to 2050 are 80% above the 450ppm case, which obviously leads to unsustainable temperature effects. The OECD energy system is sufficiently large to allow for economic deployment of new technologies permitting for considerable carbon reductions in power generation, energy savings and the electrification of road transport. Whereas the transformation of the OECD energy system is similar to that obtained under the 450ppm case, the mitigation costs are found higher than the 450ppm case, and, as mentioned, the OECD -80% case does not resolve climate change mitigation.

3 BASIC EU SCENARIO ASSUMPTIONS

The scenarios quantified using the PRIMES model for the EU project energy demand, supply and prices dynamically from 2010 up to 2050, divided in 5-year steps. The scenarios were developed for each EU Member-State individually and for the EU as a whole regarding electricity trade and the EU Emissions Trading Scheme (ETS). All energy scenarios for the EU assume the same macroeconomic and sectoral activity scenario and the same world energy prices scenario; the former is derived using the GEM-E3 general equilibrium model and the latter was derived using the Prometheus world energy model.

3.1 WORLD AND EU MACROECONOMIC SCENARIO

World economic growth in the future is divided in four broad periods: The recession (2008-2012), the recovery (2013-2022), a gradual slowdown (2022-2030) and the longer term (2030-2050). The average rate of growth of the global economy over the period 2006 to 2030 was quantified in accordance with the latest IEA World Energy Outlook, i.e. 3.3% per year (in volume terms). However, growth rates vary considerably within parts of this time period.

The recession period is characterized by negative growth rates in 2009 and almost zero in 2010 for the OECD countries and a serious slowdown of growth in emerging economies. The average growth rate over the period 2008-2012 is assumed merely to be exceeding 2% per year. The recovery period is characterized by re-deployment of productive resources and re-establishment of global trade, allowing accelerated economic growth in emerging economies (more than 6% per year in the period 2012-2020). OECD economies are projected to grow by 2.7% per year during the same period; that growth, however, is not sufficient to compensate for a permanent loss of GDP incurred as a result of the financial crisis. Both the period 2020-2030 and the longer term (2030-2050) are characterized by a gradual slowdown of world economic growth. The reasons behind this slowdown are ageing in some societies, the exhaustion of potential gains in productivity by labour movement away from traditional employment areas of the economy, the maturing of economic structures (notably in China beyond 2030) and even stagnation in the growth of the active population (in some regions). Global economic growth is projected not to exceed 3% per year in the period 2020-2030 and becomes 2.2% per year in the period 2030-2050.

The macroeconomic scenario for the EU includes numerical projections of GDP (volume), households' income, population and activity by sector (22 sectors in total) for each EU Member-State. The 22 sectors are divided in 10 energy intensive industries, 6 non energy intensive industries, 3 sectors of services, construction, agriculture and the energy supply sector.

Extensive use was made of the recently published DG ECFIN's 2009 Ageing Report regarding long term trends for GDP and demographics. For short term prospects, the projection has used world economy forecasts published in January and February 2009 by DG ECFIN, the ECB and the IMF.

The economic prospects of the EU *(see Figure 7)* mirrors global economic developments when distinguishing between three phases: the recession (2008-2012), the recovery (2013-2022) and the low but stable growth period (beyond 2022). The financial crisis induced a marked deterioration of global economic prospects in the final quarter of 2008. The causes of the vicious recession spiral were the loss of financial assets, the reduction in business confidence accompanied with increased uncertainty, and the resulting reduction in bank lending.

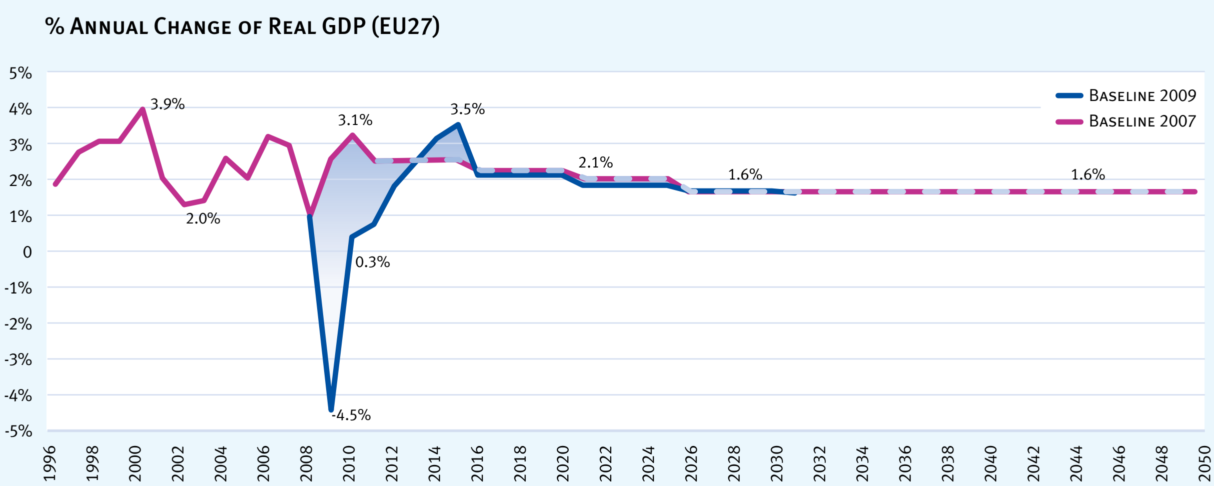


Figure 7: *GDP Projection for the EU27*

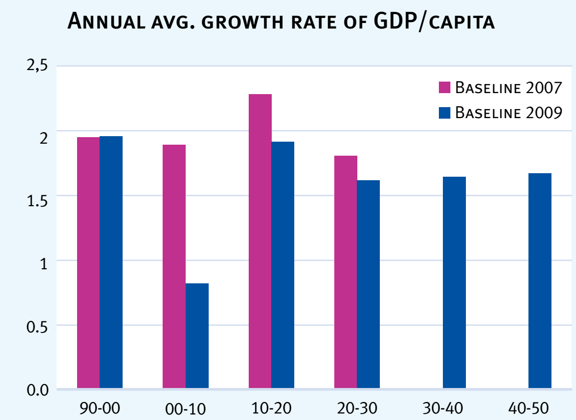
A credit rationing practice, synchronized worldwide, had detrimental effects for emerging economies through reduction in global trade. Thus EU exports were driven significantly downwards. Credit rationing together with increased uncertainty resulted into a slowdown of private investment in all sectors and in lower households' expenditures in durable goods and new houses. The rate of private savings increased, exerting further depressive effects on consumption. All together – drop in exports, lower consumption and lower investments – explain the recession in GDP terms for the EU economies. The GEM-E3 model simulated successfully these effects for all EU member-states.

To alleviate the effects of the crisis, the governments put in place extraordinary measures, including a reduction in basic interest rates, the expansion of money supply and facilitation of credit availability. These measures remove the effects of credit rationing and encourage private investment in production as well as in durable goods and houses. The relatively low oil and commodity prices facilitate economic growth as costs of domestically produced goods fall. Expanding such measures worldwide facilitates the re- establishment of global trade. Thus, demand for exports as well as domestic consumption and investment is progressively re-established in the EU. The recovery process is logically accompanied with efficiency and productivity gains in many sectors, further boosting growth. As a result, the growth performance of the EU is higher during the recovery period, than it was before the crisis, albeit for a limited time period. Despite this higher growth, a permanent loss of GDP and welfare is encountered when comparing performance against scenarios without the crisis for the entire period from 2005 to 2030.

Beyond the recovery period, the growth of the EU GDP (in volume terms) is projected to decelerate. The annual growth rate is 2% per year between 2020 and 2025 and 1.7% per year between 2025 and 2030. For the period beyond 2030, an average growth rate of 1.55% per year is retained for the EU27. The slowdown of growth is due to the ageing population, a slow-down in productivity growth and to increasing competition from emerging economies.

The demographic projection, in accordance with ECFIN's 2009 Ageing Report, includes a dynamic immigration trend which helps keep growth rates positive but is not sufficient to sustain higher growth. Both total population and active population are assumed to grow at a positive, albeit very low, growth rates over the entire projection period. As for households' per capita income the scenario shows this increases at an average rate slightly lower than 2% per year during the projection period *(see Figure 8)*.

The growth patterns differ by EU Member-State: the northern and central old members of the EU suffer more than other members from the recession and recover more slowly, returning, however, to a significant and positive growth pace over the long term; the new member-states may experience lower growth rates than in the period before the crisis, but their recovery is more pronounced than the EU average, a recovery followed by a slowdown in growth rates as their growth drivers are progressively saturated; southern economies display a similar growth recovery pattern, but their long term prospects are slightly lower than those of the new member-states. The macroeconomic scenario involves gradual and steady convergence of GDP/capita among the Member-States. Significant economic dispersion, notably between the old and the new member-states, remains over the entire projection period, but it is lower in magnitude than at present.



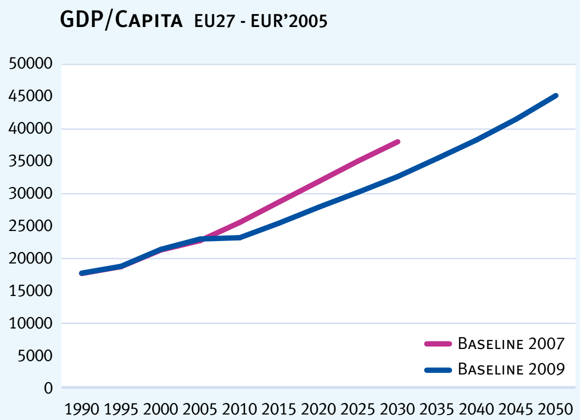


Figure 8: *GDP per Capita Projection for the EU27*

The projection of future activity by sector is of great importance for the energy model. The following points illustrate the sectoral outlook:

a) The Services sectors are projected to dominate the EU's GDP throughout the projection period. The services produce 72% of gross value added in the EU in 2005 and are projected to produce 75% of the total in the long term.

b) Non energy intensive industries display the second faster rate of growth among the sectors and their share is projected to remain stable throughout the projection period. The engineering industry, producing equipment goods, is the dominant industry within the non energy intensive industrial sector, growing faster than the average. Pharmaceuticals and cosmetics display high growth in the scenario but their share remains rather low. The food industry and various other industries, including wood, rubber and plastics, show significant dynamism in contrast to textiles, which are projected to decline.

c) The energy intensive industry (chemicals, basic metals, building materials, pulp and paper) represent a small share in GDP. The scenario assumes that the bulk of industrial activity in this sector will stay in the EU territory and will even display a slow but steady growth (1% per year on average over the projection period). The scenario involves restructuring of processing technology, projecting a shift towards higher value added product varieties, as for example specialist steel, specialist ceramics and high quality glass. These shifts have consequences on energy consumption and the fuel mix. Chemicals are the fastest growing industry within the energy intensive sector. Petrochemicals and organic chemicals grow faster than fertilizers and inorganic chemicals. The building materials industries experience considerable slowdown during the recession period driven by the downturn in construction.

Mobility projections in transportation *(see Figure 9)* are linked to macroeconomic drivers, such as GDP, private income and volume of trade. Mobility is measured in person-km for passenger transportation and in tonne-km for freight transportation. The basic relationship between mobility and the macroeconomic drivers comes from data produced by the model SCENES. The extrapolation of that relationship to the future shows gradual decoupling of mobility growth from economic growth; such decoupling has not been observed, according to statistics covering the period from 1990 to 2005. Saturation factors drive the decoupling in future periods. Saturation is more pronounced for passenger mobility than for freight. Regarding the latter, the establishment of a broader common market in Europe drove growth in freight transportation, which has exceeded GDP growth over the past decade. The projections for the future assume a discontinuation of that trend.

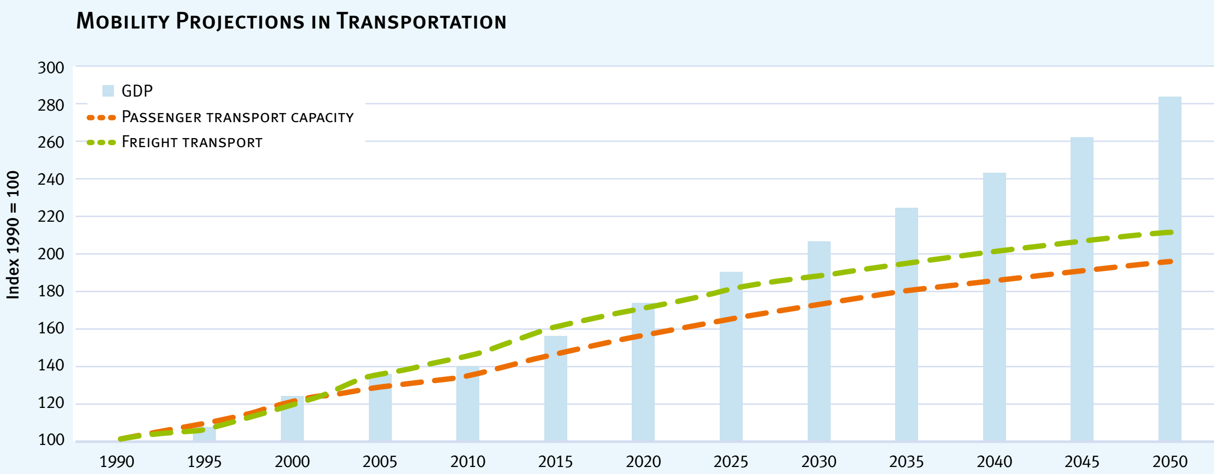


Figure 9: *Mobility Projections for the EU27*

3.2 WORLD FOSSIL FUEL PRICES

World fossil fuel prices are projected using the Prometheus model. The projection was made in the context of the baseline scenario which incorporates the effects of the current crisis.

Car ownership per capita is a key assumption for projecting future oil demand. Whereas car ownership per capita in the OECD has already reached saturation and its further growth is very slow, there is significant uncertainty about the evolution of this indicator in the emerging economies for which the projection displays continuous and substantial increase in car ownership. Nevertheless, the absolute level of that indicator by 2050 is projected to stay below the level observed in Europe in the 80s.

There is significant uncertainty about the volume of undiscovered conventional oil reserves. The expectations accepted for the projection are that undiscovered conventional oil will deliver close to 750 billion barrels of oil to 2050; this compares to around 1350 billion barrels of oil in known reserves of conventional oil. There is less uncertainty about the volume of gas undiscovered: it is assumed that 130 trillion cubic meters of gas will be discovered to 2050, compared to 170 trillion cubic meters of gas reserves known today. This volume of gas includes tight gas and coal-bed gas exploited today or expected to be exploited in North America but not unconventional gas, such as hydrates.

In the context of the baseline scenario for the world energy system, world primary energy requirements will continue to grow and will double by 2050 from today's level. Fossil fuels will continue to dominate the energy balance and coal use is likely to expand noticeably over the entire period. Renewables and nuclear are projected to increase at a pace higher than average but their contribution in share terms is projected to remain low at a global level. There is a significantly higher probability of CO_2 emissions deviating substantially from levels that would comply with the aim of avoiding a dangerous rise in global temperature.

Within that context, production of oil and gas are shown to increase continuously in the long term. The projected average growth rate per year is 1.1% for oil and 1.9% for gas over the period 2007-2050. According to the model results, the probability of peak oil (conventional) occurrence around 2020 is low (20%) but becomes close to 50% a few years after 2030. It is projected that the share of non conventional oil will reach 25% of total oil production by 2030 and 55% by 2050. The R/P (reserve over production) ratio for oil is projected to drop, from around 45 years today, down to a level less than 35 years by 2050, including non conventional oil.

The same ratio for gas also displays a declining trend, from 70 years today down to 35-40 years by 2050. The economic analysis indicates that it is more likely that gas prices will be linked to oil prices; without imposing any contractual-type limitation. The model-based analysis confirms that view showing strong correlation between oil and gas prices over the entire projection period.

The model-based analysis also shows that opportunity costs, i.e. the relative prices of competing fuels, drive up coal prices when gas prices increase, albeit to a lesser extent.

Regarding the period of economic recovery, the projection considers that productive capacity expansion slows down or is delayed as a result of low prices and the previous recession in the global economy. This holds true for both oil and gas, in the upstream business area whilst being true only for gas regarding transportation infrastructure. It is thus projected that as the recovery period drives higher oil and gas demand with capacity building lagging behind, oil and gas prices will tend to increase in real terms: oil prices could then exceed $80/bbl (in constant 2008 money terms) before 2020.

Resource constraints and the sustained growth of demand is projected to drive prices even higher, leading to oil prices being above $100 (2008 money)/bbl by 2030 and beyond *(see Table 2 and Figure 10)*. According to the model results, the probability that oil prices remain below $80/bbl is less than 30% over the entire period following the recession. There is more than a 50% chance that oil prices exceed $100/bbl continuously after 2030.

Gas prices follow a trajectory similar to oil: the projection shows gas prices approaching $10/MBtu (in constant 2008 money terms) before 2020 and then continuously increasing up to a level of $15/MBtu by 2050. There is less than 30% probability to get gas prices below $10/MBtu after 2020.

Coal prices follow an upwards sloping trajectory, starting from a sharp increase during the economic recovery period, followed by a more moderate increase in prices in the longer term. The sharp increase in the medium-term is driven by high demand for coal used in power generation in emerging countries. The projection shows coal prices between $135 and $150/t of coal (in constant 2008 money terms) between 2020 and 2050.

The gas to coal price ratio is important for power generation. In the absence of carbon pricing, a ratio of approximately 1.8 brings the two fuels into equivalence regarding the total cost of base-load power generation by means of the most efficient generation technologies. Carbon prices make gas more competitive vis-à-vis coal. A continuously increasing gas to coal price ratio is projected, from 2.2 in the short term and rising to 3.45 by 2050.

Fossil fuel Prices as imported to the EU ($'2008)					
	Oil US$/bl	Gas (GCV) US$/MBtu	Coal US$/t	gas (NCV)/oil	gas (NCV)/coal
1980	96.0	7.82	144.3	0.55	1.77
1990	39.0	4.63	95.1	0.81	1.59
1995	24.0	3.34	75.4	0.95	1.45
1999	23.2	2.32	45.9	0.68	1.65
2000	35.5	4.05	42.4	0.78	3.12
2005	59.4	6.49	67.4	0.74	3.14
2006	69.2	9.24	64.2	0.91	4.70
2007	75.5	9.19	74.7	0.83	4.02
2008	97.7	13.16	100.4	0.92	4.28
2009	48.2	6.28	84.0	0.89	2.44
2010	71.9	7.70	95.5	0.81	2.25
2015	72.6	8.08	108.6	0.73	2.23
2020	88.4	10.14	129.8	0.75	2.33
2025	101.6	12.19	143.7	0.78	2.61
2030	105.9	12.51	141.8	0.77	2.77
2035	111.2	13.37	141.9	0.78	2.98
2040	116.2	14.18	141.2	0.79	3.18
2045	120.4	15.02	141.2	0.80	3.37
2050	126.8	16.06	146.1	0.81	3.45

Source: Prometheus model (E3MLab)
1 b.o.e. = 1/7.2 toe = 1/(7.2*0.0252) MMBtu = 1/(7.2*0.666) t of coal
NCV = 0.90 GCV (gross calorific value)
Coal prices are CIF prices of steam coal

***Table 2:** World Energy Prices Projection*

Fossil Fuel Prices in Baseline (Constant Euro of 2008 per boe)

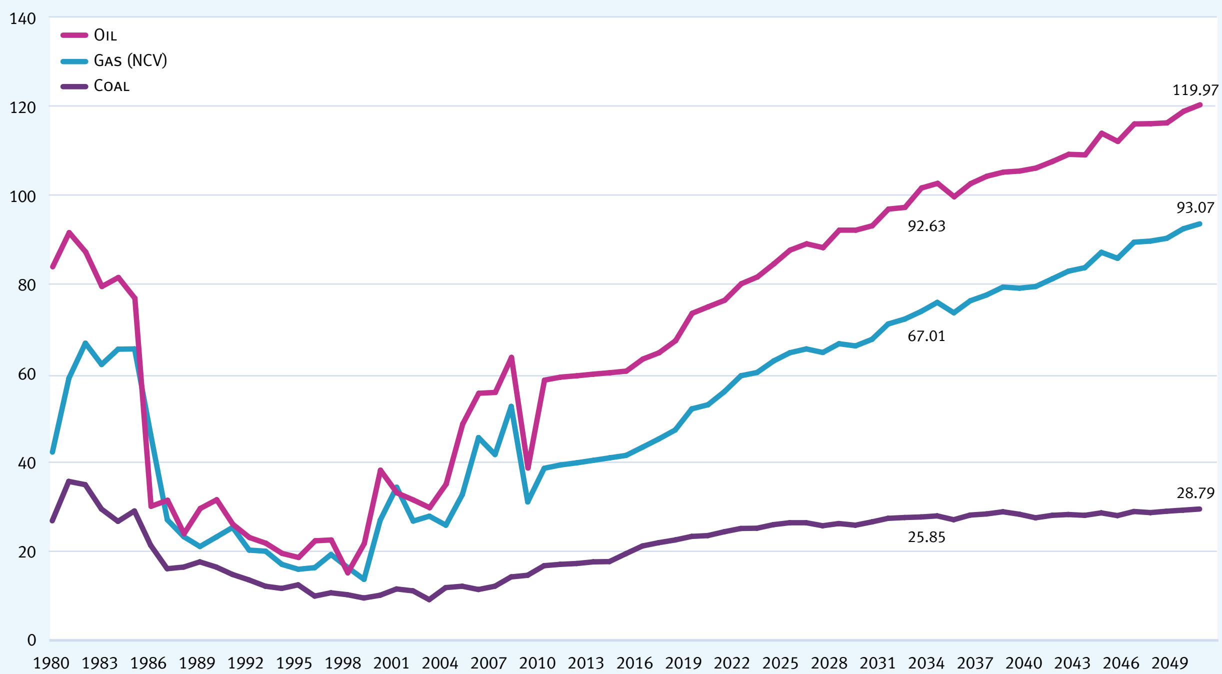


***Figure 10:** Fossil Fuel Prices*

3.3 INVESTMENTS IN TRANSMISSION LINES

The model version used in the study considers 241 existing and new transmission line interconnections. For each line, power capacity and reactance parameters are assumed exogenously. Projects for building new lines or extending the capacity of existing lines were also assumed exogenously. 40 of the total of 241 are new transmission lines builds. The total capacity of the transmission lines between countries was 179 GW in 2005; this is projected to increase to 245 GW by 2020 and to 253 GW by 2030; after 2030 the transmission capacity remains stable. It is also assumed that grid reinforcements will allow an increase in Net Transfer Capacities, which are assumed to gradually move closer to technical capacity figures.[3]

The model simulates a DC linearised power flow operation (for the broader European continent) with least cost unit commitment and endogenous investment. Since the study does not assume the development of new power sources of very large scale that would be located on specific places on the European (or non European) continent, the economics suggest that it is more likely to develop power sources close to consumption centres. Differentiated power source potentials do exist for some sources, such as nuclear, wind and solar, but the differentiation is not so large as to justify major additional interconnection projects (other than the increase of 40% in total transmission capacity projected by the study). The model simulations show no major congestion problems in the projected transmission network within the broader European grid.

3 These interconnections do not include DC lines which will be constructed in order to link with future offshore wind projects (these are accounted for in the development costs).

4 SCENARIOS WITH THE PRIMES MODEL

The main scenario quantified using the PRIMES model develops a roadmap which charts the optimal path to be pursued to enable the EU power sector to become almost carbon neutral by 2050 together with the EU economy as a whole following a CO_2 emission pathway in accordance with a 450ppm global scenario. As shown by the Prometheus model results, in the context of a 450ppm global climate mitigation effort, the EU will have to reduce CO_2 domestic emissions in 2030 by 40% from 1990 emissions and in 2050 by 75% from 1990.

For the main scenario, termed ***Power Choices***, the following key assumptions are made:

- The EU energy system develops until 2020 so as to meet the targets and fulfil obligations arising from the Climate Action and Energy policy package, adopted in 2008 by the EU; beyond 2020, the EU reduces emissions by 40% in 2030 and by 75% in 2050, relative to 1990 levels.
- Electricity becomes a major transport fuel as plug-in hybrid and electric cars develop.
- All power generation options remain available, including nuclear power in those countries that currently produce it or plan to produce it, but envisaged national phase-out policies remain.
- CCS technology is commercially available from 2025.
- No binding RES-targets are set after 2020; RES support mechanisms remain fully in place until 2020 and are then gradually phased out over the period 2020-2030.
- Energy efficiency is pushed forwards by specific policies and standards on the demand-side during the entire projection period, which will result in slower demand growth.
- The price of CO_2 ('carbon-value') applies uniformly to all economic sectors, not just those within the ETS, so that after 2020 all major emitting sectors pay for their emissions. A single CO_2 price is formed for the EU and for all sectors, resulting from a sufficiently flexible EU carbon market.
- After 2030 the CO_2 price is the only market-based driver for deployment of low-carbon technologies. Bottom-up supports, notably through R&D and demonstration, continue to develop.

It is generally assumed that the economic agents act in the context of perfect foresight without uncertainty, anticipating the targets, the carbon market prices and the technology possibilities.

A baseline energy scenario (termed Baseline 2009) was also developed for the EU, which follows the Baseline 2009 scenario developed for DG TREN (version of late December 2009) for the projection to 2030 and then extrapolates the trends to 2050. The baseline scenario assumes that only legislation adopted by spring 2009 is applicable and no further legislative actions take place after that. The scenario includes EU ETS with its cap on allowances, which decreases linearly by 1.7% per year, accompanied by the auctioning of allowances after 2015. Power generation, heavy industry and aviation are subject to the EU ETS obligations. The scenario does not consider specific targets or limitations regarding both renewables and emissions from the non-ETS sectors. Therefore carbon prices and associated auctioning payments apply only to sectors belonging to the EU ETS[4]. Nevertheless, the scenario includes bottom up measures and policies aimed at higher energy efficiency (for buildings, houses, cars and electric appliances) and the RES supporting mechanisms as defined by national and community policies known in spring 2009. In the context of the baseline assumptions, electricity does not become a major fuel in transportation. Carbon capture and storage (CCS) pilot power plants as envisaged today become operational by 2020.

The robustness of results was tested by quantifying several sensitivity analyses which alter some of the assumptions of the main scenarios.

The first sensitivity (named *Power Choices with CCS Delay*) assumes that the commercialisation of CCS is delayed and becomes mature only from 2035 onwards.

The second sensitivity (named *Power Choices with Nuclear*) assumes abolishing the nuclear phase out in Belgium and Germany.

The third sensitivity (named *Power Choices with Less Wind Development*) assumes that difficulties arise for onshore wind development limiting additional onshore wind after 2015 to one third of that obtained under the assumptions of the main scenario.

4 The model simulate by 5-year time periods and considers 2015 as the first year of ETS auctioning. The derogations (free allocation at a certain percentage) applicable to 2020 for some new EU Member-States are taken into account.

Finally, for comparison purposes, a scenario was quantified (named *Power Choices without Efficiency Policies*) which assumes that only the ETS policy is pursued and all other policies (for RES, energy efficiency, electrification in transportation) are excluded, while maintaining the 75% emission reduction target. This sensitivity was run for the sole purpose of quantifying the impact of energy efficiency policies.

In scenarios involving explicit targets for emission reductions and for RES (applicable only to 2020), carbon prices and RES incentives vary until the targets are reached. For intermediate years or in case of absence of explicit targets, the outcomes are driven by market dynamics and by anticipation of other targets. Performance in terms of energy efficiency (shown, for example, in the above table by the column on energy intensity of GDP) is not driven by any explicit target and corresponds to a result of the model. Similarly, as RES targets do not apply beyond 2020, RES deployment increases as a result of carbon prices.

Table 3 shows the resulting carbon prices in 2008 constant money terms. For 2020, carbon prices cover the ETS market only, whereas for subsequent years they cover a carbon market extended to all sectors of the EU 27, except for the two baseline scenarios and the *"Power Choices without Efficiency Policies"* case, in which only the ETS market is covered.

Carbon Price €'08/tCO_2	2020	2030	2050
BASELINE 2009 - EURELECTRIC	25.0	39.0	42.3
Power Choices	25.0	52.1	103.2
Sensitivities			
POWER CHOICES WITH CCS DELAY	25.0	53.1	103.9
POWER CHOICES WITH MORE NUCLEAR	25.0	51.9	100.0
POWER CHOICES WITH LESS WIND DEPLOYMENT	25.0	52.6	104.4
POWER CHOICES WITHOUT EFFICIENCY POLICIES	32.2	128.1	304.2

Table 3: *Carbon Prices estimated with the Primes Model for each Scenario*

5 TECHNOLOGY PORTFOLIO

The *Power Choices* scenario (and its variants) associates the achievement of emission reduction targets with the successful evolution of several technologies in all energy demand and supply sectors. The technology portfolio includes the following:

- End-use energy efficiency (thermal integrity of buildings, lighting, electric appliances, motor drives, heat pumps, etc.)
- Renewable energy for centralised and decentralised power generation, as well as for direct heating and cooling applications
- Supercritical coal plants, advanced gas combined cycle plants and CHP
- CO_2 carbon capture and storage
- Nuclear energy
- Advanced transmission and distribution grids and smart metering
- Plug-in hybrid and electric vehicles, both for passenger and freight road transportation

Although the technologies in the portfolio are known today, the assumed evolution of their technical and economic characteristics presupposes that substantial industrial research and demonstration takes place before deployment at a wide scale.

The modelling also assumes that learning curves apply by technology, thus reflecting decreasing costs and increasing performances as a function of cumulative production. The steepness of the learning curve differs by technology, depending on their current stage of maturity.

The deployment of some technologies entails significant changes and investment in infrastructure, including the power transmission and distribution grid and the CO_2 transportation and storage facilities.

It is presupposed that regulatory arrangements take place without delay and generally that policy implementation entails no transaction costs. Such optimistic view about policy effectiveness is assumed also for all bottom-up policies, including the promotion of energy efficiency and the facilitation of RES projects. In such a context, investment in new technologies is not surrounded by uncertainty related to regulation and common infrastructure.

5.1 END-USE ENERGY EFFICIENCY

End-use energy efficiency improvement is known to be one of the most efficient ways of reducing emissions, as it leads to lower final energy consumption and hence lower energy supply. Engineering-based economic evaluations show that some of the energy efficiency improving measures imply negative total net costs for the energy consumer. However, there is no evidence in energy consumption statistics supporting the realisation of such negative-cost energy saving potential in a spontaneous way. Several factors explain this paradox, such as market and non market barriers (lack of information, uncertainty surrounding the performance of new technologies and non zero transactions costs) and the conditions influencing economic decision-making by individuals (limited availability of cash, risk aversion leading to high subjective discount rates). In addition, rebound effects tend to partly offset the demand-reducing effects of energy efficiency measures, as energy cost reduction allows for higher levels of energy use.

The PRIMES model combines a detailed representation of energy consuming technologies with modelling of the economic behaviour of consumers. Energy prices, carbon prices and other incentives influence consumer choices towards more advanced technologies, the penetration of which depends on the pace of capital turnover. In doing so, consumers perceive higher costs for advanced technologies than engineering-based estimations because of uncertainty, barriers and the imperfections mentioned above. Public policy promoting energy efficiency acts through price drivers but also through the removal of uncertainty and barriers for new technologies. Standards imposed by legislation on new technologies also influence the menu of technology choices. These interventions are modelled in PRIMES by sector and type of energy use and are assumed to intensify in the context of emission abating scenarios.

In the context of carbon pricing, the prospect of achieving carbon-neutral electricity generation is anticipated by final energy consumers and so they shift fuel mix in favour of electricity, for example by increasing the use of heat pumps and direct electric heating, hence substituting fossil fuels.

Simultaneously, consumers turn in favour of energy saving investment and advanced technologies which reduce specific energy consumption and lead to fossil fuel and electricity savings. For example, energy requirements for heating, lighting and specific electrical uses decrease while more electricity is used through heat pumps.

The EU Directives and regulations promoting energy efficiency are assumed to be fully implemented in the emission abating scenarios, notably legislation concerning energy services, buildings, electric appliances, lighting, motor drives, boilers, etc.

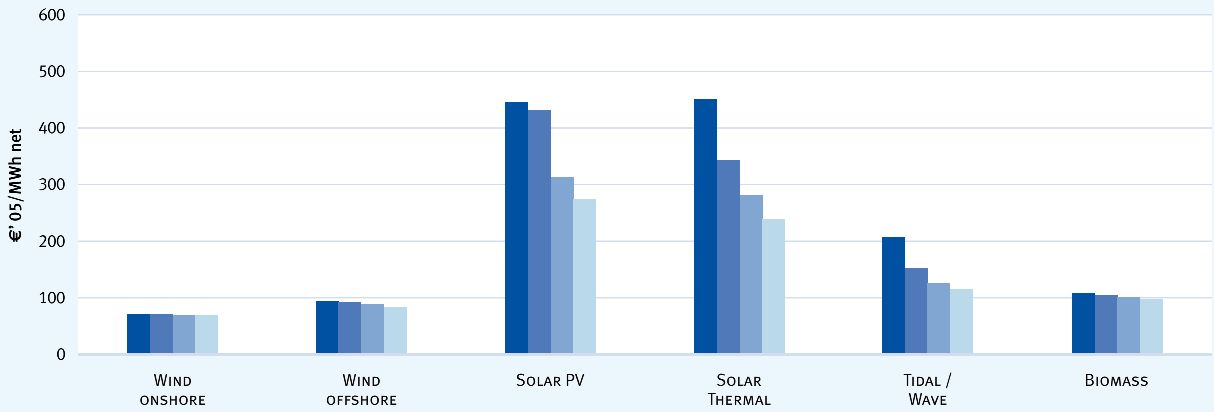
5.2 RENEWABLE ENERGY TECHNOLOGIES

The deployment of renewable energy technologies is one of the major options for reducing emissions in power generation and is also important for reducing fossil fuel consumption in end-uses. Although the RES technologies included in the analysis are commercially available today, considerable potential exists for improving their technical and economic performance. *Figure 11* shows the levelised unit costs of RES technologies assuming a discount rate of 9% in real terms. RES deployment over time, driven by carbon pricing and other incentives wherever applicable that induce scale effects on equipment production makes RES technologies more attractive for future investment.

Although primary energy renewable resources are abundant compared to energy demand, the realisable potential is strongly limited by many factors such as land availability, conflict with other land uses, environmental pressures other than atmospheric emissions and lack of infrastructure. Biomass and waste energy potential resources are also dependent on policies and measures in non-energy sectors, notably in agriculture and waste management. In economic terms, the supply of primary RES is thus fundamentally non-linear exhibiting strong cost increases as it approaches realisable potentials.

In the context of emission reduction scenarios, it is reasonable to consider that public policy takes all necessary measures aimed at increasing the realisable primary RES potential. Facilitation measures span a large variety of domains, including land use planning, infrastructure provision, new regulations and specific agricultural and waste management policies. Consequently, primary RES supply increases in volume and decreases in non-linear cost terms. Thus, in the context of carbon reduction scenarios, the modelling analysis assumes a left and downward shifting of the cost-supply curves for renewable resources.

Levelized Generation costs



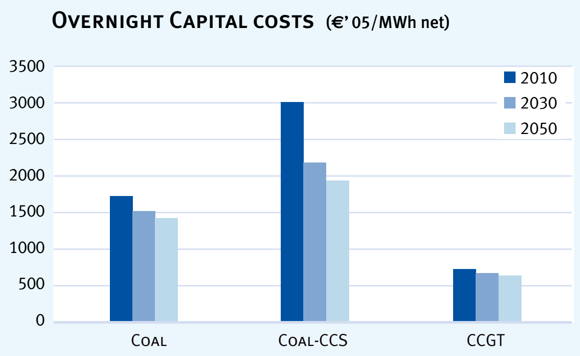
	Wind onshore	Wind offshore	Solar PV	Solar Thermal	Tidal / Wave	Biomass
2010	68	94	448	453	208	112
2020	68	93	435	343	158	108
2030	67	89	316	282	137	101
2050	66	84	273	240	121	97

Figure 11: *Key Assumptions about Costs of RES Technologies*

5.3 FOSSIL FUEL POWER TECHNOLOGIES AND CCS

The PRIMES model database represents 45 different fossil fuel power technologies, differentiated by fuel, scale, whether the application is for utilities or for industrial uses and according to the type of technology. The technical and economic characteristics assumed for the modelling were based on estimations by VGB PowerTech and from literature reviews.

Fossil fuel power technologies are expected to evolve in the future towards higher thermal efficiency and lower unit capital cost *(see Figure 12)*. The combined cycle gas turbine power technology already delivers high efficiency rates which are expected to further progress, albeit at a slower pace. Coal and lignite firing supercritical power plant technologies are assumed to become commercially mature after 2015, allowing for thermal efficiencies in excess of 45%. Significant progress is also assumed for Combined Heat and Power (CHP) power plants and for biomass/waste firing and co-firing, in particular regarding investment costs which are assumed to decrease following standardisation and large-scale production.



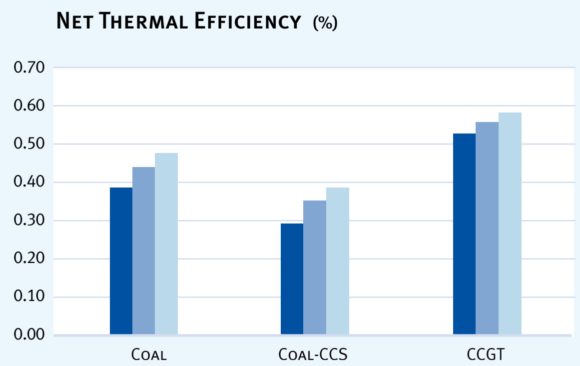


***Figure 12:** Change in Performance of Fossil Fuel Plant Technologies*

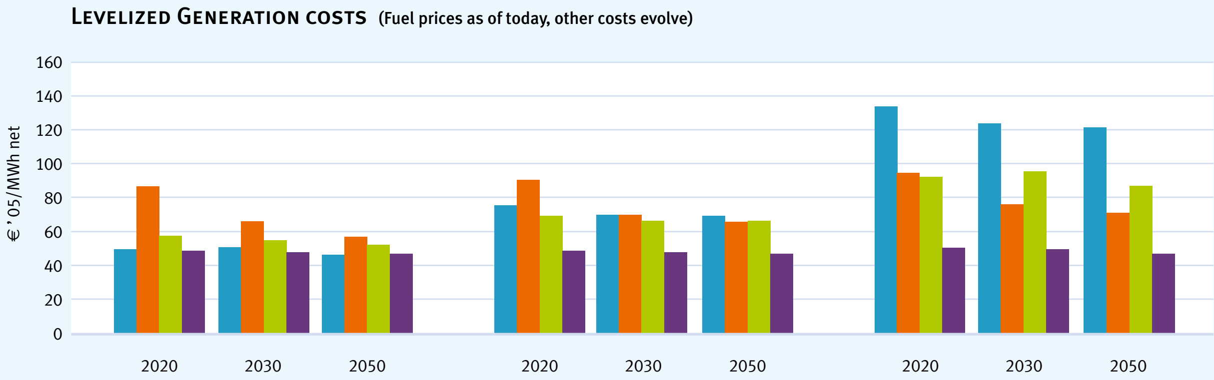
The generic carbon capture technologies, namely capturing at post-combustion stage, capturing at pre-combustion stage and the oxyfuel technology (which consists in burning with oxygen instead of air), are applicable to several power plant technologies including conventional steam turbine plants, supercritical steam turbine plants, fluidized bed combustion plants, integrated gasification combined cycle plants and gas turbine combined cycle plants.

The PRIMES model distinguishes between plants with carbon capture integrated from construction and plants that are retro-fitted with carbon capture equipment. The costs, the performance and the technical possibilities differ in these two cases.

Generally carbon capture plants have higher costs and lower thermal net energy efficiency than the corresponding plants without capture. The cost difference, which is significant today, is projected to decrease over time with the commercial development of mature capture technologies and their large-scale application.

Consequently, carbon capture plants exhibit a faster rate of technology improvement than the corresponding plants without capture. For the modelling it is assumed that only pilot CCS power plants operate in 2020, and that commercially mature plants start operating from 2025.

The CO_2 captured will be transported by pipelines and stored in underground facilities. The transportation and storage of CO_2 involves non-linear cost factors which increase with the total volume of CO_2 to be stored underground. The data used for the non-linear curves for CO_2 storage potential and marginal costs are based on information from various sources collected within the research project SAPIENTIA (FP6). In general, the unit cost of CO_2 transportation and storage ranges from €6/t CO_2 to in excess of €25/t CO_2 depending on the storage potential and its rate of utilisation.



	No Carbon Price			30 € ' 08/tCO2			100 € ' 08/tCO2		
Coal	49	47	43	76	69	64	134	121	113
Coal-CCS	82	65	58	86	69	61	96	77	69
CCGT	57	55	52	68	65	62	94	89	83
Nuclear	45	45	44	45	45	44	45	45	44

Figure 13: *Comparison of Fossil Fuel Technologies in Terms of Unit Costs of Generation*

Figure 13 compares in a stylized manner the unit costs of power generation from fossil fuels and nuclear with varying carbon prices. The technical and economic data assumed show that at a carbon price above €30(2008)/tCO_2 CCS is competitive vis-à-vis non-CCS fossil fuel plants in the period beyond 2030.

The data on potential storage areas and costs differ by country. Except for a few cases (e.g. Benelux), the modelling assumes no trade in transported CO_2 between EU countries, thus each member-state individually arrange its own CO_2 transportation and storage. It is assumed that adequate regulation is adopted enabling third party access and, consequently, total average cost pricing for the CO_2 transportation and storage infrastructure.

5.4 NUCLEAR ENERGY

The scenarios reflect the current policies of the EU Member-States regarding nuclear energy and do not assume any revision of that policy that might take place under strong emission reduction objectives. The scenarios thus adopt thus a conservative view about the future development of nuclear energy.

The nuclear phase-out in Belgium (decisions in late 2009 have been incorporated) and Germany are pursued to 2050, except in one scenario which serves as sensitivity analysis. Some countries, notably Austria, Cyprus, Denmark, Estonia, Greece, Ireland, Latvia, Luxembourg, Malta and Portugal, do not develop nuclear energy. Italy and Poland develop nuclear in accordance with recently announced plans. The extension of the lifetime of old nuclear plants, which is under consideration in some countries, is not considered as an option in the scenarios, except for Sweden.

Other than nuclear projects under construction or for which firm decisions have been taken, nuclear investment in the modelling analysis depends on economic conditions and emission reduction drivers. Only nuclear power technologies that are commercially developed today are considered in the analysis i.e. excluding new nuclear designs. The total costs of nuclear power differ by country, depending on the degree of maturity of the nuclear industry. Costs of new nuclear investment are not constant and are considered to increase non-linearly as the development of new nuclear sites come close to full nuclear potential, which is assumed specifically for each country. In contrast, nuclear investment on an existing site, replacing or extending old nuclear plants, is assumed to cost significantly less than developing new sites. The costs of nuclear decommissioning, as provided for in current legislation, were taken into account in the total capital costs. It was verified that nuclear waste treatment associated with further nuclear development to 2050 is manageable; the energy consumed in nuclear fuel treatment and waste management was accounted for in energy balances.

5.5 ADVANCED ELECTRICITY GRIDS AND SMART METERING

As shown in this report, the main energy system challenge will be threefold: increasing energy efficiency (including savings in electricity where possible), substituting fossil fuels by electricity (predominantly in transportation) and generating electricity with a high share of intermittent and decentralised carbon-free energy resources. The latter, in particular, will challenge the reliability and operational management of the electricity system.

The corresponding transformations will depend primarily on the ability of the transmission, distribution and metering system to provide adequate price signals to reduce demand, to smooth the load profile and to deliver electricity quality within specification from a considerably more complex generation system. Therefore, the success of the *Power Choices* scenario is closely related to the timeliness of investments in technologically advanced power grids, smart metering, control and communication systems.

In fact, the widespread deployment of energy efficient appliances, heating and cooling control systems, plug-in and electric vehicles require an intelligent, interactive infrastructure at the level of the distribution system, as well as electricity pricing policies based on time-of-use principles. Digital metering for real-time data acquisition, interoperability and communication systems are components of the required smart distribution system supporting electricity and energy savings. The extension and reinforcement of the distribution system, in order to handle the efficient charging of plug-in vehicles and to exploit their batteries for storage potential, if the widespread use of electricity in transportation is to be achieved while at the same time ensuring a smoothing-out of the total load profile.

The large-scale deployment of generation from renewable resources implies both connecting remote areas with high RES potential to the transmission grid and connecting very small scale and widely dispersed RES generation connected to the distribution grid. Revision of the currently predominant hierarchical grid structure and topology will be required, together with considerable investment in advanced technologies and grid extension. The new grid architecture will also imply integration between transmission and distribution system operation.

A prospective generation system with 20-30% intermittent renewables will require the development of a market for the provision of ancillary services, with significantly larger volume and variety than present systems. Thermal power plants will have to manage ramping burdens and will have to recover part of their costs from markets for ancillary services. Flexible thermal generation and the expansion of energy storage will be integral to this market.

The modelling analysis simulates the aforementioned changes in some detail, including decentralised RES, transmission grid investment and the provision of ancillary services. The analysis is clearly less detailed than short-term engineering-oriented power system models. However, it ensures full accounting for the additional costs and system operation implications. This includes the additional costs in distribution networks, smart metering and other smart devices needed to support the emerging decentralised power generation system.

5.6 PLUG-IN HYBRID AND ELECTRIC VEHICLES

Emissions reduction in transportation is particularly difficult if the current fuel-technology paradigm dominates in the future. Transport modal shifts require heavy investment and are very slow. Efficiency gains in internal combustion engines are possible to a certain extent but past experience shows the offsetting of these gains by higher energy consumption in delivering more comfort and power.

It has thus become evident that significant emissions reduction can only be achieved in transportation through shifting to a carbon free energy carrier. The candidates are renewables (biofuels), hydrogen and electricity, provided that their production has a low carbon footprint.

Electrified mobility is currently being given high priority in many countries. The choice of electricity as a potential carbon-free carrier in transportation is justified as follows:

- The required supply of biofuels presents limitations in relation to land availability for biomass uses. Although the potential contribution of biofuels can increase in the short term, it is unlikely biofuels can become the dominant energy carrier in transportation due to resource availability factors.
- Carbon-free hydrogen can be produced from a variety of primary energy sources, such as RES, nuclear and fossil fuels with CCS. The supply of Hydrogen to fuel vehicles will require a new transportation and distribution infrastructure, which will require considerable capital investment and poses several technical problems. The most important limitation is the high cost of fuel cells, which are required to decrease by a factor of 10 from today's levels in order to become competitive with other systems.
- Carbon-free electricity can be produced by the same primary energy sources used to produce hydrogen and can be used to fuel vehicles by extending the existing electricity infrastructure. Cost gains are more likely to take place for batteries and power trains used by plug-in vehicles than for fuel cells.

Electrification of road transportation incorporates all types of vehicles, including motorcycles, passenger cars, light utility vehicles, busses and trucks. Plug-in vehicles provide a proportion of their range using the battery-electric power train, which may be periodically charged through the power grid. The share of electricity relative to liquid fuel used in such vehicles will depend on the capacity of the batteries with regard to the normal travel range, the battery power density and the charge time.

The electrification roadmap assumed in the modelling analysis is built on the success of firstly plug-in hybrid vehicles becoming commercially available from 2015. Such vehicles allow for energy savings but in the early stages the share of electricity will remain low as battery ranges are small. Technological progress regarding battery cost and range is assumed to take place at a fast pace as mass-production increases. This rate of progress allows rapid penetration of plug-in vehicles between 2025 and 2035. In the longer term, pure electric vehicles and hybrids operating with a large electricity share will dominate new vehicle registrations as a consequence of which the vehicle stock is progressively electrified.

The milestones for such development are summarised as follows:
a) 2015: adaptation of existing vehicle designs,
b) 2020: 2nd generation power trains,
c) 2025-2030: mass production of dedicated vehicles.

Grid extension to enable the charging of vehicles is assumed to start by 2015. This will be followed by the widespread development of fast charging facilities after 2020 and the development of bi-directional and smart capabilities in the longer term.

The same process is assumed to take place also for heavy duty vehicles but staring later than for cars and progressing at a slower pace until 2050. Aviation and maritime transportation is assumed to continue using oil products. In rail transport it is assumed that all diesel trains will be replaced by electric ones.

Figure 14 shows the assumptions regarding the reduction in battery costs over time for the *Power Choices* scenario.

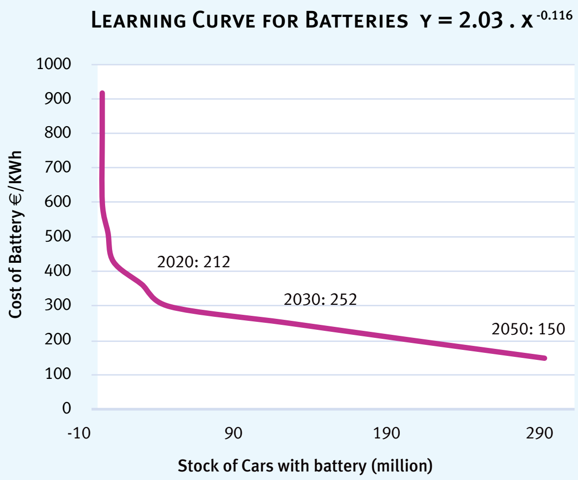


Figure 14: *Illustration of Technological Progress for Batteries*

6 THE POWER CHOICES SCENARIO

6.1 INTRODUCTION

The *Power Choices* scenario projects the EU27 energy system to 2050 with an emission pathway that shows 40% less CO_2 emissions in 2030 and 75% less CO_2 emissions in 2050, compared to 2005 levels. The scenario also shows the accomplishment of all targets included in the Climate and Energy policy package (the so-called 20-20-20 package). Detailed forecasts are quantified for each Member-State.

The analysis is based on the PRIMES energy model which simulates the economic and technical decisions of demand and supply side energy users, as well as their interaction through energy markets cleared by prices calculated by the model. The economic decisions are influenced by price signals that, either as shadow prices or as explicit prices (e.g. the ETS), adjust until the emission and other targets (e.g. RES target for 2020) are fully met. Bottom-up policies and technological developments influence the range of technical possibilities and the cost-supply curves of resources and technology deployments. These are taken into consideration by the energy users on the demand and supply sides in their economic and technical decisions. The decisions are dynamic (over time) and consider not only consumption but also investment, the purchasing of durable goods and energy savings expenditures.

The results of the projection for the *Power Choices* scenario are compared against the *Baseline 2009* scenario, which assumes that only policies implemented up to Spring 2009 apply, notably the ETS and energy efficiency measures, ignoring non-ETS and RES targets throughout the remaining projection period.

All the results presented below refer to EU27 as a whole, aggregating national figures.

6.2 IMPACT ON ENERGY REQUIREMENTS

In the context of the *Power Choices* scenario it is assumed that carbon emissions from energy use are included in prices[5].

Energy suppliers pay for getting emission allowances and pass through costs in consumer prices. Therefore, consumers bear a cost both for their direct CO_2 emissions and for energy purchased from suppliers. Higher costs induce substitutions towards less carbon emitting energy forms, but as substitutions cannot be perfect, the total cost of energy input increases. Energy savings are thus induced through various channels: in the short term by reducing useful energy where possible, depending on technical limitations and the degree of loss of utility associated with lower useful energy; in the longer term by shifting investment towards more energy efficient technologies and by undertaking expenditure that reduces unit energy consumption of existing technologies and buildings.

When selecting among technologies, decision makers associate costs to reflect uncertainty and the lack of information surrounding technologies that are not yet commercially mature. They also associate costs reflecting removal of non-market barriers, where applicable. Bottom-up policies are aimed at delivering higher energy efficiency by imposing standards on new appliances and buildings, undertaking information campaigns and removing uncertainty and non-market barriers. Consequently, the perceived costs of new technologies decrease, relative to business-as-usual, incentivising the adoption of new and advanced technologies.

The resulting lower energy demand per unit of activity is mostly beneficial for emission reduction, where economic, because of the effect of saving emissions both directly at the end-use level and indirectly at the energy supply level. Hence, improvements in energy efficiency are the first priority for emissions abatement.

The model simulations confirm that great potential exists in the EU under the assumptions of the *Power Choices* scenario for reducing energy demand per unit of activity by means of the widespread use of advanced technologies in all sectors.

5 After 2020, carbon prices apply on a uniform way for all sectors and countries. Between 2015 and 2020 only ETS sectors pay for carbon emissions, whilst consumers in non ETS sectors are not subject to direct emission constraints but rather reduce emissions as a result of bottom-up policies.

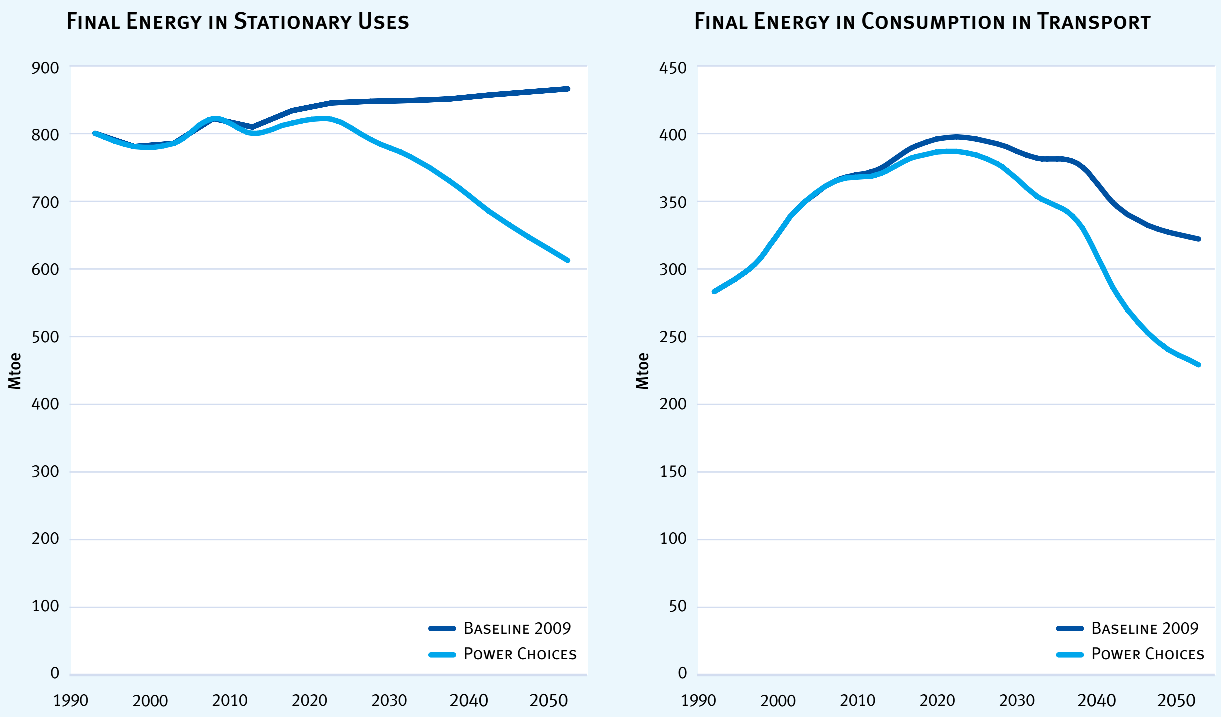


Figure 15: *Impact on Energy Demand in Stationary and Mobility Uses*

Final energy demand in stationary uses (industry, households, tertiary, agriculture) is found *(see Figure 15)* to be 10% lower in *Policy Choices* than in *Baseline 2009* in 2030 and 19% lower in 2050. Investments in more energy efficient equipment, direct energy savings and the increasing use of heat pumps explain the reductions in final energy demand in stationary uses.

Final energy demand in mobile uses (transportation) *(see Figure 15)* is found to be 7% lower in *Policy Choices* than in *Baseline 2009* in 2030, and 29% in 2050.

The electrification of road transportation and energy optimisation in the aviation and maritime sectors explain the reduction of final energy demand in mobile uses.

Table 4 shows the implicit energy savings enabled in *Power Choices* relative to the *Baseline 2009*. *Figure 16* shows total final energy consumption and the split by sector. It indicates the considerable reduction in the final energy demand trajectory within the *Power Choices* scenario, which comes from demand reductions in both the domestic (residential – tertiary) and the transportation sectors.

The stabilisation of final energy demand seen in the *Baseline 2009* case reflects a significant improvement in energy efficiency but is not sufficient to address the ambitious climate change objectives.

Energy efficiency legislation (as adopted to spring 2009), which is incorporated in the *Baseline 2009* scenario, limits growth in final energy demand: the projection shows stabilisation of energy consumption in stationary uses and stabilisation followed by a decrease in energy consumption for mobile uses. For the latter, the drivers in the *Baseline 2009* scenario are emission regulations for vehicles and the penetration of hybrid vehicles.

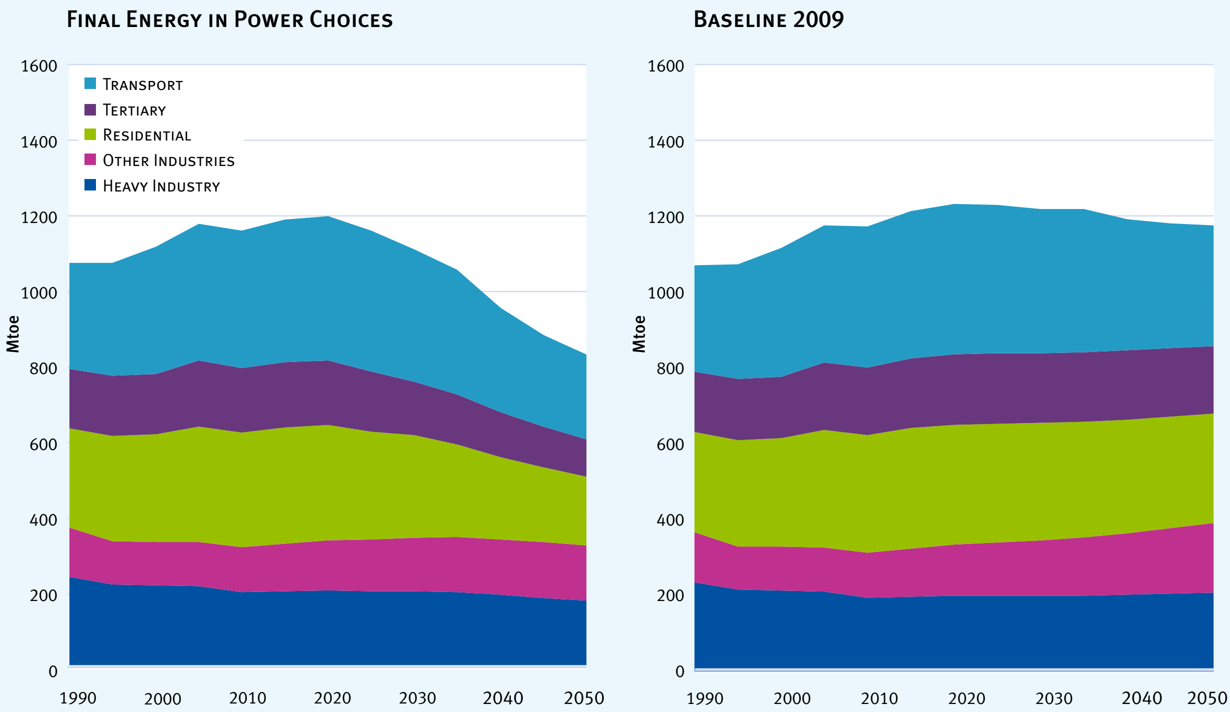


Figure 16: *Final Energy by Sector*

Final Energy Savings in %									
EU27 - PRIMES model	Power Choices vs Baseline 2009			Power Choices vs No Policy Case			Baseline 2009 vs No Policy Case		
	2020	2030	2050	2020	2030	2050	2020	2030	2050
INDUSTRY	0.4%	1.1%	19.1%	4.4%	8.1%	23.0%	4.0%	7.0%	4.8%
RESIDENTIAL	2.7%	11.8%	36.6%	10.1%	23.9%	49.7%	7.6%	13.7%	20.5%
SERVICES	7.9%	24.1%	46.6%	15.6%	32.6%	56.6%	8.3%	11.3%	18.7%
AGRICULTURE	4.5%	10.5%	29.9%	7.1%	14.9%	36.3%	2.7%	4.9%	9.2%
TRANSPORT	2.6%	7.4%	29.3%	12.2%	25.2%	53.5%	9.9%	19.2%	34.2%
TOTAL	2.7%	8.8%	31.3%	10.2%	21.4%	45.4%	7.7%	13.8%	20.4%

Table 4: *Summary of Changes in Final Energy Demand*

The *Power Choices* scenario includes all the energy efficiency measures incorporated in the *Baseline 2009* scenario and additional measures, notably for buildings, motor drives, boilers and electric appliances. The incremental effects on energy consumption of the additional measures are rather small. Nevertheless, compared to the *Baseline 2009* scenario, the *Power Choices* scenario *(see Table 4)* shows an impressive reduction of energy demand in stationary uses. This is due mainly to the effect of carbon prices which are high in this scenario and apply to all sectors. Thus, the decline in final energy demand in the *Power Choices* scenario is partly due to bottom up policies and measures, based on current legislation in place or in the pipeline, and partly driven by higher end-consumer prices. The results show that market forces alone are not able to deliver energy efficiency gains sufficient to meet emission reduction targets. The rather strong bottom-up policies, enabling efficiency gains over and above pure market trends, are also insufficient in terms of delivering ambitious emissions cuts. As assumed for the *Power Choices* scenario, carbon prices have also to be raised significantly. The reduction of total energy demand in mobile uses in the *Power Choices* scenario is a result of the growing electrification of transport, since electric vehicles consume significantly less final energy than conventional technology vehicles. Total final energy demand, adding up both stationary and mobile uses, declines in the *Power Choices* scenario reaching by 2050 a level that is significantly below historic levels.

The results provide more refined insights into energy efficiency gains by sector and by type of use of energy. The detailed model results allow quantification of energy intensity indi-cators by end-use category, as ratios between energy demand per type of use and as an activity variable relevant for each end-use category. A summary of the analysis by end-use category is shown in the appendix.

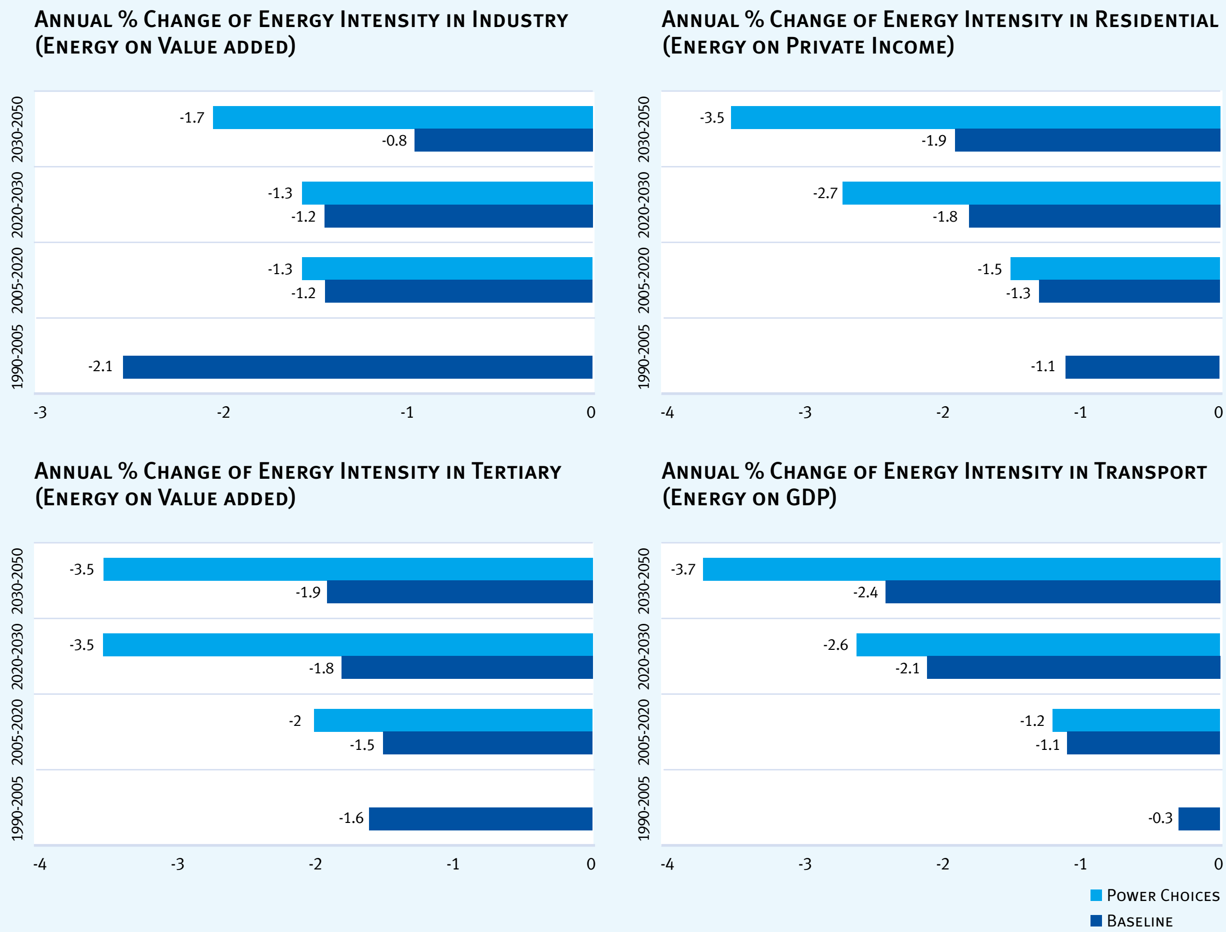


Figure 17: *Aggregate Energy Intensity Indicators*

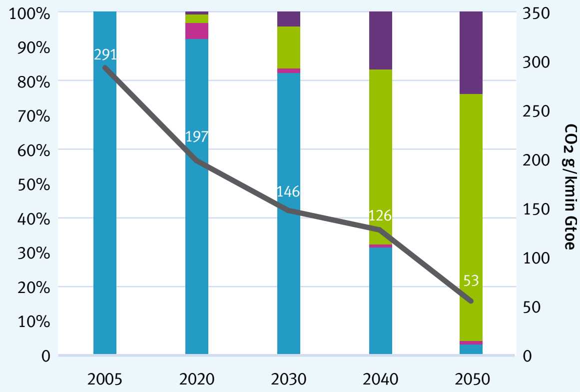
Those end-use categories which are electric, or can be electrified, show remarkably high energy efficiency improvements within the *Power Choices* scenario compared to the *Baseline 2009*. These improvements are partly related to substitution of fossil fuels by electricity, as for example in heating and transport uses. Heating and cooling demand in houses and buildings depends mainly on thermal integrity, which is shown to further improve under the assumptions of the *Power Choices* scenario. The results for the demand sectors show a greater decrease in final energy demand in houses and buildings compared to industry. Energy demand reduction in transportation, in the context of the *Power Choices* scenario, is related to the penetration of plug-in and electric vehicles, which present higher efficiencies than conventional technology vehicles. Through the travel optimisation and the use of more efficient aircraft, aviation exhibits noticeable efficiency gains in both scenarios.

In more aggregate terms, energy intensity indicators may be computed as ratios between final energy demand of a sector and an economic index of activity, such as value added or income. Projections of such indicators can be compared to historical values, contrary to engineering-oriented energy intensity indicators for which historic statistics are not always available. *Figure 17* provides a summary of projections for four sectors.

According to the statistical data, aggregate energy intensity in industry increased impressively, (by 2.1% per year on average), between 1990 and 2005, a time period marked by extensive restructuring in new member-states and a shift in industry away from energy intensive products. All scenarios show a slowdown in energy intensity improvement. The *Power Choices* scenario projects a doubling of energy intensity gains in industry, relative to the *Baseline 2009*, in the period between 2030 and 2050.

Aggregate energy intensity in the residential and tertiary sectors has decreased at average yearly rates of 1.1% and 1.6% respectively between 1990 and 2005. The policies included in both the *Baseline 2009* and the *Power Choices* scenarios drive increased acceleration of energy efficiency improvement in these sectors in the period up to 2020. Carbon prices and the additional policies included in the *Power Choices* scenario drive further acceleration of energy efficiency improvement, compared to the *Baseline 2009*, in the entire period beyond 2020.

Aggregate energy intensity in transportation improved very slowly in the historical period, as a result of mobility increasing faster than GDP and the poor performance of average vehicle energy efficiency (as technical progress was offset by higher comfort and power). Both the *Baseline 2009* and the *Power Choices* scenarios project considerably higher energy intensity gains in transportation going forward, owing to car regulations, hybrid developments and full electrification (the latter



Fuel Mix Cars	2030	2050
Oil	76%	7.5%
Biofuels	12.2%	2.1%
Electricity	11.1%	90.3%
Natural Gas	0.7%	0.1%

Electric
Plug-in hybrids
Hybrid vehicles
ICE vehicles
CO_2 intensity (right axis)

***Figure 18:** Shares in Passenger Vehicles Stock*

only in the *Power Choices* scenario). *Figure 18* shows a summary of structural changes in the vehicle fleet, as projected for the *Power Choices* scenario.

The energy efficiency improvements described above have been compared with the results from bottom-up studies. The comparison generally indicates that bottom-up studies show the existence of larger energy saving potential than that achieved in the *Power Choices* scenario; hence the energy saving potential is not exhausted in this scenario.

The decrease in total final energy in *Power Choices* compared to *Baseline 2009* is 2.8% in 2020, 9.1% in 2030 and 29.6% in 2050.

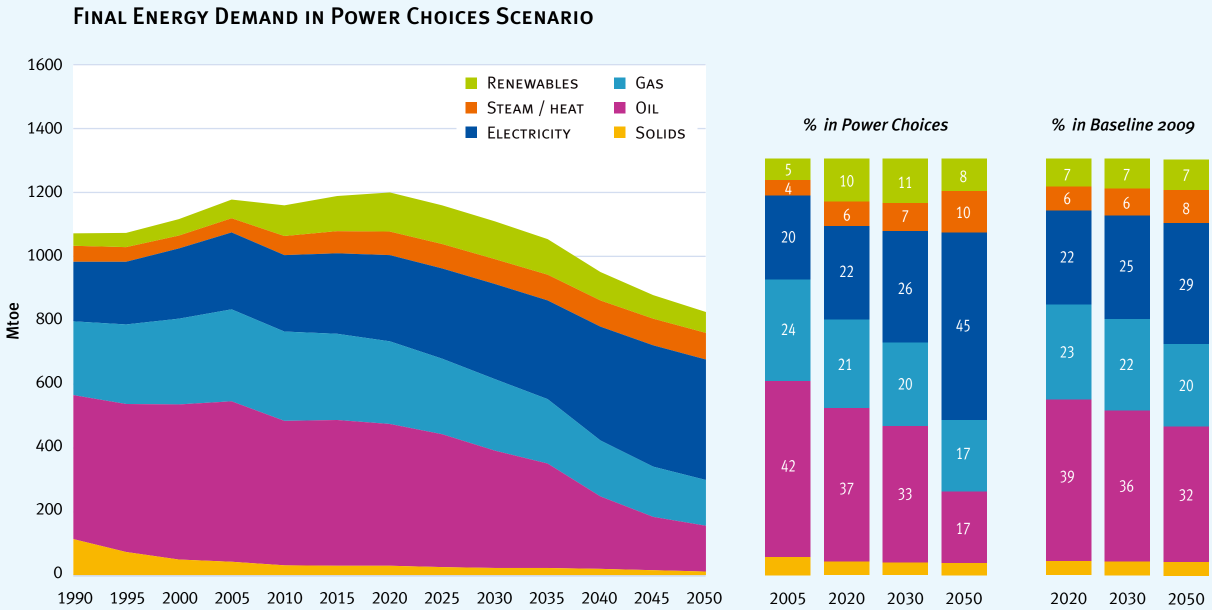


Figure 19: *Final Energy by Fuel*

The transformations simulated within the *Power Choices* scenario entail considerable changes in the fuel mix of final energy demand in the long term *(see Figure 19)*. Final energy demand has been dominated by hydrocarbons (mainly oil and gas); business-as-usual projections, such as the *Baseline 2009*, show continuation of such dominance until 2050. Oil products were in the past and will be in the future, according to business-as-usual projections, almost the exclusive fuel type for transportation. Under business-as-usual conditions, there is a strong tendency in favour of using gas and oil products in heating and processing applications for stationary end-uses. Without replacing the direct use of fossil fuels in downstream energy consumption, it will be impossible to meet ambitious carbon reductions even under extreme energy efficiency improvement assumptions.

Regarding the projections of demand for electricity, the *Power Choices* scenario involves lower demand than the *Baseline 2009* up to 2030 but higher demand after 2030. This is a result of combined effects: electricity demand in *Power Choices* is reduced in stationary uses and increased in transportation. This is shown in *Table 5*.

Electricity demand in Power Choices versus Baseline 2009 (differences)			
TWh	Stationary uses	Mobile uses	Total
2020	-168	47	-121
2030	-436	330	-106
2050	-1 156	1 521	364

Table 5: *Impact on Electriciy Demand*

Growing electrification of end-user stationary applications is an important trend which was observed in the past and is projected to continue in the future, even under business-as-usual conditions. Welfare and comfort improvement drive an increasing use of a multitude of electric appliances by consumers. Automation and IT technologies, enabling higher productivity, also drive increasing use of electric devices in the services and industrial sectors. In thermal uses, such as heating and cooling, both demand for energy services and electricity use increase, as progress in heat pump technologies allows for the achievement of useful thermal requirements more efficiently.

As the CO_2 emission reduction is very ambitious in the context of the *Power Choices* scenario and electricity becomes progressively a carbon neutral energy carrier, substitution of fossil fuels by electricity gradually takes place, both in transportation and in heating applications. The process is boosted by the assumed deployment of facilitating policies, such as R&D (e.g. in heat pumps, batteries and electric power trains), the promotion of new technologies and new infrastructure for grids and metering. Under the *Power Choices* scenario, electricity progressively becomes the dominant energy carrier both in stationary and mobile uses, displacing the direct use of fossil fuels and thus helping in the decarbonisation of society. As explained above, the substitution process takes place together with impressive energy efficiency improvement leading to massive energy and electricity savings where possible and especially in stationary energy uses.

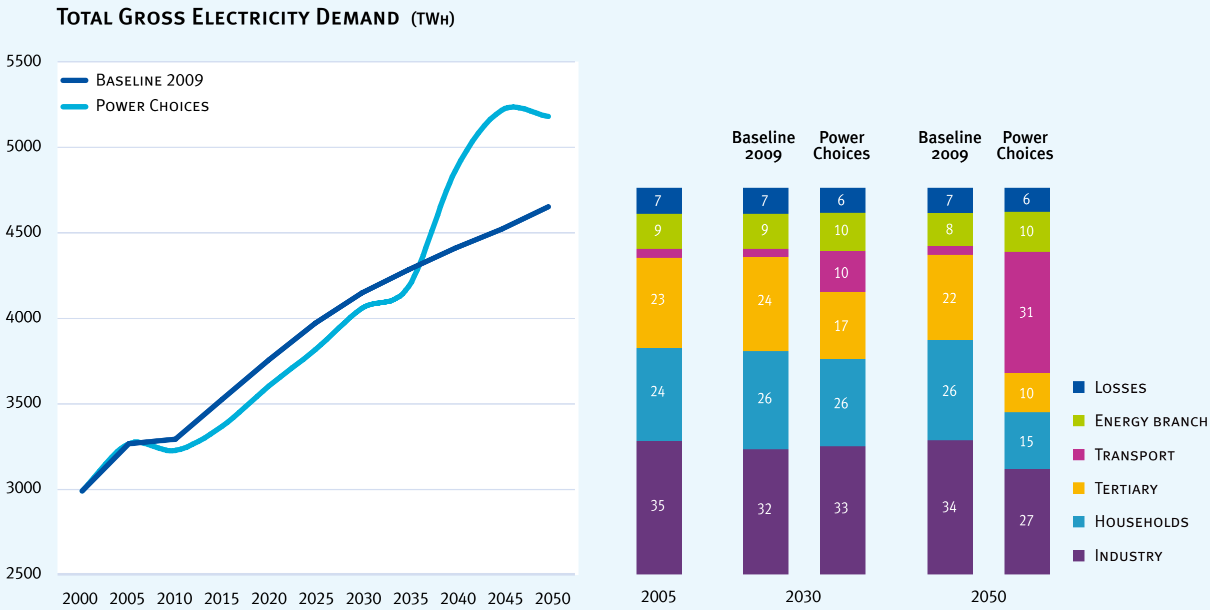


***Figure 20:** Impact on Total Electricity Requirements*

Electricity accounted for 20% of total final energy demand in 2005. Business-as-usual projections, such as the *Baseline 2009*, show an increase of electricity's share up to 28-29% of total final energy demand by 2050. Under these assumptions, oil products will still meet at least one third of total final energy in 2050 and the share of gas will stay rather stable at roughly 20% throughout the projection period.

In the *Power Choices* scenario electricity is projected to gain a share of 26.5% in total final energy demand, which grows up to 45% by 2050. The bulk of incremental electricity consumption takes place in transportation, as 80-90% of road transport becomes electrified by 2050.

Electricity penetration in end-uses mainly displaces oil products, as the major substitutions take place in the transport sector. Natural gas preserves its share in the Power Choices scenario, except for a small decline towards the end of the projection period. Direct uses of renewables in stationary applications, such as solar heaters, geothermal energy of low enthalpy and conventional biomass for heating and other uses, increase in this scenario, significantly more than in the business-as-usual cases. The amount of biofuels used in transportation increases in the *Power Choices* scenario as part of changes required to meet the 20-20-20 policy package by 2020. The projection shows continuation of the use of biofuels in transportation beyond 2020, but gradually it also shows the displacement of biofuels by electricity in the long term. This explains the decline in the share of direct renewables in total final energy as shown by the projection for the time period after 2030.

Electricity's share increases in stationary energy uses but in volume terms electricity consumption decreases as energy efficiency improvements offset the effects of substitution; in other words electricity savings in stationary uses are larger than additional electricity growth from substituting for fossil fuels. In the time period to 2020, energy and electricity savings constitute the predominant trend leading to a decrease in total electricity demand within the *Power Choices* scenario compared to the *Baseline 2009*. This is reasonable since the scenario is designed to deliver the policy objectives set for 2020 by the EU. A similar trend, showing lower demand for electricity compared to the *Baseline 2009*, is shown for the time period between 2020 and 2030, despite the increasing penetration of electricity in transportation *(see Figure 20)*.

Beyond 2030, substitutions in favour of electricity dominate over electricity saving effects. The strong penetration of electricity in transportation, in the time period between 2030 and 2050, implies significant increase in electricity demand, which in cumulative terms is larger than electricity demand reduction from stationary uses. It is worth noting that electrification, progressing at a high rate in *Power Choices*, could lead to unsustainable development – making the pathway to a carbon-neutral power generation system significantly more difficult and expensive – if not accompanied by significant energy and electricity efficiency improvements in stationary energy uses, which should dominate over the effects of electrification through heat pumps and direct heating.

The structure of electricity sales by sector changes considerably in the *Power Choices* scenario compared to business-as-usual projections. Starting before 2030 and mainly in the longer term towards 2050, the share of residential and tertiary sectors in total electricity sales shrink progressively and the share of the transportation sector increases, attaining almost one third of total sales by 2050.

This large restructuring has consequences for the shape of the total power load. Electricity savings mostly occur in end-uses presenting high demand in peak and middle power load time, as in the case of consumption in the residential and services sectors. Electricity demand expansion will take place mainly in base load time, since the assumed development of smart metering and time-of-use tariffs will incentivise charging of plug-in and electric vehicles at off-peak hours. The model simulation shows that the yearly load factor of total electricity demand is likely to gradually increase and reach a level as high as 85% by 2050, which is significantly above the 68% level observed today, in contrast to the *Baseline 2009* which projects a slight reduction of the load factor in the future. The smoothing-out of the power load curve has beneficial effects on the economics of the power system, which operates with limited storage possibilities available.

It is remarkable that the *Power Choices* scenario projects total energy requirements of final consumers to be only 1.8% higher in 2020 than 2005, and 6% and 30% lower than 2005 by 2030 and 2050 respectively. The reduction in energy requirements, combined with the substitution of fossil fuels by electricity (which progressively becomes carbon neutral), induces impressive decarbonisation in final energy consumption: direct CO_2 emissions by final consumers are 64.1% lower in 2050 compared to 1990.

As shown in *Table 6*, the overall renewable share indicator (the percentage of renewables in total gross final demand) in the *Power Choices* scenario is equal to 20% in 2020, as required by the EU Directive and afterwards it increases substantially, despite the absence of a mandatory RES target in this scenario. The RES performance in the other scenarios is by far lower than the *Power Choices*.

The renewable heating and cooling (RES-H&C) indicator, as defined by the recent EU renewable energy Directive, measures gross final energy delivered by renewables for heating and cooling purposes. The value of this indicator increases from 10% in 2005 to 20% in 2020, due to the changes needed to meet the 20-20-20 policy targets. It further increases to 26.7% in 2050, despite the absence of binding RES targets in the *Power Choices* scenario beyond 2020. This performance is significantly higher than in business-as-usual projections which show a value of 18% for 2050 and is due to both the increasing direct use of renewables by final consumers and the increasing share of renewables in power generation, in the *Power Choices* scenario.

The renewable transport (RES-T) indicator is a measurement of gross final energy delivered by renewables for transportation uses. In business-as-usual projections the value of the RES-T does not exceed 10%, and depends on the extent of use of biofuels in gasoline and diesel blends. In the *Power Choices* scenario, where electricity penetrates transportation uses and simultaneously progressively displaces biofuels, the value of the RES-T indicator increases significantly reaching 53.6% in 2050 (21.4% in 2030) as a result of electricity itself being increasingly generated from renewables.

	2005	2020	2030	2050
Power Choices				
RES-H&C (%)	10.0	20.1	22.2	26.7
RES-E (%)	15.2	31.0	35.4	37.7
RES-T (%)	1.4	13.3	21.4	53.6
Overall RES share (%)	8.6	20.0	23.6	30.8
Baseline 2009				
RES-H&C (%)	10.0	14.4	16.8	18.9
RES-E (%)	15.2	25.8	31.7	32.8
RES-T (%)	1.4	7.4	9.3	10.1
Overall RES share (%)	8.6	14.8	18.4	20.7

Table 6: *Renewable Share Indicators*

6.3 IMPACT ON POWER SECTOR

6.3.1 INTRODUCTION

Aggressive carbon reduction in the EU power sector is a challenge, but according to the model simulations is feasible. The view taken in designing the *Power Choices* scenario is that all options for a carbon-neutral power sector will be available. The extent of deployment of each option depends on power system economics, given that each option has a certain potential and its use entails costs which increase when approaching that potential. The modelling considers non-linear cost-supply relationships for all options, including nuclear, CCS and renewable energy resources. The potentials and their costs are differentiated by country.

Regarding power system economics the modelling takes a long term perspective and performs least cost long term capacity expansion planning and a time-sequence of least cost unit commitment programmes. ETS carbon prices, varying at the EU level until CO_2 emissions by ETS sectors match available allowances, are considered as a true cost for power suppliers.

It is generally assumed that power sector agents and investors have a perfect knowledge about the escalation of carbon prices in the future, the evolution of technical and economic characteristics of power technologies and the cost-supply mappings for resources. The model simulates a well functioning market, ignoring distortions such as perpetual price mark-up margins. Power sector investment develops as required to match demand for electricity and deliver uninterrupted power of good quality; in turn, demand adjusts influenced by electricity prices, which are formed freely so as to recover total power system costs. It is assumed that no uncertainty surrounds market balancing and capacity planning.

It is also assumed that the EU Internal market for electricity and gas exploit interconnections in an economically optimal way[6]. The interconnector capacities, including the building of new interconnections (as known based on announced projects up to spring 2009), are assumed exogenously.

Although the reality is more likely to diverge from such ideal conditions, the possible distortions are ignored in the scenario building, since the aim is to illustrate the feasibility of a carbon-neutral road map and evaluate cost implications. The model results on costs should be considered as a minimum boundary of true costs, which may rise in reality as a result of uncertainty and market distortions.

The PRIMES model projects electricity prices going forward for each sector (industrial sectors, residential, tertiary, etc.). The model establishes an equilibrium between demand and supply at the level of the projected prices. The system load is derived from the load profiles of each consumer category as projected forward by the demand sub-models. Generation costs are calculated in detail, including: a) annuity payments for capital, determined by using a weighted average cost of capital; b) fixed operation & maintenance costs, and variable operating costs; d) fuel purchasing costs or fuel extraction costs increased by any applicable taxes; e) any other cost, as for example the cost of purchasing emission rights, etc. Long term marginal costs are associated with each class of load, depending on the load factor, by simulating the operation of a gross power pool which forms system marginal prices for a sample of load variations. Capital and operation costs of the transmission and distribution system are determined at an aggregate level per country, by distinguishing only between high voltage, medium voltage, and low voltage grids and interconnectors. Costs for grids depend in a non-linear way on the portion of supply delivered by intermittent sources and decentralised generation. A simple capacity credit approach is followed to determine the amount of thermal standby generation required for reliability purposes and for ancillary services, ignoring the stochasticity of intermittent resources and failures. The total recoverable budget for the transmission and distribution system is considered as a fixed cost. The model applies the Ramsey-Boiteux methodology for determining electricity tariffs per consumer type so as to reflect long term marginal costs and to recover all fixed costs seeking maximisation of social surplus. Subsidy payments (e.g. for RES) are recovered by raising consumer levies. Price mark-up factors are also considered to apply to tariffs to reflect market power conditions or regulatory interventions for pricing below total recoverable costs (this is necessary to calibrate prices against statistical data). Price mark-up factors are assumed to change over time, depending on country conditions, influenced by a trend towards convergence of tariffs across countries.

Future electricity trade flows among EU member-states and other non-EU countries are projected endogenously in the model. This projection was made only for the baseline scenario and it was kept unchanged in the other scenarios (except in cases involving changes in assumptions about nuclear energy). Future electricity trade is projected by simulating the operation of regional markets (British islands, Iberian Peninsula, Central and Eastern Europe, Scandinavia, Baltic and South East Europe). For each regional market, a capacity power planning and a time-sequence of unit commitment programmes are simulated; the regional system is solved as a whole, subject to the given capacities of interconnectors between countries and a DC-linearized transmission system operation.

6 *A DC-linearised optimal power flow and unit commitment problem is applied to each regional power system within the UCTE for projecting future imports and exports of electricity. The simulation takes into account the net transfer capacities of the interconnectors and their average resistance and reactance characteristics.*

6.3.2 DRIVERS OF POWER GENERATION RESTRUCTURING

In the context of the *Power Choices* scenario power generation restructures firstly to comply with the policy targets set by the EU for 2020 and secondly to get onto a pathway towards carbon neutrality by 2050.

The 2020 horizon is short-term for the power sector as power generation equipment is long-lasting and investment involves significant lead times. Demand for electricity is likely to increase more slowly than anticipated a few years ago, affected by the downturn in the economy and the deployment of energy efficiency policies. If a business-as-usual view prevailed, capacity expansion would slowdown, as significant new constructions, planned before the crisis, are ongoing and few of the Member-States are experiencing capacity shortages. In this context, new investment to 2020 is needed mainly for replacing obsolete plants and for remedying cases not complying with environmental regulations.

Moving towards the prospect of 20-20-20 policy implementation implies changes of plans for the period to 2020. The 20-20-20 policy has defined RES targets (20% of total gross final energy demand from RES) separately for each Member-State and has assigned responsibility to the Member-States for setting concrete policies addressing the RES obligation.

It is assumed that despite deployment of RES policies that differ by Member-State, flexibility will prevail in the EU allowing countries facing high marginal costs for meeting the national RES target to obtain RES credits from other countries facing lower marginal costs. It is assumed that the power generation sector receives benefits from developing generation from RES, which is measured in marginal terms by a variable, called RES-value, adjusted by the model until all the Member-States meet their national RES targets by 2020. Due to the assumed flexibility in exchanging RES certificates of origin in the EU, a single RES-value is obtained for the EU. The marginal benefits from RES do not entail money benefits but only costs associated with RES deployment.

The policy approach for the EU ETS has been different, since the emitters belonging to ETS sectors (which include power generation) will need to buy emission allowances at an EU-wide market with a continuously decreasing total volume of allowances.

By 2020 the available ETS emission allowances will be approximately 21% lower than emissions in 2005, and the allowances will continue to decrease by a constant factor beyond 2020, in accordance with the EU Directive in force. Banking of allowances and contribution from CDM credits, up to a certain small fraction, is possible. For the modelling, ETS carbon prices to 2030 are evaluated so as to match cumulative allowances (between 2008 and 2030) with the actual emissions of the ETS sector.

Evidently, carbon prices will increase from today's levels, driving restructuring investments away from carbon-intensive generation and, among others, favouring RES development. Beyond 2020 it is assumed that the ETS with auctioning extends in scope and covers all sectors and countries of the EU. However, mandatory targets for RES do not apply beyond 2020. RES deployment will be driven by carbon prices which will increase in order to deliver 75% lower CO_2 emissions in 2050 than in 1990.

It is assumed that public policies develop to facilitate access to RES potentials, including biomass and waste. This is modelled as shifts in the cost-supply curves of renewable resources, allowing exploitation of higher RES amounts at lower marginal costs than business-as-usual.

6.3.3 POWER SECTOR TRENDS TO 2020

Total fossil fuel power capacity operating in the EU in 2010 is 455 GW (net) and nuclear power capacity is 127 GW (net). Coal and lignite plants account for 42% of total fossil fuel capacity in 2010, natural gas combined cycle plants account for 26% and the rest are open cycle and peak load plants using gas and oil.

Forecasting trends to 2020 requires the inclusion of power plants that are under construction or under confirmed construction decisions. Such construction decisions are considered as irreversible and are identified in the model's database in detail.

According to this data, most of the power plants under construction or with confirmed construction decisions will use natural gas in gas-turbine combined cycle technology: 73 GW are expected to be commissioned by 2015. Few new coal plants are under construction at present, but there exist confirmed decisions to build 27 GW of coal and lignite plants with commissioning dates before 2020. The pilot coal/lignite CCS plants that received the green light for construction have a total capacity of 5.4 GW (net) and will operate before 2020. Small gas and oil plants that are under construction amount to 12 GW. In total, there is 117 GW (net) of new fossil fuel plant confirmed projects; this represents one fourth of current fossil fuel power capacity.

According to the model's database, 147 GW (net) of fossil fuel plants are expected to be decommissioned by 2020, of which 77 GW use coal / lignite, 5 GW are GTCC and 64 GW are open cycle and peak load plants using gas and oil. All coal/lignite plants under construction will replace plants to be decommissioned and no replacement decisions have been taken yet in respect of more than half of the coal plants to be decommissioned.

As the analysis has taken a conservative view concerning the life-extension of existing nuclear plants (except for Sweden) and it is assumed nuclear phase-out is pursued in Germany and Belgium. 27 GW (net) of nuclear capacity is expected to stop operation by 2020 and only 12 GW (net) of new nuclear plant projects are confirmed for commissioning before 2020.

As shown in *Table 7*, the total capacity of power plants using RES is, at present, 232 GW (28.5% of a total of 814 GW net), of which 24 GW use biomass/waste, 84 GW are wind mills, 107 GW are hydropower plants and 16 GW are solar and other RES plants. Power generation from non-dispatchable intermittent resources at present is close to 6% of total power generation. The estimation of total RES capacity under construction or under confirmed construction decisions is more uncertain than for thermal and nuclear plants. According to the model's database, 176 GW of new RES projects have been identified as confirmed projects for the time period to 2020 (15 GW biomass, 79 GW wind onshore, 35 GW wind offshore, 38 GW solar and 8 GW hydropower).

In summary, based on confirmed information from the market, coal and nuclear capacities present a declining trend in the current decade, gas firing power capacity tends to expand by developing GTCC technology and RES power plants show an impressive development pace.

The model takes the information on confirmed power plant projects as given and determines the additional investment that will be needed to balance demand under the policy and market conditions set by the 20-20-20 policy package. According to the model results for the *Power Choices* scenario, total investment in power capacities is 438.5 GW (net) for the time period 2010-2020. Investment in coal/lignite plants (48.5 GW) is not sufficient to replace all plants that are planned for decommissioning and so coal/lignite power capacity is projected to decline by 13% in 2020 relative to 2010. The expansion of fossil fuel power capacities is projected to take place mainly through gas-fired combined cycle plants: operating capacity increases in 2020 by 28% from 2010. Investment in smaller gas plants and oil plants (open cycle and peaking devices) is substantial during the same period, but in terms of total operating capacity there is a small decrease in 2020 compared to 2010. Planned and model-suggested investment in new nuclear capacity to be commissioned by 2020 is not sufficient to replace nuclear plants that will stop operation in the same period; hence total nuclear capacity in 2020 is 3.5 GW lower than 2010.

Driven by the RES and carbon targets included in the 20-20-20 policy package, the *Power Choices* scenario projects an impressive expansion of RES power capacities to 2020. RES power investment between 2010 and 2020 amounts to 257.6 GW and results in a more than a doubling of the total RES power installed in the EU in 2010. The bulk of that expansion is in wind power, both onshore and offshore. Solar PV deployment is also impressive. Biomass/waste firing power plants also develop and reach a capacity of 46.2 GW in 2020 (in pure biomass/waste plants i.e. not accounting for co-firing in coal/lignite plants), which is more than a doubling from 2010. The majority of the biomass/waste plants are cogeneration plants. Hydropower development is modest and limited to roughly a 10% increase in 2020 from 2010.

GW net	Observed	Projection	Market Data		Model results for Mitigation scenario	
	Capacity in 2005	Capacity in 2010	Decommissionings 2010-2020	Confirmed constructions 2010-2020	Capacity in 2020	Investment 2010-2020
Coal/lignite	195.7	191.9	76.9	32.0	167.3	48.5
Gas Turbine CC	74.1	117.4	5.4	73.2	150.8	82.1
Small gas plants	84.0	89.5	27.5	9.1	76.0	19.5
Oil	62.1	55.8	36.8	2.7	40.0	14.7
Nuclear	134.4	127.0	27.0	12.0	123.5	16.1
Biomass	17.5	24.1	2.3	15.4	46.2	31.0
Wind onshore	39.9	80.1	-	79.5	162.7	122.8
Wind offshore	0.7	4.3	-	35.0	53.1	52.4
Solar etc.	2.9	16.2	0.4	38.0	43.9	41.4
Hydro	104.5	107.3	0.2	7.7	114.3	10.0
TOTAL	**715.7**	**813.8**	**176.4**	**304.6**	**977.9**	**438.5**

***Table 7:** Summary of Power Capacity Trends to 2020*

	TWh net			Shares in %		
	2000	2010	2020	*2000*	*2010*	*2020*
Nuclear energy	**892**	**880**	**849**	***31.7***	***28.5***	***24.5***
Fossil Fuels	**1 503**	**1597**	**1 511**	***53.5***	***51.7***	***43.5***
Solids fired	870	786	707	*31.0*	*25.5*	*20.4*
Oil fired	158	62	63	*5.6*	*2.0*	*1.8*
Natural gas	449	722	704	*16.0*	*23.4*	*20.3*
Derived gasses	26	27	37	*0.9*	*0.9*	*1.1*
Renewable energy	**416**	**612**	**1 112**	***14.8***	***19.8***	***32.0***
Hydro (pumping excluded)	348	318	335	*12.4*	*10.3*	*9.7*
Wind on-shore	22	147	349	*0.8*	*4.8*	*10.1*
Wind off-shore	0	14	174	*0.0*	*0.5*	*5.0*
Solar	0	17	50	*0.0*	*0.5*	*1.4*
Other renewables (tidal etc.)	0	0	3	*0.0*	*0.0*	*0.1*
Geothermal heat	4	6	12	*0.2*	*0.2*	*0.3*
Biomass-waste fired	42	110	188	*1.5*	*3.5*	*5.4*
Total	2 812	3 090	3 473	*100*	*100*	*100*

Table 8: *Net Power Generation by Source in the Power Choices Scenario until 2020*

As shown in *Table 8*, power generation from non-dispatchable intermittent resources reaches 16% of total in 2020, a share which obviously poses challenges to reliable system operation. This explains the relatively high investment in flexible gas and oil units and drives investment in the grids and their control systems. Total peak load in 2020 is projected to reach 563 GW (9.5% up from 2010) but total installed capacity is projected to increase in 2020 by 20% from 2010. The EU power system is experiencing some overcapacity today (39% in terms of a reserve power index which includes dispatchable units and some capacity credits[7] for intermittent resources); the projection for the *Power Choices* scenario shows that the reserve power index reaches 23% in 2020, which implies higher needs for inter-country balancing than today. The increase in generation by intermittent resources implies lower average load factors for thermal dispatchable plants: 48.8% in 2020, a drop from 54% in 2005.

High carbon prices drive the development of power and steam cogeneration. The *Power Choices* scenario projects the CHP indicator (percentage of electricity produced from CHP normalised according to the CHP directive) to attain a value of 19% in 2020, significantly above the 11.7% level of 2005. Cogeneration is projected to develop both for industrial and district heating uses, mainly through gas and biomass plants.

The *Power Choices* scenario projects a considerable restructuring of power generation to 2020. According to the model calculations RES power generation will have to develop and reach a share of almost one third in total power generation by 2020 in order to meet the 2020 targets in the most economic way. RES develops mainly to the detriment of coal-fired generation, which drops by 10% in 2020 compared to 2010. Gas-based and oil-based generation in 2020 remain close to their levels in 2010. Total power from RES in 2020 exceeds production from nuclear and also exceeds coal generation. Wind generation increases by a factor of 3.2 in 2020 from 2010 and solar increases by a factor of 3. Biomass is also used in co-firing and thus biomass-fired generation increase by 70% in 2020, relative to 2010.

The carbon intensity of power generation reduces by 25% in 2020 compared to 2010. Considerable benefits are also obtained for other pollutants, mainly for SO_2 and particulate matter (PM), which reduce by more than 20% in 2020 from 2010.

7 The capacity credit from intermittent re-sources is assumed to decrease as total intermittent capacity as percentage of total installed capacity increases, but to increase with higher geographical dispersion of intermittent resources (the latter effect is however applicable in only a few EU countries).

€'05/MWh	Power Choices vs Baseline 2009
Capital and O&M	4.4
Fuel and variable costs	-2.2
Grid tariff	1.1
Tax and Auction	-0.8
Gross Sales margin	0.2
Avg. total cost	2.5
Avg. Pre-Tax Price	2.6

Table 9: *Differences in Unit Costs and Prices of Electricity for 2020*

Emission allowances are purchased at auctions in both the *Baseline 2009* and the *Power Choices* scenarios. As ETS carbon prices rise with a tightening cap, end-consumer electricity prices increase. This is firstly to recover auctioning payments and secondly to reflect additional supply costs. At a carbon price of €25(2008)/tCO_2, as estimated by the model for balancing the ETS in 2020, auctioning payments are €35 billion by 2020 in 2008 money terms, which is €5 billion below auctioning payments in the *Baseline 2009* scenario. Auctioning payments in 2020 correspond approximately to €9.5/MWh, which represents a 10% increase in average end-use electricity prices relative to 2010. A summary of the cost impacts by 2020 is shown in *Table 9*.

Power generation investments in the *Power Choices* case that contribute towards meeting the RES target and additional investments induced by carbon prices lead to a 21% increase in annual capital costs per MWh produced in 2020 relative to 2010. Grid costs also increase substantially in order to accommodate system operation with a high RES share: 35% up in 2020 from 2010 per MWh consumed. In general fuel costs increase in 2020, relative to 2010, driven by rising world energy prices. However, in the *Power Choices* scenario fuel costs are lower than in the *Baseline 2009* in 2020, since the former scenario involves restructuring away from fossil fuels. Summing up, the *Power Choices* scenario implies an increase of only 2% in average end-use electricity prices relative to the *Baseline 2009* scenario.

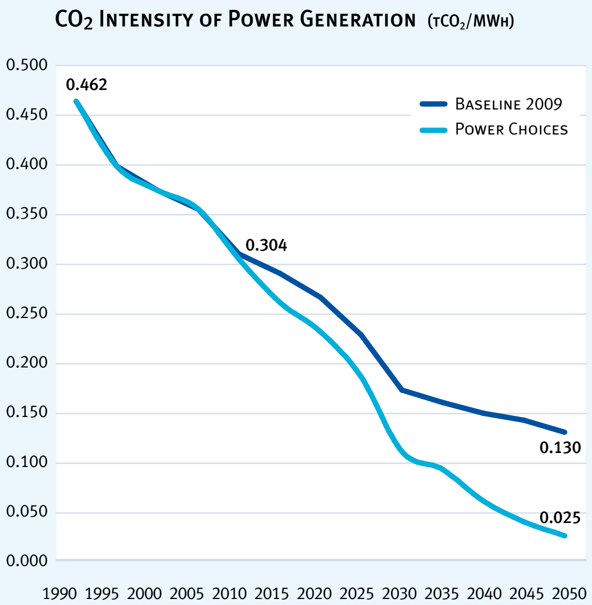
6.3.4 Power sector trends to 2030 and 2050

Carbon prices alone drive changes in the power sector after 2020, as no binding RES targets are considered beyond 2020. The carbon prices are determined at the energy system level in order to deliver emission reductions of 40% in 2030 and 75% in 2050 in the EU relative to 1990 levels. The model-based estimations suggest that carbon prices should rise to €52.1/tCO_2 (in 2008 money terms) in 2030 and €103.2/tCO_2 in 2050, significantly increased from €25/tCO_2 in 2020.

The scenario takes the view that technology and market conditions beyond 2020 will allow for the deployment of more low-carbon options than in the period to 2020:

- Additional renewables for power generation can be deployed as new possibilities will arise from grid expansions, the exploitation of offshore wind potential, energy related developments in agriculture and waste management for and the gradual decrease in capital costs for solar energy. As shown below, RES in the period after 2020 develops substantially more than the RES targets set for 2020, despite the absence of binding targets.
- Carbon capture and storage is assumed to become technically and commercially mature and so it will be possible to commission commercial CCS power plants from 2025.
- New nuclear plants can be built in countries that favour nuclear energy.
- Extensive development of small scale generation, including very small scale RES connected to the distribution grid, becomes possible, benefiting from technology progress and the smart grids.

The model simulation under the *Power Choices* assumptions displays a steady decrease in carbon intensity for power and steam generation, leading to almost carbon neutral generation by 2050. Carbon intensity in 2050 is more than five times less than in the *Baseline 2009* scenario. Even by 2030, power can be generated that emits less than one third CO_2 per MWh compared to 2010.



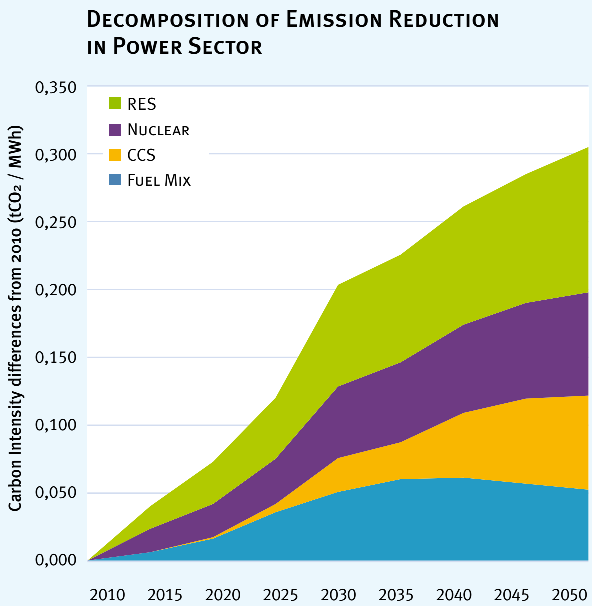


Figure 21: *Decarbonisation of Power Generation in Power Choices*

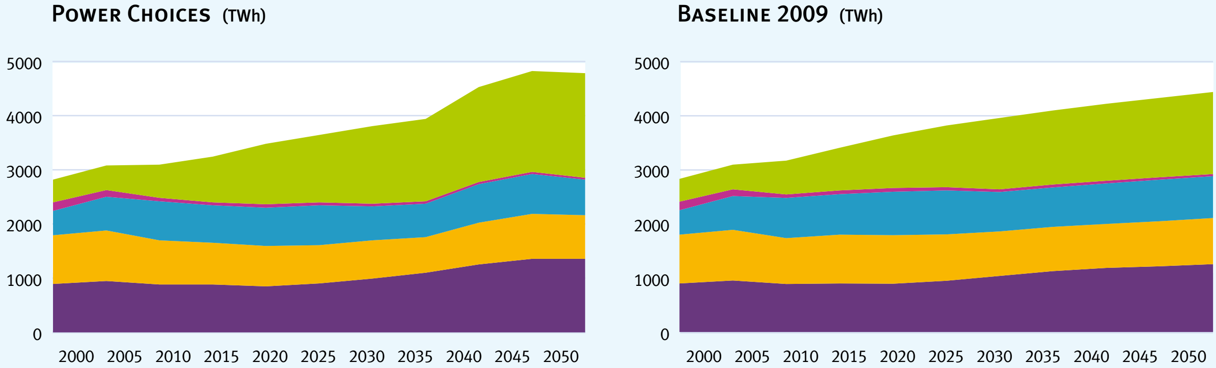
Figure 21 shows the carbon intensity of power generation as it steeply decreases in the *Power Choices* scenario and presents a decomposition of emission reductions by main mitigation option. It should be noted that the *Power Choices* scenario traces a trajectory which uses all mitigation options in power generation. Also of note is that the role of fuel-switching in the input mix to power generation is important in the short/medium term but saturates in the longer term, while CCS emerges as a mitigation option of growing importance.

All four main options, notably RES, CCS, nuclear and fuel switching, are used in the Power Choices scenario to progressively reach a carbon-neutral power sector: 37% of the emission reductions in the power sector in 2030 (relative to 2010) is contributed by RES, 25% comes from nuclear energy, 27% from fuel switching (from solids to gas) and 12% from CCS; RES contributes 35% to emission reductions in the power sector in 2050 (relative to 2010), nuclear 24%, fuel switching 19% and CCS 22%.

Emission reductions in power generation also take place in the *Baseline 2009* scenario, which includes only the current ETS legislation. In this scenario, emissions in 2050 are five times higher than in the *Power Choices*. Emission reductions in 2050 (relative to 2010) come mainly from fuel switching (33%) and RES (32%), followed by nuclear (27%), but with much less from the CCS (8.5%).

Fuel switching away from solids and oil and in favour of RES (biomass) and gas explain emission reductions in steam production: for industrial and district heating boilers the carbon intensity in the *Power Choices* scenario drops by 20% in 2050 compared to 2010. Cogeneration's share in power generation almost doubles in the *Power Choices* scenario by 2020, relative to 2010 levels. It approaches 20% in 2030. Cogeneration penetration, however, slows down after 2030 because, although CHP allows for a significant improvement in the overall thermal efficiency, CHP cannot deliver a fully decarbonised output. According to the modelling assumptions, CCS is excluded for small and medium CHP applications (which usually are of a scale adequate for supplying industrial steam and heating) as this would entail very high costs due to scale and geographic limitations.

Net thermal efficiency (on average over all fossil fuel plants) is lower in the *Power Choices* scenario than in the *Baseline 2009* scenario because of the higher deployment of CCS. This uses part of gross power generated to capture the emissions of CO_2. Consequently, the average net thermal efficiency does not exceed 40% throughout the projection period.



%	2005	2020	2030	2050	2020	2030	2050
		Power Choices			Baseline 2009		
RES	14.8	32.0	37.7	40.4	26.7	33.3	34.2
Oil	5.6	1.8	1.2	0.7	1.9	1.2	0.9
Gas	16.0	20.3	16.5	13.6	22.2	18.5	17.3
Solids	31.9	21.4	18.5	16.9	24.7	20.8	19.3
Nuclear	31.7	24.5	26.1	28.4	24.5	26.2	28.3

Figure 22: *Summary of Power Generation Structure*

In the *Power Choices* scenario, power generation *(see Figure 22)* from solid fuels declines by 1.2% per year in the period 2005-2035; it increases after 2035 driven by the application of CCS technology but despite this re-emergence, the projection shows that solid-fuel based generation is likely to be 12% lower in 2050 than its level in 2005.

The utilisation rates (load factor) of old solid fuel plants and those built without CCS decline progressively to low levels, contrary to solid fuel plants with CCS which operate at high utilisation rates. Lignite-based generation declines less than coal-based generation. In the absence of high carbon prices power generation from solids would increase steadily throughout the projection period.

Natural gas-based generation in the *Power Choices* scenario increases by 15% in 2020 relative to 2005, but remains roughly stable after 2020. The short-term increase in gas-based generation is partly due to the massive investment in GTCC plants that has already been decided and partly due to the effect of carbon prices, which act to favour gas in power generation as CCS is not commercial before 2020. The projected stagnation in gas-based generation development in the longer term is due to relative costs: CCS coal plants become commercial and gas plants with CCS are less competitive than solid fuel plants with CCS.

Investment in gas-based plants *(see Figure 23)*, however, continues to increase after 2020 because, in the context of the *Power Choices* scenario, gas-based generation plays an important role in the provision of balancing and back-up services which are needed to manage the increasing power generation from intermittent resources. Consequently, gas-firing power capacity increases faster than gas-based generation and therefore gas plant utilisation rates decline.

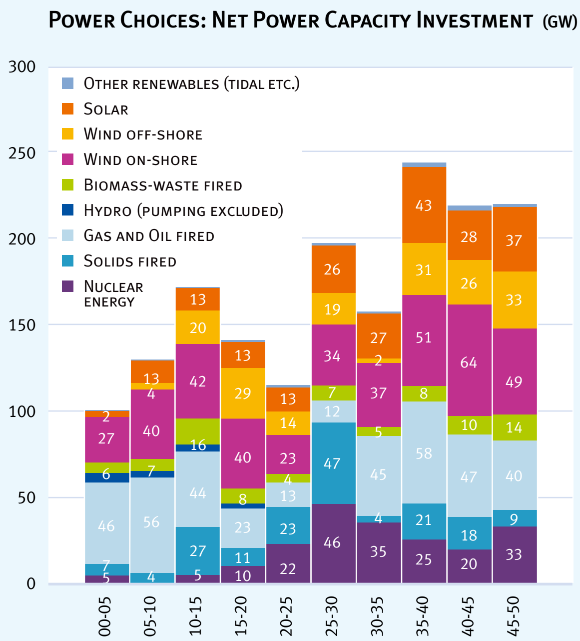


Figure 23: *Power Generation Investment in Power Choices*

Power generation from oil products declines substantially in all scenarios, a trend seen already in the short term, and thus oil plants are used progressively for specific purposes, such as in remote areas, in non-interconnected islands and for peak load following or back-up requirements. Oil products are also used for power generation (and CHP) in some industrial applications, notably in refineries, which however show a declining trend in terms of activity as oil used in transportation is strongly substituted by electricity in the *Power Choices* scenario.

In the context of the *Power Choices* scenario nuclear power increases and produces 42% more power in 2050 than in 2005. Despite this increase, the share of nuclear in 2050 is below its share in 2005. An increase in nuclear generation is also projected under the assumptions of the *Baseline 2009* scenario, but the increase in 2050 relative to 2005 is only 30%.

Power generation from renewable energy sources exhibits a spectacular development in the *Power Choices* scenario: RES sources produce 4.2 times more electricity in 2050 than they produced in 2005. There is a threefold increase in RES power by 2030, compared to 2005. RES power in *Power Choices* increase by 28% in 2050 compared to the *Baseline 2009* scenario. The drivers are the ETS carbon prices and the dynamic technology learning features of RES technologies.

Total power generation investment *(see Table 10)* between 2011 and 2050 amounts to 1460 GW in the *Power Choices* scenario, 625 GW of which are commissioned between 2011 and 2030 and 835 GW after 2030. For the time period between 2011 and 2050, the *Power Choices* projection shows the commissioning of 821 GW of new renewable plants, 442 GW of new fossil fuels plants and of 197 GW of new nuclear plants.

In the context of the *Baseline 2009* scenario nuclear power investment is slightly lower than in the *Power Choices* scenario, but the differences are much larger for fossil fuels and RES: investment in RES power plants is 25% lower in the *Baseline 2009* compared to the *Power Choices* scenario and investment in fossil fuel power plants is 25% higher.

Total investment in CCS power plants amounts to 191 GW in the *Power Choices* scenario, for the period 2011-2030, significantly above the 61 GW projected in the *Baseline 2009* scenario. The bulk of CCS investments in the *Power Choices* scenario concern plants using solid fuels. Gas plants with CCS develop after 2030, but not all new gas plants are equipped with CCS. On the contrary, almost all solid fuel plants built after 2030 are equipped with CCS. A large additional capacity of CCS coal plants is projected to be commissioned between 2025 and 2035 in the *Power Choices* scenario. The technical and economic assumptions about the evolution of CCS technology are such that oxyfuel CCS technology becomes more competitive in the long term, followed by the pre-combustion capture technologies. Post-combustion capture is competitive only in the early stages of the CCS development. Average storage and transportation cost start from €10/tCO_2 in 2030 and rise to €20/tCO_2 on average between 2030 and 2050; the rise is due to the substantial increase in storage costs as the cost-supply curve for CO_2 storage is strongly non linear. Storage and transportation prices are assumed to be regulated and are defined as the levelised costs over a sufficient time scale; they are meant to recover the total costs of the facilities over the long term (the rate of return on capital is assumed to be regulated). The total cumulative amounts of CO_2 stored underground in the Power Choices scenario do not exceed 15% of the total known storage capacity potential today (according to TNO data).

The entire stock of nuclear plants that exist today (127 GW) are decommissioned by 2050 and the projected investment primarily serves to replace decommissioned units (especially between 2025 and 2035). The expansion of total operating nuclear capacity in the *Power Choices* scenario is rather moderate: the capacity in 2050 is 40 GW above its level in 2005.

GW net	2011-2030	2030-2050	Total	2011-2030	2030-2050	Total
	Power Choices : Capacity Expansion			Baseline 2009 : Capacity Expansion		
Nuclear	83.3	113.6	196.9	85.7	98.4	184.1
Solids w/o CCS	46.0	4.0	50.0	64.4	37.7	102.1
Solids with CCS	61.9	48.4	110.3	35.0	23.6	58.6
Gas/Oil w/o CCS	90.1	110.4	200.4	136.0	270.9	406.9
Gas/Oil with CCS	1.0	79.6	80.6	0.1	2.3	2.4
Hydro	12.2	5.1	17.3	12.0	5.3	17.4
Wind onshore	139.8	200.2	340.0	108.6	129.8	238.3
Wind offshore	82.0	91.8	173.8	79.0	60.4	139.5
Solar	65.0	134.3	199.3	61.1	90.7	151.7
Biomass	35.3	37.2	72.5	30.0	39.1	69.1
Tidal. Geothermal	6.6	10.9	17.6	6.0	6.0	12.0

Table 10: *Power Generation Investment*

Investment in RES power plants expands spectacularly in the *Power Choices* scenario following a pathway which can be summarised as follows:

- **Wind onshore:** a total investment of 340 GW in the period 2011-2050 (40% of total RES power plant investments) leading to an installed capacity in 2050 equal to 257 GW; this is 3.2 times higher than the capacity in 2010; the pace of wind onshore investment slows down after 2020, as specific RES targets do not apply, but accelerates significantly after 2030, driven by high carbon prices.

- **Wind offshore:** a total investment of 174 GW in the period 2011-2050 (21% of total RES power plant investments) leading to an installed capacity in 2050 equal to 125 GW; there is a massive deployment of investment after 2025 but it is also significant before 2025.

- **Solar electricity:** a total investment of 199 GW in the period 2011-2050 (25% of total RES power plant investments) which develops uniformly during the projection period; the operating capacity in 2050 is equal to 140 GW, of which 125 GW are photovoltaic systems and 15 GW use the concentrated solar thermal technology.

- **Biomass** and **waste energy:** a total investment in plants using biomass/waste amounts to 72.5 GW in the period 2011-2050 leading to an installed capacity in 2050 equal to 70 GW (2.9 times higher than its present level); biomass plants with CCS are considered as not possible in the present modelling exercise for technical reasons related to the fact that most of the biomass/waste plants are cogeneration plants of medium or small scale. In addition to pure biomass power applications, electricity from biomass is also develops strongly in co-firing applications in the *Power Choices* scenario: biomass is projected to represent 17% of total input to solid fuel plants in 2050.

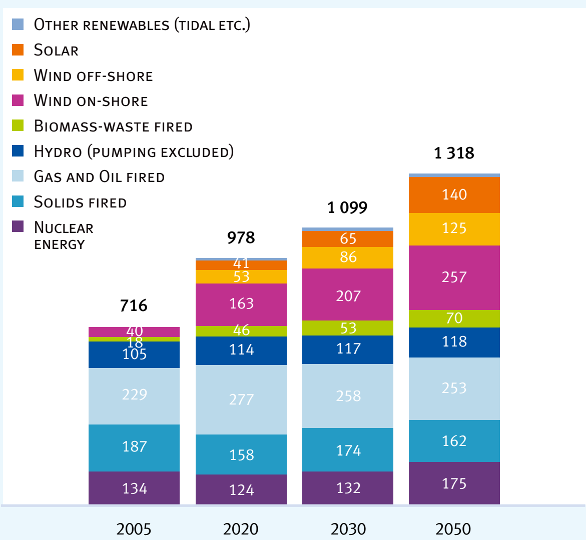
- **Tidal/wave** and **geothermal** energy: a total investment of 17.6 GW leading to a total installed capacity in 2050 equal to 13 GW for tidal/wave plants in 2050 and 4.6 GW for geothermal plants.

- **Hydropower:** a total investment of 17.3 GW in the period 2011-2050, mainly in run-of-river hydropower applications; total operating capacity in 2050 is equal to 118.2 GW (excluding pumping), of which 72.3 GW are lakes and 46 GW are run-of-river installations; the increase of total installed hydropower capacity in 2050 is only 10% compared to 2010. Pumped storage is projected to more than double in the period between 2010 and 2050.

Figure 24 shows the evolution of total installed capacity in the Power Choices scenario decomposed by type of energy. It shows also a decomposition of total installed capacity into dispatchable and intermittent generation and compares this evolution against total peak demand for power.

Throughout the projection period, it is ensured in all scenarios that the dispatchable part of total installed power capacity (thermal plants, nuclear, lakes and pumped storage) exceeds significantly the level of total peak load in each country as well as at the level of the EU regional electricity markets. Wind and solar share in total power generation attains a level of 25% in 2050 in the

Net Power Capacity (GW)



Net Power Capacity (GW)

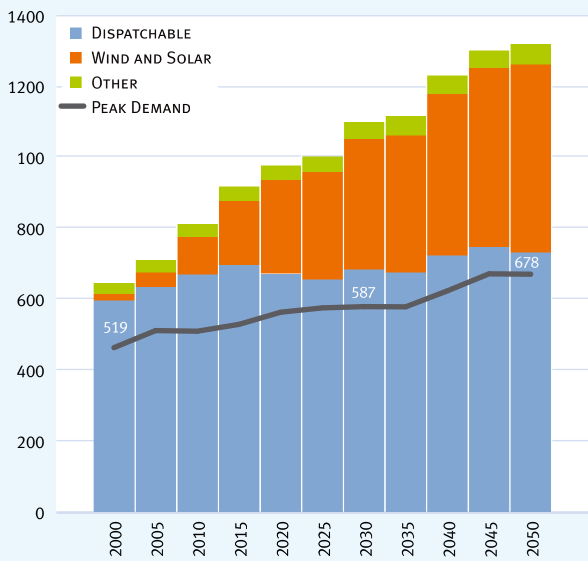


Figure 24: Operating Power Capacity in Power Choices

Power Choices scenario. In the extreme case of assuming zero capacity credit for intermittent resources, the nominal reserve margin decreases over time and reaches a level of 10% in 2050, which is below the 30% level observed at present. If, on the other hand, capacity credit for the intermittent resources is considered to be greater than zero, then the nominal reserve margin comes close to 20% by 2050, as shown in the *Power Choices* scenario.

The simulation of power dispatch shows that nuclear and CCS operate in base load and thus achieve high utilisation rates, compared to gas plants and non-CCS equipped thermal plants. These achieve low utilisation rates (close to 40%) and are used for load following. Pumped storage facilities and hydropower lakes serve peak loads.

Both the *Power Choices* and the *Baseline 2009* scenarios involve important changes over time in the structure of imports and exports of electricity within the EU. Nuclear energy development, which is different by country, is among the major drivers of change in electricity trade; the influence of fossil fuel generation on electricity trade weakens over time, because the scenarios involve high ETS carbon prices leading to a weakening of competitiveness of fossil fuel generation in all countries.

The results of the model-based projection of future electricity trade flows can be summarised as follows:
a) As a result of pursuing the nuclear phase-out, Belgium and Germany are projected to increase imports, despite the strong development of RES power in Germany; however, this growth of renewables in Germany prevents net imports from further increasing.
b) Netherlands is projected to increase exports, driven by new coal-based generation with CCS.
c) The development of nuclear energy in Italy allows for a significant reduction in imports.
d) Consequently, French electricity exports gradually decrease and are mainly addressed to the German market.
e) Benefitting from further nuclear construction, many new member-states, including Poland, the Czech Republic, Romania and Bulgaria, increase their electricity exports over time.
f) The British isle region remains a net importer but avoids a further increase in electricity imports because of the expansion of nuclear and renewable generation.
g) A similar trend is observed for the Iberian Peninsula region, which thanks to renewables and to nuclear development in Spain succeeds in stabilising net imports.

6.4 EMISSION IMPLICATIONS

The *Power Choices* scenario implies a reduction in EU27 GHG emissions in 2050 to a level which is 75% below the level of emissions in 1990. The reduction is 40% for 2030 and 20% for 2020. The emission reduction is delivered entirely domestically, without recourse to credits generated by international carbon offsets. By accessing such credits, the EU could achieve even higher GHG emission reductions, in line with the EU target of 80-95% emission reductions by 2050.

Emission reductions in the ETS sectors develop faster than in the non ETS sectors to 2030, because of the effort sharing arrangements provided for in the EU's Climate Action and Energy legislative package, which is assumed to be implemented in 2020. Beyond 2030, non ETS sectors reduce emissions faster than the ETS sectors because of the massive electrification of transportation. The energy-related CO_2 emissions are reduced as much as total GHG emissions. *See Table 11* for further details.

Reductions in process related CO_2 emissions are significantly lower than energy-related emissions because marginal costs are higher for process emissions and the possibility of applying CCS for capturing process emissions was ignored in the present modelling exercise. Non CO_2 GHGs[8] are reduced substantially, especially in the period beyond 2030, because they are driven by the high carbon prices included in the *Power Choices* scenario.

A basic assumption for the design of the *Power Choices* scenario is that all emission reduction options will be available and will be used according to their relative economic potential. It was also assumed that beyond the 2020 date of implementation of the 20-20-20 policy package, the *Power Choices* scenario traces a roadmap for emission reductions driven solely by carbon prices.

The decomposition of emission reductions *(see Figure 25)* by mitigation option is carried out by doing ex-post calculations using the model results. The decomposition is done for illustration purposes and is a result (not an assumption) of the modelling.

In Mt of CO_2 equivalent	1990	2005	2020	2030	2050
Total GHGs	5 559	5 195	4 455	3 318	1 390
Index 1990=100	*100*	*93*	*80*	*60*	*25*
ETS Emissions		2 404	1 954	1 394	717
Index 2005=100		*100*	*81*	*58*	*30*
non ETS Emissions		2 791	2 501	1 924	672
Index 2005=100		*100*	*90*	*69*	*24*
Energy CO_2 Emissions		3 947	3 305	2 438	1 063
Index 2005=100		*100*	*84*	*62*	*27*
Process CO_2 Emissions		304	306	301	197
Index 2005=100		*100*	*101*	*99*	*65*
Non CO_2 GHGs		944	844	579	129
Index 2005=100		*100*	*89*	*61*	*14*

Table 11: *GHG Emissions in Power Choices Scenario (EU27)*

8 The modelling exercise uses aggregate marginal abatement cost curves (by gas type and by country) for the non CO2 GHGs. The basic data, which cover the period until 2030, come from IIASA's GAIN model as available in early 2008. For the period beyond 2030, simple extrapolations were made by E3MLab.

The methodology of the decomposition is summarised as follows:

- If both the technology and the structure of the energy system were "frozen", then GDP growth would drive CO_2 emissions significantly upwards. The "frozen" emission trajectory is taken as the starting point for the evaluation of the amount of avoided emissions that a scenario carries out. Thus, the amount of emissions avoided by a scenario is the difference between incremental emissions from 2005 within the "frozen" trajectory and the amount actually emitted in the context of the scenario, such as the *Power Choices* one.

- The total amount of emissions avoided is further split by mitigation options, such as renewables, nuclear, CCS, changes in the fossil fuel mix (shifts towards less carbon intensive fossil fuels) and energy efficiency. The energy efficiency contribution is further decomposed in two components: the autonomous energy efficiency improvement which is attributed to pure market forces and the induced energy efficiency improvement which is associated with the policies, measures and technology changes that take place specifically in the emission reductions scenario.

- The improvement in energy technology performance is a dynamic process which is not only influenced by policy but also by market forces, which seek higher productivity. Therefore part of the energy efficiency improvement over time should be attributed to market forces; in economic literature this is often referred as "autonomous" progress.

- The contribution of the autonomous energy efficiency improvement is important, otherwise, in the absence of structural changes, the growth of emissions would closely follow GDP growth. The role of autonomous efficiency improvement is more important in the early stages of the process, as other emission reduction options need time to deploy.

The results of the decomposition are summarised as follows:

- The induced energy efficiency progress, which relates to policies and measures aimed at higher energy savings and to the introduction of more efficient end-use equipment, such as for example the electric cars, proved to be a considerable constituent of the emission reduction effort, as traced by the *Power Choices* scenario. If autonomous energy efficiency improvement is excluded from the decomposition, then the induced energy efficiency improvement accounts for almost one fourth of total emission reductions throughout the projection period; towards 2050 it shows an increase in terms of its percentage contribution, which is due to the massive electrification of transportation.

- The development of renewables plays a major role in emission reductions around 2020 because RES is one of the specific targets within the 20-20-20 policy package. RES represent 38% (excluding autonomous energy efficiency improvement) of total emission reductions in 2020. The contribution of RES reduces to one fourth of the total in 2030 and to one fifth of the total in 2050, because the *Power Choices* scenario does not include a specific RES target but allows RES to develop driven by carbon prices.

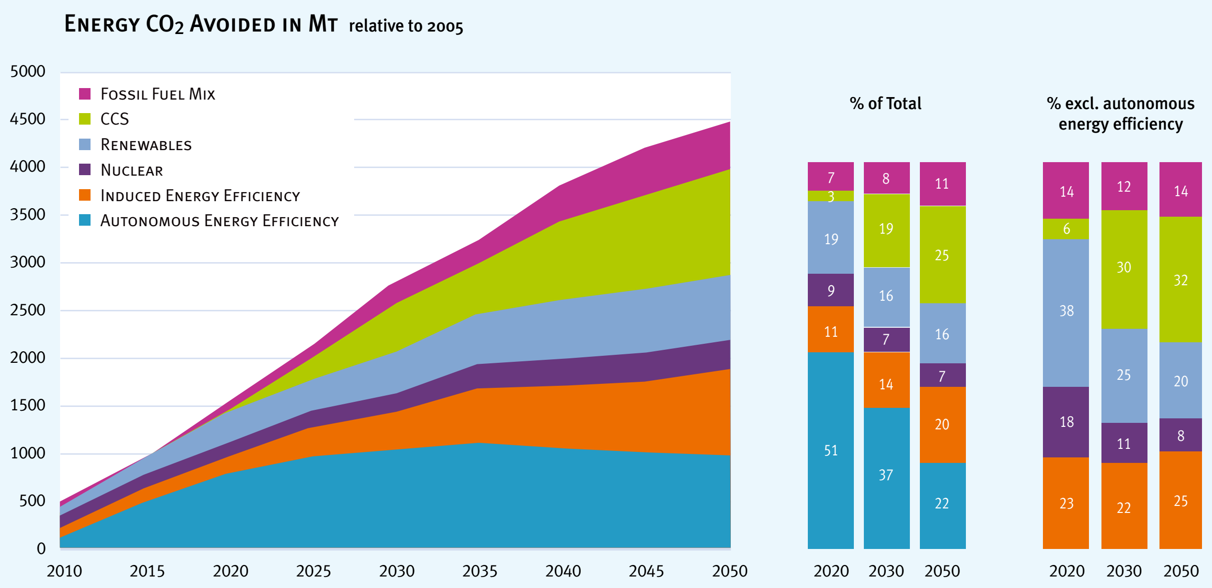


Figure 25: Decomposition of Emission Avoidance in Power Choices

- The contribution of nuclear energy (on average of the order of 10% of the total) to emission reductions is smaller than that of other mitigation options. Despite this apparently small contribution in emissions abatement, the *Power Choices* scenario includes a large nuclear development program with its focus primarily on replacing the stock of nuclear plants which are planned for decommissioning. Nuclear capacity expansion relative to 2005 is rather limited in the *Power Choices* scenario (30% above in 2050 from its level in 2005), firstly because the potential for developing new nuclear sites is considered to be rather limited for several reasons and secondly because the phase-out in Belgium and Germany is maintained.

- The contribution of CCS is 30% of the total (excluding the autonomous energy efficiency component) in 2030 and further increases to a level of 32% in 2050. Before 2030 the contribution of CCS is much smaller.

- Fuel switching, i.e. the shift in fossil fuel mix in favour of natural gas, contributes to the total emission reduction effort by a percentage varying between 12 and 14%.

Looking at emission reduction by sector, interesting conclusions can be drawn about the role of electricity in the achievement of the drastic emission cuts that are shown by the *Power Choices* scenario.

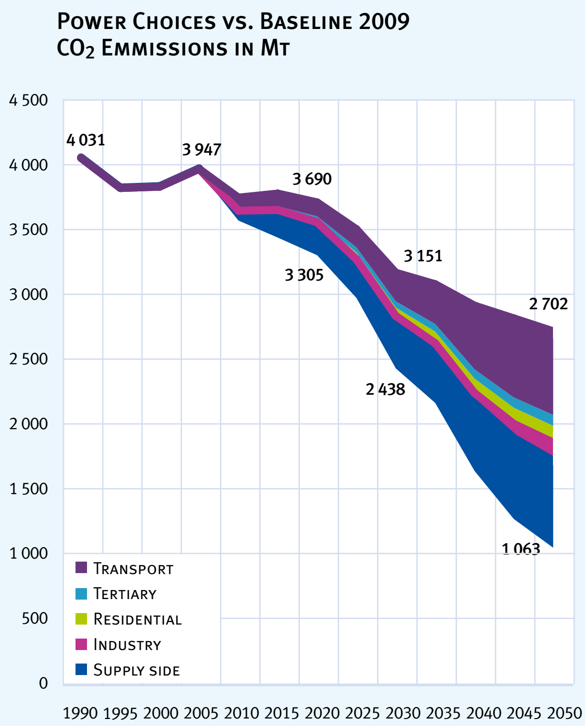


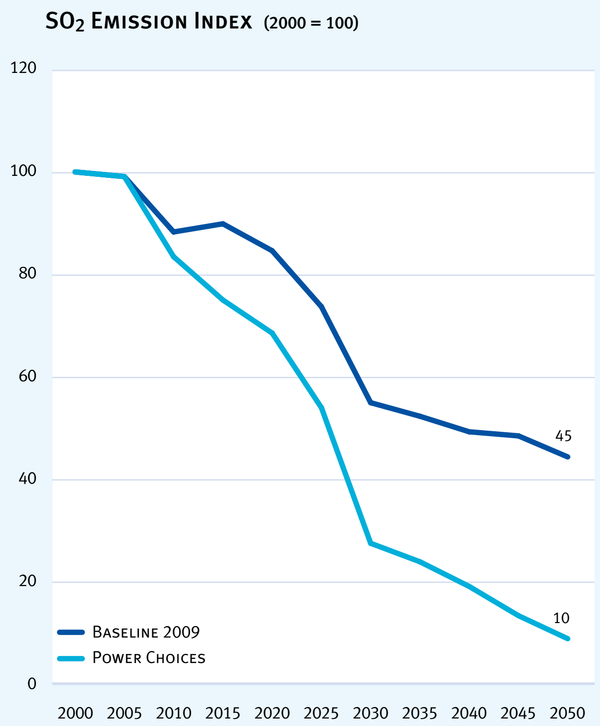
Figure 26: *Energy CO_2 Emissions by Sector*

It is noted that the *Baseline 2009* scenario includes policies directed towards delivering less CO_2 emissions, such as bottom-up energy efficiency improvement measures and the ETS system, which provides a reduction in emission allowances over time. However, it does not act directly on non-ETS emissions and does not involve substitution of fossil fuels by electricity in transport. Nonetheless, the reduction of emissions in the *Baseline 2009* scenario is significant in power/steam production and also in final demand sectors, including the transport sector, where emission reductions are solely effected by efficiency improvements.

The *Power Choices* scenario, which acts also on non-ETS sectors and involves electrification in the demand sectors, notably in transport, delivers significantly higher emission reductions than in the *Baseline 2009*. The additional emission reductions take place in power/steam generation, where it leads to an almost carbon neutral generation fleet, but also in all final demand sectors and especially in road transportation where the reduction in all direct emissions tends to zero thanks to electrification. By doing so the *Power Choices* scenario succeeds in overcoming the inelastic behaviour of the transport sector towards emission cuts. It is also notable that the *Power Choices* scenario succeeds in cutting more emissions in stationary energy uses than the *Baseline 2009* scenario because of electrification (e.g. heat pumps). The additional emission cuts in this sector are, however, small in magnitude because the dominant effect comes from energy savings, which are considerable.

Figure 26 shows step-by-step the structure of emission reductions by sector, in both the *Baseline 2009* and the *Power Choices* scenarios. It is obvious from the graphical analysis that the success of the *Power Choices* scenario compared to the *Baseline 2009* is due to the role of electricity which allows for emission cuts in final demand sectors significantly above those in the *Baseline 2009* case.

Besides reducing GHG emissions, the *Power Choices* scenario delivers large reductions in emissions responsible for acid rain and other local or regional damages. Emissions of SO_2 fall by 4.5 times compared to the *Baseline 2009*. The reduction in NO_x emissions is smaller but also impressive: for 2050 they fall by half the level of emissions in *Baseline 2009 (Figure 26)*. The ancillary environmental benefits for urban areas are also considerable, as transport is massively electrified in the *Power Choices* scenario. These benefits have not been quantified in the present modelling exercise.



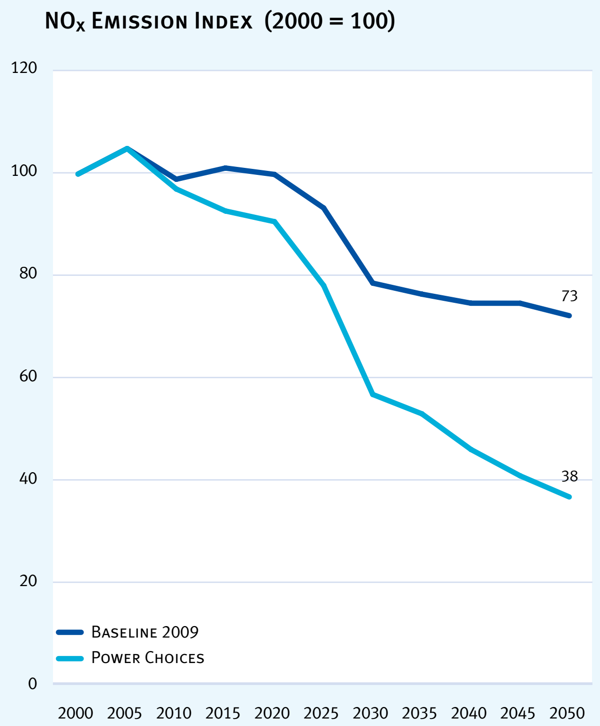


Figure 27: *Emission of Acid Rain Pollutants*

6.5 Import Dependency Implications

It is well known that the EU is concerned about growing dependence in the future on fossil fuel imports under business as usual conditions. The increase in dependency is not only due to growing energy demand but it is primarily related to the progressive exhaustion of indigenous fossil fuel reserves.

Figure 27 shows the model results for net imports of fossil fuels and the import dependency indicator.

The policies included in the *Baseline 2009* scenario, such as the ETS and the bottom-up energy efficiency measures, reduce demand and import dependence but do not succeed in curbing the growing trend of import dependency; they only succeed in limiting its increase to a level of 60%.

On the contrary, the *Power Choices* scenario results in a lowering of import dependency to a level of 57% by 2020 and also delivers a continuing decrease in import dependency reaching a level of 46% by 2050, which was last observed in the EU27 before 2000. This performance is due to the important energy efficiency improvements in the *Power Choices* scenario, which implies a decrease in total primary energy requirements, and to the strong substitution of oil by electricity in transport, combined with increasing power generation from domestic sources, such as renewables.

As a result of these changes, oil import requirements by 2050 are, in the *Power Choices* scenario, 52% below their level in 2005; this is a remarkable disengagement by the energy system from oil. For the whole period after 2010, the *Power Choices* scenario exhibits a steady decrease in net oil imports, which has important consequences also in terms of reducing oil import dependency.

Regarding natural gas, which plays an important role within the *Power Choices* scenario, the initial increase of 20% in net imports of gas by 2020, relative to 2005, is followed by a slight decrease in gas imports; thus net imports of gas in the *Power Choices* scenario in 2050 equal their level in 2005. Hence, the carbon reduction process in the *Power Choices* scenario is not accompanied by any increase in security of supply concerns related to gas imports.

It is clear from the above analysis, that both the energy efficiency improvements and the carbon reduction process included in the *Power Choices* scenario play a considerable role, together with oil substitution in transportation, in achieving a reversal of business-as-usual trends regarding the dependency of the EU on imported fossil fuels. This is an important additional benefit of the *Power Choices* pathway.

The same conclusion is drawn by looking at total cumulative net imports of fossil fuels for the period between 2005 and 2050. The *Power Choices* scenario implies roughly 20% lower requirements for all fossil fuels, relative to the *Baseline 2009*.

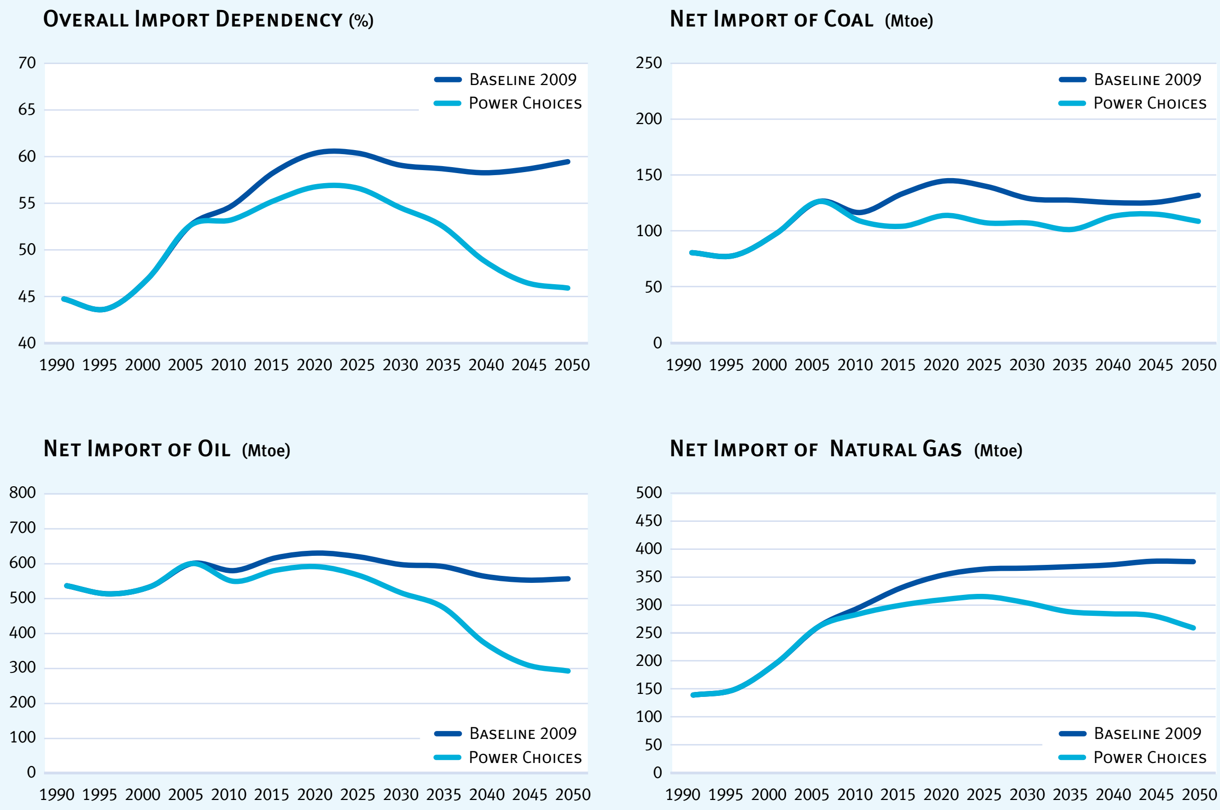


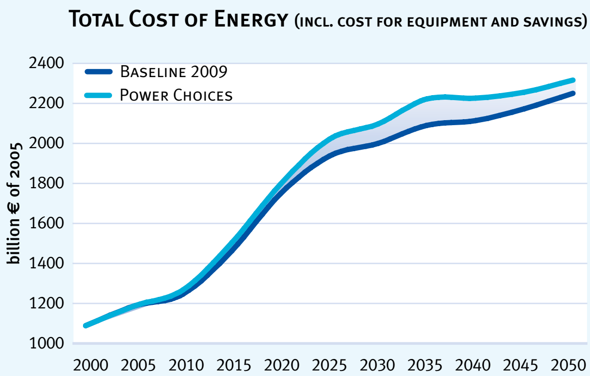
Figure 28: *Net Imports and Import Dependency*

6.6 COST AND INVESTMENT IMPLICATIONS

The extensive restructuring of the energy system implied by the *Power Choices* scenario entails not only additional costs for final energy consumers but also a considerable redistribution of cost elements, which is briefly discussed below:

Energy efficiency improvement incurs costs in purchasing new assets or in refurbishing old assets that have better energy performance, such as houses, buildings and industrial processing capital; it also implies higher capital spend on energy efficient electric and non-electric appliances and equipment in all sectors, including the plug-in and electric cars, lighting devices, home and entertainment appliances, boilers, motor drives, cooling and heating systems, etc. Even if mass production of advanced technology equipment reduces their prices, the capital cost in annuity terms per unit of useful energy output is expected to be higher than for conventional technology. Additional capital costs arise indirectly also when consumers replace old assets and equipment before the end of their technical life time, a behaviour which is also included to some extent in the *Power Choices* scenario. Consequently, the scenario entails a general rise in capital costs within all end-consumer energy uses.

- Energy efficiency improvement implies lower variable costs for the end-consumer as better energy performance of assets and equipment make savings on the fuel and electricity purchasing budgets. The modelling approach takes the general view that there are no negative cost opportunities in the area of energy efficiency decisions within the baseline projection, at least from the perspective of end-users, who apply high subjective discount rates for annualising the capital costs. This is because they reflect onto the cost various uncertainties, market barriers and other factors. Hence, there needs to be an additional driver, such as a carbon price or command and control policy measures, which makes the total cost per unit of energy service from advanced technologies more competitive versus conventional equipment. The presence of the driver, however, implies higher costs for a scenario such as *Power Choices*, compared to no policy scenarios.



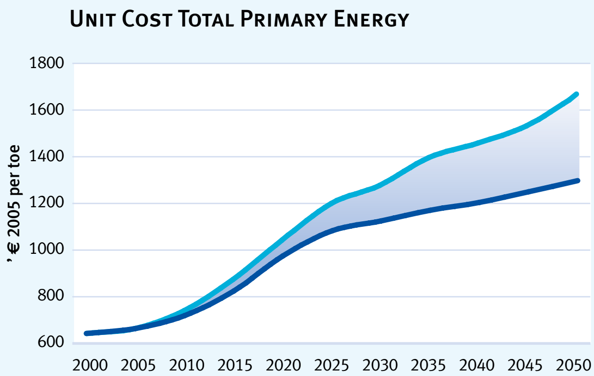


Figure 29: *Total Cost of Energy Services and Unit Cost of Primary Energy*

- For the energy supply sector, the targets and the drivers included in the *Power Choices* scenario imply shifting investment towards more capital intensive options, such as RES, CCS, nuclear and others. They also imply higher investments for energy infrastructures, notably for the power grid. Additional capital costs arise also because the supply system becomes more complex to handle as a result of high RES penetration and decentralised generation. The new production structure, however, saves on fuel costs, as the aim is to shift away from fossil fuels. Similar changes in the cost structure take place in decentralised production, where end-users incur high capital costs which allow them to save on their electricity bill.

- In the context of scenarios, such as *Power Choices* and *Baseline 2009*, where carbon prices correspond to emission allowances prices in public auctions, energy producers incur these additional costs arising from the auctions and pass them through in their consumer prices. There is thus a transfer of money from the energy sector to the rest of the economy, as if a tax was applied. Lower fossil fuel consumption implies of course lower auction payments.

The model calculates total cost of energy as an annual cost inclusive of all direct and indirect expenses for energy purposes, such as: a) the annual capital payments for energy savings, energy equipment and durable goods (accounting only for the part which corresponds to energy); b) the variable and fixed operating costs; c) the payments for fuel and electricity; d) the annualised cost of infrastructures, and e) all other payments for taxes, subsidy recovery and auctioning of emission permits. The total cost of energy is calculated at the level of the final energy consumer.

Hence, the total cost of energy is the amount that the rest of the economy has to pay annually to the energy system in order to receive the required energy services, such as mobility, lighting, heating and cooling, industrial processing, etc. The cost of energy consumed is part of total cost of energy services, the rest being the cost of energy savings.

Since energy services are among the primary factors (together with labour, capital and materials) that enable the production of goods and services as well as comfort and welfare, an increase in the total cost of energy as a percentage of GDP is a loss for the economy, which constitutes a measure of the macroeconomic impact.

Ancillary economic benefits associated with the *Power Choices* scenario were not quantified. At least the following are identified as ancillary benefits: a) damages avoided because of mitigating climate change; b) damages avoided because of a significant reduction in local pollution in urban areas; c) damages avoided because of a significant reduction in acid rain pollution; d) lower exposure to geopolitical and economic threats because of a significant reduction in fossil fuel imports.

The results regarding cost implications are shown in *Figure 30*.

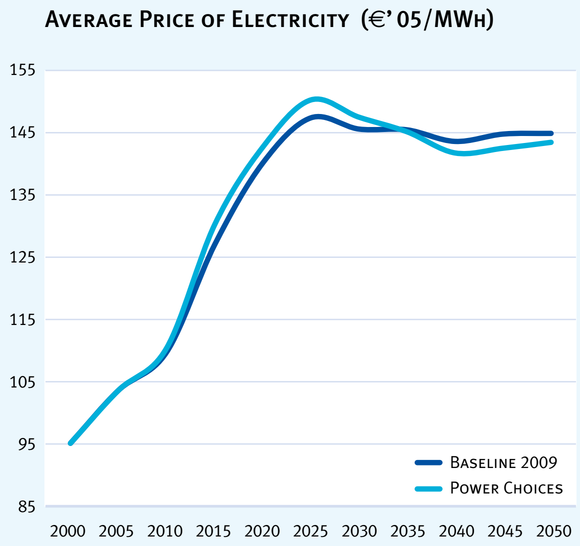


Figure 30: *Comparison of Electricity Generation and Supply Costs*

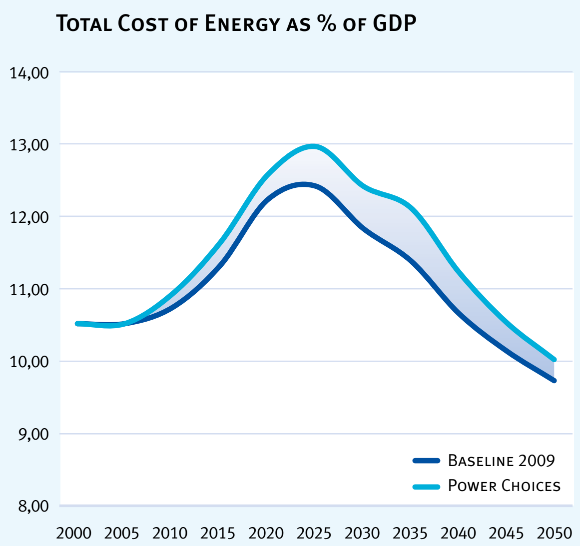


Figure 31: *Total Cost of Energy of GDP*

Energy efficiency improvements imply that the cost of energy consumed as part of total costs decreases. The *Power Choices* scenario entails higher capital costs but lower fuel and variable costs. The calculations show that in cumulative terms, over the period 2010-2050, total energy cost in the *Power Choices* scenario is found to be just 4% higher than in the *Baseline 2009* scenario.

The unit cost of primary energy consumption in 2050 is 30% higher compared to the *Baseline 2009* scenario. But because the *Power Choices* scenario involves lower primary energy consumption then despite the unit cost increase, the payments for energy consumed are lower in the *Power Choices* scenario compared to other scenarios, thus largely offsetting the capital cost increases implied by the *Power Choices* scenario.

The average price of electricity is projected to remain at a similar level in both *Power choices* and the *Baseline 2009* scenarios. Prices *(see Figure 30)* strongly increase until 2025, driven by the increase in world fossil fuel prices (which is projected to take place during the period of recovery of world economic growth), carbon price within the ETS and the additional costs of power generation induced by carbon emission reductions and RES policies.

Beyond 2025, electricity prices are projected to remain rather stable, as fossil fuel prices increase at a slower pace and technology performance in power generation succeeds in offsetting the fuel price effects.

The similarity in the level of average electricity prices between the Power Choices and the Baseline 2009 scenarios does not imply that the structure of electricity generation and supply are similar in the two scenarios. On the contrary, there are large differences in the structure of costs, as summarised below:

- The annualised capital costs of power generation per MWh in *Power Choices* are 8 – 9 % higher than in the *Baseline 2009* scenario, throughout the projection period. This is reasonable, since the former scenario develops more capital intensive options, such as nuclear, CCS and RES in order to reduce carbon emissions in power generation.

- The increase in unit capital costs is alleviated because the *Power Choices* scenario involves a much higher average load factor (80%) , compared to the *Baseline 2009* scenario (67%). This is due to the electrification of transport in combination with considerable electricity savings in the residential and tertiary sectors; the penetration of electricity in transportation and the savings in mid load and peak load time segments from standard electricity uses help shave the peaks in the overall load curve. Hence the capital intensive plants, which develop strongly in the *Power Choices* scenario, are used at higher rates compared to the *Baseline 2009* scenario. This moderates the increase in capital costs per MWh.

- The average grid tariff, as estimated to recover the total costs of transmission, is between 15% and 20% higher in the *Power Choices* scenario compared to the *Baseline 2009* scenario. To put this difference in a perspective, it is noted that in the *Power Choices* scenario the average grid tariff is estimated to be 50% higher in 2020 and 100% higher in 2050 than its level in 2005. The increase in grid tariffs also takes place in the context of the *Baseline 2009* scenario, because of the RES developments included in this scenario, but the rate of increase relative to 2005 ranges only between 35% and 70%.

- The *Power Choices* scenario implies lower consumption of fossil fuels, hence lower fuel costs per MWh than the *Baseline 2009* scenario. The reduction in fuel costs partly compensates for the increased capital and grid unit costs (roughly between 30 and 40%).

- It should also be noted that the *Power Choices* scenario moves towards an almost carbon free system by 2050, contrasting with the *Baseline 2009* scenario which, although involving the ETS in line with current legislation, shows continued significant carbon emissions from power generation in 2050. Consequently, the *Power Choices* scenario implies considerably lower payments for allowances in auctions than *Baseline 2009* throughout the projection period, and especially after 2025. The reduction in auctioning payments cancels out the effects of higher capital costs, hence average electricity prices in the *Power Choices* scenario are found almost equal to the prices projected for the *Baseline 2009* scenario or even slightly lower in the period close to 2050.

INVESTMENT EXPENDITURE IN POWER CHOICES
(10-years periods billion €' 05)

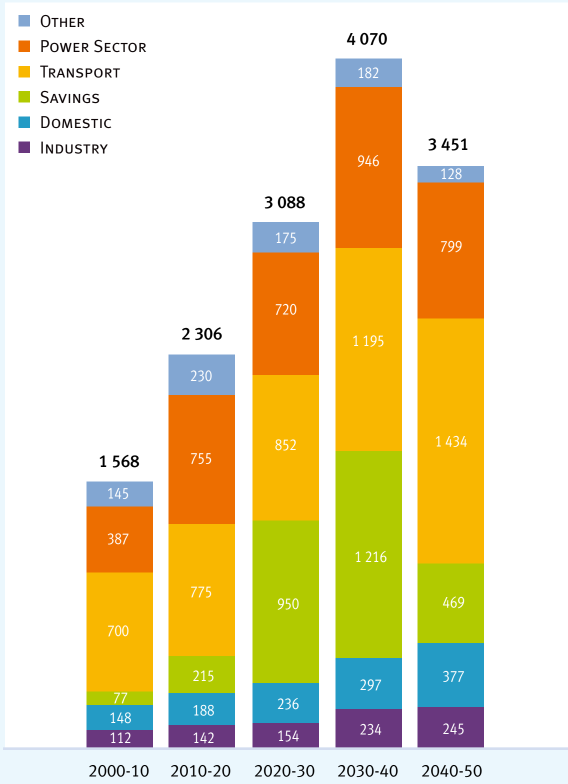


Figure 32: *Investment per Sector*

The total cost of energy as a percentage of GDP (inclusive of all types of costs incurred for the provision of energy services) increases significantly to 2025, as a consequence of the rising world fossil fuel prices *(see Figure 31)*.

The *Power Choices* scenario implies a faster pace in price rises during this period. As the *Power Choices* scenario meets the 20-20-20 policy targets by 2020 and requires additional investments in energy efficiency, energy cost as % of GDP is up to 0.6 percentage points above its level in the *Baseline 2009* scenario by 2035. After then, the difference starts reducing to reach 0.3 percentage points by 2050. In cumulative terms, over the period 2010 – 2050, the *Power Choices* scenario implies a €300 billion incremental energy system cost compared to *Baseline 2009*.

Figure 32 shows the model results regarding investment expenditure in the various energy sub-sectors as projected for the *Power Choices* scenario.

Total investment in power generation, during the period between 2010 and 2050, amounts to €1.75 trillion (in 2005 money terms), in the *Power Choices* scenario[9]. This amount is 12% higher than in the *Baseline 2009*. Total investment for the power grids is estimated to amount to €1.5 trillion (2005 money) in the *Power Choices* scenario for the period 2010-2050, which is 35% up from the *Baseline 2009* scenario.

Investment in energy savings and in energy efficiency improvement requires very substantial investments in the *Power Choices* scenario: they represent 20% of total energy system investment costs in cumulative terms over the period 2010-2050. According to the projection, end-users need to spend a total amount of €2.9 trillion (2005 money) for energy savings. They spend in addition €2 trillion for equipment replacement (15% up from the *Baseline 2009*) for standard energy uses and €5 trillion (2005 money) in the transport sector (accounting only for energy-related investment).

9 At the time of publication of this report, new environmental legislation was under discussion at European level. Its impact has not been assessed, although it is likely to trigger additional costs in power generation in the short run.

The *Power Choices* scenario requires total energy system investment in the time period 2020-2050 that amounts to €350 billion (2005 money) per year. This represents a very substantial increase compared to past years (roughly €150 billion (2005 money) per year on average). The increase is significant even when compared to the *Baseline 2009* scenario, which implies average investment of €265 billion per year over the period 2020-2050. The difference from *Baseline 2009* primarily concerns energy savings and the acquisition of advanced energy equipment. For the power sector the *Power Choices* scenario requires 25% higher annual investment amounts per year on average, relative to *Baseline 2009*.

Investment in other energy supply sectors (e.g. refineries, fossil fuel extraction) is roughly 25% lower in the *Power Choices* scenario, compared to the Baseline 2009 over the period 2020-2050.

Total energy system investment during the time period 2010-2050 is estimated at €12.5 trillion (2005 money) in the *Power Choices* scenario, which is 30% higher than the *Baseline 2009* scenario. The largest part of the additional investment is undertaken by end-users in the various final energy demand sectors. This constitutes a challenge for policy making because it implies that the policy must be adequately shaped to ensure that such high investment actually takes place. In practice it is difficult to address effective incentives to a large number of highly dispersed decision-makers such as the end-use consumers.

Moreover, it has to be noted that the cost of deploying low-carbon technologies and the impact on local communities will vary quite substantially across Europe. This implies that the allocation of costs and benefits would not be even among or within countries.

7 KEY RESULTS OF SENSITIVITY ANALYSIS

A series of additional PRIMES model simulations were performed for sensitivity analysis purposes. The simulations consisted in altering some of the assumptions of the *Power Choices* scenario.

The main aim was to investigate whether the results would be different if the conditions regarding the deployment of the emission reduction options turned differed from that assumed within the *Power Choices* scenario. Such investigations were performed for CCS, nuclear energy and onshore wind power.

Moreover, to assess the impact of energy efficiency policies, the impact of the assumed bottom-up policies was further assessed by quantifying a scenario in which these policies were not included but where the emission reduction targets were met solely by adjusting carbon prices.

7.1 NUCLEAR ENERGY

As already mentioned, the *Power Choices* scenario assumes that the nuclear phase-out in Germany and Belgium is pursued in the future while other countries that do not use nuclear energy at present, such as Italy and Poland, develop nuclear power in the future.

The *Nuclear Facilitated* scenario assumes that Germany and Belgium do not pursue their nuclear phase-out policies, do not decommission the nuclear plants prematurely and consider new nuclear investment where proved economic under market conditions. New nuclear investment in these two countries was restricted only to existing nuclear sites. This assumption implies a limitation on the possible future expansion of nuclear in these two countries.

The *Nuclear Facilitated* scenario reduces GHG emissions to the same extent as the *Power Choices* scenario. The additional availability of nuclear energy within the *Nuclear Facilitated* scenario evidently facilitates emission reductions in the EU and consequently carbon prices readjust in order to deliver the same emission reduction target.

(% change from Power Choices)	2020	2030	2050
Total Electricity Generation	0.5	1.0	0.8
From Nuclear	16.4	26.3	19.5
From RES	-0.5	-3.1	-7.8
From Fossil fuels	-7.8	-12.9	-5.0
Carbon Price	0.0	-0.5	-3.1
Average Electricity Price	-1.5	-3.5	-3.4
Total Energy System Cost	-0.2	-0.7	-0.6
(Difference from Power Choices)	**2010-2050**		
Cumulative Energy System Cost	€ -358 bill.		-0.4%
Cumulative CO_2 Emissions	-1 488 Mt CO_2		-0.9%

Table 12: *Impacts of the Nuclear Facilitated Scenario*

The abolishment of the phase out in the *Nuclear Facilitated* scenario allows net electricity generation from nuclear energy to increase in the EU by 16% in 2020, by 26% in 2030 and by 20% in 2050, relative to the *Power Choices* scenario *(see Table 12)*. In the *Nuclear Facilitated* scenario, total operating nuclear capacity is 33 GW higher in 2050 than in the *Power Choices* scenario and 73 GW higher than in 2005.

The additional nuclear development takes place by replacing both RES power and CCS:

- electricity generation from RES in the *Nuclear Facilitated* scenario is 7.8% lower in 2050 than in the Power Choices scenario;

- the share of CCS generation in total power generation drops between 2 and 3 percentage points in the *Nuclear Facilitated* scenario compared to Power Choices (power generation from fossil fuels decreases between 7 and 10%).

Total energy system costs are lower in the *Nuclear Facilitated* scenario compared to *Power Choices*, while both scenarios meet almost the same emission reduction targets.

Average electricity prices in the *Nuclear Facilitated* scenario are 3% lower than in *Power Choices*.

In cumulative terms, over the period 2010-2050, the *Nuclear Facilitated* scenario implies savings of €360 billion (2005 money) on total energy system costs compared to *Power Choices*.

7.2 CARBON CAPTURE AND STORAGE

The *Power Choices* scenario assumes that CCS technology becomes commercially mature for power plants commissioned after 2025. In an alternative scenario, termed *"CCS Delay"*, it is assumed that the maturity of CCS is delayed by 10 years and so commercially mature CCS power plants are not commissioned until after 2035. The *"CCS Delay"* scenario is assumed to meet the same emission reduction targets for 2050 as the *Power Choices*. To achieve this carbon prices are re-adjusted.

The delay in CCS implies cancelling the commissioning of new power plants with CCS taking place in the *Power Choices* between 2025 and 2035. It also implies that significantly less CCS plant is commissioned by 2040. CCS investment is comparable to *Power Choices* only in the last decade of the projection period.

The lack of the CCS emission reduction option in the period 2025-2035 implies that other options, such as nuclear and the RES develop at a higher scale in the *CCS Delay* scenario. As developments close to potentials imply higher non-linear costs, power generation costs and prices increase in the *CCS Delay* scenario, relative to the *Power Choices*.

The increase in power generation from nuclear energy is roughly 2% in the period 2030-2050 and the increase in RES power is 3% in 2030 and 6% in 2050 *(see Table 13)*.

The carbon price increase in the *CCS Delay* scenario and the total system costs in cumulative terms over the period 2010-2050 increase the *CCS Delay* scenario costs by €164 billion (2005 money) relative to *Power Choices*.

The lack of the CCS option implies that the trajectory of emissions in the period before 2050 corresponds to higher emission levels in *CCS Delay* compared to *Power Choices*. In cumulative terms, the increase in emissions is equal to 2.3% and total emissions captured in *CCS Delay* are 12% below that of *Power Choices*.

(% change from Power Choices)	2020	2030	2050
Total Electricity Generation	-0.1	-0.5	0.6
From Nuclear	-0.3	2.1	1.6
From RES	-0.1	2.9	6.2
From Fossil fuels	-0.1	-6.0	-7.6
Carbon Price	0.0	1.9	0.7
Average Electricity Price	0.1	0.1	-0.1
CO_2 captured	0.0	-91.8	-10.1
(Difference from Power Choices)		2010-2050	
Cumulative Energy System Cost	€ 164 bill.		0.2%
Cumulative CO_2 Emissions	3 612 Mt CO_2		2.3%

Table 13: *Impacts of the CCS Delay Scenario*

7.3 LOWER WIND ONSHORE

Wind onshore is a competitive technology under present conditions. Consequently onshore wind develops rapidly in the context of the *Power Choices* scenario, even before 2020.

Although the model assumes that non-linear costs are associated with the large scale development of wind power, onshore wind delivers the largest contribution from RES power technologies in the *Power Choices* scenario.

In many countries the large scale development of onshore wind raises concerns particularly from people living close to prospective wind farms. It is possible that such objections and other concerns may prevent onshore wind from developing as projected in the *Power Choices* scenario.

(% change from Power Choices)	2020	2030	2050
Total Electricity Generation	0.1	-0.1	0.0
From Nuclear	0.4	0.8	1.4
From RES	-1.2	-2.4	-3.4
From onshore and offshore wind	-2.6	-5.4	-8.0
From onshore wind	-4.3	-10.2	-16.7
From offshore wind	0.8	2.2	3.6
From solar	0.0	3.6	4.3
From Fossil fuels	0.8	1.7	3.0
Carbon Price	0.0	0.9	1.1
Average Electricity Price	0.1	0.1	-0.1
CO_2 captured	0.0	3.8	3.5
(Difference from Power Choices)		2010-2050	
Cumulative Energy System Cost	€ 119 bill.		0.1%
Cumulative CO_2 Emissions	6 Mt CO_2		0.0%

Table 14: *Impact of the Lower Wind Onshore Scenario*

This issue is analysed by quantifying a scenario *(Lower Wind onshore)* which assumes that incremental onshore wind development beyond 2020 is limited to one third of the development under the *Power Choices* assumptions. As shown in *Table 14*, the reduction in power generation from wind (including onshore and offshore wind) by 2050 is 8% lower in the *Lower Wind onshore* scenario compared to *Power Choices*. The reduction in onshore wind is higher but it is partly offset by the development of additional offshore wind.

Since this assumption implies a decreased contribution from one of the less expensive emission reduction options, other more expensive options must develop at a higher scale. Consequently the carbon price must rise in order to meet the same emission reduction target for 2050. The carbon price is found to be 1% higher in the *Lower Wind onshore* scenario compared to *Power Choices* for the whole time period between 2030 and 2050.

The reduction in onshore wind development leads to an increase in total cumulative energy costs estimated at €119 billion (2005 money), relative to the *Power Choices* scenario. Average electricity prices are less affected by reduced onshore wind development.

Lowering power generation from onshore wind affects the structure of power generation in the *Lower Wind onshore* scenario. Power generation from nuclear and fossil fuels (including CCS) increase relative to the *Power Choices*. Total power from RES decreases, but RES technologies other than onshore wind develop more in the *Lower Wind onshore* scenario than in *Power Choices*.

7.4 NO EFFICIENCY POLICIES

As explained in previous sections, the *Power Choices* scenario assumes a series of bottom-up policies to promote energy efficiency. These policies are aimed at overcoming non-market barriers and at developing infrastructures which facilitate the achievement of the ambitious emission reduction targets.

The bottom-up policies concern advanced energy efficiency in buildings, facilitating the penetration of technologically advanced appliances and equipment and the development of electrified road transportation.

In the context of the *No Efficiency Policies* scenario it is assumed that none of these policies take place and thus the carbon price, as a market-based instrument, is the sole means of achieving the emission reduction target.

In the absence of the bottom-up policies the carbon price needs to increase considerably in order to overcome the non-market barriers affecting energy efficiency improvement and the adoption of advanced technologies by end-consumers. Hence energy demand in stationary uses decreases significantly more in the *No Efficiency Policies* scenario than in Power Choices.

Regarding the transport sector, the absence of infrastructure development does not allow electricity to penetrate and so road transportation continues to be based on conventional fuels and technologies. Consequently, since electricity as a carrier that is (almost) carbon free is absent, emission reductions from transport proves difficult and takes place only through energy savings and modal shifts in favour of public transportation.

As a result of the lowering of energy demand in stationary uses and the non penetration of electricity for transport uses, total demand for electricity is 25% lower in the *No Efficiency Policies* scenario than in *Power Choices*. *See Table 15* for further details.

The structure of power moves more towards carbon free emission in the *No Efficiency Policies* scenario driven by the high carbon price. The nuclear, RES and CCS options develop as in the *Power Choices* scenario but are lower in magnitude since total power generation is lower.

Since perfect foresight is assumed in the modelling, carbon prices increase over the entire projection period in order to ensure that the emission reduction target is met by 2050. The carbon price needs to rise at such level in the period before 2050 that emissions reduce before 2050 more than in the *Power Choices* scenario.

The *No Efficiency Policies* scenario implies €3552 billion (2005 money) of additional cumulative cost relative to the *Power Choices* scenario; this represents 4.2% higher total cumulative energy costs.

Carbon prices need to rise at rather extremely high levels in order to meet the emission reduction target in 2050 in the absence of the bottom-up policies and the electrification of road transportation. In the *No Efficiency Policies* scenario, carbon prices rise to €146/tCO_2 (2008 money) in 2030 and €195/tCO_2 in 2050.

Total cumulative emissions are, however 7.3% lower in the *No Efficiency Policies* scenario than in the *Power Choices.*

Both the high carbon prices and the absence of electrification of transport, which drives a smoothing out of the power load curves, induce an increase in electricity prices, which is estimated to range between 3 and 5% for the *No Efficiency Policies* scenario compared to *Power Choices.*

(% change from Power Choices)	2020	2030	2050
Gross Inland Consumption	-0.1	-0.7	-1.2
Total Electricity Generation	-2.7	-13.7	-24.5
From Nuclear	1.3	-10.1	-26.8
From RES	-5.4	-10.1	-23.3
From Fossil fuels	-2.9	-20.1	-24.2
Carbon Price	28.9	145.8	194.8
Average Electricity Price	1.9	9.5	11.8
CO_2 captured	7.8	42.1	-17.8
(Difference from Power Choices)		2010-2050	
Cumulative Energy System Cost		€ 3 552 bill.	4.2%
Cumulative CO_2 Emissions		-11 426 Mt CO_2	-7.3%

Table 15: *Impact of the No Efficiency Policies Scenario*

7.5 SUMMARY OF SENSITIVITY ANALYSIS

Table 16 shows the effects of the various scenarios on emissions and energy system costs in cumulative terms.

	Cumulative effects over 2010-2050			
Scenarios	**GHG Emissions (Gt CO_2)**	***% change from Power Choices***	**Total Energy System Costs (trillion €'2005)**	***Diff. from Power Choices (billion €'2005)***
Power Choices	156.9		85.1	
CCS Delay	160.5	*2%*	85.2	*164*
Nuclear Facilitated	155.4	*-1%*	84.7	*-358*
Less Onshore Wind	156.9	*0%*	85.2	*119*
No Efficiency Policies	145.5	*-7%*	88.6	*3 552*

Table 16: *Summary of Sensitivity Analysis Results*

8 KEY OUTCOMES OF THE STUDY

The model-based analysis provides evidence that a practically zero-carbon emission power generation sector, within a -75% GHG emission reduction pathway in the EU, is technically and economically feasible by 2050. The *Power Choices* scenario presents a road map which involves considerable transformation in all energy sectors, both in demand and in supply activities. The road map shows that the transformations have to be pursued dynamically over thirty years in order to achieve an emission pathway consistent with the climatic objectives.

Moreover, the transformations will require the greatest portion of the energy system investments to be undertaken by a large number of highly dispersed decision-makers outside the electricity sector, mainly end-users from industry, transport and the tertiary sectors.

Although feasible, realisation of the road map is thus certainly a challenge:

- The transformation challenges energy consumers and energy producing enterprises, because it requires considerable investment, risk-taking regarding capital and technology decisions and acceptance of high costs and prices compared to business-as-usual.

- The transformation also challenges public policy making in the energy sector as it requires a wide spectrum of bottom-up policies aimed at:
  - delivering higher energy efficiency,
  - facilitating access to advanced technologies,
  - developing the common infrastructure which allows CCS to expand,
  - facilitating the development of a power system with high shares of RES and decentralised generation,
  - developing the common infrastructure permitting the replacement of fossil fuels by electricity in road transportation.

- Energy consumers are required to save energy in existing uses, including electricity, and gradually move the vehicle stock towards electrified mobility.

- Energy producers are required to develop carbon free energy production at an unprecedented scale, which includes:
  - the replacement and further expansion of the stock of nuclear power plants;
  - the large-scale development of RES power of all resources and technology types; and
  - the adoption of CCS technology for almost all new solid fuel plants after 2025.

The trajectory illustrated by the *Power Choices* scenario constitutes a radical change compared to business-as-usual practices.

Under the conditions examined, electricity plays a pivotal role in achieving the requisite emission reductions:

- firstly by achieving de-carbonisation of power generation through phasing in a wide range of zero or very low carbon production options;

- secondly by assisting further improvement of energy efficiency in all demand sectors;

- thirdly by penetrating deeply the energy demand sectors and especially by making massive inroads in the hitherto intractable road transport energy market.

Cost implications are reasonable, provided that electricity is saved in domestic uses and at the same time its use expands considerably in road transportation. These combined changes for energy use in stationary and mobile applications constitute a key for the success of the *Power Choices* roadmap, because it allows a smoothing of the power load curve and prevents a large increase in total power generation which would otherwise be required to accommodate the electrification of road transportation.

High costs and prices are already inevitable given the adoption of the EU Directive introducing an ETS involving the auctioning of emission allowances and a continuously shrinking total amount of allowances. The *Power Choices* scenario demonstrates that reducing carbon emissions provides savings on auctioning payments that are almost sufficient to finance the additional investment costs which enable achievement of the carbon-neutral goal. In addition, under the *Power Choices* assumptions, the additional capital intensive investment costs are partly offset by the savings resulting from a smoothed load curve, as cars are charged at off peak time, which further reduces auction payments and fuel costs.

The *Power Choices* roadmap requires a considerable increase in investment within all energy sectors (demand and supply), for energy savings and for developing a smarter and larger grid infrastructure. The high pace of energy investment needs to be sustained over a long period of time.

It is imperative that the large variety of small and dispersed end-users of energy undertake investments in energy savings and bear higher costs for the purchase of durable goods embedding advanced technologies. This is a challenge for public policy which will have to enhance interventions aimed at removing the non-market barriers and market failures which at present block progress on delivering energy efficiency. Market-driven signals alone, such as carbon prices, are not sufficient to incentivise all these small-scale and dispersed consumers to undertake sustained investment.

Higher investment in the power sector is needed for the following reasons:

- old and inefficient power plants will need to stay at low operation levels for reserve reasons,
- the RES penetration implies capital intensive investment far beyond business-as-usual,
- power grid infrastructure and smart grids require higher investment, relative to baseline, in order to operate the increased RES penetration and support energy efficiency improvements,
- power system operation will involve higher capital costs in order to preserve thermal and hydro capacities delivering ancillary services,
- companies will need to start investing in capital-intensive, low carbon technologies such as nuclear, CCS, off shore wind etc. in the early stages.

Regarding large utilities and energy companies, undertaking high cost investment over a long period of time constitutes an obvious challenge:

- According to the *Power Choices* projection, the long term prospects are optimistic for electricity sales, as demand rises sharply on foot of electricity replacing fossil fuels in final energy demand, including transportation.
- The medium term prospects are gloomy for electricity sales as energy efficiency improvements dominate over substitution.
- Nevertheless, in order to follow a cost effective carbon reduction process, electricity companies are required to increase investment even in the early stages and in advance of seeing a rise in electricity demand.
- Since high uncertainty usually surrounds capital intensive investment, as is the case of the electricity sector, low-carbon investments risk being postponed or only partially implemented.
- This situation can be prevented provided market signals can be anticipated with sufficient certainty, such as the carbon prices, and if public policy commitments regarding emission reduction targets and the development of the common infrastructure address the long-term horizon.

Electricity market design and regulatory policies need to address this complex decision making context, which will involve volatile carbon prices and cost margins with a simultaneous requirement for high capital intensive investment.

The market design needs also to address the challenges arising from a progressive shrinking of the portion of the market portion exposed to competition and a corresponding progressive enlargement of the market portion under regulatory protection; the latter include the RES sectors, common infrastructure for the grid and carbon dioxide transportation and storage and the extensive ancillary services that will be required to accommodate high RES penetration levels.

Decarbonising society is a complex system-wide process, which must proceed both in energy demand and in energy supply. The process has to start early and has to persist over a long period of time.

Consequently, the cost-effective success of the *Power Choices* roadmap depends crucially on the removal of long term uncertainties, on the provision of sufficient price signals through carbon pricing combined with wide-ranging bottom-up policies.

The extensive sensitivity analysis carried out has shown that all low-carbon options must be available and deployed according to their cost-effective potential.

For example, delays in the commercialisation of CCS technology or barriers that prevent the deployment of some RES technologies (such as onshore wind) entail significant additional costs for meeting the emission reduction targets. On the other hand, the removal of the nuclear phase-out in some countries will induce a reduction in mitigation costs. The absence of bottom-up policies, including the possible failure to electrify the transport sector, implies dramatic increases in mitigation costs.

9 POLICY RECOMMENDATIONS

A carbon-neutral power sector will have a growing role to play in decarbonising society. Reaching the global objective of a -75% reduction in GHG for the EU by 2050, will imply both:

- An increased degree of electrification of final energy usage
- Decarbonise power generation

To achieve this objective, strong and immediate political action is required to:

- **Enable the use of all low-carbon technologies and ensure investments in transmission and distribution lines**

  Very substantial investment will have to be ensured, particularly in:
  - large-scale uptake of renewable energies
  - early deployment of carbon capture and storage (CCS) technologies, which must be tested and proven by 2020
  - new nuclear power plants
  - transmission and distribution capacity, and the development of "smart grids"
  - widespread energy efficiency in our economy and society

  Provided that strong and consistent political action is taken to enable the use of all low-carbon technology options, carbon-neutral power in Europe by 2050 is achievable within the context of a liberalised electricity market.

  There is also an urgent need to address on transmission and distribution infrastructures as additional renewable energy generation capacities will require timely investments in grid expansion and modernisation.

- **Support well functioning carbon and electricity markets so as to deliver carbon reductions at least cost**

  Efficient use of energy and investment in low carbon technologies require a well functioning energy market and an adequate incentive system. It requires a carbon price that reflects the cost of abating CO_2 emissions. A realistic CO_2 emissions reduction trajectory will determine the long term forward price curve, which gives the right signal for low-carbon investments.

  Investments in the electricity sector will be substantial and need to be undertaken in the most cost-efficient way. Particularly in view of the ongoing financial crisis, the scale of finances needed requires an adequate framework to promote large scale capital investment.

  It is thus important that carbon and electricity markets are allowed to function properly and that the right price signals are provided to customers. The industry needs to be able to plan and deliver investments in a timely and efficient manner. As price signals are the main drivers for efficient investments in low-carbon technologies, it is important that these are not artificially distorted.

- **Ensure that all sectors internalise the cost of greenhouse gas emissions**

  Attaining significant emission reductions in Europe requires all sectors to play their role in reducing emissions. To avoid market distortions, policy-makers should set up mechanisms requiring sectors across the whole economy to internalise the cost of their emissions.

  It is necessary to consider the energy system as a whole and to stress that energy efficiency gains accomplished through electrification will lead to a reduction in the cost of energy as a percentage of GDP.

- **Actively promote an international agreement on climate change**

  Much of the economic benefit of a carbon-neutral power sector in a low-carbon EU economy, derive from having an international carbon market. While encouraging Europe in pursuing its leading role in promoting an international agreement on climate change, it has also to be recognised that significant carbon reductions need to be undertaken outside Europe. Policy-makers should thus ensure a proper transition towards a global commitment on climate change, which would deliver the right policy framework for investing in low-carbon technologies.

➤ Ensure that public authorities take a leading role in energy efficiency, adopting standards and incentives to help consumers choose energy-efficient technologies

Without the efficient use of energy, Europe will not be able to meet its carbon reduction targets. However, market and non market barriers and the conditions influencing economic decision-making by individuals still prevent customers from fully exploiting energy efficiency potentials.

It is important to note that the greater part of the additional investments needed to reduce final energy consumption will have to be undertaken by end-users in sectors others than the power sector. This certainly constitutes a challenge for policy making. Consequently, the development and diffusion of energy-efficient technologies needs the support of public authorities – e.g. by adopting standards on energy-consuming products, buildings and on new technologies – and, where appropriate, setting incentives to encourage consumers to invest in those technologies.

➤ Encourage public acceptance of modern energy infrastructure

The involvement of all stakeholders and decision makers is necessary to contribute to increasing public understanding of the need for energy infrastructures to meet the energy-climate targets. In parallel, and while preserving the environmental integrity of the ecosystem, licensing procedures must be further streamlined and simplified, so as to encourage timely investments in the electricity sector.

➤ Recognise that the cost of technology deployment differs substantially across the EU Member States and distribution effects will vary

Moving to a carbon-neutral electricity production sector will require substantial investments in the power sector. Although results are reported only at European level, the cost of deploying low-carbon technologies and the impact on local communities will vary quite substantially. Policy-makers should acknowledge that the allocation of costs and benefits will not be even across Europe and take the necessary steps to mitigate these effects.

➤ Facilitate the electrification of road transport and efficient electro-technologies for heating and cooling

Electrification of road transport and heating and cooling has many benefits, such as:

- Making Europe's energy consumption more efficient,
- Reducing downstream CO_2 emissions,
- Improving air quality in urban areas,
- Accommodating electricity supplied by renewable energy sources,
- Facilitating promotion of demand-side programmes.

However, the electricity industry alone will not be able to deliver this step change in society. Policy-makers should:

- Develop joint partnerships with all relevant stakeholders to promote a paradigm-shift in energy use;
- Remove barriers hampering a prompt and smooth fuel-switching to efficient electro-technologies;
- Recognise the benefits of electro-technologies, particularly as the carbon content of electricity is expected to continuously decline over the period of the study;
- In road transport, adopt policies to promote electric vehicles (incentivising R&D, deployment of charging infrastructure, etc);
- In the heating sector, adopt measures to internalise the cost of carbon emissions in direct use of gas and oil.

➤ European and national budgets should radically refocus towards supporting a new intelligent energy economy

Energy R&D should receive priority in overall R&D budgets. Support should focus only on technologies which have a reasonable chance of reaching market viability anticipated under carbon reduction regimes. Priority should thus be given to technologi es which can result in the highest carbon reductions – e.g. nuclear, CCS, RES, smart grids and electric transport. Funds should be distributed in a transparent way, ensuring benefits for the whole of society.

10 APPENDIX

10.1 TABLES FOR MACROECONOMIC SCENARIO FOR THE EU (GEM-E3 MODEL RESULTS)

GDP (volume)	Rate of growth per year in %										
	95-00	00-05	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Baseline 2009	2.93	1.82	0.58	2.29	2.13	1.82	1.65	1.69	1.58	1.57	1.57
Baseline 2007	2.89	1.74	2.57	2.49	2.22	1.94	1.59	NA	NA	NA	NA

population	Rate of growth per year in %										
	95-00	00-05	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Baseline 2009	0.17	0.34	0.41	0.33	0.24	0.15	0.08	0.01	-0.03	-0.07	-0.14
Baseline 2007	0.17	0.35	0.16	0.10	0.04	-0.01	-0.06	NA	NA	NA	NA

GDP (volume)	Rate of growth per year in %											
	90-95	95-00	00-05	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
Austria	2.17	2.99	1.67	0.81	2.07	1.94	1.70	1.48	1.50	1.60	1.50	1.50
Belgium	1.98	2.70	1.62	0.61	2.45	2.08	1.67	1.62	1.60	1.70	1.80	1.70
Bulgaria	-2.61	-0.83	5.29	3.31	3.41	2.62	2.10	1.87	1.70	1.50	1.40	1.40
Czech Republic	-0.96	1.48	3.74	2.67	3.36	2.72	1.90	1.51	1.70	1.50	1.40	1.40
Germany	1.49	2.01	0.60	0.34	1.93	1.64	1.03	0.97	1.30	1.10	1.10	1.20
Denmark	2.34	2.86	1.26	0.15	1.66	1.61	1.76	1.54	1.50	1.60	1.70	1.90
Estonia	-7.33	6.04	7.86	0.18	3.75	2.79	2.37	2.24	2.20	1.30	1.20	1.10
Greece	1.25	3.45	4.20	2.11	2.79	2.91	2.15	1.70	1.70	1.60	1.55	1.50
Spain	1.94	4.11	3.27	0.88	2.98	3.17	2.78	2.10	1.80	1.30	1.20	1.10
Finland	-0.76	4.82	2.51	1.06	2.13	1.84	1.53	1.44	1.50	1.60	1.60	1.60
France	1.23	2.80	1.66	0.38	2.04	1.96	1.78	1.72	1.70	1.70	1.80	1.80
Hungary	-2.18	4.01	4.25	-0.24	2.91	2.56	2.14	2.05	2.10	1.60	1.50	1.40
Ireland	4.88	9.76	5.56	-0.42	3.68	3.10	2.71	2.44	2.30	2.10	1.80	1.50
Italy	1.27	1.90	0.89	-0.37	1.69	1.92	1.77	1.49	1.40	1.35	1.30	1.25
Lithuania	-10.05	4.71	7.79	0.55	4.12	2.94	2.02	1.58	1.60	1.50	1.50	1.50
Latvia	-11.63	5.37	8.19	-0.17	3.65	2.44	1.95	1.85	1.80	1.55	1.50	1.40
Netherlands	2.56	4.05	1.32	1.00	1.77	1.60	1.36	1.25	1.50	1.50	1.50	1.60
Poland	2.20	5.41	3.08	4.05	3.49	2.79	2.73	2.12	2.00	1.60	1.50	1.40
Portugal	2.77	4.08	0.87	-0.17	1.89	2.04	2.04	2.20	2.50	2.20	1.80	1.50
Romania	-2.09	-1.28	5.72	3.29	4.23	3.19	2.35	1.84	1.60	1.80	1.50	1.50
Sweden	0.98	3.34	2.56	0.65	2.41	2.10	1.89	1.80	1.70	1.80	1.90	1.80
Slovenia	-0.58	4.36	3.66	2.64	3.25	2.77	1.82	1.04	1.10	1.00	1.00	1.00
Slovakia	-0.43	3.39	4.91	4.59	4.84	3.73	2.46	2.11	2.00	1.50	1.50	1.50
UK	1.66	3.44	2.44	0.55	2.53	2.16	2.04	2.03	2.10	2.10	2.10	2.10
EU27	1.45	2.93	1.82	0.58	2.29	2.13	1.82	1.65	1.69	1.58	1.57	1.57

Source: E3MLab/GEM-E3

Energy Intensive Industries	Index of activity												
	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Iron and steel	96.0	96.1	100.0	114.6	95.4	102.0	109.5	115.5	121.5	126.8	132.1	137.3	142.1
Non ferrous metals	70.7	72.0	100.0	95.2	87.5	94.7	103.4	110.7	118.3	125.6	133.2	141.1	149.0
Fertilisers/inorganic chemicals	80.6	83.9	100.0	111.4	108.9	116.2	123.4	128.8	133.3	137.4	141.0	143.6	145.3
Petrochemicals	63.9	69.1	100.0	121.4	119.5	126.3	133.3	138.6	142.2	146.5	149.9	152.6	155.3
Other chemicals	87.9	97.5	100.0	104.8	103.6	113.2	123.8	133.8	142.7	153.0	162.9	173.0	183.9
Cement and derived products	88.8	81.4	100.0	107.5	100.1	107.6	117.6	126.5	134.7	142.7	150.4	158.1	165.7
Ceramics. bricks. etc.	91.0	94.4	100.0	97.6	90.3	96.6	105.6	113.7	120.7	127.4	133.6	139.5	145.2
Glass production	77.8	86.5	100.0	100.8	94.3	101.7	111.0	118.9	126.6	134.2	141.6	149.2	156.7
Other non metallic minerals	101.1	106.8	100.0	104.5	97.5	105.2	115.7	125.6	135.2	144.6	154.2	164.0	174.0
Paper and pulp production	83.8	88.4	100.0	95.1	88.0	92.2	98.4	103.3	108.0	112.1	116.1	119.9	123.2
Energy Intensive Industries	83.5	86.2	100.0	105.8	98.0	104.8	112.8	119.5	125.7	131.7	137.5	143.1	148.4

Non Energy Intensive Industries	Index of activity												
	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Pharmaceuticals/cosmetics	68.8	85.2	100.0	122.4	138.1	159.8	185.3	212.1	238.9	269.5	302.0	337.1	375.9
Printing and publishing	88.2	90.5	100.0	100.7	103.4	113.8	127.2	139.9	153.4	167.3	182.0	197.6	213.9
Food. drink a nd tobacco	88.8	92.0	100.0	101.8	105.7	116.7	129.4	142.7	155.5	168.6	182.8	197.2	212.6
Textiles	116.0	104.2	100.0	85.3	75.2	74.1	73.9	73.1	70.7	66.0	60.9	53.8	45.1
Engineering	80.9	83.0	100.0	107.9	111.5	125.4	139.8	152.3	163.7	177.9	191.3	205.8	221.6
Other industries	92.4	88.1	100.0	102.9	105.0	115.1	127.2	139.8	151.8	164.1	177.4	190.8	205.0
Non Energy Intensive Industries	86.2	87.3	100.0	104.8	107.8	119.7	132.9	145.3	157.0	170.2	183.4	197.2	212.2

Other sectors													
	1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	92.0	93.1	100.0	99.5	95.6	98.9	103.6	108.9	114.0	115.6	118.7	120.3	120.7
Construction	98.0	94.8	100.0	106.8	101.4	114.0	127.7	138.8	149.8	161.7	172.6	184.8	197.3
Services	78.0	85.6	100.0	111.6	116.2	131.7	147.0	161.8	176.5	192.8	209.8	228.2	248.0
market services	73.4	81.1	100.0	116.0	119.2	136.7	154.2	171.2	188.5	207.8	228.1	250.2	274.4
non market	84.7	92.3	100.0	106.1	113.0	124.8	136.0	146.0	155.3	165.4	175.5	186.0	197.1
trade	78.3	85.9	100.0	109.3	113.6	130.1	147.5	165.2	183.0	202.6	223.6	246.2	271.0
Energy	81.6	84.0	100.0	101.7	97.8	102.8	106.8	111.2	115.9	117.5	120.5	122.1	122.7
Total other sectors	80.0	86.4	100.0	110.5	113.8	128.3	142.8	156.6	170.4	185.4	201.0	217.7	235.7

Source: E3MLab/GEM-E3

10.2 TABLES ON ENERGY EFFICIENCY

	Efficiency Improvement (% change of specific energy intensity indicators from 2005)								
EU27 - PRIMES model	Power Choices			Baseline 2009			No Policy Case		
	2020	2030	2050	2020	2030	2050	2020	2030	2050
Industry									
Specific Electricity	7.0	13.2	39.6	6.5	11.1	15.6	3.0	6.7	12.7
Steam uses	8.8	18.2	56.8	8.4	16.3	24.9	4.5	9.2	18.6
Low Enthalpy Heat	10.4	18.3	54.8	9.6	17.3	24.8	3.9	9.7	20.3
Thermal Processing	10.2	19.3	54.3	9.7	18.9	29.4	3.0	6.1	20.2
Electric Processing	12.6	21.4	49.8	11.3	20.5	29.5	2.4	6.2	19.6
Specific processes	8.5	20.0	66.5	7.8	17.8	27.5	1.0	5.8	19.5
Raw Material Processing	5.4	10.8	51.1	5.4	10.7	17.8	1.9	5.3	14.1
Residential									
Heating and cooling	10.7	29.9	101.5	10.3	24.8	55.7	7.2	15.2	44.9
Heating	6.3	19.6	60.4	5.9	15.3	26.0	3.2	6.7	19.8
Cooling	19.6	42.9	116.5	19.5	26.1	49.2	6.7	9.9	12.9
Other heat uses	5.2	13.0	42.8	8.6	16.3	24.5	5.2	8.4	17.4
Water Heating	9.1	21.2	52.2	14.7	27.9	39.9	7.8	12.2	23.9
Cooking	0.2	2.8	30.0	1.0	2.5	6.1	1.8	3.3	7.8
Specific electricity uses	47.5	51.1	85.2	47.1	49.5	49.2	16.2	24.3	28.3
Lighting	328.8	394.4	479.3	324.0	393.5	399.5	25.0	44.3	60.4
Electric appliances	19.6	23.5	52.0	19.7	23.3	25.0	13.2	19.0	21.4
Services									
Heating and cooling	25.3	47.2	107.0	23.1	40.5	65.7	18.0	32.8	56.6
Heating	9.1	18.2	56.9	6.7	13.9	22.3	3.6	9.1	22.8
Cooling	21.7	42.2	88.2	20.6	33.0	58.4	9.8	18.1	28.6
Other heat uses	18.5	24.7	51.6	10.6	15.3	19.6	4.4	9.4	16.9
Electric equipment and lighting	23.6	77.2	190.7	20.9	24.3	42.2	19.2	19.3	20.1
Agriculture									
Greenhouses and heating uses	3.3	6.0	32.8	2.2	4.5	7.0	1.8	3.2	6.9
Pumping	6.0	11.7	49.3	5.6	9.8	20.2	5.0	7.5	11.2
Electric equipment and motor drives	8.9	28.7	88.4	6.4	9.3	17.2	3.7	3.8	6.8
Transport									
Busses (ktoe per Gpkm)	8.6	20.3	58.6	8.1	17.5	39.5	1.1	2.8	8.2
Motorcycles (ktoe per Gpkm)	12.0	22.4	38.5	11.6	21.6	31.7	1.4	3.4	6.7
Cars (ktoe per Gpkm)	18.2	28.3	59.5	18.5	32.4	53.1	7.0	11.6	25.5
Passenger Rail (ktoe per Gpkm)	25.0	32.7	49.8	24.5	29.9	42.4	15.4	17.5	21.9
Aviation (ktoe per Gpkm)	17.0	35.0	54.7	17.3	34.0	51.0	4.2	18.6	34.1
Trucks (ktoe per Gtkm)	6.4	19.1	48.8	5.4	13.0	34.7	0.7	(1.7)	(4.0)
Freight by Rail (ktoe per Gtkm)	14.5	40.3	57.8	13.0	36.8	43.5	8.5	23.0	23.2
Inl. Navigation (ktoe per Gtkm)	2.3	3.4	10.5	1.9	1.7	2.5	0.4	(1.1)	(1.4)
Total Final Energy and non Energy									

Note: *Efficiency improvements is not the only explanatory factor for reduction (+) or increase (-) in energy consumption. because useful energy changes and substitutions among processes also take place driven by relative prices*

Reduction in Final energy Consumption (Ktoe)									
EU27 - PRIMES model	Power Choices vs Baseline 2009			Power Choices vs No Policy Case			Baseline 2009 vs No Policy Case		
	2020	2030	2050	2020	2030	2050	2020	2030	2050
Industry	1651	5319	98446	20561	40243	124253	18910	34923	25807
Specific Electricity	236	875	10488	2137	3295	12240	1901	2420	1752
Steam uses	195	1433	22868	3861	8154	29287	3665	6720	6419
Low Enthalpy Heat	495	1099	9664	1739	2995	10891	1244	1896	1226
Thermal Processing	485	1044	14068	4394	9031	18739	3909	7987	4671
Electric Processing	112	-1186	5594	6655	7333	10787	6543	8520	5193
Specific processes	165	2044	7989	-2211	3259	10259	-2376	1214	2270
Raw Material Processing	-37	10	27775	3986	6176	32050	4024	6166	4275
Residential	8617	36514	105684	34539	85336	180226	25922	48822	74542
Heating and cooling	7028	26179	64839	16070	53058	107548	9042	26879	42709
Heating	6877	24642	58604	15247	49957	93601	8371	25315	34997
Cooling	152	1538	6235	823	3101	13947	672	1563	7712
Other heat uses	164	5127	17266	3374	13122	30081	3209	7995	12815
Water Heating	-496	2037	8227	2479	8754	17397	2975	6717	9170
Cooking	660	3090	9039	895	4368	12684	235	1278	3645
Specific electricity uses	1425	5208	23579	15096	19156	42597	13671	13948	19018
Lighting	118	187	958	10643	10213	11281	10525	10026	10323
Electric appliances	1307	5021	22622	4452	8943	31317	3145	3922	8695
Services	12399	37678	69952	26600	57556	104517	14201	19878	34565
Heating and cooling	5370	14956	31840	11453	23232	43884	6083	8276	12044
Heating	4535	11935	25447	8899	17548	32374	4364	5614	6928
Cooling	835	3022	6393	2553	5684	11510	1718	2662	5117
Other heat uses	3140	5826	11101	5963	8777	15140	2823	2951	4039
Electric equipment and lighting	3889	16896	27012	9184	25547	45493	5295	8651	18482
Agriculture	1297	2927	8126	2088	4370	10880	791	1442	2754
Greenhouses and heating uses	971	2089	6060	1500	3046	7673	529	956	1614
Pumping	252	613	1640	408	941	2505	156	329	866
Electric equipment and motor drives	74	226	427	181	383	702	106	157	275
Transport	10384	28073	93468	53615	118285	259113	43231	90212	165646
Busses (ktoe per Gpkm)	-34	-82	870	367	821	2950	401	903	2080
Motorcycles (ktoe per Gpkm)	167	507	1757	1020	2204	4373	853	1698	2616
Cars (ktoe per Gpkm)	3076	544	30474	27692	48881	100710	24616	48337	70236
Passenger Rail (ktoe per Gpkm)	-18	-34	-30	219	324	659	237	358	689
Aviation (ktoe per Gpkm)	1079	5372	15657	11271	20799	38145	10192	15427	22488
Trucks (ktoe per Gtkm)	6192	21913	43756	12578	43772	108586	6387	21859	64830
Freight by Rail (ktoe per Gtkm)	-109	-271	435	361	1204	2851	470	1475	2416
Inl. Navigation (ktoe per Gtkm)	31	123	549	107	278	841	76	155	292
Total Final Energy and non Energy	33051	107584	367550	135316	301420	668110	102265	193836	300560

Note: *Efficiency improvements is not the only explanatory factor for reduction (+) or increase (-) in energy consumption, because useful energy changes and substitutions among processes also take place driven by relative prices*

Figures

Tables

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