CHAPTER 9:
Comparison of scenarios and conclusions

9.1. Key findings for the scenarios examined

The scope of the analysis presented in the previous chapters of this volume was to exploit the possible evolution of the EU-25 energy system in the horizon to 2030 under different assumptions as regards economic growth, international fuel prices and the level of implementation of various policies. In that framework a number of scenarios and variants were defined and examined against the Baseline scenario which reflects the evolution of the EU-25 energy system under current trends and policies. The different aspects examined in that context were the following:

- Different views for the world economic and energy developments that give rise to alternative scenarios with contrasting oil and gas price profiles.
- Alternative economic growth cases for the future economic development of the EU-25 given the currently prevailing uncertainties.
- The role of a faster implementation of policies towards energy efficiency, guided by the "Action Plan to Improve Energy Efficiency in the European Community", further enhanced by substantial policies on renewables with a view to achieving the 12% renewables target set for 2010.
- Different developments as regards the use of nuclear energy in the EU examining two quite divergent directions: one in which improved technology that would find acceptance in the Member States leads to a higher contribution of nuclear energy in the long run, and a second in which a phase-out of nuclear in the entire EU occurs.
- The implementation of policies in the transport sector in line with the Option C scenario of the White paper on Common Transport Policy.
- Combinations of the above policies with a view to improving security of supply for the EU and reducing CO_2 emissions.
- Analysis of the repercussions that the introduction of Kyoto type constraints (and possible post Kyoto targets) would generate for the EU-25 energy system.

In the following the main findings of the key scenarios examined as well as the possible synergies and/or trade-offs of the various policies for the EU-25 energy system are discussed.

The **Baseline scenario** (presented in Chapter 1), which acts as the reference case against which all other cases examined are compared, reflects a continuation of existing trends and takes into account current policies and those in the process of being implemented at the end of 2001 (without including the implementation of the renewables electricity Directive of September 2001; tax rates reflect the situation in mid 2002).In the Baseline scenario energy demand continues to grow in the EU-25, but at a considerably lower pace than GDP (+0.6% pa in 2000-2030 compared to +2.4% pa respectively), thus leading to marked improvements of energy intensity (gross inland consumption / GDP) that reach 1.7% pa. Some of the key drivers towards the projected energy intensity improvements are the structural changes in the demand side (such as the further dematerialisation of the EU-25 industry), saturation effects for a number of energy uses (including the slowdown of transport activity growth), better efficiency and technology in the individual sectors, investment decisions in power generation, and changes in the fuel mix towards the use of more efficient energy forms both in the demand and the supply side. In addition to the above, new Member States are characterised by a larger scope for energy intensity gains (given the large inefficiencies that prevailed in the past in their energy systems, especially in CEEC) compared to the EU-15.

Fossil fuels will continue playing a predominant role in satisfying energy needs in the EU-25 over the projection period, exhibiting however reverse trends in the horizon to 2015 and in 2015 to 2030. Thus, demand for fossil fuels grows at rates below average in 2000-2015 with their share over primary energy needs declining by close to -0.5 percentage points in 2015 from their 79.6% in 2000. Beyond that date, and as a substantial decline occurs in nuclear power plants capacity following the nuclear phase-out policies for a number of EU Member States, the closure of nuclear plants with safety concerns in new Member States, or the decisions of economic actors not to replace nuclear plants at the end of their lifetime with new nuclear plants, demand for fossil fuels grows at rates well above average with their share reaching 81.8% of overall energy needs in 2030.

Renewable energy forms exhibit the highest growth among all energy forms under Baseline assumptions (+1.9% pa in 2000-2030; more than three times higher than the corresponding growth in overall primary energy needs) spurred by the further exploitation of renewable options in the supply side. Nevertheless, their share in 2030 amounts to only 8.6% of primary energy needs (from 5.8% in 2000 and 7.4% in 2010), well below the indicative targets set within the EU in the horizon to 2010.

The transport and power generation sectors play a predominant role as regards the projected evolution of the EU-25 energy system in the horizon to 2030. The transport sector, characterised by the lack of alternatives as regards changes in the fuel mix away from liquid fuels in the absence of strong policies in this direction, exhibits a continuous growth of energy needs over the projection period despite the projected decoupling of transport activity from economic growth in the long run. As a result the transport sector accounts in 2030 for 32.2% of energy requirements and 49.3% of CO_2 emissions in the demand side (from 30.9% and 42.6% respectively in 2000).

The power generation sector needs to meet increasing electricity and steam demand (growing at rates of +1.5% pa and +1.4% pa, respectively, in 2000-2030) both of which gain additional market share in the demand side in the Baseline scenario. Thus, the sector is faced with strategic technology and fuel choice dilemmas in replacing existing capacity (some 90% of which will be decommissioned by 2030) and further expanding it so as to satisfy additional demand. The strong decline in the use of nuclear energy beyond 2015 that leads to a significant comeback of solid fuels results in a significant growth of CO_2 emissions from the EU-25 power generation sector. Thus, in 2030 the power generation sector accounts for 64.5% of incremental CO_2 emissions from 2000 levels in the EU-25 energy system.

CO_2 emissions for EU-25 are projected to remain below 1990 levels in 2010 (-0.3%) under Baseline assumptions, a result strongly related to the accession of new Member States in the EU but also to the changes in the fuel mix towards the use of less energy intensive energy forms. The restructuring of CEEC economies in the nineties resulted in a substantial decline of CO_2 emissions by -20.4% between 1990 and 2000 in new Member States whereas in the same period CO_2 emissions grew by +1.2% in the EU-15. In 2010, CO_2 emissions in the EU-15 are projected to increase +4.0% from 1990 levels exhibiting a significantly less pronounced growth to that for primary energy needs in the same period (+19.3%) as a result of changes in the fuel mix towards the use of natural gas and renewable energy forms. The same trends are also observed in new Member States with CO_2 emissions decreasing -19.7% from 1990 levels in 2010 compared to a decline of primary energy needs by -10.8%. However, beyond 2010, and as available options for changes in the fuel mix of the demand side become highly exploited while coal re-emerges in the supply side in replacing nuclear energy, CO_2 emissions increase to reach +14.2% from 1990 levels in 2030 (+19.0% in the EU-15, -7.6% in the NMS).

The increasing role of fossil fuels in the EU-25 energy system under Baseline assumptions, combined to the declining trends as regard their indigenous production, gives rise to a further growth of import dependency which is projected to reach 67.3% in 2030 from 47.2% in 2000. Thus, under Baseline assumptions the EU-25 energy system will be faced with increasing CO_2 emissions and security of supply concerns, despite the significant improvements in terms of energy intensity and the higher exploitation of renewables.

A different evolution of world energy prices, examined in Chapter 2, generates some changes in the future evolution of the EU-25 energy system without however altering the main trends observed under Baseline assumptions. In the **high oil and gas prices** case world oil and gas prices are 20% and 33% higher respectively than in the Baseline in 2030. With these higher prices the EU-25 energy system achieves some additional energy intensity gains of 0.4% from Baseline levels in 2030, further accompanied by changes in the fuel mix occurring to the detriment of natural gas (-13.6% from Baseline levels in 2030). Demand for liquid fuels remains rather unchanged (-1.5% from Baseline levels in 2030) as the oil price increase does not lead to changes in the fuel mix in the transport sector, the main consumer of oil products in the EU. The gap generated is largely covered by solid fuels (+16.9% in 2030) and renewable energy forms (+18.6%) whereas nuclear energy exhibits a limited growth above Baseline levels (+3.1%). The share of renewables in primary energy needs reaches 10.3% in 2030 (+1.7 percentage points from Baseline levels) whereas import dependency is also projected to decrease compared to the Baseline scenario being limited to 64.2% in 2030 (from 67.3% in the Baseline) as a result of the higher exploitation of indigenous energy sources. CO_2 emissions in the EU-25 energy system increase +13.5% from 1990 levels in 2030 (compared to +14.2% in the Baseline scenario) as energy intensity gains in combination to the higher exploitation of renewables and nuclear energy more than counterbalance the further growth of solid fuels.

Besides the "high oil and gas prices" case, three additional cases on world energy prices were examined. It is interesting to note that even in the "Soaring oil and gas prices" case, in which an increase of international oil and gas prices by 80% from Baseline levels from 2010 onwards was assumed, the EU-25 energy system would follow similar trends to those under Baseline assumptions, though at a significantly slower pace, with primary energy needs increasing by 0.5% pa in 2000-2030 (from 0.6% pa in the Baseline). Renewable energy forms, which become considerably more competitive in that context, gain additional market share accounting by 2030 for 11.2% of primary energy needs in the EU (9.1% in 2010). However, CO_2 emissions reach similar levels to those observed in the Baseline scenario as solid fuels have a significantly greater role in satisfying energy needs, leading to a worsening of carbon intensity that counterbalances the projected energy intensity gains and the higher exploitation of renewables. Import dependency is projected to grow at a slower pace reaching 62.4% by 2030.

The key importance of the economic development on the evolution of the energy system is revealed in the **high** and **low economic growth** cases, discussed in Chapter 3. The "high economic growth case" assumes a GDP growth of 2.7% pa in 2000-2030 (from 2.4% pa in the Baseline) being more in line with the Lisbon economic growth targets. On the contrary, the "low economic growth" case assumes that the current economic slowdown will continue with GDP growth in the EU being limited to only 2.0% pa in 2000-2030. The "high economic growth" case leads to a significant increase of energy requirements and CO_2 emissions compared to the Baseline scenario, the inverse occurring in the "low economic growth" one. However, the analysis shows further changes in the evolution of the EU-25 energy system. The "high economic growth" case is characterised by additional energy intensity gains (primary energy needs increase by +7.4% from Baseline levels in 2030 whereas GDP is 10.7% higher in the same year). However, there is also a worsening of carbon intensity with CO_2 emissions growing by +8.3% from Baseline levels in 2030. On the contrary, in the "low economic growth" case energy needs in the EU-25 energy system decline by -7.5% from Baseline levels in 2030 compared to a decline of -10.7% for GDP, implying a less pronounced improvement of energy intensity. At the same time CO_2 emissions decrease by -8.6% from Baseline levels, i.e. more than energy demand giving rise to a slight improvement in carbon intensity.

The higher energy intensity gains in the "high economic growth" case stem from further dematerialisation of the EU economy, accompanied by a faster adoption of more efficient equipment by consumers. However, as energy needs further grow on top of Baseline levels the potential changes in the fuel mix towards the use of less carbon intensive or carbon free energy forms become increasingly exhausted, thus leading to a worsening of carbon intensity. The opposite trends are present in the "low economic growth" case, where there is e.g. less dematerialisation, while the less pronounced growth of energy needs allows for a higher market share of low carbon intensive and non-fossil fuels in the energy system. Nevertheless, in both cases renewable energy forms gain some additional market share from Baseline levels reaching 8.8% in 2030 for the "high economic growth" case (as economic growth above Baseline levels allows for a more pronounced penetration of renewables) and 8.9% in the "low economic growth" case (as demand for renewables declines at rates well below average). Import dependency reaches 68.5% in 2030 in the "high economic growth" case and 65.7% under "low economic growth" case assumptions (+1.2 and -1.6 percentage points respectively from Baseline levels).

The **Energy efficiency and 12% renewables share in 2010** case, discussed in Chapter 4, aims at simulating the energy and environment effects (in terms of CO_2 emissions) of successfully implementing strong policies for both energy efficiency and renewables as far as such measures can be modelled. The policies included relate to those recently adopted or currently under discussion. They do not include future initiatives that address a time horizon beyond 2010 as such policies have not yet been debated, and no concrete proposals have yet been put forward. Thus, renewables policies are in a sense "frozen" at 2010 in this scenario.

The results obtained from the "Energy efficiency and 12% renewables share in 2010" case clearly reveal the large scope existing as regards further improvements in terms of energy intensity in the EU-25 energy system with primary energy needs growing at a rate of 0.07% pa in 2000-2030 (compared to 0.6% pa in the Baseline scenario). This decline is also accompanied by significant changes in the fuel mix with a large increase in use of renewable energy forms (both in absolute and market share terms) while the demand for all other energy forms declines (especially for solid fuels which falls -37.5% in 2030 compared to Baseline). The share of renewable energy forms rises to 12.1% in 2010 and 14.4% in 2030 (+4.7 and +5.8 percentage points' respectively above Baseline levels). CO_2 emissions are also projected to be strongly affected by the implementation of policies towards energy efficiency and the promotion of renewable energy forms, remaining not only well below Baseline levels over the projection period (-11.9% in 2010, -22.5% in 2030) but also below those implied in the Kyoto targets for 2010 (-12.2% from 1990 levels). Even in 2030, CO_2 emissions are projected to remains -11.5% below 1990 levels. Import dependency is also reduced by supportive policies for energy efficiency and renewables. In 2010 import dependency is limited to 48.7% (compared to 47.2% in 2000 and 53.1% in the Baseline), whereas in 2030 it is projected to be 61.5% (-5.9 percentage points below Baseline levels).

Furthermore, two additional cases were examined focusing separately on the impact of the implementation of policies towards energy efficiency and that of promoting policies for renewables. The results obtained, in comparison to the "Energy efficiency and 12% renewables share in 2010" case, show that there are synergies in combining policies promoting renewable energy forms and energy efficiency.

Nuclear energy is one of the key uncertainties and drivers for the future evolution of the EU-25 energy system. Therefore, a number of quite different cases with contrasting characteristics were examined and discussed in Chapter 5.

The **New nuclear technology accepted** case assumes that new nuclear designs (such as the European Pressurised Water Reactor (EPR) and the Westinghouse AP technology) with improved passive safety characteristics become mature by 2010. It is furthermore assumed that this would ease public opinion concerns towards nuclear energy and lead to the re-evaluation of declared nuclear phase out policies in EU-25 Member States. Under these assumptions the EU-25 power generation sector undergoes significant changes compared to the Baseline scenario while the evolution of the demand side remains similar to that in the Baseline. Nuclear capacity exhibits a significant growth above Baseline levels, especially in the long run, reaching 199.5 GW in 2030 (from 140.3 GW in 2000 and 107.8 GW in 2030 under Baseline assumptions). The projected increase in electricity generation from nuclear energy (+63.2% from Baseline levels in 2030) occurs mainly to the detriment of solid fuels (-22.9% in 2030) and, to a smaller extent, natural gas (-9.8%). This results in an increase of total gross inland consumption (+3.6% in 2030) because nuclear power plants have a lower efficiency than natural gas or solid fuel fired power stations. Nuclear energy accounts for 16.3% of primary energy needs in 2030 (the highest nuclear share ever) compared to 9.5% in the Baseline scenario. Moreover, there is only a limited decline in the market share of renewable energy sources, from 8.6% in the Baseline scenario in 2030 to 8.3% in the "New nuclear technology accepted" case. Therefore, the carbon intensity of the EU-25 energy system exhibits a significant improvement from Baseline levels with CO_2 emissions in 2030 decreasing by -5.6%. Furthermore, the lower dependence of the EU-25 energy system on fossil fuels (accounting for 75.5% of primary energy needs in 2030 compared to 81.8% in the Baseline scenario) allows for a significant reduction in import dependency, which reaches 62.1% in 2030 (-5.2 percentage points below Baseline levels).

The above trends are reversed in the **nuclear phase-out** case that assumes that nuclear production ceases in the EU-25 in 2010, with nuclear closure being well anticipated by power generators already from 2005 leading to only limited changes in the demand side. In that case solid fuels and natural gas are the main drivers for covering the gap generated in the power sector with the role of solids becoming increasingly important in the long run, while renewable energy forms are also projected to make some additional inroads compared to the Baseline scenario. Primary energy needs decline from Baseline levels (-4.0% in 2030) as a result of the replacement of nuclear power plants with more efficient ones whereas the significant worsening of carbon intensity is clearly reflected in the projected evolution of CO_2 emissions that reach 7.4% above Baseline levels in 2030. A complete nuclear phase-out would increase CO_2 emissions by more than 300 mill t CO_2 in the projection period, which means, in terms of the 1990 emission level, to add another 9 percentage points to the EU-25 CO_2 emissions of 1990. Under nuclear phase out conditions, a significant indigenous energy source is no longer available and is substituted, to a very large extent, by imported fuels. Consequently import dependency in 2030 for the EU-25 energy system increases to 74.7% in the "Nuclear phase out" case, compared to 67.3% in the Baseline scenario.

Moreover, each of the above two nuclear cases were combined with the "12% renewables in 2010" case. In the "Nuclear phase out in 2010 with strong support for renewables" case renewables account in 2030 for 51% of the gap generated due to nuclear phase-out. The share of renewable energy forms in primary energy needs rises to 13.7% in 2010 and 13.8% in 2030. However, as the growth of renewable energy forms is not enough to fully compensate for the nuclear phase-out, CO_2 emissions grow on top of Baseline levels (+2.0% in 2030) as does import dependency that reaches 71.1% in 2030 (+3.7 percentage points compared to the Baseline).

The "New nuclear technology with strong support for renewables" case combines the acceptance of new nuclear technology with the promotion of renewables showing an alternative trajectory with a high contribution of non-fossil fuels in the EU-25 energy system and thus positive effects both on the evolution of CO_2 emissions and on import dependency. The results obtained demonstrate that promotional policies for renewable energy forms and the acceptance of new nuclear technology can be complementary. The share of renewables in primary energy needs reaches 12.4% in 2030 while the nuclear share reaches 15.7%. Both nuclear energy and renewable energy forms gain additional market share in the EU-25 energy system to the detriment of solid fuels and, to a lesser extent, natural gas and liquid fuels. This results in significantly slower growth of CO_2 emissions, which in 2030 increase by only +1.9% from 1990 levels, compared to +14.2% under Baseline assumptions. In 2010 CO_2 emissions remain -5.1% below the 1990 level (compared with -0.3% in the Baseline). Due to the higher exploitation of indigenous energy sources, import dependency also improves reaching 58.7% in 2030 (-8.7 percentage points from Baseline levels).

The transport sector is one of the main drivers for the growth of energy needs in the demand side. The **promoting rail and improved load factors** case (discussed in Chapter 6) addresses the impacts that the implementation of policies along the lines of the Option C scenario of the Transport White Paper would have on the evolution of the EU-25 energy system. Option C consists of two main elements: stabilisation of the rail share in 2010 on the basis of the situation in 1998 and a considerable improvement in load factors of all modes in the EU.

In this case energy requirements in the transport sector fall -13.0% from Baseline levels in 2010 (-8.7% in 2030) whereas changes in other demand side sectors and in the supply side are insignificant over the projection period. The corresponding reduction in terms of primary energy needs is -3.0% in 2010 and -2.1% in 2030 mainly occurring in the use of liquid fuels. This leads to lower import dependency for the EU-25 energy system, which nevertheless increases to 51.8% in 2010 and 66.7% in 2030 (-1.3 and -0.6 percentage points respectively from Baseline levels). CO_2 emissions are projected to decline by -4.1% from Baseline levels in 2010 and -2.6% in 2030. As a side effect of the lower growth of primary energy needs, renewable energy forms gain some additional market share from Baseline levels (+0.2 percentage points in 2010, +0.1 percentage point in 2030).

The effects of **combining various options**, discussed in Chapter 7, are quite substantial as regards the future evolution of the EU-25 energy system. Besides the key policy drivers on energy efficiency, renewables, nuclear and transport that were analysed individually in chapters 4-6, additional policies on economic instruments and additional actions towards the use of alternative fuels were also examined in the combined cases. These combined scenarios include the available policy options to different degrees.

The **"energy policy options"** case examines the combined effect of policies on energy efficiency, renewables and the acceptance of new nuclear technology drawing on the results of the cases examined in chapters 4 and 5. The results obtained illustrate the absence of significant trade-offs between such policies. On the contrary, they allow for a significant improvement of the future evolution of the EU-25 energy system both in terms of security of supply and environmental concerns. Primary energy needs are projected to grow less than under Baseline assumptions with implied energy intensity gains of 5.9% above Baseline levels in 2010 and 11.2% in 2030. This improvement occurs despite the much higher exploitation of nuclear power in the long run (+34% in 2030), an energy form that is less efficient in power generation than solid fuels and natural gas. Total solid fuel consumption falls 42.7% below Baseline levels in 2030, whereas natural gas declines by -21.4%. Demand for liquid fuels is strongly affected by the implementation of policies towards energy efficiency declining by -13.1% from Baseline levels in 2030. On the contrary, renewables grow considerably over the projection period (+53.8% from Baseline in 2010 and +42.2% in 2030). The share of renewable energy forms is projected to reach 12.1% in 2010 (from 7.4% under Baseline assumptions), further increasing to 13.8% in 2030 (8.6% in the Baseline) while nuclear energy accounts for 13.2% of primary energy needs in 2010 and 14.3% in 2030 (compared to 13.7% and 9.5% respectively under Baseline assumptions). The increase in the use of indigenous and carbon free energy sources under the "Energy policy options" case is also reflected in the projected evolution of the import dependency and CO_2 emissions for the EU-25 energy system. Import dependency grows more slowly reaching 48.7% in 2010 and 57.4% in 2030 (-4.4 percentage points from Baseline levels in 2010, -10 in 2030). The effects on CO_2 emissions are important as emissions are projected to decrease -12.2% below the 1990 level in 2010 (from -0.3% in the Baseline scenario) and to further decline in 2030 to -14.6% below 1990 levels (from +14.2% in the Baseline scenario).

An even more favourable development for the EU-25 energy system is projected in the **"extended policy options"** case, in which besides supportive policies for energy efficiency and renewables it is also assumed that strong action is undertaken in the transport sector, both by means of changes in transport modes and load factors (as described in Chapter 6) and through shifts towards non-oil fuels. Furthermore, this case includes the 2003 Directive on taxation of fuel and electricity and economic effects of an emission trading regime following the adoption of the emission trading Directive.

Primary energy needs decline by -9.5% from Baseline levels in 2010, a decline that becomes even more pronounced in the long run

(-17.7% in 2030) while marked changes in the fuel mix occur. Renewable energy forms account for 13.1% of primary energy needs in 2010 (5.7 percentage points higher than Baseline levels). The renewables share further increase to 16.2% in 2030 (7.5 percentage points higher than Baseline). All other energy forms are projected to decline from Baseline levels. The most pronounced decline occurs for solid fuels (-67.6% from Baseline levels in 2030) as their comeback in the power generation sector is largely cancelled in an environment of promoting policies for renewables and the participation of the power generation sector in the emission trading regime. A significant decline is also projected for total liquid fuels demand, which declines by -27.3% from Baseline levels in 2030 both because of energy efficiency improvements but also as a result of the higher penetration of non-oil fuels in the transport sector. It is because of these changes in the transport sector that the demand for natural gas exhibits only a small decline in the long run (-4.2% in 2030 from Baseline levels) as gas becomes an important energy carrier in the transport sector accounting in 2030 for 11% of transport demand. Hydrogen also makes significant inroads accounting for 5.6% of transport demand in 2030. CO_2 emissions are projected to decline over the projection period reaching -18.7% and -23.3% from 1990 levels in 2010 and 2030 respectively (the corresponding decline from Baseline levels ranging from -18.4% in 2010 to -32.8% in 2030). Import dependency reaches 47.6% in 2010 (exhibiting an increase of just 0.4 percentage points from 2000 levels compared to 6 percentage point in the Baseline) further rising to 59.7% in 2030 (compared with 67.3% in the Baseline scenario).

The "**full policy options**" case combines all the above options and considers in addition the issue of carbon sequestration, which was introduced as an option for selected power generation technologies. However, in the presence of all available options such as greater energy efficiency, renewables, nuclear, modal shifts towards railways and better load factors, hydrogen and other non-oil alternatives in transport, the carbon sequestration option did not turn out to be a cost-effective solution. In the "full policy option" case (without carbon sequestration), the EU-25 energy system undergoes significant changes compared to the Baseline scenario with primary energy needs remaining rather stable at the 2000 level in the horizon to 2020 and exhibiting only a limited growth in the long run with implied energy intensity gains from Baseline levels reaching 9.5% in 2010 and 14.1% in 2030. The projected slight growth of primary energy needs in the long run is largely the result of the much higher deployment of nuclear energy in the EU-25 energy system (+49.4% compared to the Baseline scenario in 2030) which account for 16.4% of primary energy needs in 2030 (from 9.5% under Baseline assumptions). Renewable energy forms are also strongly encouraged in the "full policy options" case increasing by +60.3% in 2010 and +52.8% in 2030 from Baseline levels. The share of renewables in primary energy needs reaches 13.2% in 2010 and 15.4% in 2030 (from 7.4% and 8.6% respectively in the Baseline scenario). The shifts towards the use of nuclear energy and renewable energy forms mainly occur to the detriment of solid fuels which under the "full policy options" case assumptions become a rather obsolete energy form in the EU-25 energy system accounting for just 4.8% of primary energy needs in 2030 compared to 15.3% in the Baseline scenario. Demand for liquid fuels and, to a less extend, natural gas also exhibits a decline compared to the Baseline scenario, in line with the "Extended policy options" case. In 2010, CO_2 emissions are projected to fall -18.7% below 1990 levels further declining to -26.6% from 1990 levels in 2030, while import dependency is limited to 47.6% in 2010 and 55.1% in 2030 (-12.2 percentage points in comparison to the Baseline scenario).

In the context of a meta-analysis it was assumed, that two selected technologies (namely supercritical coal units and advanced natural gas combined cycle units) are equipped with CO_2 capture equipment. In this hypothetical carbon sequestration case, CO_2 emissions in 2030 would further decline reaching -30.2% from 1990 levels. This, however, would entail considerable additional costs, estimated at about 12 billion €'00, in 2030. Thus, it is clear from this analysis that the exploitation of CO_2 sequestration would be a costly option for the EU-25 energy system over the period to 2030. It could, however, contribute to a significant reduction of CO_2 emissions while maintaining fossil fuels with energy security advantages in the energy balance if strong supporting policies are introduced. More research into carbon sequestration and technology learning should reduce these additional costs.

The repercussions of **targeted CO_2 emissions reductions** on the future evolution of the EU-25 energy system were examined in different scenarios (reflecting different CO_2 emissions reduction constraints over the projection period). The energy consequences of the above CO_2 constraints that are compatible with Kyoto and possible post Kyoto targets were derived from treating the EU-25 energy system as one entity. The "targets" or emission constraints were achieved in modelling the energy economy in such a way as to obtain equal marginal costs across Member States and sectors, which ensures the lowest possible cost level in a given policy context.

The "**Kyoto forever**" case (described in detail in chapter 8) examines the achievement of a CO_2 emissions reduction of -5.5% from 1990 levels for the EU-25 energy system and a stabilisation of CO_2 emissions at these levels in the period to 2030. Given that under Baseline assumptions CO_2 emissions follow a growing trend, the gap between the Baseline and CO_2 emissions reduction target increases over time (from 196 Mt CO_2 or -5.2% in 2010 to 740 Mt or -17.2% in 2030). The carbon values or marginal costs involved to reach the "target"[98] rise from 15.3 €/t CO_2 in 2010 to 40.9 €/t CO_2 in 2030 (in prices of 2000). The energy system reacts to the introduction of CO_2 emissions constraints by improving energy intensity, and by improving carbon intensity through changes in the fuel mix towards the use of less carbon intensive or carbon free energy forms. In the "Kyoto forever" case the response of the EU-25 energy system is dominated by improvements in terms of carbon intensity (account-

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[98] It should be borne in mind that the Kyoto Protocol stipulates emission reductions for a basket of six greenhouse gases mainly on the basis of emissions in 1990. The analysis in this chapter concerns only energy related CO_2 emissions. While the CO_2 "targets" used for analytical purposes in this chapter are compatible with the Kyoto Protocol, there are no specific CO_2 targets in the Kyoto Protocol but only targets for all six greenhouse gases combined

ing for 53% of overall CO_2 emissions reductions achieved in 2010, further rising to 67% in 2030). Primary energy needs decline by -2.5% from Baseline levels in 2010 and -5.7% in 2030. Changes in the fuel mix involve strong shifts away from the use of solid fuels, especially in the long run; in 2030 demand for solid fuels is limited to 40.4% of that under Baseline assumptions. Demand for liquid fuels declines somewhat (-4.9% in 2030) as a result of the higher exploitation of efficiency options in the transport sector. Natural gas exhibits a limited decline in 2010 (-1.1% from Baseline levels) but gains additional market share in the long run (growing by +5.0% above Baseline levels in 2030) as it acts in replacing solid fuels in the power generation sector. Nuclear energy grows above Baseline levels in the long run (+8.9% in 2030), a significant increase taking into account that it has been assumed that Member States without nuclear and those with declared nuclear phase-out policies do not alter their approach to nuclear in this scenario.

Renewable energy forms become increasingly competitive in an environment of CO_2 emissions reduction constraints growing at rates well above those under Baseline assumptions (+7.7% in 2010, +30.6% in 2030). The market share of renewables in primary energy needs reaches 8.2% in 2010 and 12.0% in 2030 (+3.3 percentage points above Baseline levels). The higher exploitation of indigenous energy sources in combination to the additional energy intensity gains occurring in the EU-25 energy system lead to a slower pace of growth of import dependency which reaches 52.6% in 2010 and 64.2% in 2030 (-0.5 and -3.1 percentage points from Baseline levels).

The "**Gothenburg type targets with domestic action**" case, examines the achievement of a -5.5% emissions reduction from 1990 levels in 2010 and the impact of the introduction of progressively higher emission reduction targets up to 2030. This follows the approach set out in the Commission's Communication in the run up to the Gothenburg Summit. Thus in 2020 the EU-25 energy system reduces its CO_2 emissions by -13% below the 1990 level, reaching -21% in 2030. The introduction of higher CO_2 emissions reduction constraints in the long run leads in a higher exploitation of carbon intensity improvement options in the EU-25 energy system and generates the need for additional action in terms of improving energy efficiency. Thus, in 2030 energy intensity improvements account for 40.4% of the overall CO_2 emissions reduction achieved (compared to 33.3% in the "Kyoto forever" case). The need for additional effort towards improving energy efficiency, especially in the demand side, is also reflected on the carbon values or marginal costs, which reach 136.6 € 00 per t of CO_2 in 2030 in this scenario.

The reduction of CO_2 emissions by -30.8% below Baseline levels in 2030 (-21% from 1990) involves substantial changes in the EU-25 energy system. The energy intensity gains (which are equivalent to the corresponding decline in primary energy needs as macro-economic assumptions remain unchanged in comparison to the Baseline scenario) reach 12.4% from Baseline levels in 2030. Solid fuels become an obsolete energy form in the EU-25 energy system in the long run in a severely carbon constrained world. On the other hand, there is substantial growth in the use of renewable energy forms (accounting for 15.5% of primary energy needs in 2030 compared to 8.6% in the Baseline scenario). This leads to a decline in the share of fossil fuels in primary energy needs by some 10 percentage points in 2030 from 81.6% in the Baseline to 71.8% in this scenario given the required deep cuts in CO_2 emissions, while import dependency also improves reaching 60.1% in 2030 (-7.2 percentage points below Baseline levels).

Two additional cases were also examined, the "Gothenburg-flexible" case and the "Gothenburg-intermediate" case, reflecting the possibilities of achieving Kyoto type targets by other means than reducing energy related CO_2 emissions, i.e. in particular by using flexible mechanisms and by acting on other (non-CO_2) gases and sinks. The results obtained from these two cases further confirm the findings discussed above with energy intensity improvements becoming increasingly important as higher targets need to be met.

Furthermore, the same analysis has been performed at the level of the EU-15 energy system. The results obtained clearly illustrate that it is much more difficult for the EU-15 energy system to meet CO_2 emissions reduction "targets"[99] than for the EU-25 for a number of reasons. First, higher emissions reductions from 1990 levels need to be achieved in EU-15 compared to EU-25 following the terms of the Kyoto Protocol. In addition the present characteristics of the EU-15 energy system in terms of both energy and carbon intensity are more advanced than those of the New Member States' energy system. Thus there exists greater potential for low-cost improvements at the EU-25 level than for the EU-15. Third, the restructuring that took place in most of the New Member States during the 1990s led to a significant improvement of their position in terms of CO_2 emissions. In the EU-15 CO_2 emissions in 2000 were 1.2% above 1990 levels whereas in the NMS they were -20.4% below 1990 levels.

9.2. Key indicators across scenarios and conclusions

The results obtained from the various scenarios illustrate the large uncertainties that prevail as regards the future evolution of the EU-25 energy system in the period to 2030 arising from different world energy market conditions, economic developments and levels of policy intensity. In all cases the energy needs in the EU-25 are projected to exhibit a further de-linking from economic growth. Under Baseline assumptions **energy intensity improvements** of 1.7% pa in 2000-2030 are projected to occur in the EU-25 energy system. Similar energy intensity gains are projected for most of the cases examined (with small upward on downward deviations stemming from changes in nuclear deployment, international fuel prices and economic growth deviations). However, the strong policies towards improving energy efficiency (described in chapter 4) give rise to energy intensity improvements of 0.5 percentage points per year above Baseline levels throughout the projection period. Energy intensity gains of a similar magnitude also occur in the presence of deep cuts for CO_2 emissions, such as in the "Gothenburg type targets with domestic action" case, in which case they reach 2.2% pa.

Despite the higher energy intensity gains achieved in comparison to the Baseline scenario, the "high economic growth" case exhibits the most pronounced growth in terms of energy requirements, which

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[99] see the previous footnote

reach +27.5% in 2030 from 2000 levels (compared to +18.7% in the Baseline scenario). On the contrary, the implementation of the policies assumed in the "extended policy options" case result in a decline of energy needs in the EU-25 by -2.2% from 2000 levels in 2030. It should be noted that this is the only case in which such an evolution is projected while in the "full policy options" case the higher exploitation of nuclear energy results in an increase of energy requirements in 2030 by +2.0% from 2000 levels. Similarly, the response of the EU-25 energy system through improvements in energy efficiency to the introduction of high CO_2 emissions reduction constraints leads to a near stabilisation of energy requirements (+4.0% in 2000-2030) under the "Gothenburg type targets with domestic action" case assumptions.

The evolution of the level and structure of primary energy needs is of key importance as regards two main challenges that the EU-25 energy system faces in the period to 2030, namely security of supply and environmental concerns. The challenges concerning energy security are illustrated by the increase of **import dependency** from 47.2% in 2000 to 67.3% in 2030 (i.e. by 20.1 percentage points in 2000-2030) under Baseline assumptions. A lower increase in import dependency occurs in the cases that involve more renewables and/or nuclear energy. In the "full policy options" case, import dependency increases by just 7.9 percentage points in 2000-2030, while a slightly higher growth of import dependency (+10.2 percentage points) is projected for the "energy policy option" case. In the "extended policy options" case, which does not involve the further penetration of new nuclear in the EU, import dependency reaches 59.7% in 2030 (+12.5 percentage points), a result similar to that of the "Gothenburg type targets with domestic action" case with import dependency of 60.1% in 2030. On the contrary, the abandonment of nuclear energy in the EU would entail larger security of supply concerns with import dependency in 2030 reaching 75% in the "nuclear phase-out" case. Promoting policies for renewables can only partly counterbalance this development as illustrated in the results of the "nuclear phase-out with strong support for renewables" case in which import dependency in 2030 reaches 71.1%.

With import dependency increasing in all scenarios up to 2030 – albeit to a quite different degree according to the scenario – it is important to strengthen consumer– producer relations and energy partnerships. This should help ensuring secure and stable world energy market conditions. Moreover, mutually beneficial energy trade relations can exert a positive influence on geopolitical stability, which in turn exerts a positive influence on the security of energy supply.

As regards environmental concerns, the most favourable development in terms of **CO_2 emissions** occurs in the "full policy options" case, where CO_2 emissions exhibit a continuous decline over the projection period reaching -26.6% from 1990 levels in 2030 (or -30.2% if CO_2 sequestration is also taken into account). This is a substantial reduction considering that CO_2 emissions grow by +14.2% from 1990 in the Baseline scenario. Similarly, there are also deep cuts in CO_2 emissions in the "extended policy options" case (-23.3% in 1990-2030) and the "Gothenburg type targets with domestic action" case (-20.9% in 1990-2030). It is interesting to note that compared to the high costs involved in the achievement of the -20.9% reduction in the "Gothenburg type targets with domestic action" case, resulting from the introduction of carbon values that reach 136.6 €00 per t of CO_2 in 2030, the impact on energy system costs in the "full policy options" and the "extended policy options" cases are rather limited. This results from the approach retained in the CO_2 emissions reduction cases on the basis of carbon values that do not simulate additional policies (e.g. on energy efficiency, renewables or nuclear) beyond those available in the Baseline scenario but on the contrary, start from targets. In these carbon value cases, instead of widening the choices of economic actors for low carbon options through policy, CO_2 emissions reductions are achieved only through price/cost mechanisms, which leads to rather high illustrative CO_2 emission reduction costs. The carbon values (or marginal CO_2 emissions reduction costs) are indicative of the relative difficulty involved in maintaining target levels over time or in achieving progressively more ambitious targets.

The most pronounced increase in CO_2 emissions occurs in the "high economic growth" case (+23.6% in 2030 from 1990 levels) as in the absence of specific policies encouraging CO_2 emissions reduction (such as policies on energy efficiency and renewables) there is a considerable increase in carbon intensity, which is not offset by the improvement of energy intensity brought about in the context of higher economic growth., In particular, there is more use of solid fuels in the power generation in satisfying additional energy requirements due to higher GDP. The same trends occur in the cases that involve the phase-out of nuclear energy in the EU with CO_2 emissions in 2030 rising by +23% from 1990 levels in the "nuclear phase-out" case. In the "nuclear phase-out with strong support for renewables" case, the increase in CO_2 emissions in 2030 is limited to 16.5% from 1990 levels.

The combination of policies towards higher energy efficiency with promoting policies for renewables that ensure a 12% renewables share in 2010 leads to a 12% decline of CO_2 emissions below the 1990 level in 2010. Even though renewables policies are "frozen" at 2010 in this scenario, CO_2 emissions would remain broadly at 12% below the 1990 level up to 2030. Clearly, with reinforced renewables policies post 2010 even better results can be obtained and CO_2 emissions could fall further below the EU Kyoto commitments in 2008-2012 for the 6 greenhouse gases.

As regards the effects of higher oil and gas import prices, the results obtained from the cases examined illustrate that energy intensity gains achieved on top of Baseline levels are largely counterbalanced by shifts in the fuel mix towards the use of solid fuels and, thus, CO_2 emissions in 2030 are only slightly below those of the Baseline scenario.

Renewable energy forms exhibit the highest growth among all energy forms in all cases examined. Thus, the market share of renewables is projected to increase over the projection period clearly reflecting the key role that renewables will play in satisfying future energy needs in the EU-25 energy system. In the Baseline scenario the renewables share increases from 5.8% in 2000 to 7.4% in 2010 and 8.6% in 2030. Although renewables exhibit a quite significant increase of +76.3% in 2000-2030, the renewables share remains well below the target set in the EU for 2010 (12% of primary energy needs). The renewables share is an important indicator not only with a view to import dependency and climate change but also as renewables contribute to employment and cohesion objectives. The renewables share reaches the 12% target only with strong specific policies; it remains below this target in all other cases. The 12% renewables share is more easily obtained in combining strong renewables policies with ambitious energy efficiency policies; there are synergies between both approaches, e.g. in terms of cogeneration from biomass. Thus renewables shares of 12% or above in 2010 are achieved in the "full policy options" and "extended policy options" cases (13.2% in each case), in the "energy policy options" case and the "energy efficiency and 12% renewables share in 2010" case (12.1% each). The highest renewables share in 2010 (13.6%) would be achieved in the hypothetical case of a complete nuclear phase-out in 2010 that is accompanied by the same supporting policies for renewables that ensure the 12% renewables share under Baseline conditions.

In the long run, and in the absence of additional policies on renewables addressing the period post 2010, market and technology developments alone entail only a limited increase of the renewables share beyond 12%. For maintaining momentum in renewables penetration, additional policies are required addressing the period post 2010. In 2030, the market share of renewables reaches up to 16.2% in the "extended policy options" case, 15.4% in the "full policy options" case and 14.4% in the "energy efficiency and 12% renewables share in 2010" case. The introduction of ambitious CO_2 emissions reduction targets also entails a greater exploitation of renewable energy forms in the long run; the share of renewables in the "Gothenburg type targets with domestic action" case reaches 15.5% in 2030.

Nuclear is the energy source that is surrounded by the greatest uncertainty. In this scenario exercise the nuclear share in 2030 spans a wide range from an extreme 0% (nuclear phase-out in the entire EU) to 16.4% in the scenario that combines all policy options including the acceptance of new nuclear technology. This would be the highest nuclear share ever given that the highest nuclear share so far was 14.8% in 2002 (the latest statistical year available). Under Baseline developments the nuclear share would fall to 9.5% in 2030.

There is indeed a large amount of uncertainty about our energy future, which relates also to the economic and geopolitical influences on energy and transport developments. The world in which policy makers have to act to achieve sustainable development is uncertain in many respects. Scenario analysis that considers both the demand and supply side of providing energy in an integrated fashion, including its economic and environmental dimensions, is a powerful tool to support policy making.

The Green paper on the Security of Energy Supplies and the White paper on the Common Transport Policy have shown clearly that there are many challenges ahead to ensure better security of supply, better services for the users of energy and transport, and lower impacts on the environment. Today's policy makers and citizens have it within their grasp to transform Europe's energy outlook to ensure sustainable development, including its economic, social and environmental dimensions. This publication examined a wide range of energy policy options over the next three decades showing that the energy futures can be quite different. Transport policy can furthermore contribute significantly towards restraining energy demand and making our energy system more efficient. Clearly, there are synergies to be developed between energy and transport policies. This analysis of scenarios on key drivers should contribute to an informed debate among stakeholders and provide valuable pointers to future policies.

Carbon intensity: The amount of CO_2 by weight emitted per unit of energy consumed or produced (t of CO_2/tonne of oil equivalent (toe) or MWh)

Clean coal units: A number of innovative, new technologies designed to use coal in a more efficient and cost-effective manner while enhancing environmental protection. Among the most promising technologies are fluidised-bed combustion (PFBC), integrated gasification combined cycle (IGCC), coal liquefaction and coal gasification.

CO_2 Emissions to GDP: The amount of CO_2 by weight emitted per unit of GDP (carbon intensity of GDP - t of CO_2/MEuro'00).

Cogeneration thermal plant: A system using a common energy source to produce both electricity and steam for other uses, resulting in increased fuel efficiency (see also: CHP).

Combined Cycle Gas Turbine plant (CCGT): A technology which combines gas turbines and steam turbines, connected to one or more electrical generators at the same plant. The gas turbine (usually fuelled by natural gas or oil) produces mechanical power, which drives the generator, and heat in the form of hot exhaust gases. These gases are fed to a boiler, where steam is raised at pressure to drive a conventional steam turbine, which is also connected to an electrical generator. This has the effect of producing additional electricity from the same fuel compared to an open cycle turbine.

Combined Heat and Power: This means cogeneration of useful heat and power (electricity) in a single process. In contrast to conventional power plants that convert only a limited part of the primary energy into electricity with the remainder of this energy being discharged as waste heat. CHP makes use of large parts of this energy for e.g. industrial processes, district heating, and space heating. CHP therefore improves energy efficiency (see also: cogeneration thermal plant).

Efficiency for thermal electricity production: A measure of the efficiency of converting a fuel to electricity and useful heat; heat and electricity output divided by the calorific value of input fuel times 100 (for expressing this ratio in percent).

Efficiency indicator in freight transport (activity related): Energy efficiency in freight transport is computed on the basis of energy use per tonne-km. Given the existence of inconsistencies between transport and energy statistics, absolute numbers (especially at the level of individual Member States) might be misleading in some cases. For that reason, the numbers given are only illustrative of the trends in certain cases.

Efficiency indicator in passenger transport (activity related): Energy efficiency in passenger transport is computed on the basis of energy use per passenger-km travelled. Issues related to consistency of transport and energy statistics also apply to passenger transport (see also: Efficiency indicator in freight transport).

Energy branch consumption: Energy consumed in refineries, electricity and steam generation and in other transformation processes; it does not include the energy input for transformation as such.

Energy intensity: energy consumption/GDP or another indicator for economic activity

Energy intensive industries: Iron and steel, non-ferrous, chemicals, non-metallic minerals, and paper and pulp industries.

Final energy demand: Energy finally consumed in the transport, industrial, household and tertiary sectors with tertiary comprising services and agriculture. It excludes deliveries to the energy transformation sector (e.g. power plants) and to the energy branch. It includes electricity consumption in the above final demand sectors.

Freight transport activity: Expressed in tonne kilometres (1 Gtkm = 10^9 tkm); one tkm = one tonne transported a distance of one km. It should be noted that inland navigation includes both waterborne inland transport activity and domestic sea shipping. However, international short sea shipping is not included in the above category as, according to EUROSTAT energy balances, energy needs for international shipping are allocated to bunkers.

Fuel cells: A fuel cell is an electrochemical energy conversion device converting hydrogen and oxygen into electricity and heat with the help of catalysts. The fuel cell provides a direct current voltage that can be used to power various electrical devices including motors and lights.

Fuel input to power generation: Fuel use in electricity, CHP plants and heat plants.

Gas: Includes natural gas, blast furnace gas, coke-oven gas and gasworks gas.

Generation capacity: The maximum rated output of a generator, prime mover, or other electric power production equipment under specific conditions designated by the manufacturer.

Geothermal plant: A plant in which the prime mover is a steam turbine. The turbine is driven either by steam produced from hot water or by natural steam that derives its energy from heat in rocks or fluids beneath the surface of the earth. The energy is extracted by drilling and/or pumping.

Gross Inland Consumption: Quantity of energy consumed within the borders of a country. It is calculated as primary production + recovered products + imports +/- stock changes – exports – bunkers (i.e. quantities supplied to sea-going ships).

Gross Inland Consumption/GDP: Energy intensity indicator calculated as the ratio of total energy consumption to GDP – (toe/MEuro'00).

Hydro power plant: A plant producing energy with the use of moving water. For the purposes of these energy balance projections, hydro excludes pumped storage plants that generate electricity during peak load periods by using water previously pumped into an elevated storage reservoir during off-peak periods when excess generating capacity is available.

Non fossil fuels: Nuclear and renewable energy sources.

Non-energy uses: Non-energy consumption of energy carriers in petrochemicals and other sectors, such as chemical feedstocks, lubricants and asphalt for road construction.

Nuclear power plant: A plant in which a nuclear fission chain reaction can be initiated, controlled, and sustained at a specific rate. They include new nuclear designs (such as the EPR as well as the AP1000 and AP600) with passive safety features (which reduce core fusion probability from 10-5/year of existing nuclear plants to less than 5.10-7/year).

Oil: Includes refinery gas, liquefied petroleum gas, kerosene, gasoline, diesel oil, fuel oil, crude oil, naphtha and feedstocks.

Open cycle units: A turbine connected to an electrical generator. Less efficient than a combined cycle gas turbine (CCGT) because it does not recover and use the heat of the exhaust gases. Open cycle units include polyvalent units, monovalent coal-lignite units, monovalent oil-gas units and monovalent biomass-waste units.

Passenger transport activity: Expressed in passenger kilometres (1 Gpkm = 10^9 pkm); one pkm relates to one person travelling a distance of one km. Passenger transport activity includes energy consuming passenger transport on roads (public and private), by rail, in airplanes and on ships as far as this takes place on rivers, canals, lakes and as domestic sea shipping; international short sea shipping is not included as, according to EUROSTAT energy balances, energy needs for international shipping are allocated to bunkers.

Primary production: Total indigenous production.

Renewable energy sources: Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, wind, geothermal, solar, wave and tidal energy.

Solar power plant: A plant producing energy with the use of radiant energy from the sun; includes solar thermal and photovoltaic (direct conversion of solar energy into electricity) plants.

Solids: Include both primary products (hard coal and lignite) and derived fuels (patent fuels, coke, tar, pitch and benzol).

Supercritical polyvalent units: A power plant for which the evaporator part of the boiler operates at pressures above 22.1 MegaPascals (MPa). The cycle-medium in this case is a single phase fluid with homogenous properties and thus there is no need to separate steam from water in a drum, allowing for higher efficiency in power generation.

Thermal power plants: Type of electric generating station in which the source of energy for the prime mover is heat.

Wind power plant: Typically a group of wind turbines interconnected to a common utility system through a system of transformers, distribution lines, and (usually) one substation. Operation, control, and maintenance functions are often centralised through a network of computerised monitoring systems, supplemented by visual inspection.