Scenarios for a Post-2020 European Climate Policy

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Executive Summary

The ENTRACTE research project is aiming to analyse the European climate policy portfolio with special emphasis on the role of its interactions. Its final goal is to provide a pragmatic guidance for policy makers to design effective, economically efficient and politically and legally feasible climate policy mixes.

In this background paper policy scenarios are presented to serve as a common working base for subsequent numerical model analysis. We shed light on the current state of EU’s climate policy up to 2020 and on the current debate about climate policy targets for the period post-2020. Building on the scenarios used in the Impact Assessment of the Energy Roadmap 2050 (European Commission, 2011b) we derive three archetypal policy scenarios that differ in their focus on expansion of renewable energy sources in the power sector, improve the energy efficiency of the economy and the direct reduction of greenhouse gas emissions.
Content

Executive Summary .............................................................................................................. 2
1. Introduction ........................................................................................................... 5
2. Current and future European climate policy ........................................................... 6
   2.1. Current climate policy in Europe ............................................................................ 6
   2.2. The EU climate policy beyond 2020 ...................................................................... 7
   2.3. How many targets and instruments? ..................................................................... 8
3. In Search for Post-2020 Policy Scenarios .............................................................. 9
4. Broad Drivers and Applied Models .......................................................................11
   4.1. Drivers ..................................................................................................................12
   4.2. Numerical Models Applied in ENTRACTE ............................................................14
5. Policy Scenarios on the Road towards Decarbonisation .......................................17
   5.1. Reference Scenario ..............................................................................................19
   5.2. Scenario Focussing on Direct Reduction of Emissions .........................................20
   5.3. Scenario Focussing on Energy Efficiency .............................................................21
   5.4. Scenario Focussing on Renewable Penetration ...................................................22
6. Final Remarks ......................................................................................................22
7. References ...........................................................................................................24

Appendix
A1. Macroeconomic and demographic assumptions .............................................................26
A2. Energy Import Price Perspectives ..................................................................................27
A3. Technology Projections ..................................................................................................28
A4. International Climate Policy Perspectives .......................................................................29
List of Figures and Tables

Figures
Figure 1: Emission reduction pathway towards an 80% domestic reduction in 2050 .............. 8
Figure 2: The ENTRACTE approach to develop policy scenarios ........................................11
Figure 3: Shares in net electricity generation by source ........................................................18
Figure 4: Historical and modelled change in electricity intensity ...........................................19
Figure 5: EU-27 demographic forecast ...............................................................................26

Tables
Table 1: Structure of the numerical models used in the ENTRACTE research project ........16
Table 2: Energy prices, economic growth and technological assumptions ............................17
Table 3: Reference scenario ................................................................................................20
Table 4: Direct CO₂ reduction scenario ..............................................................................20
Table 5: Energy efficiency scenario ....................................................................................21
Table 6: High RES scenario ...............................................................................................22
1. Introduction

The current European climate policy with the Climate and Energy Package as its most important manifestation is based on three main pillars. Besides a 20% reduction in greenhouse gas (GHG) emissions, a 20% share of renewables in EU energy production, and a 20% reduction in energy consumption is envisaged until 2020. This multiple target approach is also reflected on the level of member states where a large number of measures in a wide range of areas have been implemented.

Tinbergen's rule for the design of public policies states that for each policy target one policy instrument has to be employed (Tinbergen, 1952). In practice, public policies typically violate this rule, either because there is a lack of instruments (e.g. incomplete sectoral coverage of the EU Emission Trading System (EU ETS) or because multiple instruments are employed to serve the same target (e.g. both cap-and-trade through EU ETS and feed-in tariffs aim at emission reductions).

However, a successful climate policy has to cope not only with the externality related to carbon emissions. Potentially, also other market failures have to be taken into account. This may include externalities in the innovation process as well as market imperfections, e.g. in the energy sector. Further, the global nature of the externality demands a global solution. But international agreements are (and might be too in future) often suboptimal. Hence additional instruments such as trade measures might be necessary to secure competitiveness and reduce carbon leakage in case of subglobal agreements or unilateral mitigation efforts. Finally, the pursuit of an efficient climate policy co-exists and interacts with several other political goals like equity or energy security.

Thus, the ambitious long term climate policy goals of the European Union outlined in the different Roadmap documents cannot be reached by the use of a single policy instrument only. While the EU ETS is key to promote the transition toward a low-carbon economy, ambitious GHG emission reduction will be reached only if this scheme is improved and supported by complementary policies which address the above outlined challenges. So far these measures have been examined mostly individually without taking into account the interactions between the different policy goals. This is the contribution that the ENTRACTE research project envisages. It aims for a better understanding of the interaction between the instruments already or potentially applied in the European climate policy portfolio.

While several driving forces such as economic growth or expectations of future prices of energy carriers shape the efficiency of measures to reach the goal of a largely decarbonized EU as it is envisaged in the Energy Roadmap 2050 (European Commission, 2011b), there are still different routes possible that will lead to this goal.

One policy route might be to put a rather strong emphasis on the pricing of carbon while putting less weight on specific policies to support the deployment of renewable energy sources or reducing energy consumption. However, it is also thinkable that the major burden of the decarbonisation goal lies on the shoulder of policies supporting renewable energy sources or such that increase energy efficiency.

It is beyond the scope and capabilities of ENTRACTE to endogenise all the different complex dimensions that influence this policy decision and derive directly an optimal mix of policies. Therefore, we propose a small set of three policy scenarios that allow the ENTRACTE modelling teams to assess climate policy instruments and their interactions in the light of harmonized different policy “futures” which each sets different emphases in the three main
fields of action direct control of GHG emission, penetration of renewables in the energy sector, and energy consumption.

Hence, our scenarios focus on the policy target dimension within the set of different climate policy futures. Other dimensions such as different energy price trajectories or economic growth rates are covered differently by the different modelling teams and will be only loosely harmonized.

The use of harmonized policy scenarios is also crucial for the aim of ENTRACTE to derive overarching and comprehensive conclusions about the interaction and interdependences of policy targets and instruments and the endeavour to derive grounded statements on preferable policy mixes.

In the following, we firstly identify the major drivers and analyse how the numerical models applied in ENTRACTE are positioned in the range of these drivers. Second, based on the findings of the EU Energy Roadmap Impact Assessment and the scenarios used there, three climate policy scenarios are derived. Each scenario places different foci on one of the three major fields of action (direct reduction of GHG emissions, increasing share of renewables as well as energy efficiency improvements) to achieve the long-term decarbonisation goals stated in the Roadmap documents.

The remainder of this background report is organized as follows: Section 2 studies briefly the current EU climate policy as well as the options and aspirational goals for the mid- (2030) and long-term (2050). On what we learned from there, we outline the policy scenario defining process in Section 3. Section 4 sketches the exogenous drivers that shape the “futures” in which the climate policy scenarios will be embedded and how this is represented in the applied models. Section 5 analyses different possible pathways to reach the envisaged decarbonisation by mid of the 21st century as they were assessed by other studies and then develops three decarbonisation scenarios plus a reference scenario with different emphasis on the different routes to long-term decarbonisation by 2050. We draw here on earlier work on scenario development to assess EU’s climate policy, in particular on the scenarios that were developed to assess the impact of the Energy Roadmap 2050 (European Commission, 2011b). Finally, Section 6 concludes.

2. Current and future European climate policy

2.1. Current climate policy in Europe

The European Union and its Member States have binding legislated climate policy targets up to 2020. The Climate and Energy Package – implemented in 2007 - sets targets in three domains: (i) a 20% reduction in EU greenhouse gas emissions relative to 1990 levels, (ii) a 20% share of renewables in EU energy production, (iii) a 20% reduction in in EU’s energy consumption relative to a business as usual scenario.

The first target is addressed by the EU Emission Trading System and by binding annual national targets for emissions of sectors outside the EU ETS. The current economic recession reduced economic activity and hence GHG emissions and consequently makes it easier than expected to reach the targets. But as a consequence, emission allowances are also cheaper than expected. This caused concerns about the incentives of regulated firms to invest in low carbon technologies. Therefore, several proposals are in the debate to influence the allowance price, e.g. by holding back planned issuances of allowances (“back loading”). This shows that even the ETS is the corner stone of EU’s mitigation strategy it is still not an established instrument and the direction of its future evolution is not conclusively defined yet.
The second pillar, the Renewable Energy Directive, sets binding national targets – taken in account the Member States different starting points and potentials - for the share of renewable energy by 2020. The first round of National Renewable Energy Action Plans submitted in 2011 to the European Commission shows a positive picture. However, the current recession might also affect these plans negatively. Some countries like Spain but also the Czech Republic cut financial support for renewables. This might lead to a reduction in the expansion efforts for renewable technologies. Moreover, the Renewable Energy Directive contains also a target for renewable fuels in the transport sector. By 2020 10% of the used fuels in the transport sector should come from renewable sources. So far, there has been no significant progress in this domain. However, if this sub-target cannot be reached, it might also become difficult to reach the overall 20% target.

The third target is addressed with the framework that has been established with the Energy Efficiency Directive. It demands 20% energy savings relative to the 2020 baseline. However, this EU wide target has not been translated into binding targets for member states yet. So far, only a fragmented set of single measures has been implemented (e.g. the ban of conventional light bulbs). Without a stringent implementation of broader measures and binding targets for the Member States it seems rather unlikely that this target will be reached. The projections indicate that with the rates of implementation of the current energy efficiency policies in Member States only half of the objective might be achieved by 2020. Furthermore, while the economic crisis contributed to this decrease in energy consumption, it has also negatively impacted energy efficiency investment decisions. As a response, the Commission has recently adopted two new initiatives- an Energy Efficiency Plan and the Directive 2012/27/EU on energy efficiency- aiming at stepping up efforts towards the 20% target.

2.2. The EU climate policy beyond 2020

These policies mark the course of the European Climate Policy up to 2020. However, in order to reach the long-term goal to limit global warming below 2°C above pre-industrial levels as it has been supported by all Parties at the UN climate conference in Cancun in December 2010, more stringent efforts are necessary. Therefore, the European Council reconfirmed its objective to reduce GHG emissions by 80 to 95% below 1990 levels by 2050. These long-term aspirational targets are outlined in the “Roadmap for Moving to Competitive Low Carbon Economy in 2050” (European Commission, 2011a). The Roadmap proposes that the EU should cut its GHG emissions to 80% below 1990 levels by 2050. Following a cost-effective pathway emissions have to be reduced in the order of 40% by 2030. Figure 1 shows a cost-effective reduction pathway as presented in the Impact Assessment of the Roadmap.
However, how the post-2020 European Climate Policy might look like in detail is still unclear yet. The official political debate has been initiated by the European Commission’s Green Paper very recently (European Commission, 2013). How many targets and in which domain the targets will be set, the degree of stringency for both medium-(2030) and long-(2050) term, is still an open question and some of the answers lay at the heart of the analysis in ENTRACTE.

An indication can be derived by existing mid- and long-term national targets. Several member states passed strategies with national targets for emission reduction, renewable energy and energy efficiency going beyond the agreed EU targets. Denmark, for instance, is aiming to have a power sector that produces 100% of electricity and heat out of renewable sources by 2030. By the same date France aims at a reduction of GHG emissions by 40% to 45% while the United Kingdom sets the goal to reduce its GHG emission by 50% by the period of 2023 to 2027.

By 2050 France, UK and Germany aim at a reduction target that corresponds to the targets set in the EU roadmap. Germany has also already targets in other fields of action for that period. So primary energy consumption should be 50% lower than in 2008 and renewables should be responsible for 60% of the total energy production and have an 80% share in the production of electricity.

2.3. How many targets and instruments?

As these examples indicate there is evidence for multiple targets in existing climate policies legislation as in the Energy and Climate Package as well as in national targets that reach beyond 2020. However, from simple economic reasoning it is unclear what the reasons for such a policy mix might be. In a world where the externality caused by GHG emissions would be the only market failure, a single instrument that puts the correct price tag on these emissions would be sufficient to reach still a first best outcome. Every supplemental policy instrument to increase the deployment of renewable energy sources or the reduction of

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1 For an overview on the national mid- and long term strategies of six north-western European countries, see Notenboom et al. (2012).
energy consumption would not lead to additional emission reductions but might rather cause distortions in the choice of the most cost-effective abatement measures and hence increase overall compliance costs (see e.g. Boehringer and Rosendahl, 2010)

However, there are also justifications for the application of multiple instruments and targets:

First, eventually the use of multiple instruments has a rationale due to the existence of multiple targets. As we know from Tinbergen (1952) several policy targets need also a similar number of instruments. Hence, a simple justification for the application of multiple instruments are the existence of additional policy targets such as air pollution reduction, the consideration of energy security issues, job creation, or international competitiveness issues that are affected differently by different GHG abatement options. The additional instruments have thus the aim to support the respective supplementary target.

Second, supplemental instruments might be necessary because market failures additional to the climate externality make an adjustment of distorted incentives necessary. A market failure may lead to insufficient demand for energy efficiency. These imperfections may arise due to the lack of credible information, landlord-tenant arrangements, or myopic behaviour. Another market failure may arise due to the non-consideration of spillovers from accumulated knowledge and learning by doing on the benefits from new innovations in the energy sector. Because of this imperfect appropriation incentives for develop and deploy new technologies might be too low (Fischer and Newell, 2008).

Third, regulation failures and imperfect information by regulators may make it necessary to implement supplemental instruments. Hoel (2012) shows that uncertainty about the social costs of carbon may justify a subsidy for renewable energy sources, also if a carbon tax is already in place but investors are risk averse. Additionally, the same study shows that also uncertainty about the future political valuation of emissions might provoke a government to implement a subsidy of renewables as a supplementary policy instrument. In the same vein, a renewable energy subsidy can be rationalized in a policy setting with volatile emission prices and a positive risk that the price drops to zero (Lecuyer and Quiron, 2013).

Additionally, the global nature of the climate externality demands a global solution. But international agreements are and might also in the conceivable future be often suboptimal. Consequently they will be only able to regulate a fraction of global GHG emissions. Hence additional instruments such as trade measures might be taken into consideration to secure competitiveness and reduce carbon leakage in case of unilateral mitigation efforts.

3. In Search for Post-2020 Policy Scenarios

This illustrates that policy makers do not act in a textbook world. They have to take decisions in a world with an endowment of an existing legislative stock and competing interests about the importance of the multiple, sometimes overlapping, policy goals as well as interactions of externalities and policy needs.

It is beyond the scope and capabilities of ENTRACTE to model all these different dimensions in the analysis of prospective policy instrument interactions. Therefore, policy scenarios are needed that address the possibilities in these different dimensions.

This is not the first attempt to design scenarios in order to assess the European climate policy. We therefore draw to a large extent on previous scenario analysis, in particularly the impact assessments of the Energy Roadmap 2050 (European Commission, 2011b).

The policy scenario defining process encompasses three parts:
1. In a first step, broad drivers that shape the economy and society in mid- and long term and particularly affect the efficiency and effectiveness of climate policy measures are defined. This contains parameters such as economic growth rates or future oil prices.

A full harmonization on the assumed manifestations of these drivers is beyond the scope of the ENTRACTE scenario efforts. Since ENTRACTE uses within its work programme several different models with different foci, such a harmonization might bring only limited benefits but could be time-intensive and absorb substantial capacities. Thus, a rather loose harmonization process concerning the fundamental drivers is proposed, which collects and presents information on the assumptions of the different models but demands an adjustment of these fundamentals only in cases where the assumptions are significantly different.

2. From what is state of the discussions as presented above we assume in the following that the long-term goal of the European climate policy is a reduction of domestic GHG emissions by 85% in 2050. Depending on the state of the economy and society, available abatement options and their costs, welfare costs due to losses in competitiveness but also the incentives to encourage innovations, several pathways that lead to the envisaged emission reduction are possible. Following the research structure of ENTRACTE as well as the current set up of climate policies, we distinguish between three different main routes:

(i) The first route puts its emphasis mainly on a direct reduction of GHG gases with the EU ETS as the main instrument. A sufficient high price per tonne of CO₂ should trigger the abatement decisions. Therefore, additional sectors might be included in the EU ETS or covered by an emission tax.

(ii) The second route focuses on the decarbonisation of the power sector and the respective deployment of renewable energy sources. This route puts its major emphasis on the decarbonisation of the power sector with a high penetration of renewable energy sources. Energy efficiency measures are less stringent and also the inclusion of other sectors in a stringent GHG mitigation regime is less comprehensive.

(iii) The third route puts a strong emphasis on energy savings and energy efficiency measures and addresses the reduction of GHG emissions mainly as a reduction in energy consumption. The deployment of renewables and stringent reduction targets play a less dominant role.

These three routes form the policy scenario set will be used within the ENTRACTE modelling studies. The potentials of the different routes have been already assessed in previous studies. Combinations of EU ETS reduction targets, non-EU ETS sector reduction targets and targets for energy savings and share of renewables for the respective scenarios that still reach the GHG reductions as demand by the Roadmap and the recent Green Paper have been analysed in the Impact Assessment. The targets act as markers reflecting the differences in the emphasis of the different fields of actions. For each of these three routes mid(2030)- and long(2050)-term targets will be set.

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2 For an overview about the different models used in ENTRACTE see Section 4.2
3. However, through which policy instruments those targets are addressed, stays open to the respective modelling teams and their research task. The detailed instrument choice depends on the respective task in ENTRACTE and the focus of respective analysis. By default it is assumed that the targets are always reached in a cost-effective way, i.e. the respective measures are undertaken with least cost. In the analysis of the respective tasks it is clear that the modelling teams will deviate from that principle and assess more specific situations.

Figure 2 explains the scenario process graphically. Each policy scenario has to be embedded in a specific model that assumes a set of economical, technological, and socio-political conditions that have to be classified according to the framework explained below. This classification will facilitate integration of outcomes concerning these drivers. The policy scenarios differ in their emphasis of renewables, energy efficiency measures and stringent CO₂ prices. These differences materialize in different targets in the respective fields of action. The instruments that are used to reach these targets are not defined at this stage. The instrument choice depends on the respective task and scope of analysis.

4. Broad Drivers and Applied Models

The total costs of any decarbonisation strategy depend on several factors which can be influenced by policy makers to a limited extent only. Variables that may influence the cost-effectiveness of the European climate policy depend on the evolution of several dimensions: (i) the state of the European economies after the current crisis and their potential to provide growth and jobs; (ii) fundamental determinates of energy markets such as projected fossil fuel prices on world markets, costs and public acceptance of technologies such as Carbon Capture and Storage (CCS) and nuclear power generation may lead to different costs; (iii) the international climate policy architecture influences the competitiveness effects of climate policy measures on the European industry and, hence, may call for counter measures such as border carbon adjustments.

The numerical models that are used in the ENTRACTE project are heterogeneous in their focus. Rather aggregated top-down models of the world economy with a relatively
aggregated set of sectors and regions coexist with integrated assessment models and bottom-up models of the European energy and electricity markets. The models applied in the projects have different modelling approaches, perspectives and tasks. Hence, they are also currently calibrated to different economic growth rates, projections of international commodity prices and other assumptions such as costs and penetration of technologies.

In light of the heterogeneity of the applied models and their different tasks reaching full harmonization in these underlying assumptions would be a demanding exercise. It should also be emphasised that the ENTRACTE project is focused on the evaluation of policies and its interactions rather than comparison of different model results. Thus, the benefits of such a full harmonization would be limited but binds scarce resources which should be invested rather in the policy evaluation.

Therefore, a strategy that aims for only a loose harmonization concerning underlying drivers and assumption has been proposed. The different modelling teams report their assumptions on fundamental drivers. Only in cases where the assumptions differ significantly from the framework assumptions applied in the Impact Assessment of the EU Roadmap which act as our reference additional harmonization efforts are necessary. The main purpose of this exercise is to understand better and classify the findings of the different models. The policy scenarios then are focussed mainly on different manifestations of policy routes to the long-term decarbonisation target. In the following, we span the space for the different dimensions of underlying assumptions.  

4.1. Drivers

Macroeconomic and demographic assumptions

As we know from the Kaya-Identity major factors that drive CO$_2$-emissions are population and GDP. Following the impact assessment (IA) of the Energy Roadmap 2050 (European Commission, 2011b) we draw on long term projections on population by Eurostat (EUROPOP2010, EUROpean POPulation Projections$^4$) as our main source. In 2010, the EU-27 had 501 Million inhabitants. EUROPOP2010 projects an increase to 525 Million but then starts to decline fast to 516 Million in 2060.

In the short term uncertainties regarding the economic perspectives in Europe and the world are substantial. The 2012 Ageing Report (European Commission, 2012) is the most recent long term economic projection of the European Union and also provides GDP growth rates for the impact assessments of the Energy Roadmap 2050. Following their Reference scenario, it is assumed that the recent economic crisis has long lasting effects, leading to somewhat subdued short run growth prospects. However, productivity gains lead to faster growth in the aftermath of the crisis. The average annual growth rate for the EU-27 in the period 2010–2030 is 2%. For the period of 2030–2050, 1.5% is projected. The high uncertainties in this domain are addressed with two variations. In the high growth variant, GDP per capita is 0.4 percentage points (pp) higher than in the Reference case throughout the projection period, whereas it would be 0.4 pp lower in the low growth case.

3 See the Appendix for a more detailed description of fundamental drivers.
4 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_projections. Note that is an updated version compared to the projections used in the impact assessment of the Energy Roadmap where the EUROPOP2008 convergence scenario has been used.
Energy Import Price Perspectives

Oil prices have been exceptionally volatile over the past several years, reaching a high of $145 in July 2008 (daily spot price in nominal dollars) and a low of USD 30 in December 2008, as the global recession substantially dampened energy demand and prices. This price uncertainty is also reflected in different oil price projections. In the Reference scenario of the Energy Roadmap 2050, prices per barrel crude oil are projected to reach 109 USD in 2030 and 132 USD in 2050 (in 2011 USD).

Driven by a combination of a shift to a lower demand and an increased supply, prices may also significantly fall. The differences among projections remain large. In the Impact Assessments low end variation a crude oil price of 95 USD/bbl in the year 2030 and 88 USD/bbl in 2050 is projected. On the other hand, higher demand growth in Non-OECD and supply restrictions may lead to a price increase. In the high end variation used in the Impact Assessment a crude oil price of 156 USD/bbl in the year 2030 and 167 USD/bbl in 2050 is projected.

Technology Projections

The 2020 Europe’s technology strategy to reach its environmental targets focus in three technological directions: Nuclear technology, Carbon Capture and Storage (CCS) and renewable technologies. The Roadmap assumes as Reference that CCS technologies face still some challenges before becoming commercially appealing. However, faster technological learning rates lead to decreasing adoption costs of renewable energy technologies compared to the Reference case. In addition, confidence in CCS as a credible and commercially viable technology increases.
International Climate Policy Perspectives

Climate change is a global problem and can tackled successfully only in a broad coalition. The costs of a unilateral regulation of GHG emissions also affect the competitiveness of the European companies and may have to cope with a reduced effectiveness due to the so called “carbon leakage”-effect.

A plausible reference case might hence include a global agreement implemented by 2020 on the basis of the Durban Platform. Within in this agreement developed countries are committed to reduce GHG emissions gradually from 2020 onwards. It is also possible scenario that by 2020 no comprehensive agreement is reached. Only unconditional planned measures are implemented with high regional variation in the stringency of policies. Nevertheless, in another possible future all major emitters, i.e. the developed countries as well as the BRIC countries begin to reduce their GHG emission in a coordinated fashion by 2020. Copenhagen Pledges will be further developed and made more stringent.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reference Future</th>
<th>Low End Variation</th>
<th>High End Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Capture and Storage (CCS)</td>
<td>Increase of its adoption after 2020 when there are more improvements in its application and reduction in adoption cost.</td>
<td>Lower CCS penetration in 2020 compared with the reference scenario given little progress in demonstration plants and storage management.</td>
<td>There are two variations in this case: higher and low penetration rate compare with reference scenario.</td>
</tr>
<tr>
<td>Nuclear Technology</td>
<td>Replacement of old plants for new ones and new projects in Poland. Phase out in Germany and Belgium.</td>
<td>Consequences of Japan nuclear accident Stress tests and other safety measures reflected through higher costs for retrofitting</td>
<td>Increase in acceptance due a safer use and waste management of this technology.</td>
</tr>
</tbody>
</table>

4.2. Numerical Models Applied in ENTRACTE

In the following we discuss briefly the different models in ENTRACTE and how they incorporate the above outlined assumptions.

LIBEMOD

LIBEMOD is a partial equilibrium model of the Western European natural gas and electricity markets, developed and maintained jointly by the Frisch Centre in Oslo and Statistics Norway. The model’s focus on EU climate and energy policy and its full range of instruments
– from taxes, tradable quotas to green certificates and feed-in tariffs – can be imposed. It
also allows for investments in CCS with customizable assumption on its costs. CCS can be
either added to existing plants and or new plants with CCS technology can be set up. The
model’s detailed representation of the energy markets permits for an endogenous calculation
of prices of energy commodities. LIBEMOD will be used in Task 3.2 examining the
interaction between renewable energy and climate policies with special emphasis on the
German nuclear phase out.

LIMES-EU+
LIMES-EU+ is a novel perfect foresight partial equilibrium model of the European electricity
sector to analyse climate and renewable policies and has been developed at PIK. It is
possible to model different scenarios of investment costs for nuclear technologies and CCS
as well as political restrictions on these projects. LIMES is relative flexible in its assumptions
on economic growth as well as energy prices. The model will be applied in Task 3.2 in order
to compare individual renewable policies of the EU with a harmonized EU-wide renewable
policy with special emphasis on differences in economic efficiency and technology choices.

OIL MODEL SN
OIL MODEL SN is a novel dynamic partial equilibrium model of the global energy sector with
emphasis on the oil market run by Statistics Norway (SN) as part of the joint CREE Centre
between SN and FCO. The model may consider several climate and energy policies such as
standards for biofuels and carbon prices in various world regions. Concerning its assumed
economic growth rates for the EU, the model can be located in the low end, while it is rather
optimistic for the rest of the world. As the model name may indicate, the oil price is
endogenously determined. The assumptions on future production and technology costs and
substitutability among alternative energy sources can be varied. The model has no explicit
specifications of the impacts of Nuclear and CCS technologies. The OIL MODEL SN will be
used in Task 3.1 to examine rebound effects and interactions via the petroleum markets
between climate policies and energy efficiency policies within transportation.

SNoW_No and SNoW_W
SNoW (Statistics Norway World models) describes a family of Computable General
Equilibrium (CGE) models run by Statistics Norway (CREE/FCO) used for energy and
environmental policy analyses. Whereas SNoW_No has a strong focus on Norway SNoW_W
is more focussed on policy consequences for world markets. SNoW_No assumes economic
growth rates for Norway well above what has been assumed in the Roadmap documents for
the EU. In addition, it allows for the option of CCS. SNoW_NO assumes that gas power
production in Norway can be subject to CCS and includes also bottom-up information on
energy efficiency technologies. SNoW_W assumes per default only little or no CCS. In the
analyses, the international climate policy coalition sizes are varied. The models will be
applied in Task 3.1 and Task 5.2, respectively.

WITCH
WITCH stands for World Induced Technical Change Hybrid model. It is a hybrid model
because the representation of technological details in the energy sectors has a rather
Bottom-up character whereas the long run dynamics induced by a neoclassical optimal
growth Top-down models are included as well. The model endogenously accounts for
technological progress, both through learning curves affecting prices of new vintages of
capital and through R&D investments. In addition, the model captures the main economic
interrelationships between world regions and is designed to analyse the optimal economic
and environment policies in each world region as the outcome of a dynamic game. Energy
commodity prices are an endogenous outcome and the model is flexible regarding underlying
assumptions on CCS and nuclear penetration. The assumptions on the baseline growth rate
are located rather in the high end variation assumed in the Roadmap impact assessment. WITCH will be used mainly in Task 4.2 to assess the implications of second-best international climate policies in terms of effectiveness and the ability to promote clean energy innovation.

**PACE**

PACE (Policy Analysis based on Computable Equilibrium) is an established dynamic multi-region, multi-sector computable general equilibrium model of global trade and energy use. In addition to the consistent representation of trade links PACE contains a detailed tracking of international energy flows and all energy prices are endogenous. In its current calibration it is rather located in the high end variation of the economic growth rates assumed in the EU Roadmap analysis.

**WIOD**

WIOD is a novel multi-region, multi-sector computable general equilibrium model in the tradition of PACE but calibrated with the recent data of the World Input Output Database. This allows in particular for a more detailed representation of international trade among intermediate producers. So far, WIOD is static and can be easily calibrated to any year provided with the WIOD database (1995-2009). The WIOD model will be mainly applied in Task 5.2 in order to investigate whether carbon tariffs succeed in reducing the carbon content of imported goods from non-regulated countries by creating an effective signal to foreign exporters.

Table 1 and Table 2 present an overview about the applied models, their structure and their underlying assumptions, respectively.

<table>
<thead>
<tr>
<th>Model</th>
<th>Economic coverage</th>
<th>Geographic coverage</th>
<th>Inter-temporal solution</th>
<th>General Solution</th>
<th>International trade</th>
<th>Time horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIBEMO D</td>
<td>PE energy sector</td>
<td>EU (30)</td>
<td>Static</td>
<td>Market equilibrium</td>
<td>F, E, B, CSS</td>
<td>2009 to open</td>
</tr>
<tr>
<td>LIMES- EU+</td>
<td>PE electricity sector</td>
<td>EU27</td>
<td>Perfect foresight in power sector</td>
<td>Optimization</td>
<td>Electricity</td>
<td>2010-2050</td>
</tr>
<tr>
<td>OIL MODEL SN</td>
<td>PE energy sector</td>
<td>Global</td>
<td>Inter-temporal optimization</td>
<td>Optimization</td>
<td>Oil</td>
<td>2007-2050</td>
</tr>
<tr>
<td>SNoW_ No</td>
<td>CGE</td>
<td>Norway</td>
<td>Possible Inter-temporal optimization</td>
<td>Market equilibrium</td>
<td>20 goods</td>
<td>2007-2050</td>
</tr>
<tr>
<td>SNoW_ W</td>
<td>CGE</td>
<td>Global</td>
<td>No</td>
<td>Market equilibrium</td>
<td>16 goods</td>
<td>2007, 2030</td>
</tr>
<tr>
<td>WITCH</td>
<td>FEC in optimal growth model</td>
<td>Global</td>
<td>Inter-temporal optimization</td>
<td>Optimization</td>
<td>Fossil fuels</td>
<td>2005-2010</td>
</tr>
<tr>
<td>WIOD</td>
<td>CGE</td>
<td>Global</td>
<td>Static</td>
<td>Market equilibrium</td>
<td>All commodities</td>
<td>2006-2030</td>
</tr>
<tr>
<td>PACE</td>
<td>CGE</td>
<td>Global</td>
<td>Recursive dynamics, Possible Inter-temporal optimization</td>
<td>Market equilibrium</td>
<td>All commodities</td>
<td>2006-2030</td>
</tr>
</tbody>
</table>

Table 1: Structure of the numerical models used in the ENTRACTE research project. PE=Partial equilibrium, FEC=Full economic coverage F=fossil fuels, E=electricity, B=biofuels, CSS=CO2 storage services.
Even though sharing similarities in their structure the models have considerable differences in their main assumptions. Regarding economic growth, one can see that most of the models can be classified according to the provided growth scenarios.

<table>
<thead>
<tr>
<th>Model</th>
<th>Economic growth</th>
<th>Oil Price</th>
<th>Gas Price</th>
<th>Coal Price</th>
<th>CCS</th>
<th>Nuclear technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIBEMOD</td>
<td>Reference Scen</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>LIMES-EU+</td>
<td>Static model</td>
<td>Flexible</td>
<td>Flexible</td>
<td>Flexible</td>
<td>Flexible</td>
<td>Flexible</td>
</tr>
<tr>
<td>OIL MODEL SN</td>
<td>EU: Mid-/Long-Term: Low</td>
<td>Endogenous</td>
<td>mid:468, long:535</td>
<td>mid:158, long:182</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>ROW: Mid-/Long-Term: High</td>
<td>Endogenous</td>
<td>mid:468, long:535</td>
<td>mid:158, long:182</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>SNoW_No</td>
<td>Mid-/Long-Term: High</td>
<td>Growth rate 2%</td>
<td>NA</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>SNoW_W</td>
<td>Reference to be determined</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Flexible</td>
<td>Flexible</td>
</tr>
<tr>
<td>WITCH</td>
<td>Mid-/Long-Term: High</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Flexible</td>
<td>Flexible</td>
</tr>
<tr>
<td>WIOD</td>
<td>Static model</td>
<td>Bench. calib. 2009</td>
<td>Bench. calib. 2009</td>
<td>Bench. calib. 2009</td>
<td>NA</td>
<td>Flexible</td>
</tr>
<tr>
<td>PACE</td>
<td>Mid-/Long-Term: High</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>Endogenous</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2: Energy prices, economic growth and technological assumptions used in the project’s models. Regarding economic grow assumption the models assumed values closely related with the reference, low and high end variations described above.

5. Policy Scenarios on the Road towards Decarbonisation

As discussed above, the EU plans to reduce its GHG emissions by 80% in 2050. First steps in this direction are set in the Energy and Climate Package that cover the period until 2020. The debate about post-2020 targets has just been started and it still an open question how many and how stringent midterm climate policy targets up to 2030 shall be in order to be on pathway that leads to the decarbonisation goals stated in the Roadmap.

Therefore, assumptions about the pathway to 2030 are necessary. Depending on underlying assumptions, inter alia, cost-effective decarbonisation pathways may differ. This can also be seen in different alternative decarbonisation scenario analyses that were commissioned by several different actors. Förster et al. (2012) summarizes the outcomes of the different decarbonisation scenario studies. Their analysis includes four different scenario studies.5

Figure 3 shows the actual shares in net electricity generation by source in 2008 as well as the shares in the different examined scenarios in 2050 for the EU-27. One key finding is the fact that in all scenarios renewable energy sources play a major role in the electricity sector.

5 Förster et al. (2012) include the following studies: Greenpeace and European Renewable Energy Council (2010), the 40%, 60% and 80% RES scenarios in European Climate Foundation (2010), the Eurelectric (2009) the Power Choices scenario and the decarbonisation scenarios in the European Commission (2011) Roadmap.
on the pathway to decarbonisation. Without a decarbonised power sector the envisaged decarbonisation targets are hard to meet. However, the scenario differ significantly in the potential of wind generated electricity. Whereas in the EU Roadmap High RES scenario about 50% of the electricity is produced by wind, other scenarios such as the Eurelectric and ECF 40% RES sees a larger role for CCS technologies with about 30% of electricity produced with either natural gas or coal in combination with CSS. The same holds for nuclear. While ten of eleven decarbonisation scenarios analysed envisages a declining role of nuclear power compared to 2008, the Eurelectric (2009) sees a marginally increased share of nuclear power.

Figure 3: Shares in net electricity generation by source (including imports) in the different scenarios in 2050 for the EU-27 (including Norway and Switzerland for ECF scenarios) and actual shares in 2008. Source: SEFEP 2012

The second similarity among all scenarios is the requirement to significantly improve energy efficiency and reduce electricity demand in non-transport sectors (where increasing electrical mobility causes an increase in demand). Förster et al (2012) contrast the EU’s past change in electricity intensity (electricity demand/GDP) with the future changes assumed in the four scenarios studies analysed. Figure 4 presents these findings and shows that in all scenarios electricity intensity has to be reduced much faster that it has been in the past two decades if an 80% decarbonisation of the European economies by mid of the 21st century is the objective.
Figure 4: Historical and modelled change in electricity intensity. The light blue area shows the variation within the scenarios of a certain study (data source: SEFEP 2012).

Having this uncertainties in mind, we derive in the following section from the different scenarios assumed in the Impact Assessment of the Energy Roadmap 2050 (European Commission, 2011b) policy targets that are compatible with the targets formulated in the EU Roadmap. The Impact Assessment assumes possible scenarios with differences in the weight of policy efforts in the different fields of action. The presented targets are based on the findings of the Impact Assessment where the PRIMES model has been used to calculate the impacts of the respective scenarios. Therefore, the presented targets are roughly consistent with the overarching target to reduce domestic European emissions by 80-90% in 2050.

5.1. Reference Scenario

The reference scenario corresponds to the same-titled scenario in the Impact Assessment. It projects the development in the absence of new policies beyond those adopted by March 2011. It is therefore not a scenario that fulfils the decarbonisation targets. It achieves the 2020 targets for RES and GHG, but there is no assumption on targets for later years besides the annual 1.74% reduction of the cap as outlined in the ETS directive.

It is estimated that a continuation of current policies would result in a 26% reduction in energy related CO₂ emissions between 1990 and 2030 and by 40% in 2050. Since today’s legislation addresses the emissions in the non-ETS sectors with a few measures only the majority of reduction will take place in the ETS sectors.

The Reference scenario assumes that the target on renewables set by the 20-20-20 Package will be achieved. Due to phasing out of financial support for mature renewable technologies penetration increases after 2020 only slowly.

The 20% energy saving objective, the third pillar in the Energy and Climate Package, has not been translated into binding legislation. Hence, this target would not be achieved under current policies. Under current developments energy consumption would decrease by 10% in 2020 compared to the 2007 projections. This can be translated into energy intensity improvements relative to 1990 levels of 46% (2030) and 59% (2050), respectively.

This scenario may serve as a reference to which the different scenarios are compared to.

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6 PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand and is maintained at the National Technical University of Athens.
5.2. Scenario Focussing on Direct Reduction of Emissions

The EU ETS is the cornerstone of European Climate Policy. Today, the EU ETS covers more than 11,000 installations in all 27 Member States plus installations in Iceland, Norway, and Liechtenstein. The installations regulated by the EU ETS are responsible for almost half of the EU's CO2 emissions and 40% of its total greenhouse gas emissions. So far, the EU ETS covers CO2 emissions from installations such as power stations, combustion plants, oil refineries and iron and steel works, as well as factories making cement, glass, lime, bricks, ceramics, pulp, paper and board, and since 2012 also aviation. With the start of the third trading period not only the current National Allocation Plans will be replaced by single, EU-wide cap and auctioning will become the default method for allocating allowances, but also further sectors will be included in the emission trading such as petrochemicals, ammonia and aluminium industries.

However, in order to reach the ambitious targets set in the roadmap, very likely additional sectors have to be included and deeper emission cuts are necessary. Decarbonisation in this scenario is mainly driven by carbon prices (in ETS and non-ETS sectors) without putting significant emphasis on other fields of action. The carbon price set abatement incentives, influences technology choices and demand behaviour.

The scenario corresponds to the Diversified Supply scenario in the EU Energy Roadmap 2050. Following the PRIMES calculations its achievements can be translated into targets as presented in Table 2. Under this scenario, GHG emissions have to be reduced within ETS sectors in 2030 by 54% and 15% in non-ETS sectors. This leads to share of 28% of renewables in gross final energy demand. Energy efficiency has to be improved by 51% relative to 1990 levels. In 2050 the respective targets are 84% reduction in GHG emissions (91% in ETS sectors, 73% in non-ETS sectors), 55% share of renewables, and 72% improvement in energy efficiency. Not that any target for renewables and energy efficiency below this number would just be not binding.

Table 4: Key figures and targets in different fields of action under the direct CO2 reduction scenario. All changes are relative to 1990 levels (source: European Commission 2011b).
5.3. Scenario Focussing on Energy Efficiency

This scenario is driven by a political commitment of very high primary energy savings by 2050. It includes a very stringent implementation of the Energy Efficiency Plan and aims at reaching close to 20% energy savings by 2020. Strong energy efficiency policies are also pursued thereafter. Policy measures in the respective sectors in order to reach these ambitious targets are listed in the following:

**Buildings**

High renovation rates for the existing building stocks need to be induced. From 2020 onwards, new buildings will have to be close to a zero-energy standard. This can be reached by the consequent refurbishment of public buildings, the use of financial mechanisms that allow to use the savings from the retrofit to pay for the investment costs (i.e. energy performance contracting), removing legal obstacles that limit the adoption of energy efficient measures (i.e. the landlord-tenant case), as well as training and the promotion of new energy-efficient technologies.

**Industry**

It is also key that energy efficiency in the industrial sector increases. This is expected to be achieved by the application of more advanced industrial processes and equipment, efforts to increase energy efficiency in electricity and gas networks, and more research and innovation that catalyses cost-effective energy efficient technologies in the industry.

**Transport**

Substantial improvements in the energy efficiency of the transport sector can be achieved by technological innovation in new engines, materials and design; cleaner energy use through new fuels and propulsion systems; better use of networks and safer and more secure operation through information and communication systems.

The scenario corresponds to the Energy Efficiency scenario in the EU Energy Roadmap 2050. Following the PRIMES calculations its achievements can be translated into targets as presented in Table 3. Under this scenario, GHG emissions will be reduced within ETS sectors in 2030 by 52% and 20% in non-ETS sectors, i.e. a shift in abatement from ETS sectors to non-ETS sectors. The share of renewables in gross final energy demand amounts to 28%, identical to the scenario focusing on direct CO2 emissions reduction. Energy Efficiency has to be improved by 53% relative to 1990 levels, somewhat more than in the first decarbonisation scenario. In 2050 the reduction in GHG emissions corresponds to the targets stated in the Roadmap (90% in ETS sectors, 75% in non-ETS sectors), 53% share of renewables, and 75% improvement in energy efficiency. Note that every target for renewables below this number (e.g. no target at all) would just not be binding.

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG reduction [%]</td>
<td>-40</td>
<td>-85</td>
</tr>
<tr>
<td>Reduction ETS sectors [%]</td>
<td>-52</td>
<td>-90</td>
</tr>
<tr>
<td>Reduction Non ETS sectors [%]</td>
<td>-20</td>
<td>-75</td>
</tr>
<tr>
<td>RES in gross final energy demand</td>
<td>28</td>
<td>57</td>
</tr>
<tr>
<td>Change Energy Efficiency [GFED/GDP]</td>
<td>-53</td>
<td>-75</td>
</tr>
</tbody>
</table>

Table 5: Key figures and targets in different fields of action under the energy efficiency scenario. All changes are relative to 1990 levels (source: European Commission 2011b).
5.4. Scenario Focussing on Renewable Penetration

In order to reach a share of 20% of renewables in the EU energy mix, electricity production from renewables should increase from the current 15% to approximately 34% of total electricity consumption in 2020. Wind generation is expected to contribute with 12% of EU electricity by 2020. It is also expected that one third of those will come from offshore installations. The biomass sector should grow significantly using wood, energy crops and bio-waste in power stations. Technologies such as photovoltaic (PV), solar thermal power, wave & tidal power, are expected to face a significant cost reduction and therefore a faster penetration rate.

But in order to reach the long term decarbonisation targets by 2050 the power sector has to become almost carbon free (around 90% share of renewables and close to 100% related to final consumption).

The scenario corresponds to the High RES scenario in the EU Energy Roadmap 2050. Following the PRIMES calculations its achievements can be translated into targets as presented in Table 6. Under this scenario, GHG emissions will be reduced within ETS sectors in 2030 by 57% and 15% in non-ETS sectors. The share of renewables in gross final energy demand envisages to 31%, about 3 percentage points higher than in the previous scenario, Energy Efficiency improves by 50% relative to 1990 levels, 3 percentage point lower than in the Energy efficiency scenario. In 2050 the respective targets are an 84% reduction in GHG emissions (90% in ETS sectors, 35% in non-ETS sectors), 73% share of renewables, and 75% improvement in energy efficiency. Note that in this scenario that focuses on RES, every target for energy efficiency below this number would just be not binding.

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emission reduction [%]</td>
<td>-40</td>
<td>-84</td>
</tr>
<tr>
<td>Reduction ETS sectors [%]</td>
<td>-57</td>
<td>-90</td>
</tr>
<tr>
<td>Reduction non-ETS sectors [%]</td>
<td>-15</td>
<td>-73</td>
</tr>
<tr>
<td>RES in gross final energy demand</td>
<td>31</td>
<td>73</td>
</tr>
<tr>
<td>Change Energy Efficiency [GFED/GDP]</td>
<td>-50</td>
<td>-73</td>
</tr>
</tbody>
</table>

Table 6: Key figures and targets in different fields of action under the High RES scenario. All changes are relative to 1990 levels (source: European Commission 2011b).

6. Final Remarks

To design effective, economically efficient and politically as well as legally feasible climate policy mixes to reach the decarbonisation targets of the European economy is the final aim of the ENTRACTE project. This goal requires a better understanding of the interactions between instruments and targets. Those analyses are based to some extent on numerical ex-ante simulations. In order to facilitate the drawing of overarching conclusions it is therefore crucial to harmonize future policy assumptions having a clear idea of the weight that is placed on renewable targets, carbon emission reductions and explicit energy efficiency goals. This paper provides a set of four policy scenarios along these three different decarbonisation routes:
(i) A reference scenario that achieves the 2020 targets for RES and GHG, but without assumptions on targets for later years besides the annual 1.74% reduction of the cap in the ETS as outlined in the ETS directive.

(ii) A decarbonisation scenario that is mainly driven by carbon prices (in ETS and non-ETS sectors) without putting significant emphasis on other fields of action. The carbon price set abatement incentives, influences technology choices and demand behaviour.

(iii) A scenario that is driven by a political commitment of very high primary energy savings by 2050. It includes a very stringent implementation of the Energy Efficiency Plan and aims at reaching close to 20% energy savings by 2020.

(iv) A scenario that aims for a strong decarbonisation in the power sector in particular and envisages in particular the deployment of renewables in the energy sector.

The broad range of analysed topics with multidimensional policies with a broad set of different models, from bottom-up energy market models to integrated assessments models, makes it difficult to define a set of scenarios that fits to all purposes. We therefore propose a structure which gives the individual modelling teams as much freedom as possible in order to implement the respective policies to analyse but harmonize as much as possible in order to be able to draw conclusions that go beyond the single model analyses and benefit from the heterogeneity and different strengths of the different models. This is a balancing act and it needs a careful understanding of needs of the different modelling groups. We hope this paper facilitates the cooperation and communication and helps to sharpen the view about the consequences of the different decarbonisation routes of the European economies.
7. References


Appendix

A1. Macroeconomic and demographic assumptions

As we know from the Kaya-Identity major factors that drive CO2-emissions are population and GDP. Following the impact assessment (IA) of the Energy Roadmap 2050 (European Commission, 2011b) we draw on long term projections on population by Eurostat (EUROPOP2010, EUROpean POPulation Projections\(^7\)) as our main source. EUROPOP2010 is the most recent population projection scenario for the 27 Member States of the European Union (EU). Three topics are of particular importance and may also affect European climate policy: (i) the decreasing growth of Europe’s population and an even negative growth after 2045, (ii) the increasing ageing of the European society, and (iii) inward migration. In 2010, the EU-27 had 501 Million inhabitants. EUROPOP2010 projects an increase to 525 Million but then starts to decline fast to 516 Million in 2060. However, on member state levels the pattern is more divergent. United Kingdom steadily grows from 62 Million now to almost 80 Million in 2060 and is becoming Europe’s most populous country. Also France is growing, although with a slower pace, from now 62 Million to 71 Million. This contrasts strongly with the sharp decrease of the current most populous country in the EU. Germany, with a population of 81 Million in 2010, is confronted with a fast decrease to only 66 Million inhabitants in 2060; then only the third biggest EU country in terms of population size. Expressed in growth rates, the EU-27 population grows with 0.3% per annum (p.a.) in 2015 but with a decreasing rate and a decreasing rate from 2040 on. The old-age dependency ratio increases from 26 to 52.5. However, due to slow changes in population patterns there is no significant variation to be expected between scenarios.

![EU-27 demographic forecasts](http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_projections). Note that is an updated version compared to the projections used in the impact assessment of the Energy Roadmap where the EUROPOP2008 convergence scenario has been used.

Figure 5: EU-27 demographic forecasts. Source: EUROPOP2010

In the short term uncertainties regarding the economic perspectives in Europe and the world are substantial. The 2012 Ageing Report (European Commission, 2012) is the most recent long term economic projection of the European Union. It provides the GDP growth rates for the European Commission’s impact assessments of the Energy Roadmap 2050. However, compiled in 2011, it does not take into account the impacts of measures that are envisaged...
to be implemented under the economic adjustment programmes as well as the monetary policy measures by the European Central Bank.

Following the Reference scenario of the Impact Assessment of the Energy Roadmap 2050, it is assumed that the recent economic crisis has long-lasting effects, leading to somewhat subdued short-run growth prospects. However, productivity gains lead to faster growth in the aftermath of the crisis. Average annual growth rate for the EU-27 in the period 2010 – 2030 is 2%. For the period of 2030 – 2050, 1.5% is projected. EU-12 growth is considerably higher in 2010-2030 (2.7% p.a.) but significantly smaller post 2030 due to shrinking and ageing population (0.9% p.a.).

The high uncertainties are addressed with two additional scenarios. In the high growth variant, GDP per capita is 0.4 percentage points (pp) higher than in the Reference case throughout the projection period, whereas it would be 0.4 pp lower in the low growth case. Higher economic growth would be driven mainly by growth in the service sector, which would hence lead to a decrease of the energy intensity of the European economy. The output reduction in the low growth scenario would affect all scenarios by the same degree, only agriculture would be confronted with somewhat smaller losses compared to the Reference case.

<table>
<thead>
<tr>
<th>Reference Future</th>
<th>Low End Variation</th>
<th>High End Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU-27 population grows with 0.3% p.a. in 2015 but with a decreasing rate. From 2040 on the EU-27 population decreases. Average annual GDP growth rate for the EU-27: 2010 – 2030: 2%. 2030 – 2050: 1.5%</td>
<td>EU-27 population grows with 0.3% p.a. in 2015 but with a decreasing rate. From 2040 on the EU-27 population decreases. Average annual GDP growth rate for the EU-27: 2010 – 2030: 1.6%. 2030 – 2050: 1.1%</td>
<td>EU-27 population grows with 0.3% p.a. in 2015 but with a decreasing rate. From 2040 on the EU-27 population decreases. Average annual GDP growth rate for the EU-27: 2010 – 2030: 2.4%. 2030 – 2050: 1.9%</td>
</tr>
</tbody>
</table>

**A2. Energy Import Price Perspectives**

Oil prices have been exceptionally volatile over the past several years, reaching a high of $145 in July 2008 (daily spot price in nominal dollars) and a low of $30 in December 2008, as the global recession substantially dampened energy demand and prices. This price uncertainty is also reflected in the different oil price projections. In the reference scenario used in impact assessment of the Energy Roadmap 2050, prices per barrel crude oil are projected to reach 109 US$ in 2030 and 132 US$ in 2050 (in 2011 US$). The reference scenario in the International Energy Outlook 2011 (EIA 2011) projects a price of 128 US$/bbl by 2030. The new policies scenario of the most recent World Energy Outlook 2012 (IEA 2012) projects a price of 125 US$/bbl.

Driven by a combination of a shift to a lower demand and a shift to an increased supply, prices may also significantly fall. The differences among projections remain large. In the IA a crude oil price of 95 2011US$/bbl in the year 2030 and 88 US$/bbl in 2050 are projected. The Low Oil Price case of the International Energy Outlook 2011 (EIA 2011) projects by 2030 a price of 52 US$/bbl. The 450 Scenario of the WEO 2012 (IEA 2012) projects 105 US$/bbl by 2030.
Higher demand growth in Non-OECD and supply restrictions will lead to an increase of prices. The high price scenarios are even more heterogeneous among the different sources. In the High End scenario used in the IA a crude oil price of 156 2011US$/bbl in the year 2030 and 167 US$/bbl in 2050 are projected. The High Oil Price case of the International Energy Outlook 2011 (EIA 2011) projects by 2030 a price of 194 US$/bbl. The Current Policies Scenario of the WEO 2012, the scenario with the highest oil prices, (IEA 2012) projects 140 US$/bbl by 2030.

<table>
<thead>
<tr>
<th>Reference Future</th>
<th>Low End Variation</th>
<th>High End Variation</th>
</tr>
</thead>
</table>

**A3. Technology Projections**

The 2020 Europe’s technology strategy to reach its environmental targets focus in three technological directions: Nuclear technology, Carbon Capture and Storage (CCS) and renewable technologies. We consider these technologies and their possible evolution based on the Roadmap. In the Roadmap there are three scenarios that – based on assumption on learning curves and economies of scale – project the adoption cost of several technologies. Note that in the Roadmap quantifying the effect of technological changes on cost and prices also implies assuming the application of certain policies. Consequently, we only concentrate in the qualitative aspect of the Roadmap technological scenarios.

Based on assumptions about macroeconomic, technological and socio-political conditions these scenarios are used to identify the challenges that the EU will face to reduce its greenhouse gas emissions (i.e. 80-95%) below 1990 levels by 2050. However, there are variations in the technological and socio-political dimensions of these assumptions.

The Roadmap modelling in the reference scenario assumes a gradual reduction on operational aid to renewable (RES) for power generation according to the maturity of the individual technology that is used. In particular, technologies, such as solar PV, wave, tidal and off-shore wind at difficult sites are expected to receive aids in the longer term. However, for more mature technologies such as onshore wind, aid is assumed to be phased out completely by 2025. It is assumed that renewable (RES) technology costs come down as well as government aids. Carbon Capture and Storage (CCS) technologies face still some challenges to become commercially appealing. In this scenario, it is assumed that this will happen after 2020. There are also new projects of nuclear generation in Poland and replacement of old plants for new ones in already existing places. However, nuclear generation in Germany and Belgium is phased out.

Unlike the reference scenario, in the low end variation scenario the consequences of the Japanese nuclear accident are taking into consideration. It is also assumed that the nuclear program in Italy and Germany are abandoned. In addition it is assumed a higher generation costs of this technology reflecting higher safety requirements as well as introduction of a risk premium for new nuclear power plants. This scenario assumes significantly lower CCS penetration in 2020 compared the reference scenario due to moderate recent progress in
demonstration plants. These concerns also comprise potential problems with storage management.

In the Decarbonisation scenarios, the use of the same technologies is assumed as in the reference scenario, however, it is also assumed more optimistic and faster technological learning rates that decrease of the adoption cost of renewable technologies compared with the reference scenario. It also assumes more stringent climate policies to increase the adoption of these technologies. In addition, there is an increase in confidence in CCS as a credible and commercially viable technology. In this scenario there are two variations in nuclear and CCS technology. In the first one, there is high acceptance of investors and society in nuclear power generation because safety is considered adequate and waste issues are solved. Simultaneously, CCS technologies have a low rate of adoption due to increase in its adoption cost. There is also an opposite scenario called low nuclear. Here after the Fukushima accident and problems with the waste management of nuclear technology prompt low adoption rates whereas CCS has overcome its technical difficulties increasing its acceptance and market penetration.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reference Future</th>
<th>Low End Variation</th>
<th>High End Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Capture and Storage (CCS)</td>
<td>Increase of its adoption after 2020 when there are more improvements in its application and reduction in adoption cost.</td>
<td>Lower CCS penetration in 2020 compared with the reference scenario given little progress in demonstration plants and storage management.</td>
<td>There are two variations in this scenario: higher and low penetration rate compare with reference scenario.</td>
</tr>
<tr>
<td>Nuclear Technology</td>
<td>Replacement of old plants for new ones and new projects in Poland. Phase out in Germany and Belgium.</td>
<td>Consequences of Japan nuclear accident Stress tests and other safety measures reflected through higher costs for retrofitting</td>
<td>Increase in acceptance due a safer use and waste management of this technology.</td>
</tr>
</tbody>
</table>

A4. International Climate Policy Perspectives

Climate change is a global problem and can tackled successfully only in a broad coalition. However, the degree of carbon regulation in countries outside the EU matters not only for the classical freerider problem that comes along with unilateral contribution to a public good such as the climate. The costs of these regulatory measures also affect the competitiveness of the European companies and may reduce the effectiveness due to the so called “carbon leakage”-effect.

An observer of the current state on the efforts to conclude negotiations on a multilateral agreement to reduce worldwide GHG emissions may notice two key facts: (i) the institutionalized Kyoto process under the auspices of the UNFCCC is stagnant and in a dead-end. The Kyoto protocol was a first attempt to regulate the emissions of GHG on a multilateral level. This attempt was only partly successful: worldwide GHG emissions increased by almost 40% between 1990 and 2009. (ii) The frustrating multilateral consensus–finding approach within the UNFCCC is replaced to some extent by a web of unilateral commitments and sub-global initiatives such as the Major Economies Forum.
Essential to these approaches, summarized and enhanced in the Copenhagen Accord, Cancun Agreements and in the Durban Platform for Enhanced Action, is the departure from the old Annex I/non-Annex I dichotomy. This distinction between developed countries with reduction targets and less developed without targets was one of the building blocks of the Kyoto process but became through the fast growth in wealth and emissions in the emerging economies rather a stumbling block (see Aldy and Stavins, 2012). The Durban Platform calls now for a comprehensive legal regime by 2020 that essentially eliminates the Annex I versus non–Annex I distinction.

A plausible reference scenario might hence include a global agreement implemented by 2020 on the basis of the Durban Platform. Within in this agreement developed countries are committed to reduce GHG emissions from 2020. Following the assumptions in the EMF 22 scenarios on international policy architectures (Clarke et al., 2009) we assume a gradually increase in the efforts of developing countries to reduce emissions from 2020 on. There is an increasing incentive to coordinate international climate policy measures and to link national emission trading schemes. This leads to a gradually convergence of emission prices towards the least cost mitigation options.

However, international climate policy has been always characterized by unsteady developments. The difficulties to negotiate a new multilateral trade agreement may also indicate that the international political landscape is becoming more complex since boundaries between developed and developing countries are more blurry. Stagnant economic development shifts the political attention to other fields and economic costs of mitigation are rated with higher weight. It is therefore also a possible scenario that there is no comprehensive agreement by 2020. Only unconditional planned measures are implemented with high regional variation in the stringency of policies.

Nevertheless, in another possible future all major emitters, i.e. the developed countries and the BRIC countries begin to reduce their GHG emission in a coordinated fashion by 2020. Copenhagen Pledges will be further developed and made more stringent. The already existing but as well the new regional emission trading schemes are linked and regulated comprehensively. This leads to an efficient global carbon price and mitigation is undertaken where it is least costly.

<table>
<thead>
<tr>
<th>Reference Future</th>
<th>Low End Variation</th>
<th>High End Variation</th>
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<tbody>
<tr>
<td>Following the Durban Platform there is a comprehensive global reduction scheme by 2020. BRIC countries enter mitigation gradually later. There is slow convergence in emission prices.</td>
<td>No global agreement by 2020. Only unilateral implemented and fragmented policies with little international coordination and large heterogeneity in the stringency of policies.</td>
<td>All major emitters (Annex 1 plus BRIC) start to reduce GHG emissions in a coordinated fashion in 2020. Cap-and-Trade systems are linked worldwide and mitigation is undertaken where it is least costly.</td>
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