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SECURITY OF ENERGY SUPPLY

The potential and reserves of various energy sources, technologies furthering self-reliance and the impact of policy decisions

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Preface

This study has been commissioned by the European Parliament under no. IP/A/ITRE/ST/2005-70. The Wuppertal Institute was the main contractor, carried out the model calculations and carried the overall responsibility for the reporting process. The Government Institute for Economic Research (VATT) was engaged as a sub-contractor, primarily for the purpose of consultancy and review.

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Executive Summary

Rationale for intensified action

Recent increases in world market energy prices, combined with ever more alarming evidence from climate research, have highlighted the urgency of two profound challenges that have been recognised for over a decade.

Firstly, the overview of the current and projected situation of fossil and nuclear energy sources and projections on future availability and extraction cost support the vision that the era of cheap and abundant conventional energy resources is coming to an end. Additionally, these conventional energy resources are becoming more and more geographically concentrated, just at a time when the European Union (EU) is increasingly relying on energy imports and when newly emerging large energy importing economies (i.e. China, India) can be expected to intensify international competition.

Secondly, parallel to this and to some extent in conjunction with these fundamental changes in fossil fuel supply, handling of climate change requires substantial reductions in global greenhouse gas emissions, which essentially means using less energy and switching to carbon neutral energy carriers.

As a conventional, albeit advanced, "business as usual" (BAU) strategy is likely to face increasing problems when trying to cope adequately with these simultaneous challenges. With this in mind five scenarios which highlight important strategic options and a range of possible future energy solutions for the EU25 have been developed in this study.

Options to go ahead

These scenarios can be grouped into *two main strategies*. The first type of strategy could be called "*advanced conventional*". This strategy represents a more conventional supply side oriented course. The analyses show that this route would not be merely 'business as usual'. On the contrary, it would require an intensification of the policies for energy efficiency, including cogeneration, and for renewable energies. In addition, nuclear energy would need to have unequivocal support in order to allow for new capacity to be installed. Climate policy would consist of (1) the support of domestic energy efficiency and renewable energy policy combined with the large scale options of nuclear and carbon capture and storage (CCS) and (2) a strong policy to achieve significant emission reductions abroad by elaborating clean technology transfer mechanisms and emission trade systems. However, due to the definition of the pre-selected scenarios this strategy has not been analysed to the same extent as the alternative one.

The *advanced conventional* strategy essentially relies on the successful implementation of an active foreign energy and technology transfer policy. Strong international competition for energy resources may become an increasing threat for this crucial foreign policy link. However, this scenario would be less risky in relation to the management of domestic European change, since changes tend to be less radical than in alternative scenarios.

The other type of strategy, "*domestic action*", basically relies on the domestic potential and has the capability to cope adequately with both major challenges. This strategy, however, needs more radical domestic political action in order to accelerate progress in energy efficiency and renewable energy supply and to achieve the already agreed (indicative) targets for the expansion of renewable energy supply and cogeneration and the enhancement of energy efficiency. In the context of this type of strategy international relations could be less strained.

Clean technology transfer would still be very welcome, but would be less burdened by demands emanating from very large scale emission trading. Furthermore, the acceleration of energy innovations in the EU would provide a useful perspective on the lasting export potential of domestic solutions. By lessening the macroeconomic vulnerability and, hence, increasing the predictability of the economy the strategy actively contributes to the Lisbon process.

The *domestic action* strategy would swap, to some extent, the external threats from climate change and geopolitical turmoil for greater challenges with respect to the management of the more radical changes inside the domestic European society (i.e. the EU and its Member States). More specifically, this strategy would stand or fall at the successful restructuring of the EU energy system and good part of the investment decisions. Consequently, a well developed and broadly endorsed 'transition management approach' becomes an important ingredient for the successful implementation of this scenario.

Robust choices

In spite of these diverging and, at least partly mutually exclusive, strategic directions a number of *robust policy choices* are apparent. These options would be required in any strategy and differ only in terms of intensity – consequently, these policy areas should be given high priority for securing energy supply regardless of the strategy prioritised[1]:

The first issue is the enhancing of *demand side energy efficiency,* including cogeneration. Political action is necessary to actively and successfully implement the Energy end-use Efficiency Directive in order to achieve the efficiency targets with a focus on: building efficiency; the transport sector; where comprehensive policy packages of technical and non-technical measures are needed; and for the efficient use of electricity.

The next robust option concerns the increased support of *renewable energies*. All the scenarios assume high increases in renewable energies, particularly in wind power generation and biomass use. What is more, some policies are already partly in place and the current targets on the EU level already correspond to a very ambitious "renewable scenario" (RE scenario), but would need to be supported by stronger policy and would have to be expanded by 2020 and 2030. Particular fields of relevance in all scenarios are offshore wind energy, biomass and the use of renewable energies for heating and cooling purposes.

With regards to the *energy market* and the regulation and development of European electricity and natural gas grids, it would be necessary to support demand side management measures, equitable access for new decentralised power generation and the upgrading of electricity networks in order to allow for the integration of large (offshore) wind generation, decentralised generation and for improved interconnection of the Member States.

Robust steps towards a future *EU external* energy and climate *policy* include the fostering of clean development and clean technology transfer, as this will strengthen international relations, partly release demand pressure on energy markets, create additional or strategically

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[1] Carbon capture and storage (CCS) is generally not regarded as long term sustainable solution. However, under certain conditions it could be regarded as a robust choice to ensure sufficient R&D effort for assessment of the potential of CCS and its technical prerequisites for a sound use of the option as one potential transition strategy.

needed emission credits and expand markets for renewable and efficiency technologies, which would, in turn, support the domestic development of these technologies.

0 Summary

Two different challenges with regard to the future development of the European Union (EU) energy system and the question of the 'security of energy supply' are currently being faced.

Firstly – as shown by the overview of future prospects of fossil and nuclear energy reserves – the era of cheap and abundant conventional energy resources appears to be coming to an end. This means that maintaining reliable supply levels implies significant and timely investment in new and more expensive oil and gas production, which will put upward pressure on world market prices for oil, gas and, to a lesser extent, coal – with potential impacts for economic development and growth. Furthermore, the geographical concentration of oil and gas export potential, combined with newly emerging large energy importing economies (i.e. China, India) can be expected to intensify international competition for market access to the declining resources and, ultimately, may also generate international conflicts.

Distinct from these issues, a second challenge has emerged. Handling climate change requires substantial reductions in global greenhouse gas emissions, which essentially means using less energy and switching to carbon neutral energy carriers.

Both challenges require determined and timely action from the EU and its Member States, as well as from the international community at large. A conventional, albeit advanced, "business as usual" (BAU) strategy is likely to face increasing problems when trying to cope adequately with these simultaneous challenges.

In order to analyse important strategies and/or technology decisions (higher/lower nuclear share in electricity generation; increased energy efficiency and use of combined heat and power (CHP); increased use of renewable energies) and highlight a range of possible future energy solutions for the EU25, five different scenarios have been developed according to the strategies and targets requested by the Committee on Industry, Research and Energy (ITRE Committee).

The report starts with brief technical descriptions of these scenarios, after which follows a detailed discussion of the policy choices and challenges embodied by the scenarios in a number of energy areas and relevant framework policies.

Future prospects of fossil and nuclear energy

The current discussion on the global production peak of crude oil is controversial. The range varies from an early global production maximum (in 2010 for all liquid hydrocarbons) to a scenario whereby a maximum is not reached at all in the coming decades. However, there is a strong indication that prices will remain high, or even increase, in the future. It is also possible that at least a temporary production crisis could occur if existing alternatives are not explored and exploited in a timely way. The same holds true for natural gas which, with prices coupled more or less to oil and with a tight market lying ahead for the next decades, faces the challenge of satisfying increasing demand while requiring significant investment in new and more expensive production technologies and in transmission capacity.

The situation for coal is somewhat different from that of oil and gas. There are no structural supply restrictions for coal expected in the coming decades. However, current production capacities are, in many cases, at a maximum and a number of countries are currently considering increasing coal production again after years of decline.

Coal production is, in many cases, critically dependent on public acceptance (due to environmental damage and social aspects in the producing regions) and this could become a limiting factor to production increases.

Nuclear fuels are expected to reach their limits in the coming decades. Taking into consideration the fact that currently a large part of the uranium needed for nuclear fuel is not mined, but supplied from existing civil and military stocks, the industry will face the challenge of securing the necessary sources by increasing mining capacity at the opportune point in time. However, as there is the possibility of storing large amounts of energy, using further military sources and also increasing efficiency of use, restrictions in production do not appear to be inevitable.

Domestic production of oil and gas in the European Union is declining. This decline has to be cushioned either by the diversification of suppliers or by stronger dependence on a few importers such as Russia. Irrespective of the chosen solution, import dependence on fossil fuels will increase significantly in the EU25 from 59% in 2000 to 84% in 2030 (BAU), and will increase for all types of energy carriers. This trend is amplified by growing energy demand. Import dependence can directly influence the security of energy supply, as political and other aspects in supplier and transit countries play major roles in the stability of supply chains.

It can, consequently, be concluded that the situation in the EU25 is dominated by decreasing domestic production capabilities and increasing energy demand. Therefore, import demand will rise significantly.

- Currently the EU25 already relies heavily on oil and natural gas imports from its two main suppliers, Russia and Norway, and it will have to import even more in the future. However, oil production in Norway is in decline and its natural gas may reach its production peak in the coming years. In the case of Russia, there are a couple of as yet unresolved factors which will decide whether or not exports can be increased significantly. Therefore, the EU25 will have to diversify its supplier structures and turn to less stable countries (e. g. import from the Caspian region, increase imports from Middle East countries and from Africa).
- Another important development is the increasing competition for energy resources, as the other two large consuming regions (North America and South-East Asia) are also becoming more and more dependent on foreign supplies due to the entry of new players (such as India and China) to international energy markets and the rising demand of already large consumers (such as the USA).

Technological developments

The implementation of a sustainable, resource efficient and climate protecting energy system is a major condition for achieving a high level of security of energy supply. To meet these requirements, a broad range of innovative technologies already exists and further innovations are under development and expected in the near future. Although there are many possible options, only the most promising technologies are discussed in this report.

The classification relates to technological as well as economical criteria: on the one hand, the technology must have significant potential to increase energy efficiency; on the other hand, only those technologies that are expected to be commercially available in the near future, or which are already on the market, are considered. In a complex energy system, not only single stand-alone solutions, but also the interaction of different measures, are of importance. Therefore, the following scenarios contain fields of action rather than single technologies: energy efficiency in road transport (main focus on passenger cars); alternative transport fuels (incl. hydrogen); distributed generation (incl. biomass and stationary fuel cells); advanced coal power (incl. carbon capture and storage); wind energy; solarthermal power generation; nuclear fusion. This selection corresponds for the most part to the technologies that are considered in the recent IEA (2006) *World Energy Outlook (WEO)*.

As in the WEO, the different forms of maritime energy sources, such as tidal and wave energy, are regarded as not yet sufficiently developed to be on the market in the next decades. Unlike the other technologies listed, nuclear fusion is still a long term option.

Energy scenarios for the EU25

In order to draw different possible futures of the EU energy system, five exemplary scenarios were designed according to the definitions requested by the EP (see table). It has to be noted that the first three scenarios (BAU, and its variants N+ and N-) assume significantly less ambitious policies and strategies than the EE and the RE scenarios and that other scenarios with different ambitions are also imaginable.

In the *business as usual (BAU) scenario* – which has been developed to be compatible with the most recent baseline scenario by the EU Commissions Directorate-General Energy and Transport expected for publication in 2006 – the continuation of energy policy trends would already lead to a strong primary energy efficiency increase within the EU25. However, this increase would not be sufficient to compensate for growing Gross Domestic Product (GDP). As a consequence, primary energy demand would increase by almost 15% and import dependency by more than a third. Due to an increased share of renewable energy sources (RES) and a switch to natural gas, CO_2 emissions would increase by only 3% to 6.6%, depending on the nuclear energy policy. With regard to climate policy it is assumed in the BAU scenario that the EU25 will accept international emission reduction targets for the commitment periods after 2012 of 15% by 2020 and 30% by 2030[2].

The Scenario: +25% nuclear capacity in 2030 (*N+ scenario*) – as defined in accordance with the request by the ITRE committee – is a variant of the BAU scenario. While in the BAU scenario nuclear capacity declines by 28% from 141 GW (2000) to 101 GW in 2030, in the N+ scenario the construction of about 10 more new nuclear power plants of 1300 MW each is assumed, which would result in a nuclear capacity of about 126 GW in 2030 – or 25% more than in the BAU scenario. CO_2 emissions in power and steam generation decrease by about 6.6% vs. BAU by 2030, whereas total emissions from the EU25 decrease by 1.9%.

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2 This would be more or less equal to the lower end of the corridor given in the Council Decision from May 2005 "reduction pathways for the group of developed countries in the order of 15-30% by 2020 […] should be considered" (EU 2005).

Furthermore, this scenario also includes the use of carbon capture and storage (CCS), which can further reduce CO_2 emissions, albeit fairly modestly in the case of the EU (another 6%~7% of the power sector emissions compared to BAU).

Table 0-1: Comparison of the scenarios – results for 2030

Scenario	**CO_2 emissions (% Δ 1990)**	**Primary energy demand (% Δ 1990)**	**Import dependen–cy**	**Nuclear share of electricity generation**	**RES share of PE demand**	**Energy efficiency growth rate (2000 - 2030)**
BAU	+4.7%	+14.6%	64.8%	18.7%	12.2%	1.5%/year
N+ (+CCS)	+3.0%(+1.3%)	+16.4%	62.7%	23.6%	12.0%	
N-	+6.6%	+12.2%	66.5%	13.8%	12.4%	
Energy Efficiency (EE)	-18.8%	-8.2%	59.8%	15.7%	15.0%	2.2%/year
Renewable Energy (RE)	-45.1%	-20.1%	49.1%	16.4%	31.4%	2.7%/year

Source: own calculations, Wuppertal Institute, 2006

The Scenario: -25% nuclear capacity in 2030 (*N^- scenario*) marks the other end of a range of possible nuclear energy BAU scenarios. Power plants are assumed to perform less well in this scenario and this, together with waste issues and a stronger perception of the risks of nuclear energy, combine to increase the pressure on plant operators. Consequently, no new nuclear power plants are commissioned and a number of nuclear power plants will not reach a lifetime of 40 years. This results in a decline of nuclear capacities to 76 GW in 2030. In total, CO_2 emissions in this scenario would be at a level of 72 million tonnes, or 1.9%, more than in the BAU scenario by 2030.

The *energy efficiency (EE)* scenario assumes strong policy at EU level, as well as within the Member States, targeted at accelerating the rate of increase of energy efficiency in order to reach a level of energy efficiency 50% higher than in the BAU scenario by 2030. This means that energy efficiency (GDP per ktoe primary energy use) would increase by 2.2% per year and reach 10.5 MEur/ktoe in 2030 (BAU: 8.5).

The *renewable energy (RE)* scenario describes a restructuring towards a renewable energy system with a target of approaching a renewable energy supply as high as possible by 2030. To achieve such a high share of renewable energy, the scenario combines an even stronger drive towards energy efficiency (11.9 MEur/ktoe by 2030) with an accelerated expansion strategy of renewable energies which reach a share of 31% of total primary energy supply in 2030. This strategy depends on the feasibility of the projected 34% share of fluctuating energies (wind, hydro, solar, tidal and wave) in the electricity system and on the feasibility of accelerating energy efficiency improvement to 2.7% per year. The RE scenario, therefore, describes an ambitious strategy which would, however, be capable of delivering on a number of important political targets: ambitious CO_2 emission reductions including fulfilment of the Kyoto targets would be achieved, renewable energy and CHP expansion targets would be realised and import dependency and vulnerability to high energy prices and possible supply shortages would be significantly reduced compared to the BAU scenario.

Analysis of policy choices

The five scenarios developed for the study have been analysed with regards to the core energy policy fields. Brief discussions on recent trends, followed by implications for policy needs with regard to the different scenarios, have been discussed for every scenario.[3]

The energy issues considered in this report interact directly and indirectly with many European policies, in particular the climate policy, the Lisbon strategy and the external (energy markets) policy which do not focus exclusively on energy but function as framework policies. These policy areas with wider scope can significantly influence the feasibility of potential pathways for the development of the energy system. Further to these cross cutting policies the following key energy policies are touched upon in the study: Single European energy market, energy efficiency, renewable energies and energy technology policy.

Climate policy

With regards to *climate policy* the scenarios can be grouped into two main clusters:

- The *BAU and the N+ and N- scenarios* offer mixed prospects on future climate policy. On the one hand, a prolongation of current active climate policy is assumed in these scenarios and will be needed to achieve further increases in energy efficiency and renewable energy generation. On the other hand, there are constraints to climate policy, as the Kyoto target (and the assumed targets for future commitment periods) might be missed by the EU as a whole, unless a very strong strategy is introduced including both emission reductions in the non-energy sectors *and* purchasing emission credits from outside the EU. In the long run, far reaching emission reduction targets will conflict with: (1) increasing energy demand, notably caused by the transport sector, and (2) investment in new coal fired condensing power generation. This will limit the capability of the EU to negotiate strict targets for subsequent commitment periods under the Kyoto Protocol.

  The N+ scenario shows that – given its assumptions – the net CO_2 emission reduction potential of nuclear energy is limited to about 70 Mt in 2030. The same is probably true for CO_2 capture and storage which might provide another 70 Mt – at costs above €25/t of CO_2. Both measures would reduce the EU25 energy related CO_2 emissions by 7.2%. If, in addition, extra emphasis were to be put on (equitable) clean technology transfer (CTT), the amount of credits available for purchase would increase, whereas an intensified CTT policy would make it easier to purchase credits. If done fairly, it would make host countries more willing to participate in CTT as well as improve the EU position in post Kyoto negotiations. However, in order to achieve emission reductions according to the supposed BAU scenario, mitigation targets of -15% by 2020 and -30% by 2030 more than 500 and 1,000 Mt of CO_2 credits in 2020 and 2030 respectively would have to be purchased and/or generated by over proportional reductions of the emissions of other greenhouse gases. At an assumed price of €25/t this would mean costs increasing from €12.5bn to €25bn per year, from 1.2% to 2.3% of the energy cost and from 0.1% to 0.16% of GDP in the respective years.

[3] "Policy" here (and in the following chapters) always implies the implementation of the mentioned policy, also.

- The *energy efficiency and the renewable energy scenarios*, however, offer completely different prospects and challenges to climate policy. Kyoto targets are within reach and EU energy policy and climate policy are very much coherent over the whole scenario period. This opens up the opportunity for the EU to pursue an active role in international negotiations. On the other hand, these scenarios suppose that climate policy would incite substantial restructuring of the energy system by means of target setting in conjunction with market based instruments (such as EU ETS) and by strongly promoting energy efficiency improvements and renewable energy generation. However, in order to achieve the EE and even more so the RE strategy a very strong and active policy would also be indispensable. Much greater effort in energy efficiency would be needed, requiring a determined redirection of investments from conventional energy supply and standard energy using technology to more efficient technologies and renewable and cogeneration power plants.

  Regarding the restructuring of the electricity system this could be achieved with lower investment than in the BAU scenario – because of lower capacity needs due to electricity savings and, at the end of the period, due to a decrease in cost of renewable energy technology (notably wind) which makes renewable energies competitive with other fuels. However, higher investments in energy efficiency and renewable heat generation at the demand side are needed. Between 0.5%(EE) or 1.0%(RE) in 2010 and 1.3% or 2.5% of the EU25 GDP is available for such investment, given the calculated reductions in overall primary energy costs.

Lisbon strategy

Regarding the character of the *Lisbon strategy* as a framework strategy, links to different energy futures exist in two directions. The energy strategy can contribute to the Lisbon targets and the realisation of certain parts of the Lisbon agenda can support the development of the energy sector.

- The *BAU scenario* (like the N+ and N- scenarios) would probably contribute to the Lisbon strategy by the huge investment needed in conventional energy infrastructures. This might also put pressure on the further development of a single European energy market. Contributions to knowledge and innovation would be limited due to the focus on conventional energy sources. However, renewable energies - in particular wind power - would be developed at a fast rate, thereby requiring innovation and delivering additional job opportunities. A common EU energy policy would, however, be urgently needed in the BAU scenario as a significant increase in import needs would have to be secured and reliable external supply and internal transport and delivery of energy would have to be maintained. Assuming a relatively strong emphasis on clean fossil fuel technology and CO_2 capture and storage in the BAU and N- scenarios, there would be technology clusters in the EU that would probably also constitute *expanded* export potentials to developing economies such as China and India. However, the BAU and N+ scenarios (and to a lesser extent the N-) would result in higher imported energy and final energy costs for the EU economy than the EE and RE scenarios, which might be contradictory to the Lisbon targets.

- The *energy efficiency scenario* would be connected to a different investment path, focusing more on decentralised energy efficiency investment: fostering markets for small and medium enterprises, supporting regional labour markets for e.g. refurbishment of buildings and providing technology and know-how development for efficiency technologies. It is assumed that between 0.5% and 1.3% of the EU GDP would be channelled into these segments rather than into power plant investment and energy imports. On the other hand, the scenario would mitigate need and time pressure for the implementation of a common EU energy policy as import demand would increase more slowly than in the EE scenario. In addition, the vulnerability of the EU economy to energy price shocks and potential energy shortages would be reduced and, accordingly, potentially deliver an important element to increased competitiveness. Assuming that advanced energy saving technologies, both in industry and buildings, would increasingly require intelligent designs (i.e. using information & communication technology (ICT) and artificial intelligence), such energy saving technologies could significantly expand the export potentials.
- Comparable effects could be expected from the *renewable energy scenario*. Investment in the energy sector would have to be switched, to a large extent, from conventional power plants, where investments would be reduced by about three quarters, to CHP plants and renewable generation where it would have to be increased by about 50%. This restructuring needs substantial innovation, from the discovery of new solutions for different supply problems to the development of renewable energy technology production and energy storage technologies, with the effect of creating new fields for highly skilled new jobs in the EU and opening up potential export markets. On the other hand, the RE scenario would be even more successful in slowing down the growth of energy imports – oil and coal would even show declining absolute imports. Consequently, it would be a powerful strategy for defending the EU from future energy market problems. The common EU energy policy would also be needed for the RE scenario but would have a completely modified focus, more targeted at improving domestic renewable energy generation and disseminating renewable energy and energy efficiency strategies. International cooperation would be much easier as pressure on securing ever increasing demand would be much lower than in the BAU scenario.
- The geopolitically favourable effect of the EE and RE scenarios on the energy sector can be regarded as a risk reduction benefit (also relevant on a macroeconomic level), which could compensate, to some extent, for the possible short term higher macroeconomic cost caused by the – generally cost efficient – restructuring costs (in the absence of surprises). As regards the judgement of the economic implications of the various scenarios it counts to what extent time profiles of annual costs and benefits differ. By and large the BAU (and N+ and N-) scenarios may initially result in lower net costs, but over time this changes, whereas the initial benefit comes at the (unknown) price of an increased risk of import price sensitivity and of other geo-political instability effects. As stated before a higher level of uncertainty usually affects willingness to invest negatively.

It is however fair to say that neither the PRIMES model used by the European Commission (cp. Mantzos et al. 2003) nor the present study's tools are particularly designed for an in-depth assessment of such complicated intertemporal trade-offs.

Policies on EU external energy markets

The comparison of scenarios with regard to *policies on EU external energy markets* shows that quite different challenges lie ahead in each scenario.

- In the *BAU scenario* – and in both nuclear scenarios – particular emphasis would be needed on external energy supply through the establishment of stable political relations with oil and gas producing countries and (for gas) transit countries and the mobilisation of huge investments – most of all for natural gas. In BAU/N+ the extended efforts to promote clean energy technology transfer in conjunction with a widening use of emission trade (notably EU Emissions Trading Scheme (ETS) and Clean Development Mechanism (CDM)) are, to some extent, favourable to global stability but, on the other hand, also need global political stability.
- The *energy efficiency scenario* and a fortiori the *renewable energy scenario* would significantly relieve the pressure on external supplies to the EU due to decreased imports, while offering additional options to mitigate the worldwide depletion of fossil resources.

Single European energy market

In spite of the general current policy lines for the creation of the legal and technical provisions for a *single European energy market*, which are important in all scenarios and have still to be developed, quite different challenges would lie ahead in each scenario.

- In the *BAU scenario* – and in both nuclear scenarios – current policy trends would have to be pursued and even accelerated. Large investment would be needed for improvements to gas and electricity networks – about €45bn to €50bn for electricity grid investment including cross border transmission, about €11bn to €14bn for long distance gas transmission, gas storage and terminals for the unloading and re-gasification of liquefied natural gas (LNG) (CESI et al. 2005) and about €800bn over the 25 year scenario period for huge replacements in the existing stock of condensing power plants.
- The *energy efficiency scenario* and, to an even greater extent, the *renewable energy scenario* would present significant new challenges regarding accelerating progress in energy efficiency and the restructuring of the energy system towards higher shares of renewable energy sources and of CHP in district heating and industry. Grid investments for electricity would be expected to be near the upper limit of the above mentioned numbers, while those for natural gas would approach the lower end. Investments for new power generation would be 20% lower in the EE scenario than in the BAU scenario and 10% lower in the RE scenario. In the RE scenario the effect of much lower capacity is partly offset by higher cost per kilowatt installed. Furthermore, investment would be completely different.

While even in the BAU scenario investments in new CHP and renewable capacities are projected to overtake investments in fossil and nuclear generation, the latter will stand in the EE scenario for only 20% of total investment and in the RE scenario for less than 10%.

Energy efficiency

The comparison of the current EU policy towards *energy efficiency* with the three scenarios - BAU, EE and RE - shows some core results.

- The current EU demand side energy efficiency policy would (by definition) be sufficient in many fields to realise the *BAU scenario* as well as the two nuclear scenarios N+/N-. However, particularly in the transport sector, in electrical appliances and in industry, further action would be needed, e.g. in order to achieve the voluntary agreement with the European automobile manufacturers´ association (ACEA agreement). Further action would be necessary as well to protract these policies until 2030. On the other hand, the current political targets with respect to energy efficiency, as set out by the Green Paper "Doing more with less" and the Energy End-Use Efficiency Directive, would not be achieved in the BAU scenario.
- A much stronger policy for energy efficiency in the EU would be needed in order to meet the *energy efficiency* and the *renewable energy scenarios*. This policy would have to instigate strong *and* rapid action in order to implement ambitious efficiency targets close to the technical optimum, introduce further stepwise improvements in the energy efficiency of cars, appliances, buildings and businesses, strengthen technology development and provide substantial financial support and appropriate institutions. The evolution in energy market design (see above) would also affect the progress in energy efficiency and renewable energy use by affecting end use prices, investment in new and efficient (combined heat and power) generation capacity and the prospects for the introduction of demand side management (DSM) policies.

Renewable energies

It is assumed that the EU will pursue a very active policy to promote *renewable energies* in all scenarios.

- As the analysis of the existing policy shows, broad additional activities are indispensable even in the *BAU scenario*. However, in this scenario – as in all the others apart from the RE scenario – set targets will be missed and the EU would have to solve the problem of further fostering a supportive framework for renewable energies against a background of possible disappointment.
- In the *renewable energy scenario* on the other hand, both current targets and ambitious targets for the future (20% in 2020, 35% in 2030) are achievable. However, the scenario also illustrates that these targets require a substantial restructuring of the whole energy system and economy by using the opening window of opportunity presented by the ageing energy system and its subsequent high reinvestment need.

It appears that current policy for renewable energy– in spite of its impressive success – is not yet in a position to implement the changes needed for the realisation of this scenario.

Energy research and technology policy

With regard to the major *technology* areas discussed in this report, the intended structure of the seventh framework work programme covers all relevant aspects. Most of the key technology areas are supported by technology platforms that contribute to a market-orientated design of research and technology development (RTD) actions. Moreover, the RTD topics foreseen for FP7 represent a robust portfolio that will be needed for implementing any scenario philosophy of the BAU, energy efficiency and renewable energy scenarios. However, the crucial question will be the weighting of the budgets for the different technologies – the outcome of which is not yet fully clear. Another critical point is the fact that the EU RTD funds represent only a limited share of the whole RTD budget in the EU25. The priorities of Member States and companies are also relevant. With regard to the area of energy efficiency, however, a much broader range of technologies and players would need to be addressed. In the field of buildings and urban planning in particular, a dedicated need for integrated approaches can be identified that bundle high-efficient end-use technologies, optimised fossil and renewable energy supply with a strong focus on CHP, and related aspects of integration in energy networks e.g. as supported under the CONCERTO initiative.

Conclusion: Policy development needs and upcoming topics

The scenarios discussed in this report can be grouped into two main strategies.

The first type of strategy could be called "*advanced conventional*". This route is described by the BAU scenario combined with the N+ scenario and specific greenhouse gas (GHG) mitigation options of carbon capture and storage and, particularly, the use of clean technology transfer and other flexible mechanisms to achieve emission reductions outside the EU[4]. Therefore, it represents a more conventional supply side oriented course. The analyses above show that this route would not be merely business as usual. On the contrary, it would require an intensification of the policies for energy efficiency, including cogeneration, and for renewable energies. In addition, nuclear energy would need to have unequivocal support in order to allow for new capacity to be installed. Climate policy would consist of (1) the support of domestic energy efficiency and renewable energy policy combined with the large scale options of nuclear and carbon capture and storage (CCS) and (2) a strong policy to achieve significant emission reductions abroad by elaborating clean technology transfer mechanisms and emission trade systems.

This strategy would have to be supported by a strong international energy policy securing the substantially increasing energy import flows from abroad. This policy would also need to be strong and credible enough to prevent supply disruptions and sudden price shocks.

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[4] It has to be noted that this strategy has not been elaborated to the same extent and is based on less ambitious scenarios than the second strategy, due to the definition of the scenarios which was given for the study.

It would probably require the establishment of stronger relations with the main suppliers (Russia, Northern Africa and the Caspian Sea region) as well as the creation of a common understanding among the large energy importing nations to avoid destructively fierce international competition. In this scenario the EU and its Member States would become more dependent on international relations for tackling climate change as well as for securing energy supply.

The other type of strategy, "*domestic action*", relies much more on the domestic potential of renewable energy sources and energy efficiency and seems to have the capability to cope adequately with both major challenges, so that the risks emanating from these are significantly lower. This strategy, however, would need more radical domestic political action in order to speed up progress in energy efficiency and renewable energy supply and to achieve the already agreed (indicative) targets for the expansion of renewable energy supply and cogeneration and the enhancement of energy efficiency. In the context of this type of strategy, international relations could be less strained. Clean technology transfer would still be very welcome and relevant, but would be less burdened by demands emanating from very large scale emission trading required in the BAU scenario. Furthermore, the acceleration of energy innovations in the EU would provide a useful perspective on the lasting export potential of domestic solutions, not the least in the framework of clean technology transfer to developing countries. Furthermore, the strategy has the potential to contribute significantly to the Lisbon process by lessening the macroeconomic vulnerability and hence increasing the predictability of the economy. This, in turn, helps to increase the willingness to invest in more risky endeavours typically related to innovation processes throughout the economy.

Both strategies have crucial preconditions which may impose severe challenges to their feasibility. The *advanced conventional* strategy crucially relies on the successful implementation of an active foreign energy and technology transfer policy. Strong international competition for energy resources may become an increasing threat for this crucial foreign policy link. However, this scenario would carry less risk with respect to the management of change inside the domestic European society, since changes tend to be less radical than in alternative scenarios. The *domestic action* strategy, on the other hand, would swap, to some extent, the external threats from climate change and geopolitical turmoil for bigger challenges with respect to the management of the more radical changes inside the domestic European society (i.e. within the EU and its Member States). More specifically, this strategy would stand or fall at the successful restructuring of the EU energy system and the bulk of all investment decisions.

Robust policy choices

In spite of the diverging, and at least partly mutually exclusive, directions in which energy policy could steer the survey of (energy) policy choices, there are a number of policy actions that would be required in any strategy and which differ only in terms of intensity.

Consequently, these policy areas should be given high priority for securing energy supply regardless of the strategy prioritised[5].

- The first robust policy option is the enhancing of *demand side energy efficiency* including cogeneration. All the scenarios discussed in this study assume further significant increases in energy efficiency in all demand sectors. This means that the current policies should be actively implemented at the opportune point in time and that further action should be taken in order to foster the development of efficiency.
- The next robust option concerns *renewable energies*. All the scenarios assume high increases in this area as well, particularly in wind power generation and biomass use. What is more, some policies are already partly in place and the current targets on the EU level already correspond to a very ambitious RE scenario, but would need to be supported by stronger policy and expanded by 2020 and 2030.
- In the *energy market* overall, and taking into account the efforts being made to enhance energy efficiency, it is also important that retail pricing of electricity appropriately reflects its scarcity and emission impacts on the wholesale market. In this context demand side management (DSM), demand side bidding (DSB), product differentiation by origin of fuel type, an equitable market treatment for decentralised generation and storage facilities deserve more attention. It would also be necessary to upgrade electricity networks with respect to larger variable power sources, such as wind; to a larger share of small scale generation and storage capacity tied to the distribution network; and to the improvement of inter-connector capacities.
- Robust steps towards a future *EU external* energy and climate *policy* include the fostering of clean development and clean technology transfer, as this will strengthen international relations, partly release demand pressure on energy markets, create additional or strategically needed emission credits and expand markets for renewable and efficiency technologies, which would, in turn, support the domestic development of these technologies.

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5 Carbon capture and storage (CCS) and nuclear power are generally not regarded as long term sustainable solutions. However, under certain conditions and for certain countries they may constitute helpful transitory options with which to some extent 'time can be bought' to develop and test the fundamental solutions adequately. In this respect for example it could be regarded as a robust choice to ensure sufficient R&D effort for assessment of the potential of CCS and its technical prerequisites for a sound use of the option.

1 Analysis of Resource and Technology Trends

1.1 Current Situation of Energy Reserves and Projections for the Future

This overview begins by outlining the debate concerning the different definitions of fossil fuel reserves and resources that lead to dissimilar interpretation of data and, therefore, to different results. Subsequently, the focus will be on current energy reserves and production, together with projections for future production of, and demand for, the most important non-renewable energy carriers: oil, gas, coal and nuclear fuels. This will be followed by a conclusion of the global situation in general and, in particular, of the situation in the EU25.

The other two major energy resources - energy efficiency and renewable energy - are not discussed here in detail but play an important role in the following chapter 1.2 on technology and in the scenario analysis. The scenario analysis is based on a review of energy efficiency and renewable energy potentials carried out by Lechtenböhmer et al. (2005a/b).

1.1.1 Definitions

Publications on fossil fuel endowment are numerous. As it is a time consuming process to calculate total reserves from data derived from single oil and gas fields, many authors rely on a limited number of data sources. These data sources assess a large share of global oil and gas fields and create **different categories of oil and gas resource types**. This is then interpreted by different institutions in order to distinguish between different types of oil and gas and different reservoir types and their own categories of "conventional" and "unconventional", as well as "reserves" and "resources", are applied.

Using an economic approach, **reserves** are defined as "economically to produce with current technology at current price levels"; all other oil sources are termed **resources.**

Data on **conventional and unconventional oil and gas reserves and resources** is the subject of controversial discussion. This is due mainly to the following reasons:

- Certain types of resources are categorised differently: e. g. tar sands are categorised by some authors as conventional oil, by some as unconventional, by others as resources (not as reserves). Therefore, the terms conventional and unconventional reserves and resources contain different types of oils and gases.
- Technological progress is assessed differently.
- Depending on the type of reserves calculation, different probability values are chosen as the base data for publication.

Over time, sections of the reserves currently deemed 'unconventional' may become more or less conventional. For example, the exploitation of oil fields in open (semi) deep sea was, 30 years ago, regarded as largely unconventional. The same applies to Arctic oil fields. It also means that the exploitation cost (per barrel of oil) of such edge technology fields could well decrease over time. However, the unit cost usually remains higher than that of the earlier, and somewhat less complex, category of oil fields.

1.1.2 Viewpoints on future oil and gas production

The definitions given above also influence the viewpoints on the outlook of oil (and gas) production. The prediction that 'easy oil as we know it' will more or less come to an end in the foreseeable future has broad (but not unanimous) support among energy economists. However, the question of global production remains the subject of much debate. Whether it will reach its (physical) limits over the next one or two decades not only depends on the physical facts (however controversial they may be) but is also determined by the following factors:

- The rates of growth in demand for oil, gas and, to a lesser extent, coal (this may depend on how quickly carbon sequestration technologies are adopted).
- The substitution between fossil fuels, in some sectors notably towards coal (in this case clean coal technologies and carbon capture and storage could see a rise in application).
- The faster and more widespread adoption of energy efficiency and renewable energy sources, if future energy prices are believed to be structurally higher.
- The ongoing enhancement of recovery techniques for (existing) oil and gas fields (the higher the fuel prices, the higher the incentive for advanced enhancements).
- The ongoing improvement of exploitation capabilities of (now) unconventional oil and gas reserves: once there is sufficient belief in lasting higher prices, unconventional developments and Research and Development (R&D) will increase.

All of these factors depend not only on the potential of the mitigating possibilities – e.g. whether they are capable of satisfying growing energy demand – but also on the ability of major players to react in good time, as all the alternatives will require time in development.

Based on the geological production profile, which generally follows a bell-shaped curve with a production maximum at the point when about 50% of the recoverable oil has been produced, possibly followed by a short plateau, many institutions expect a **global production peak,** e.g. BGR (2005) for 2015 to 2025 and ASPO (2006) for 2010.

However, if and when a **global production peak** will occur is the subject of controversial discussion. Some authors either forecast no production peak at all – as they believe the above mentioned mechanisms will prevent it – or they make no mention of such a peak (e.g. BP 2004). International Energy Agency (IEA) falls into this category, with its biannual World Energy Outlook giving detailed information about possible energy consumption until 2030. The assumption on the supply side is that there will not be any structural restrictions to prevent the supply of the necessary amount of energy carriers. Peak discussion is mentioned in the World Energy Outlook 2004, but without comment by IEA.

It can, therefore, be concluded that the prospect of higher oil prices persisting in the future is becoming more and more generally accepted. Widely disputed, however, are the following questions:

- Will high oil prices send the necessary and timely signals to the markets?
- Will market players be aware and capable of exploiting the range of existing alternatives to prevent global oil markets from a supply shortage which could lead to price and other crises?

- Do the alternatives have the potential to make up for the shortfall?

1.1.3 Oil

Current oil reserves & production

Saudi Arabia and Russia are currently the largest oil producers, producing about 9 to 10 million barrels per day, followed by the USA, Iran and Mexico. Saudi Arabia is still producing with spare capacity, whereas Russia and the USA are producing in decline. Table 1-1 lists oil reserves of different world regions by different sources. Comparing different sources is difficult as they often use different regional separation. The same holds true for natural gas reserves and is particularly valid for Europe and Asia.

Table 1-1: Global oil reserves, estimations by different authors

	Eia		**ASPO**		**OPEC**	**BP**	**OGJ**	**IEA**
in Gb	proved	proved + growth + undisc.	conv.	un-conv.	conv.	conv.	conv.	conv.
North America		408.8	33.0		26.2	63.6	201.0	
Latin America		402.7	82.0		119.0	102.2	114.0	
Europe & Eurasia		578.4	236.0		108.9	105.9	97.2	
Middle East		1251.0	456.0		739.1	726.6	725.2	
Africa		299.0	81.0		111.7	101.8	87.0	
Asia and Pacific		10.6	6.0		39.2	47.7	38.0	
Unforeseen		-	14.0		-	-	-	
All	1262.3		906.0	455.0	1144.0	1148.0	1262.4	2600.0
all conv. + unconv.	2947.0		1360.0					

Note: *conv.*: conventional reserves; *unconv.*: unconventional reserves. Special categorisation of eia: *proved + growth + undisc.* includes all conventional and unconventional as well as yet undiscovered oil. eia uses the term *proved* for conventional oil (including oil sands), following OGJ (but using different regional separation). Europe/Eurasia and Asia partly overlap depending on the source. Asia by Opec, BP and OGJ contains reserves from Siberia which are listed under Eurasia by eia and ASPO.
In bn barrels (Gb)

Sources: ASPO (2005), BP (2004), eia (2005), IEA (2005a), OGJ (2003), OPEC (2005)

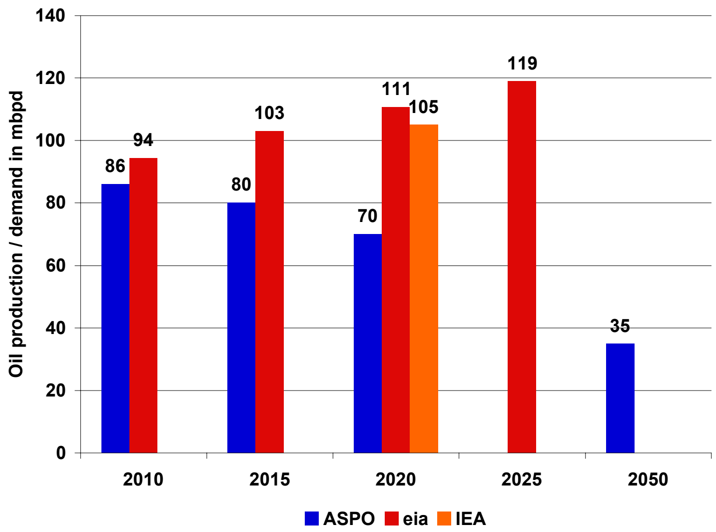
Oil reserves in Russia are of particular relevance for the EU, as Russia is a major supplier. *BP* indicates 69.1Gb of reserves (end of 2003) for the Russian Federation: *Aspo* citing *Oil and Gas Journal* predicts 60Gb (BP 2004, Aspo 2003).

Projections of oil production and demand

Future oil production capacities are the subject of controversial discussion, comparable to the debate on reserves. ASPO and BGR forecast a global oil production peak within a 15 year range: by 2010 (ASPO 2006) and between 2015 and 2025 (BGR 2005). Others, such as BP and Energy Information Administration (EIA) sources, do not assume such a production peak.

Figure 1-1 compares eia's and IEA's projected demand increase and ASPO's production projections, demonstrating significantly differing views on future developments: eia calculates possible demand (without assuming supply restrictions) whereas ASPO calculates possible supply (using the Hubbert approach of depletion mid point dynamics) via production profiles of separate countries as well as of total world production.

Figure 1-1: Possible oil production in million barrels per day



Note: ASPO: Geological production capabilities. eia and IEA: demand projections, supply follows accordingly.

Source: ASPO (2006), eia (2005), IEA (2005a)

Oil demand in the EU25 region will increase in the coming decades from 648 million tonnes of oil equivalents (Mtoe) in 2002 to 743 Mtoe in 2030 according to the IEA Reference Scenario (IEA 2004a), or will settle at about 640 Mtoe after peaking in 2015 at 672 Mtoe as projected in the new EU baseline scenario (Mantzos 2006).

As **domestic oil production capacity will decrease** in the coming years (as it already has done in previous years), the EU will have to increase imports significantly: in 2005 about 134 million tonnes of oil were produced domestically, whereas in scenario projections (BAU scenario) only about 44 million tonnes will be produced in 2030. As a consequence, import dependence will increase from the current level of 80% to well above 90% in 2030. The most important crude oil and feedstocks suppliers to the EU25 in 2004 were Norway (109 Mtoe), the Russian Federation (185 Mtoe), Saudi Arabia (65 Mtoe), Libya (51 Mtoe) and Iran (36 Mtoe) (Eurostat Online Database 2006).

Eia projects that oil supplies from the North Sea (Norway and Great Britain) to Western Europe will stand at 3.4 million barrels per day in 2025 (eia 2005). This implies a declining rate of supply (excluding supplies to regions other than Western Europe) of about 2% per year. Given the fact that oil production in the North Sea is currently declining at significantly higher rates, the data seem over-optimistic. The International Energy Agency projects that the oil production of the OECD Europe category will stand at 2.2 million barrels per day in 2030, which represents an annual rate of decline of 4% (IEA 2004a). As Norway is one of the EU's most important foreign suppliers, other sources will have to compensate for these declining imports.

Possible suppliers to meet the additional demand could be OPEC members as well as some African countries. However, there are potential threats to these options:

1. The EU will experience strong competition with other consuming regions, including India, China and North America, to gain access to the remaining promising oil regions.
2. Some of the relevant oil-producing regions and countries are either involved in enduring regional (military or paramilitary) conflicts, e. g. Nigeria, or are politically unstable, making projections of future oil supply dependent on non-economic criteria.

Strategic oil reserves exist in IEA Member States. The purpose of these reserves is to compensate for sudden and temporary shortfalls of crude oil supply. They typically hold a stock of crude oil that would meet domestic oil consumption for 90 days, so a total supply disruption of three months could be bridged completely. Strategic reserves were not established to compensate for structural supply restrictions such as reaching a global oil production peak. The role that strategic reserves could play when oil supply declines globally has yet to be analysed.

To summarise:

- The oil demand in the EU25 is expected to be at, or above, current levels in BAU projections.
- Domestic oil production will substantially decline to an almost insignificant level.
- Supplies from Norway will also decline.
- The EU will have to strengthen import relationships with the Middle East, the Caspian Sea region and Africa in order to significantly increase imports from these regions under BAU conditions.
- This necessity is challenged by increasing international competition and unstable political situations in many of the potential exporting countries.
- Strategic oil reserves were established to compensate for temporary supply shortfalls, not as instruments to handle structural supply restrictions on a global scale (such as a production peak).

1.1.4 Gas

Current natural gas production and demand

Gas reserves and production are, in many aspects, comparable to oil. However, the major gas producers are not identical to the major oil producers on the global scale. Russia is the largest gas producer, followed by the USA. Nevertheless, US domestic gas consumption is dependent on gas imports, whereas Russia is the largest natural gas exporter on the global scale. Gas reserves of the Russian Federation are estimated by BP to be 47bn cubic metres. For distribution of global natural gas reserves see Table 1-2.

Table 1-2: Estimates of global natural gas reserves by region

in bn. M^3	OGJ	ENI	OPEC	BP	Laherrere
North America	7.0	7.1	7.0	7.3	
Latin America	7.5	7.5	7.9	7.2	
Europe / Eurasia	60.9	63.6	63.8	62.3	
Middle East	71.3	71.7	72.9	71.7	
Africa	12.8	13.8	14.3	13.8	
Asia and Pacific	12.6	16.9	15.9	13.5	
All	172.1	180.6	181.7	175.8	283*)
*) ultimate reserves, including already produced gas. Already produced accord. to Laherrere: ca. 40 %					

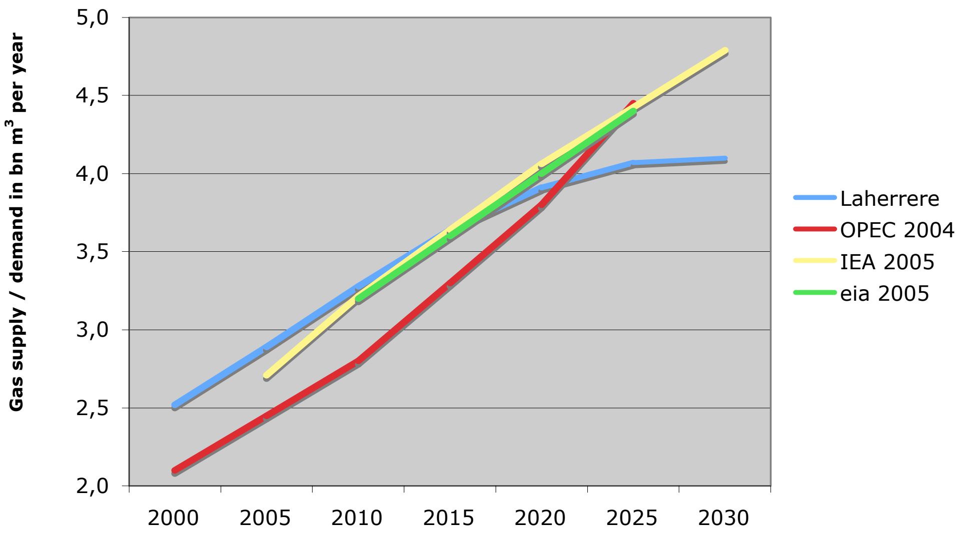
Europe/Eurasia includes: Eastern and Western E., Eurasia, GUS. OGJ and ENI taken from (EWI / Prognos 2005)

Sources: EWI / Prognos (2005), BP (2004), OPEC (2005), Laherrere (2006), (2004)

Projections of natural gas production and demand

Natural gas is – thanks to economic and ecological reasons – the preferred energy carrier in many countries and these countries are willing to allow natural gas to supply a larger share of total energy demand in the future. This leads to the greatest projected growth compared to all other energy carriers at 2.1% per year (IEA 2005a). However, if production capabilities reach a maximum as indicated by Laherrere, demand will have outstripped supply at some point after 2020. Laherrere uses the Hubbert approach, i.e. calculates geological production capabilities without taking demand into account (this is similar to ASPO) and production will reach its peak (which will be shaped more like a plateau) in 2030. IEA and eia project that supply will be able to satisfy demand. The figure compares **possible natural gas production** (Laherrere 2004) **and natural gas demand** as calculated by eia (2005) and IEA (2005a).

Figure 1-2: Possible global gas production

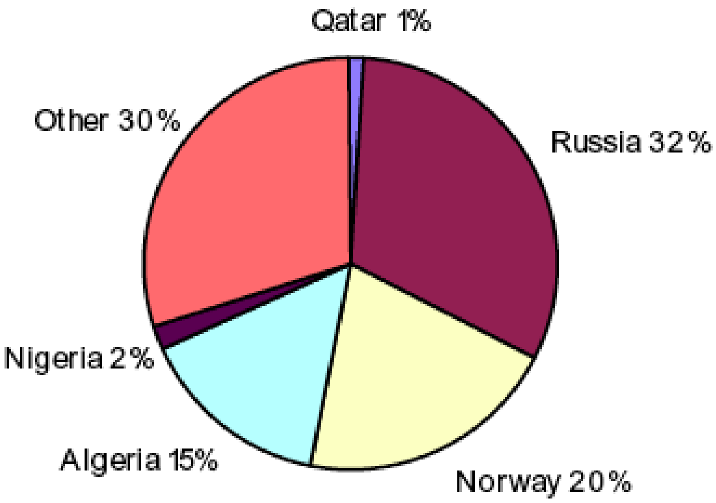


Note: according to Laherre and demand as projected by OPEC, eia and IEA, in billion cubic metres

Source: Laherrere (2004), OPEC (2004), IEA (2005a), eia (2005)

The EU's natural gas consumption is assumed to increase from 423 Mtoe in 2002 to 517 Mtoe in 2030, peaking in 2020 at 530 Mtoe, as projected by the BAU scenario (Mantzos 2006). According to Eurostat (Eurostat 2006), in 2004 Russia's import share was 32%, Norway's was 20% and Algeria's was 15% (see Figure 1-3).

Figure 1-3: EU25 gas imports by country of origin



Source: Eurostat (2006)

Its most important suppliers are the former USSR states (mainly Russia), Norway and Algeria. According to IEA, gas supply will experience dramatic shifts in the coming decades, as domestic supply will decrease and substitutes will become necessary.

When comparing the EU25's projected gas imports from Russia, it is relevant that the Russian export strategy does not plan on supplying natural gas in these volumes to Europe (Götz 2004, 2002). The resulting gap will have to be filled by other imports. **Liquefied natural gas (LNG)** is an increasingly important option for future European gas supply. The advantage of LNG is in the non-stationary transport logistics, which allow for greater supplier flexibility. The LNG option is being considered in different regional contexts: imports from Algeria could be increased and trade with Trinidad and Tobago could be established. Nigeria is also seen as a possible supplier of LNG.

However, the most promising region for supplying gas – encompassing LNG (e.g. initial projects in Bahrain) as well as pipeline natural gas (via the projected Nabucco pipeline planned to be operational in 2011) – is the Middle East, which holds large natural gas reserves. Iran, in particular, is considered to be a potentially interesting supplier for the future as it is the second largest gas reserve owner. However, the current conflict on nuclear energy (or nuclear weapons) between the USA and the EU on one side and Iran on the other puts a question mark over the prospects of European-Iranian gas cooperation.

In 2005 domestic natural gas production amounted to 198 Mtoe and supplied around 46% of the total gas consumption in the EU25. Import dependence will rise to 84% according to the BAU scenario (Mantzos 2006).

1.1.5 Coal

Coal reserves are distributed more evenly throughout the world than oil and gas reserves. However, many reserve owning countries are not utilising their reserves due to economic reasons: e.g. importing coal might be cheaper than producing it domestically or other energy carriers may be preferred. In addition to this, only a small fraction of the coal produced worldwide enters international markets.

The **Asia Pacific region** is the world's largest coal producer, due mainly to Chinese and Indian production. According to IEA, global coal production will have to be increased significantly in the coming decades, as demand will grow in all geographical regions. Coking coal must be distinguished from steam coal. The latter is used for heat and electricity generation via combustion, whereas the former (of higher quality) is an essential ingredient of steel production. In both cases domestic trade dominates over international trade: in 2004 more than 80% of total steam coal and about two thirds of coking coal were traded domestically (VDKI 2005). In 2004 about 4 billion tonnes of steam coal and 600 million tonnes of coking coal were produced. The majority of coal imported by the EU25 uses seaborne transport routes, as inter-continental transport flows are dominant.

Table 1-3: Coal reserves

in billion tonnes	BP 2005	WEC 1999	DOE/EIA 1999	BGR 2002
North America	254.0	258.0	256.2	258.0
Latin America	20.0	21.8	21.8	20.5
Europe & Eurasia	287.0	312.7	312.7	291.3
Africa & Near/Middle East	51.0	57.1	57.1	39.3
Asia Pacific	297.0	335.0	335.0	326.6
All	909.0	984.5	982.7	935.8

Data includes anthracite, bituminous and sub-bituminous coal types and lignite.

Source: BP (2005), BGR (2003)

Domestic production reached about 170 million tonnes of hard coal in 2005 in the EU25 region. Poland contributed 97 million tonnes to domestic supply, or about 60%, Germany contributed 15% and the UK 12%. Smaller amounts were supplied by the Czech Republic and Spain.

Coal demand is projected to decrease in coming decades in the EU25. While in 2002 around 300 Mtoe of coal were consumed, consumption will decrease to around 270 Mtoe by 2030 according to the International Energy Agency (IEA 2004b). The BAU scenario projects total solids consumption of 293 Mtoe by 2030. As member countries are reducing domestic coal production mainly for economic reasons (e. g. in Germany) the imports of the EU25 region will increase from 115 Mtoe in 2005 to 173 Mtoe in 2030 according to the BAU scenario (Mantzos 2006).

The major foreign suppliers of EU25 hard coal imports in 2004 were South Africa, which contributed about 54 million tonnes (mt) annually, Russia (33 mt), Australia (30 mt), Columbia (24 mt) and the US supplying 19 mt. (Eurostat Online Database 2006).

Overall, coal supply from overseas production seems to be available at a relatively competitive price, with no significant constraints predicted for the future.

However, decisions taken by the main producing countries may have significant (short term) impacts on the market, as was the case with the market for coking coal which faced shortage problems and strong price increases due to increased domestic consumption in China and its subsequent drop in exports.

1.1.6 Nuclear Energy

Nuclear energy[6] is used almost exclusively for electricity generation. Uranium ore has to be mined, comparable to coal, but is then enriched by complex processes. Currently, mining produces significantly less Uranium (U) than is used in power plants due to the utilisation of strategic (including military) stockpiles of Highly Envided Uranium (HEU). In 2004 more than 68,000 t U were utilised in plants, whereas mining produced only between 40,400 and 40,700 t U (BGR 2005, ESA 2005). This gap has been a common trend in recent years.

More than 80% of global Uranium reserves are located in four countries: Australia, Canada, Kazakhstan and South Africa (BGR 2005).

If projections for the future construction of new nuclear power plants materialise, demand for nuclear fuels will increase significantly. However, IEA projects an annual growth of electricity generation by nuclear energy of only 0.8%.

The largest reserve owners are also the most relevant Uranium producers.

The major suppliers of nuclear fuels to the EU region are the former USSR, Canada, Niger and Australia. This indicates that the EU15 region is completely dependent on importing natural Uranium.

Table 1-4: Accessible Uranium reserves in relation to price (2003/2004)

	Reasonable Assured Resources economically mineable at price of				Estimated Additional Resources economically mineable at price of			
	80 $ / kg U		130 $ / kg U		80 $ / kg U		130 $ / kg U	
	in kt	in Mtoe	in kt	in Mtoe	in kt	in Mtoe	in kt	in Mtoe
Australia	714	6997	735	7203	287	2813	323	3165
Kazakhstan	385	3773	531	5204	238	2332	317	3107
Canada	287	2813	345	3381	85	833	99	970
Namibia	139	1362	171	1676	74	725	87	853
South Africa	232	2274	315	3087	70	686	80	784
USA	102	1000	345	3381	n/a		n/a	
Brasil	86	843	86	843	57	559	57	559
Russia	124	1215	143	1401	34	333	121	1186
Niger	102	1000	102	1000	126	1235	126	1235
Uzbekistan	62	608	80	784	32	314	39	382
other	292	2862	327	3205	56	549	165	1617
World	2525	35350	3180	44520	1059	14826	1414	19796

Source: BGR (2005)

[3] Sources other than uranium were not assessed in the context of the study. It should be noted that in the long term nuclear power plants could be built which do not use only uranium or plutonium such as is used today, but which utilise uranium more efficiently (U-235, but also U-238 or depleted uranium), or which increasingly use other fuels like thorium 232 (through breeding to uranium-233 (U-233)) or other actinides as well. Therefore, overall reserves of nuclear fuels could be larger than the total reserves of uranium only, and could be used more effectively in future.

Russia has ambitious plans, with the intention of increasing its production to between 5,000 and 6,000 tonnes per year. Currently the annual mining output is 3,200 tonnes. Kazakhstan produced 3,000 t U in 2003; production projections see its production standing at 12,000 t U in 2015.

The EU25 consumed 251 Mtoe of nuclear fuels in 2005, whereas in 2000 consumption stood at 238 Mtoe; in 2030 nuclear fuel use will decrease to 211 Mtoe (Mantzos et al. 2006).

1.1.7 Conclusion

Discussion on the **global production peak of crude oil** is controversial. The range varies from an early global production maximum (in 2010 for all liquid hydrocarbons) to a scenario whereby a maximum is not reached at all in the coming decades. However, there is a strong indication that prices will remain high, or even increase, in the future. It is also possible that at least a temporary production crisis could occur if existing alternatives are not exploited in sufficient time. The same holds true for **natural gas** which, with prices coupled more or less to oil and with a tight market lying ahead for the next decades, faces the challenge of satisfying increasing demand while requiring significant investment in new and more expensive production technologies and in transmission capacity.

The situation for **coal** is somewhat different from that of oil and gas. There are no structural supply restrictions for coal expected in the coming decades. However, current production capacities are, in many cases, at a maximum and a number of countries are currently considering increasing coal production again after years of decline. Coal production is, in many cases, critically dependent on public acceptance (due to environmental damage and social aspects in the producing regions) and this could become a limiting factor to production increases.

Nuclear fuels are expected to reach their limits in the coming decades. Taking into consideration the fact that currently a large part of the Uranium needed for nuclear fuel is not mined but supplied from existing civil and military stocks, the industry will face the challenge of securing the necessary sources by increasing mining capacity at the opportune point in time. However, as there is the possibility of storing large amounts of energy, using further military sources and also increasing efficiency of use, restrictions in production do not appear to be inevitable.

Domestic production of oil and gas in the European Union is declining (EU 2006). This decline has to be cushioned either by the **diversification of suppliers or by stronger dependence on a few importers** such as Russia. Irrespective of the chosen solution, **import dependence on fossil fuels will increase significantly** in the EU25 from 59% in 2000 to 84% in 2030 (BAU), and will increase for all types of energy carriers. This trend is amplified by growing energy demand. Import dependence can directly influence the security of energy supply, as political and other aspects in supplier and transit countries play major roles in the stability of supply chains.

Table 1-5: Import dependence of EU25, baseline scenario

in % of consumption	**2000**	**2030**
Solid fuels	30	69
Oil	66	94
Natural gas	49	84
Uranium	*)	*)

*) Uranium is often treated as domestic fuel in statistics as larger amounts are stored. However, more than 80% of the uranium used in the EU is imported from abroad. Source: Mantzos (2006)

It can, therefore, be concluded that the situation in the EU25 is dominated by decreasing domestic production capabilities and increasing energy demand. Consequently, import demand will rise significantly (cp .Table 1-8).

- Currently the **EU25 already relies heavily on oil and natural gas imports** from its two main suppliers, Russia and Norway, and it will have to import even more in the future. However, oil production in Norway is in decline and its natural gas may reach its production peak in the coming years. In the case of Russia, there are a couple of as yet unresolved factors which will decide whether or not exports can be increased significantly. Therefore, the EU25 will have to diversify its supplier structures and turn to less stable countries (e. g. import from the Caspian region, increase imports from Middle East countries and from Africa).
- Another important development is the **increasing competition for energy resources**, as the other two large consuming regions (North America and South-East Asia) are also becoming more and more dependent on foreign supplies due to the entry of new players (such as India and China) to international energy markets and the rising demand of already large consumers (such as the USA).

1.2 Technological developments

The implementation of a sustainable, resource efficient and climate protecting energy system is a major condition for achieving a high level of security of energy supply. To meet these requirements, a broad range of innovative technologies already exist and further innovations are under development and expected in the near future. Although there are many possible options, in the following sections only the most promising technologies are considered - those which are expected to be able to make the greatest contribution to a sustainable energy system for the future.

The classification relates to technological as well as economical criteria: on the one hand the technology must have significant potential to reduce energy imports; on the other hand, only those technologies that are expected to be commercially available in the near future, or which are already on the market, are considered. In a complex energy system, not only single stand-alone solutions, but also the interaction of different measures, are of importance. Therefore, the following schedule contains fields of action, rather than single technologies:

- Energy efficiency in road transport (main focus on passenger cars)
- Alternative transport fuels (incl. hydrogen)
- Distributed generation (incl. biomass and stationary fuel cells)
- Advanced coal power (incl. carbon capture and storage)

- Wind energy
- Solar-thermal power generation
- Nuclear fusion

This selection corresponds for the most part to the technologies that are considered in the *World Energy Outlook* (IEA 2004a, IEA 2005a). It is generally agreed that the different forms of maritime energy sources, such as tidal and wave energy, have not yet been sufficiently developed to be available on the market in the next decades.

On the other hand, hydropower has long been exploited as a renewable energy source and its potential in the EU25 has, therefore, been almost fully explored. For this reason maritime energy sources and hydropower are not part of the following considerations.

Unlike the other technologies listed, nuclear fusion is still a long term option. In this context it is being considered, because it has the potential to provide emission-free energy and could, therefore, be seen as a solution for the future, especially with regard to securing energy supply. Therefore, a close look at its real market potential is necessary.

In the following sections, each of the listed technologies or fields of action is briefly introduced. A short overview of the state of the technology, its potentials and the price are given. The main obstacles and opportunities in introducing the technology to the market are outlined, and conclusions regarding the future role of each technology in the EU25 until 2030 complete the picture.

1.2.1 Energy efficiency in road transport (passenger cars)

A wide range of technological[7] options exists for improving energy efficiency in road transport. These options range from the further improvement of conventional vehicle concepts and components, as well as the implementation of alternative engines, to innovative concepts of downsizing and "super-efficient" vehicles. An increase in energy efficiency has an impact on fuel consumption and, consequently, in the emission of exhaust fumes. Emission reduction can, therefore, be one indication of vehicle and engine effectiveness.

Overview of the state of the technology

The technical possibilities for the reduction of fuel consumption of passenger cars can generally be divided into two different areas. These are, on the one hand, the improvement of the overall effectiveness of the technical system - regarding the on-board consumption of energy – and, on the other hand, the reduction of the friction. For the latter, the relevant components are rolling, accelerating, climbing and air resistance. The actual vehicle mass directly influences its resistance and is, therefore, an important key driver for enhancing the energy efficiency. A number of technical approaches for achieving a reduction of mechanical losses inside the engine are state of the art today, such as the lowering of friction losses through optimising the crank mechanism and the pistons, improving the bearing technology and increasing the operating temperature. In principle, these options can be used for the Otto as well as for the Diesel engine.

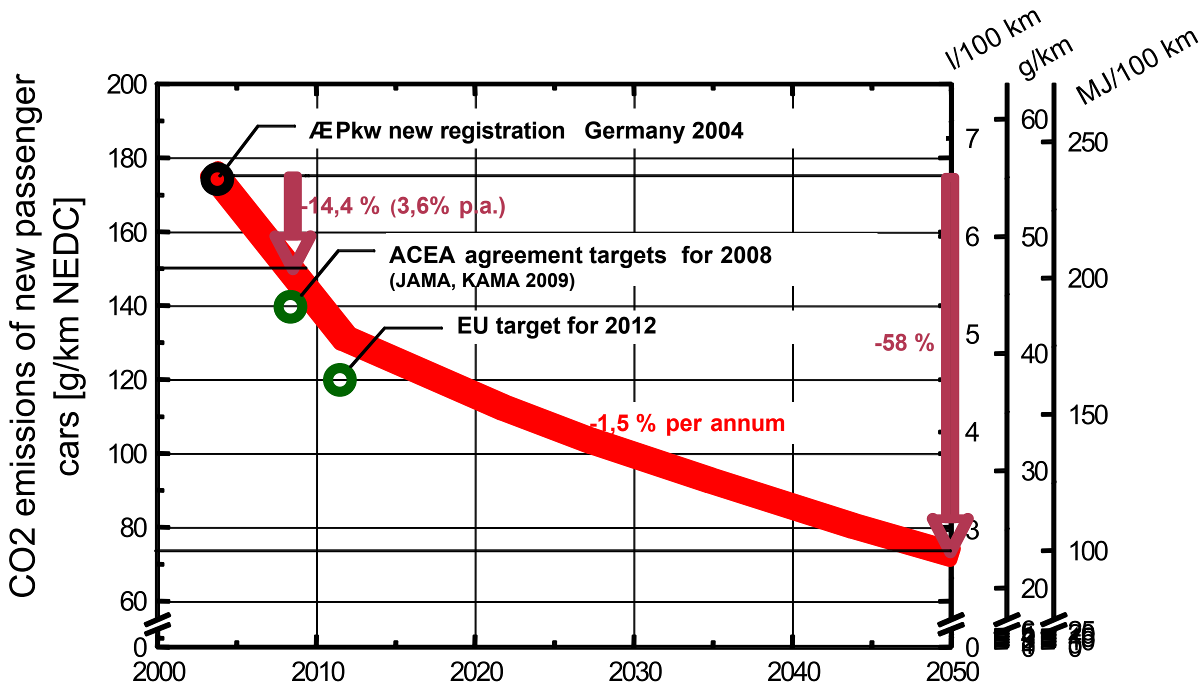
[7] Non-technological factors, as consumer behaviour, play a role, too.

Potential

In 1998, the European Commission and the European car industry, represented by the European Automobile Manufacturers Association (ACEA), agreed on a reduction of CO_2 emissions to an average of 140g/km by 2012, compared to a rate of about 186g/km in 1995 (EC, 2006e). This requires a reduction of fuel consumption to 5.1 l per 100 km of gasoline (4.6 l diesel, respectively).

According to Owen et al. (2003) it is possible to cut current emissions by half (reference: mid-size diesel car, 2003) by using technologies that already exist or are close to a market entry, with no compromise in the areas of driveability, performance or size. Consequently, changes such as massively reducing vehicle weight or significantly altering vehicle design are not considered here. In the light of the research carried out by Owen et al. (2003) and according to Ramesohl et al. (2005) an average reduction of 1.5% per year to an average of 99 g/km in 2030 can be achieved using existing technologies (Figure 1-4).

Figure 1-4: Development of CO_2 emissions of new cars in Germany and Europe



Source: Ramesohl et al. (2005)

Price

Vehicle technology is under constant development, not only in the area of fuel efficiency, but also in the fields of safety and passenger comfort, which increases the value and cost of vehicles. Therefore, an allocation of cost to single factors is complex and exceeds the scope of this synopsis. However, Owen et al. (2003) assume that to achieve a reduction in emissions of about 50% will increase vehicle cost by about 25%. The most costly step is the manufacture of hybrid vehicles, which can significantly reduce both emissions and fuel consumption, if for example regenerative breaking is implemented.

Obstacles/Opportunities

Improvements in the efficiency of passenger cars are of interest to the vehicle industry, but manufacturers generally focus more on powertrain efficiency than on reducing mass, air-drag and rolling resistance. In contrast, a trend towards rising average vehicle size can be observed, for example in the increasing popularity of *sports utility vehicles* (SUVs). Consequently, the increase in efficiency is, more often than not, offset by the increase in vehicle mass. Downsizing, on the other hand, offers additional opportunities for efficiency, but has not, so far, been an element in the strategy of manufacturers.

If powertrain improvement and rolling resistance, as well as vehicle mass reduction, are considered, the specific fuel consumption could be reduced by 20% or more in the short to medium term. This implies that an average figure of around 130 g/km should be achievable within the next 8-10 years without relying on new powertrain technologies such as full hybrids or fuel cells (Kageson 2005). The EU target of 120 g/km will not be met by 2012. The implementation of such innovative technologies could, however, generate significant progress in efficiency in the longer term. Obviously, a non-technical but very important factor is the consumer attitude regarding the use of their vehicles and their driving behaviour. Typical examples of non-technical measures to enhance the efficiency of transport include driver-training schemes, speed limits and car-pooling, just to mention a few of a broad range of possible instruments. At present, there is little quantitative and transferable data on the effectiveness and cost of these measures (Bates et al. 2001).

In road freight transport, only minimal energy efficiency improvements (0.3% per year) are expected in a BAU scenario (Lechtenböhmer et al 2005a/b). This is due to the fact that most measures have already been taken by freight operating companies in order to enhance their economic efficiency. Despite this, a variety of technological developments could be implemented to specifically improve the fuel efficiency of trucks. These include engine improvements, weight improvements, aerodynamic drag reduction and reduced rolling resistance, but also encompass non-technical factors such as the optimisation of freight transport, transport logistics, road telematics, driver training and an intermodal freight transport system (a shift from road transport to combined road-rail and road-shipping transport). If all such measures were implemented, predictions show that the growth of road freight transport would decrease from 2.6% per year to 1.7%, resulting in an emission reduction of 55 Mt CO_2 in 2020 compared to a BAU scenario (Bates et al. 2001).

Conclusions on the future role in the EU25 until 2030

In the long run, there is the significant potential to increase the effectiveness of passenger cars and transport. However, in order to achieve the targets of the European Commission (EC), strict measures and new, innovative technologies need to be implemented. A reduction of CO_2 emissions to 100 g/km and less could then be possible by 2030.

1.2.2 Alternative transport fuels (incl. hydrogen)

Alternative fuels for transport can be divided in five groups: fuels based on plant oil, alcohols, synthetic and gaseous fuels, and hydrogen. Common liquid biofuels of the so-called "first generation" are pure plant oil (PPO), fatty acid methyl ester (FAME or biodiesel) and ethanol based on sugar and starch crops. Most of the worldwide biofuel production and use today is ethanol, which is mainly produced in the USA and Brazil.

Biodiesel is mainly located on the European market, with Germany being a leader in production and marketing. Due to different combustion properties compared to fossil diesel PPO cannot be used in normal diesel engines but requires special refitting and a robust engine. A global trade in pure plant oil is not yet a reality. Biomethane from fermentative processes is an energy carrier that is not yet widely used as an alternative fuel. Within Europe so far it has only gained a small market share in Sweden (EC 2006b).

Overview of the state of the technology

The production of all common liquid biofuels is state of the art, while the production processes of the innovative biofuels listed have proven their technical feasibility but are not yet ready for commercialisation. Among the "second generation", synthetic biofuels such as biomass-to-liquids (BTL or Fischer-Tropsch-Diesel) are currently broadly discussed. The interest in the process is keen, as there is the potential to use wood as a new source in the production of a biofuel suitable for all engines. The production of ethanol from ligno-cellulosic feedstock such as wood, but also from grain residues (corn stover), is another potential option. For the production of hydrogen from biomass there are currently two possible routes: the gasification of solid biomass and the fermentation of water rich biomass to produce syngas, which then needs to be purified and reformed to make hydrogen (IEA, 2004).

Potential

The potential of common liquid biofuels is mainly a function of the available cultivation area and can, therefore, differ greatly from region to region, as aspects such as the competition for land use for food production, nature conservation areas etc. have to be considered. A major challenge in identifying the potential of biofuels is the allocation of the spend-able biomass to the different end-use purposes (mobile or stationary). New developments in fuel production, particularly in conjunction with innovative end use technologies, can significantly increase the potential of biofuel use by opening up new feedstock materials.

The respective biofuel potentials of the EU25 countries could be as high as about 1,970 PJ, based on the use of an average maximum of 18% of the available agricultural area in 2020 (EC 2004; Thrän et al. 2005). For the single countries, however, data can vary between 15% and 20%. In this scenario, ambitious nature conservation aspects cannot, however be realised and the assumption of using 12% of arable land for the cultivation of biofuel crops (Wiesenthal et al. 2006) is exceeded. In the latter study, an allocation of the available biomass for the different end use applications (e.g. stationary or mobile) is not done, so the biofuel potential cannot be estimated.

Considering the overall fuel consumption to be 11,440 PJ, taken from the updated Tremove model[8], a share of about 17% of the demand could be satisfied by biofuels, following the data of EC (2004) and Thrän et al. (2005).

[8] http://www.tremove.org/download/index.htm

Price

Production costs for common liquid biofuels vary from about €17/GJ_{fuel} for biodiesel to between €17and €19/GJ for ethanol from sugar beet and wheat feedstock respectively. Biogas from fermentative processes is a more costly option at €17- €23/GJ. Feedstock costs account for the major part of biofuel prices (EUCAR 2005). These figures are based on a crude oil price of US$50/bbl and, therefore, tend to be underestimated. Currently, based on about US$70/bbl, the production cost of gasoline is about €14.2/GJ (€12/GJ for diesel).

Among the innovative biofuels, ethanol from ligno-celluloses is expected to be more cost effective than BTL (€10 - €22/GJ for ethanol from straw and farmed wood respectively, versus €24 - €27/GJ for BTL from waste/farmed wood). Hydrogen, if produced by the gasification of wood, is costed at €10 - €13/GJ and is, therefore, the most economic option. However, it must be recognised that hydrogen production in this way is still only a possible future option requiring a specific infrastructure that is not yet in place.

Obstacles/Opportunities

Common liquid biofuel production (biodiesel and ethanol) is state of the art today (Schmitz et.al, 2005), but feedstock is limited to certain parts of specific energy crops. The quality of the fuel produced will not meet future standards such as the emission norm EURO V. On the other hand, new production processes like the BTL process or the conversion of ligno-celluloses to ethanol open up new sources of biomass. The fuels produced promise to be “designer fuels” of high quality, but the production is not yet a commercial reality. From an ecological point of view, gaseous fuels are more advantageous than fluids, because the yield of fuel per unit of biomass is higher, so the limited resources are more efficiently used. However, gaseous fuels cannot be transported and promoted in the same way as conventional fuels, but need a different infrastructure that still requires further development. All biofuels are considered to be CO_2 neutral, so their use will help to avoid greenhouse gas emissions in the transport sector (Quirin et al. 2004).

Conclusions on the future role in the EU25 until 2030

The objective of the EC is to develop and promote biofuels in the EU25 as well as in developing countries, in order to achieve a 5.75% market share by 2010 (EC 2003 a and EC 2005a). Special focus has been put on the biofuels of the so-called “second generation”, e.g. BTL, ethanol from ligno-cellulosic feedstock and biomethane, in order to achieve a diversification of feedstock material (EC 2006 b).

In the long run, biofuels have the potential to provide about 17% of the overall fuel demand. The European potential could be further expanded through importing either biofuel or biofuel feedstock from e.g. Brazil.

1.2.3 Distributed generation (incl. biomass and stationary fuel cells)

A wide variety of options for local energy supply are available today, among which the cogeneration of heat and power is highly effective. It can be achieved by using different technologies such as internal combustion engines, micro gas turbines or fuel cells. Different technologies can be served using different fuels, so aside from diesel and natural gas, biomass is a significant resource as well, combining the advantages of an efficient technology with a renewable energy carrier. Cogeneration options can broadly be divided into technologies serving the small scale power range (<10 kW_{el}) and those serving larger stationary plants (10 kW_{el} up to 1 MW_{el}). The first option is often referred as micro CHP and opens up new applications such as the residential sector.

Overview of the state of the technology

Today, cogeneration based on an **internal combustion engine (ICE)** is the most substantiated technology for distributed generation, already familiar in cars and trucks. It can, therefore, serve to pave the way for less established options such as micro gas turbines, Stirling engines or fuel cells. Disadvantages of the ICE include technical restrictions relating to emissions of exhaust fumes and noise, but also vibrations and the need for regular maintenance. In particular with regard to emissions and the technical effort required, the **micro gas turbine** offers possibilities, although its electrical efficiency is lower than that of the ICE. Both the **Stirling** and the **steam engine** operate on external combustion, allowing for a wider variety of fuel, without disadvantages regarding emissions, vibrations etc. Here, biomass, such as wood pellets, or biogas, play an important role. Neither of these technologies has been widely introduced to the market, so prices are still comparatively high. The **Fuel cell** is a technology that is still in a pre-commercial state, and cannot be expected to be available on the market before 2010. Among the many different types of fuel cells, the Proton Exchange Membrane Fuel Cell (PEMFC) and the high-temperature fuel cells Molten Carbonate Fuel Cell (MCFC) and Solid Oxide Fuel Cell (SOFC) are of particular importance. In the mid to long term, they can be operated using alternative fuels such as biogas or sewage gas (Cogen 2001).

Potential

The potential of distributed energy supply does not only depend on the availability of technology, but also, and very heavily, on the structure of the whole energy system. Therefore, the legal and financial framework is of importance, which provides an added complication when trying to determine the future potential. The European Commission set a target to double cogeneration output as a proportion of electricity generation from 9% to 18% by 2010 (EC 1997). Cogen (2001) calculated four scenarios to consider different stages of political framework and their influence on cogeneration capacities in Europe. As a result, the only way to meet the EC target is a post Kyoto scenario using flexible mechanism as emission trading and Joint Implementation while fostering micro cogeneration development. Under present policies, even when certain benefits for "green" technologies are assumed, the cogeneration potential will have only reached about 14% by 2020.

Price

The initial electricity cost for cogeneration technologies cannot be generalised, as too many aspects have to be taken into consideration. Technical factors, the type of technology, size of plant, fuel costs, demand and cost of maintenance have to be determined, while the legal and political framework is also relevant, as well as subsidies, taxes, bonuses and allowances for the generated heat and power. Consequently, an indication of electricity cost from cogeneration would exceed the scope of this technology synopsis.

Compared to the separate production of heat and power it can, however, be stated that large cogeneration plants in the range of several hundred Megawatt (MW) using coal or natural gas can produce electricity at lower cost. This is due mostly to the more effective use of energy and, therefore, to lower fuel costs, although the investment costs are higher than for conventional separate production. The cost advantage can, however, be diminished through the cost for heat transport. This is particularly relevant in the case of district heating, where the economic advantage of lower heat production costs can be reduced or even negated by the associated increased heat transport costs.

Obstacles/Opportunities

There are two general challenges in the implementation of cogeneration technologies that are relevant for all the different technologies mentioned above. Clearly, all the technologies have their own technical problems to solve but these cannot be discussed in detail at this point. For decentralised power generation in general, the **integration into the existing grid** infrastructures has to be considered carefully. In addition to certain challenges, this also offers new opportunities linked to the possibility of virtual power plants and load management aspects. As has been mentioned in the discussion of costs, the marketing of the produced heat is not only a financial issue, but also a local one. This is especially valid for larger cogeneration plants, as it cannot be assumed that excess heat can necessarily be used on site at the location. Consequently, the availability of **heat distribution grids** is a significant prerequisite for the implementation of Combined Heat and Power (CHP) plants.

Conclusions on the future role in the EU25 until 2030

Distributed combined heat and power generation allows for a more efficient use of primary energy and will, therefore, have to play a major role in sustainable future energy systems. In addition, innovative technologies such as external combustion engines and, with further development, fuel cells, open up the possibilities for new fuels to be used, for example, as biomass and waste.

1.2.4 Advanced coal power (incl. CCS)

Among fossil fuels, hard coal is the most abundant and distributed option. The major disadvantage of the use of hard coal for electricity generation is in the high level of emissions of greenhouse gases due to the combustion of the fuel. In order to meet the future challenges of reducing the environmental burden of power generation, two major strands of development can be identified. Firstly, the continuous improvement of total plant efficiency is key in reducing specific energy demand and GHG emissions of coal power.

Current developments aim to achieve conversion efficiencies of some 47% or more, and further steps even envisage efficiencies of above 50%. Major contributions result from higher pressure and temperature levels that demand new advanced construction materials and components.

Secondly, concerted efforts are being made to remove CO_2 from the power plant exhaust stream. Here, the technology of carbon capture and storage (CCS) may help to achieve a "carbon lean" power plant. In order to maintain coal power under more rigid climate policy regimes, effective CCS may become an essential precondition.

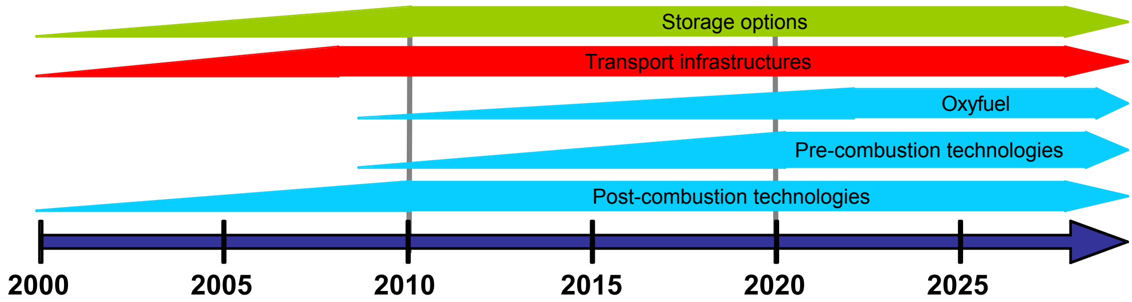
Overview of the state of the technology

The aim of CO_2 separation is to capture the CO_2 gas as simply as possible to keep the costs of compaction, transport and storage as low as possible. There are essentially three processes available. In the **post combustion** option, the separation of CO_2 is accomplished from flue gases *after* combustion. One advantage of this process is that it can be retrofitted to existing power stations. CO_2 flue gas washing is state of the art, but causes significant efficiency and capacity losses. In the **pre combustion** process coal is converted prior to combustion with oxygen or air. In this way, the majority of the CO_2 can be stripped from the combustion gas. Altogether, some 13 different technology routes for this are currently under discussion (BMWA 2003). Fuel gas decarbonising is already in use in some combined cycle power stations with integrated gasification (IGCC - Integrated Gasification Combined Cycle) although, at the moment, no CO_2 is being captured and a commercial breakthrough is not being achieved, as the coal-fired plants with integrated gasification installed in Europe so far (Buggenum in the Netherlands and Puertollano in Spain) are not sufficiently reliable for commercial power station operations. The **oxyfuel process** enables a simplified separation of CO_2 from flue gases after combustion with oxygen. This process produces a much reduced volume of waste gas, and the concentration of CO_2 in the combustion gas rises to around 80%. A further benefit is that the process does not produce any nitrous oxides, so there is no need for further treatment of the gases.

Potential

At the present time it is not possible to state with any certainty when this technology will be available on an industrial scale and with the necessary reliability. The criterion of timely availability for the EU25 favours post combustion technologies. While initial IGCC demonstration plants have been in operation for several years without yet achieving a commercial breakthrough (due, among other things, to poor availability and unsatisfactory efficiency), the oxyfuel technology is not expected to be ready for large scale use until between 2015 and 2020 at the earliest. Figure 1-5 presents this situation in graphic form. Further information can be taken from Gielen (2003) and Simader (2004).

Figure 1-5: Expected market introduction of CCS technologies



Source: Fischedick et al. (2006)

Price

The costs of CO_2 separation alone for the current five reference power stations amount to €26/t of captured CO_2 (pre combustion) and €29 - €37/t CO_2 (post combustion). This would increase power generation costs by 33.3% to 48.4% (pre combustion) and by 32% to 50% (post combustion) (Ecofys 2004a).

Obstacles/Opportunities

The power consumption for CCS reduces the efficiency of coal fired power plants by 4.8% when using pre combustion technology (5.6% for post combustion). This equates to a relative efficiency loss of up to 11% (10% to 20% for post combustion). Therefore, more resources will be needed to reach an equivalent power output. As a consequence, coal and natural gas production capacities will have to be increased (Ecofys 2004b).

Another big obstacle is the availability of secure and abundant storage facilities. Except in the case of CO_2 use for enhanced exploration of oil and gas and various R&D activities no (long term) CO_2 storage facilities exist worldwide.

Conclusions on the future role in the EU25 until 2030

There is significant need for new power plants to be built in the coming decades. Pre combustion technologies, and especially the Oxyfuel process (except pilot and demonstration plants), will probably arrive too late for mass use, as the technologies will not be commercially available by the time of new investment in the respective power plants in the EU25.

1.2.5 Wind energy

Within the EU25, wind energy has dominated recent portfolios of 'new' electricity generation from renewable energies and has the highest yearly growth rates of about 38% in electricity production over the last ten years. Within a short period of time, the dynamic development of wind power has resulted in the establishment of a relevant market for the energy economy (Chandler, 2005 and EWEA, 2006).

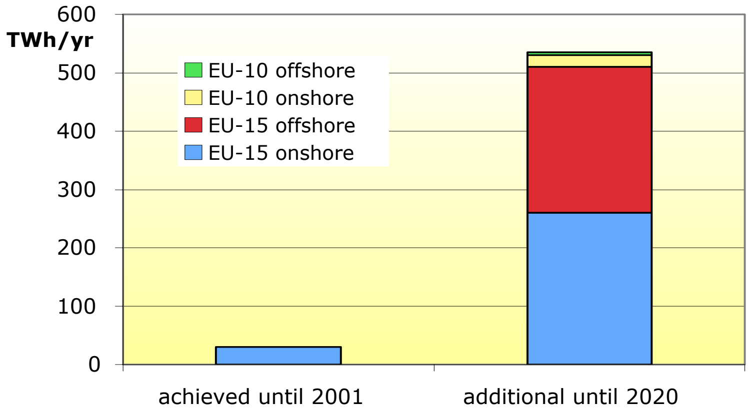
Overview of the state of the technology

Today's wind turbines are state of the art modern technology. Effective power generation is possible at wind velocities starting at 3-4 m/s, depending on the plant type. The capacity of the generator differs from small plants (up to 50 kWel) to medium (up to 500 kWel) and large (several MWel). The average capacity of new installed plants in 2004 was 1700 kWel. In 2002 a prototype 4.5 MW turbine was installed in Germany which was, at that time, the largest wind turbine in the world (Nitsch et al. 2004). In the global context, Germany is the nation with the highest capacity installed, followed by Spain, the USA and Denmark.

Potential

According to Ragwitz et al. (2005), until 2001 the achieved wind energy potential in the EU25 concentrated on onshore wind parks in the EU15 countries. So far, only 30 TWh per year have been installed, mostly in Germany, Denmark and Spain, but there is potential for an additional 260 TWh/y onshore and another 250 TWh/y offshore by 2020 (cf. figure below).

Figure 1-6: Wind energy potential (on and offshore) in EU15 and EU10



Source: Ragwitz et al. (2005)

Among the new Member States, so far only Estonia and Poland have begun to exploit their wind energy potential, accounting for less than 1% of the renewable electricity generation. By 2020, Cyprus and the Czech Republic in particular, but also Malta, Lithuania and Latvia, are expected to increase in importance in this area. Altogether, the wind energy potential in the new Member States accounts for 19% of the predicted renewable electricity generation in 2020 (16% onshore and 3% offshore).

One possibility for further expansion is so-called *repowering*, in other words replacing older small turbines by modern large systems. In this way, the potential can be expanded significantly without requiring more space (Rehfeldt et al. 2005). Furthermore, in the long term, great potential can be exploited in the *offshore sector*. Here, the potential of wind energy is much larger, and the required space is more easily available.

Price

By 2020, a reduction of about 25% in investment costs compared to the year 2002 is assumed to be possible in the business as usual case according to Ragwitz et al. (2005). Therefore, long term marginal costs of electricity generation in wind parks are calculated to be in the range of €55 - €110/MWh and €70 - €130/MWh for onshore and offshore generation respectively (Ragwitz et al. 2005). Meanwhile, Nitsch et al. (2004) conclude that the additional costs for foundations and grid connection for offshore wind parks are offset by higher yields, which means that electricity costs of less than €50/MWh could be possible in the long term.

Obstacles/Opportunities

The major issues regarding the integration of wind power into the energy system relate to changing approaches in the operation of the power system. This includes connection requirements for wind power plants to maintain a stable and reliable supply as well as extension and modification of the grid infrastructure. It must be acknowledged that the need for infrastructure investment is not only relevant for wind energy, as grid extensions, grid reinforcement and increased backup capacity benefit all system users. Taken together, the capacity of European power systems to absorb a significant amount of wind power is determined more by economics and regulatory rules than by technical or practical constraints. Already today a penetration of 20% from wind power is feasible without posing any serious technical or practical problems (van Hulle et al. 2005).

Conclusions on the future role in the EU25 until 2030

The wind energy sector is growing, not only in Germany and the EU, but also globally. While the industry initially concentrated on the German and Danish market, more recent target countries include, amongst others, Spain, Italy, France and Poland, as well as Brazil and China. As a local and renewable energy source, wind energy can help not only to reduce GHG emissions, but also to contribute to security of supply. The challenge of the integration of fluctuant load remains, but this challenge can be overcome via the necessary organisation of the grid.

Today, wind energy is used for generating electricity, which is fed into the public supply grid. In the medium and long term, however, there are also other possibilities such as using wind energy for water desalination, for saving fuel by integrating wind turbines in small diesel-electric grids, or for the production of hydrogen.

1.2.6 Solar thermal power generation

Solar thermal power plants concentrate solar radiation and convert it into thermal energy. The heat can then be transformed into electrical energy in conventional power plants, like steam generation, or be used in heating processes. In addition to providing electrical energy, thermal energy generated with concentrated solar power (CSP) can also be used for process heat in industrial processes (e.g. chemical processes), seawater desalination or solar cooling via adsorption cooling systems.

Overview of the state of the technology

Among the different options, **parabolic trough systems** are the most developed. The collector systems are installed in parabolic troughs following the sun radiation in one direction. The reflectors concentrate the sunlight onto an absorber pipe placed in the trough's focal line. A thermal transfer fluid is circulated through these tubes and heated up to 400 °C. After passing a heat exchanger, the heat is used to produce steam to drive conventional power plants.

The **Dish-Stirling-System** is operated in a similar way to the process described in the section on cogeneration, but driven by the solar heated working fluid. To reach higher temperatures (up to 900 ° C) and efficiency (up to 30%), parabolic mirrors track the sun using two axes in contrast to the one-dimensional trough collectors.

Another type of concentrated solar power technologies is the **solar tower power plant**. The radiation is concentrated to a central receiver on the top of a tower (height: 50 – 150 m) by individually tracking mirrors (heliostats), installed in a circular field. The temperature in the receiver is up to 1000 °C. By means of the concentrated heat, steam is generated and delivered to a conventional power plant unit (e.g. gas or steam turbine) or solar reformer (e.g. production of synthesis gas).

In **solar chimney power plants** the sunlight heats the air under a circular collector roof made of glass, like a greenhouse. The hot air flows to a chimney a few hundred metres high that is located in the middle of the collector roof. As hot air rises, it drives wind turbines installed in the base of the tower, thereby generating electricity. These solar chimney plants can use direct and diffuse radiant energy in cloudy weather conditions for heating up the collectors. In addition, the heat is stored in the ground underneath the roof so that the plant continues working for a few hours after sunset (Aringhof et al. 2005; Brakmann et.al, 2005).

Potential

The IEA estimates that by 2020 a potential of CSP of 20,000 to 40,000 MWel can realistically be implemented worldwide. The "Global Market Initiative for Concentrating Solar Power (GMI)" by national ministries and international organisations, aims to develop the capability and markets for solar thermal power plants (Morse 2004). The objective is to facilitate and expedite the building of 5,000 MWel of CSP worldwide over the next decade. One of the five most promising regions in terms of governmental targets is the Mediterranean, especially Spain, Greece and Italy. There, as in the Middle East, North Africa, the southern states of the USA and Australia, more than 1,000 MWel of solar thermal projects are expected by 2025 (Aringhof et al. 2005). Further information can be found in Trieb et.al (2005) and Lüpfert (2006).

Price

The **initial costs** of solar thermal power plants are around 9 to 16 Ct/kWh (compared to around 30 to 80 Ct/kWh for photovoltaic power generation). The costs are expected to decrease by half in the medium term. In 2002, the Spanish government passed a feed-in law for solar thermal power plants, guaranteeing cost covering compensation for 25 years. Consequently, the first European CSP plants are currently in operation in Spain and Italy. The installation of two 50 MWel power plants for 2007/8 has been announced by the German project developer Solar Millennium AG (Aringhof et al. 2004).

Obstacles/Opportunities

In addition to the further demands of R&D in the areas of thermal storage, direct solar steam generation and efficient integration into conventional power plant facilities (e.g. solar hot air or fuel gas generation for natural gas combined cycle power plants), there is also a financial barrier to the broad implementation of CSP. The initial investment costs and the current lack of economic feasibility compared to conventional power plants are particular obstacles to the market launching.

As well as the financial barriers there are also administrative obstacles in the target countries, taking into account elements of the planning process, such as tender or approval procedure, as well as network supply. Until now CSP has only had limited popularity and has suffered from a shadowy existence in comparison with the lobby of photovoltaic technologies. In addition, the construction of high-voltage direct current transmission (HVDC) for future long distance transmission with low losses from Sunbelt regions to Europe has not yet been clarified, which is also delaying the process and further development.

Synergetic effects can be seen in the use of CSP and in thermal processes in the areas of seawater desalination, air-conditioning or heat extraction.

Conclusions on the future role in the EU25 until 2030

Solar thermal power plants are one of the most effective and economical options for solar power supply in sunny regions. Regarding the future security of energy supply in Europe, the opportunity of solar thermal power import from North Africa could be considered. On the one hand, this could become one important component for a sustainable energy supply system in Europe, but this would, on the other hand, create new dependencies on energy imports. Although the technology is ideally used in southern regions, most of the technologies are developed in Europe (particularly in Germany and Spain). This opens up the prospects of a future export market for European companies.

1.2.7 Nuclear fusion

The use of nuclear energy for electricity generation is still a controversial topic for discussion. R&D currently focuses on security questions, the issue of final disposal of radioactive waste, the development of new reactor concepts and the realisation of nuclear fusion plants.

Nuclear energy technology has been developed in several “generations”. Current reactors like the European Pressurized water Reactor (EPR) are subsumed as third generation, designed to meet the current safety requirements.

With regard to a further exploitation of nuclear power three major obstacles can be defined: large capital cost; the nuclear risks e.g. radioactive waste and nuclear accidents and the proliferation of nuclear material.

The development of Generation IV reactors aims to address these issues. The international ‘Technology Roadmap for the Generation IV Nuclear Energy Systems’ (US DOE/GIF 2002) focuses on improving safety, economics, better use of fissile materials and minimization of waste generation. However it is still unclear whether these targets will be achieved.

Overview of the state of fusion technology

Although significant research success has been achieved in the last few years, nuclear fusion technology is still at the research stage and a long way from even reaching pre-commercial stage.

Currently, the construction of the research reactor ITER is the focus of activities in this field. The programme has significant support from the EU, USA, Japan, China, Russia and South Korea and is expected to make progress in the area of nuclear fusion technology. The 1 MW demonstration plant will be built in France, with the construction scheduled to start in 2006 with a view to producing the first plasma in 2016 (ITER 2005). ITER itself is one step on the path to producing electricity from nuclear fusion, testing the possibility of maintaining the fusion plasma for a certain time. The next step would be a demonstration plant, containing all the functions of a nuclear fusion power plant. However, the decision to build such a plant could only be made after the first plant has proven its technical feasibility during at least a five to ten year operation phase.

Allowing another 25 years for the erection of the second-generation plant, a reliable contribution by nuclear fusion to the electricity system cannot, therefore, be expected before the year 2050 (Ikeda 2006).

Potential

There will be no relevant electricity generation from the demonstration plant before 2050.

Price

The investment costs for the erection of the demonstration plant ITER are estimated at about €4,570 million. Overall, calculating the construction, operation over 20 years and the subsequent deconstruction of the site, the costs are estimated at about €10,300 million (EC 2003b).

The cost estimates for power generation at ITER are calculated in the region of €14/Wel. With economies of series production of fusion plants, capital costs could be reduced to about €4/Wel in the long term (ITER 2005). Once nuclear fusion becomes commercially viable, Vekinis (2005) expects the cost for power generation from a fusion power plant to be in the same range as that of a nuclear fission reactor.

Obstacles/Opportunities

Compared to nuclear fission technology, fusion has three main advantages. (1) The basic fuels, Deuterium and Lithium, are abundant and distributed widely around the globe. Transport of radioactive materials is not required in the day to day operation, as the intermediate fuel tritium is produced and consumed within the power plant. (2) The amount of radioactive waste will be reduced, though not completely eliminated. Radioactivity of metal parts is assumed to decay over several decades with the possibility of reuse after about 100 years. (3) The fusion reaction will be safer than the fission, because fusion is not a chain reaction and, therefore, less likely to get out of control (Vekinis 2005).

On the other hand, the technology of nuclear fusion still has to prove its technical feasibility. The fundamental challenge over the next decades is to produce more electricity than is needed to maintain the plasma. If ITER is working successfully, it will do so, but only for fractions of seconds, so it can only serve for a proof of principle. Steady electricity production cannot be expected within the next 15-20 years, and the establishment of a commercially viable operation is an even more distant prospect (ITER 2005).

Conclusions on the future role in the EU25 until 2030

As previously stated, nuclear fusion technology will not be ready for commercial electricity generation before 2050 and, except in the area of R&D will not, therefore, play any role in the energy system until at least 2030.

2 Scenarios of future energy systems

The following section firstly gives a brief description of the model used for the scenario analysis. It then discusses some basic economic assumptions and presents five scenarios regarding the development of the EU's energy systems. The scenarios have been developed according to the strategies and targets requested by the ITRE Committee. The scenarios analyse important strategies and/or technology decisions (higher/lower nuclear share in electricity generation; increased energy efficiency and use of CHP; increased use of renewable energies) and highlight a range of possible future energy solutions for the EU25. As already mentioned on page 3, these five scenarios are not the only scenarios possible.

2.1 Methodology of the scenario analysis

In order to analyse different development pathways for the European energy system an integrated scenario analysis of the EU25 has been carried out. This analysis is based on two main sources. The basic data, economic assumptions and the main results for the BAU scenario have been derived from the latest available EU energy and transport projections (Decker 2006, Mantzos 2006). Demand side projections and analyses of higher penetrations of energy efficiency and renewable energies were derived from a recent scenario analysis by the Wuppertal Institute (Lechtenböhmer et al. 2005a/b)[9].

The quantification and combination of potentials, costs, strategies, policies and measures, and the calculation of scenarios have been carried out using the Wuppertal Scenario modelling system.

- This system uses a technology-oriented, sectoral, bottom-up approach. Corresponding to its relevance for GHG emissions, the energy sector is modelled with the greatest detail using appliance or end-use specific sub-models for every demand sector (households, tertiary, industry, transport) and a purpose-oriented model of the energy conversion sector[10].
- The system applies a heuristic (i.e. based on a survey of existing literature and expert knowledge) approach in order to formulate potentials and strategies and in order to estimate market penetration rates of new technologies, market shares of fuels etc[11]. The heuristic approach allows for a flexible application of both market driven and governance driven influences. The systemised expert involvement, which is a constituent part of the heuristic approach, ensures realistic pathways within the alternative scenario settings.

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[9] The core of this scenario study combined the latest available sectoral studies, scenarios and plans for all emission sectors and policy fields. From a compilation – and where necessary – extrapolation of these studies in every sector, the available potentials and feasible strategies have been derived and combined to form a comprehensive policy scenario.

[10] A description of model detail and philosophy as applied for Germany is given in Fischedick, Hanke and Lechtenböhmer (2002). For this work the models have been adapted using the same philosophy but, in part, using lower disaggregation levels. The sub-model for appliances in the residential sector has been described in (Lechtenböhmer, Barthel, Wissner 2006)

[11] The expert-based approach is described in detail in Lechtenböhmer & Thomas (2004).

- The model can be classified as an *energy accounting system*. This approach best fits the systemised heuristic approach in the scenario building. It means, in fact, that the decision making is extensively processed and reflected upon in the heuristic process, whereas the accounting system administers the large data flow, produces derived data such as indicators, and checks that proposed developments do not violate technical or economic limits. Other types of models, such as technical-economic optimisation and equilibrium models, have internalised the decision making process by applying similar plausible decision rules. Yet, in the case of explorative scenario exercises this may mean that the latter type of models preclude pathways that are nevertheless regarded as 'not impossible' or 'worth investigating' in a systemised heuristic approach.
- The accounting model allows for the use of a lot of detailed (i.e. simultaneously sector and application specific) information. The model represents the whole energy system of the EU, including energy conversion and end-use by demand sector and energy carrier. Final energy consumption is modelled as demand by sector and energy carrier, reflecting specific energy demand and sector as well as fuel specific saving potentials. Electricity and heat supply are modelled in specific sub-models representing the plant stock by existing, retrofitted and new plants for every five years. Other energy conversions etc. are modelled in a more aggregated manner. The model also allows for moderate changes in scenario input to be made relatively easily, without large overhauls of the model and model runs.
- Based on the energy flow model a cost model of the electricity generation module[12] and the energy demand side exists. This module is able to determine energy costs by fuel and end use. The energy accounting model employed here produces unit costs for every energy carrier and year. For electricity this is based on the calculated generation capacity, its cost structure (investment costs, operation and maintenance costs, CO_2 costs) and its use, international fuel price scenarios, etc. By adding capital costs of electricity and natural gas grid investments and distribution systems and other surcharges it estimates calculatory cost-price per fuel and customer group. However, it has to be clearly stated that this type of accounting-price calculation is not a market price, which can differ significantly from the cost price determined here.
- Due to the simulation type of the model no direct feedback loop from energy prices to energy demand is implemented.

[12] The electricity generation cost module used for this study applies a simplified representation of capital costs. All investments are factored into the price of the year of investment. This means capital costs of the existing stock are not represented in the results and equally the value of the capital stock at the end of the scenario periods is not discounted. This approach delivers useful results with sufficient reliability as both can be regarded as equivalent. However, this simplification produces a slight bias as capital costs of scenarios with increasing capacity (such as BAU and N+) are slightly overestimated by this method and those with decreasing capacity are underestimated.

- The Business as Usual (BAU) results have been adapted to a prior analysis by Mantzos et al. (2006) which used the PRIMES model. The PRIMES model is an energy system market model, in other words a partial equilibrium model. The model system reacts on energy (wholesale) prices, other cost of generation and transmission, fiscal measures affecting energy prices, prices of CO_2 emissions (due to a carbon or emission trade), restrictions and obligations regarding other emissions and minimum shares of fuels (renewable, domestic, etc.). The model does not handle feedbacks into the rest of the economy (like a general equilibrium model would do), which means that the level of (end use) energy demand can be influenced by energy prices endogenous in the model, but changes in the level and structure of energy cost leaves the output of other sectors unaffected.

2.2 Basic assumptions

The following chapter gives a brief overview of the economic assumptions of oil prices, GDP population, CO_2 allowance prices and costs of energy infrastructure used for the scenario analysis.

As illustrated in Figure 2-1, forecasts for real term oil prices differ significantly.

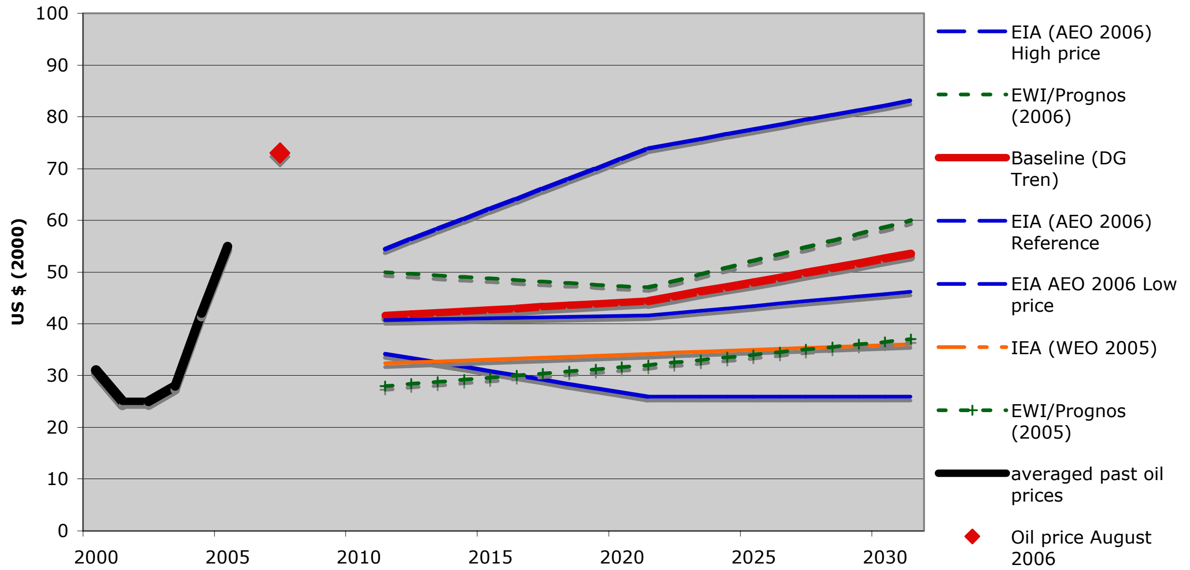

Figure 2-1: Projection of the oil price (world market)

In general, the recent available projections of the world market oil price illustrate two opposing opinions on the future of the oil market:

- On the one hand, EIA (2006) low price projection expects a calming of oil markets with a slight reduction of prices after 2010. This is forecast as an effect of sufficient resources, current investment into capacities and reactions of the demand side. Therefore, this projection is strongly linked to a more optimistic perception of the available oil resources (see chapter 1.1). The IEA (2005a) and the Prognos (2005) projections predict an oil price (significantly below the current price level), which increases after 2010. This rise is driven by increasing production costs in existing fields and the development of new and unconventional resources with higher production costs. In these assumptions, however, prices are expected to stay well below the current price level.

- On the other hand, the EIA (2006) high oil price projection shows a marked increase in oil prices. This is due to constantly high oil demand, de facto approaching the depletion mid-point, and strong technical constraints against increasing production in spite of high oil prices, which also seem to be a possibility for the future (cf. BMWT, BMU 2006, 22). In addition to this, the probability of crises putting additional pressure on the market has increased in recent years.
- The other projections (Decker 2006, EWI/Prognos 2006 and EIA 2006, reference projection) are a mixture of those two possible scenarios and reflect the current reference expectation[13]. They expect a decline from current price levels by 2010 and an increase by 2020 to around current price levels.

The GDP depends, amongst others, on the assumed oil price development, but is easier to predict. Both variables, the GDP and the population, show a positive trend. The GDP is predicted to more than double by 2030 compared to 1990. This is in line with the most recent GDP projections for the world (EIA 2005, WETO 2003) and is also valid for the oil price projection underlying this analysis. It reflects a current medium reference projection comparable to the most recent US (EIA 2006) and German energy projection (EWI/Prognos 2006).

The CO_2 price is expected in the BAU scenario to remain at current levels of about €25/t (see Decker 2006) It is assumed that these prices are fully reflected as opportunity costs in the energy costs calculated in the scenarios regardless of the fact that currently a large proportion of the allowances are handed out to the emitters via the initial allocation of allowances as specified in the national allocation plans of the Member Countries.

Table 2-1: Macroeconomic assumptions for the scenario analysis (EU25)

	1990	**2000**	**2004**	**2010**	**2020**	**2030**
GDP (€bn)	7 295	8 947	9 716	10 947	13 656	16 051
Population (mill.)	440.8	452.9	458.8	464.1	469.3	469.4
Oil price (€/bbl)	28.16	27.31	46.08	38.40	40.96	49.49
Natural Gas price (€/bbl)			26.45	29.01	32.00	38.40
Hard coal price (€/bbl)		7.25	10.24	9.36	11.09	12.80
CO_2 (€/t)	–	–	–	25	25	25

All prices in real year 2000 € / US $

Source: European Commission, new baseline, Decker 2006, Mantzos 2006

13 Reference projections of oil prices have been showing similar trends but their level has constantly increased over the last couple of years, reflecting the strong and still unbroken increase of actual oil prices since 2000/01.

The core cost parameters for new power plants used in the scenarios are listed in the table below. Retrofitting and upgrading of existing power plants is estimated to cost about one quarter of new power plants and CHP plants are between 10% and 50% more expensive than condensing plants.

Table 2-2: Cost parameters of new power plants

	Investment (€ per kw_{ela})			O&M
Plant type	**2005**	**2020**	**2030**	**€/MWh**
Nuclear	1 692	1 692	1 692	13.0
Hydro	1 800	1 800	1 800	20.0
Wind	1 280	1 140	1 104	3.6
Solar	5 500	1 590	1 250	3.6
Solids fired (condensing)	1 150	1 150	1 150	3.3
Gas fired (condensing)	550	530	520	2.0
Oil fired (condensing)	550	530	520	2.0
Biomass-waste fired (condensing)	1 875	1 445	1 420	3.6
Geothermal heat	11 714	3 249	2 791	5.0
CHP units	1 113	1 061	1 100	4.0

Source: own assumptions based on DLR 2006, IEA 2005b, 2006, CESI et al. 2005, ECN 2003; (typically overnight construction costs have been used)

Other energy system costs, such as the investment into new pipeline and electricity transmission systems, have been derived from CESI et al. (2005).

2.3 Business as usual (BAU) scenario

The BAU scenario has been developed to be compatible with the most recent DG-TREN BAU scenario expected for publication in 2006 (see Decker 2006, Mantzos 2006). The BAU scenario aims to describe the most probable development of the energy system of the EU25 taking into account all political developments and decisions made up until 2005.

The scenario, therefore, reflects the expected economic growth, increased efficiency of energy use (if measured vs. GDP), the effects of the policies and measures to promote renewable energies and the current policies of the Member States in relation to the development of nuclear energy.

Table 2-3: Overview of the BAU Scenario

	2000	**2010**	**2020**	**2030**
Gross Inland Consumption (Mtoe)	1 654	1 813	1 885	1 895
Final Energy Demand Industry (ktoe)	330 062	356 420	382 402	391 565
Final Energy Demand Tertiary (ktoe)	158 975	188 487	211 856	225 316
Final Energy Demand Residential (ktoe)	273 302	311 966	338 741	351 285
Final Energy Demand Transport (ktoe)	333 020	381 133	405 505	402 286
Share of renewable energy forms	6%	8%	10%	12%
Nuclear share in primary energy	14%	14%	12%	11%
Import dependency	47%	55%	64%	65%
Value of energy imports (bln €$_{00}$)	134	238	301	358
Energy costs of end use sectors (bln €$_{00}$)	n.e.	906	1 046	1 097
in % of GDP		8,3%	7,7%	6,8%
CO^2 emissions (Mt CO_2)	3 674	3 882	3 929	3 815
CO^2 emissions vs. 1990%	-3%	3%	4%	5%

Source: own calculations, Wuppertal Institute

With regard to climate policy it is assumed that the EU25 will accept international emission reduction targets for the commitment periods after 2012 of 15% by 2020, and of 30% by 2030[14].

The BAU scenario shows that gross inland consumption would further increase at a reduced speed until 2030. This rise in consumption would increasingly be fulfilled by renewable energies which would, by 2030, supply a greater share of primary energy than nuclear energy, which has a decreasing trend. At the same time domestic fossil fuel production would decrease, leading to considerably greater import dependency. CO_2 emissions, which were below 1990 levels in 2000, are bound to increase again to a level slightly above the 1990 value. This means that in order to meet the Kyoto targets and the assumed targets for following periods, the EU will have to achieve significant GHG emission reductions in other sectors and make significant use of the flexible mechanisms of the Kyoto Protocol.

2.4 Scenario N^+: +25% nuclear capacity in 2030 vs. BAU

The N+ scenario – as defined in accordance with the request by the ITRE committee – is a variant of the BAU scenario. Its main difference is a deviating assumption and policy with regards to nuclear power generation in the EU. A second difference compared to BAU is the assumption that carbon capture and storage (CCS) will be applied to some extent. The main aspects are listed below.

While in the (new) BAU scenario nuclear capacity declines by 28% from 141 GW (2000) to 101 GW in 2030, in the N+ scenario nuclear capacities decline more slowly to 126 GW in 2030 – or 25% more than expected in the BAU scenario. The higher capacity is assumed to result from a good performance of existing nuclear power plants, which would allow for a more positive and optimistic stance towards nuclear energy in some Member States. The assumption is that this would be achieved by the construction of about 10 more new nuclear power plants of 1300 MW each – resulting in an increase of new installed nuclear power generation capacity of about one third compared to the BAU scenario – and by retrofitting and, therefore, maintaining longer lifetimes of younger existing plants[15].

The higher electricity production of nuclear power plants vs. the BAU scenario will only occur slowly and will more or less result in a slower decrease of nuclear electricity generation in this scenario. Accordingly, the effects on the electricity and energy markets will be rather small. The most relevant effects are expected to be:

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[14] This would be more or less equal to the lower end of the corridor given in the Council Decision from May 2005 "reduction pathways for the group of developed countries in the order of 15-30% by 2020 […] should be considered" (EU 2005).

[15] In Mantzos et al. (2003) and Mantzos et al. (2004) an expansion of the lifetime of nuclear power plants to 50 years has been simulated. Under this assumption Mantzos et al. expected 230 GW of nuclear power plants in 2030 in the EU25.

- Slightly higher electricity generation and demand, due to a combination of the following factors: market pressure to use base load bulk electricity at low variable costs and the directing of investment into nuclear technology instead of energy efficiency (as it is only a variation of the BAU scenario, which has no explicit energy efficiency strategy).
- As the 50 years nuclear lifetime variant in Mantzos et al. (2003) shows, this effect will be very small. Mantzos et al. expect an increase in power production of 0.6% or 22 TWh vs. the BAU scenario.
- Most of the additional nuclear generation will substitute new coal and gas fired condensing power plants and, to a lesser extent, electricity generation from new (decentralised) plants such as gas and biomass fired CHP. Additionally, existing coal-fired plants will be operated at a reduced load factor. Other renewable electricity generation will not be affected as it has a lower elasticity on the power price and is mainly producing electricity on other load bands.

Table 2-4: Overview of the N+ scenario, changes vs. BAU

Comparison to BAU absolute and % changes	2020 GWh	2020 %	2030 GWh	2030 %
Electricity generation	**12 583**	**0.3%**	**25 111**	**0.6%**
Nuclear energy	107 038	12.1%	216 068	26.4%
Renewables *)	-6 548	-0.7%	-20 501	-1.7%
Coal and lignite	-46 122	-5.1%	-83 418	-6.9%
Natural gas	-41 785	-3.5%	-87 038	-8.3%
CHP electricity *)	-40 630	-4.7%	-93 921	-8.7%
Electricity generation costs (€/MWh)	0.58	1.3%	0 87	1.9%
	Mt	**%**	**Mt**	**%**
CO_2 emissions of power sector	-52.7	-3.8%**)	-93.7	-6.6%**)
Additional emissions heat generation	10.5		23.7	
Total CO_2 emissions	**-42.2**	**-1.1%***)**	**-70.1**	**-1.9%***)**
*) double counting of biomass CHP; **) relative to power sector emissions; ***) relative to total emissions				

Source: own calculations, Wuppertal Institute

The above overview shows that the additional nuclear energy generation of about 25 TWh per year would substitute almost equal shares of coal and gas fired power generation, and a smaller amount of renewable generation. Almost 50% of the electricity substituted would come from reduced investment into new CHP plants. This would lead to additional fuel consumption on the demand side and is the reason why CO_2 emissions in the power and steam generation decrease by about 6.6% or 94 million tonnes by 2030, whereas total emissions from the EU25 decrease by only 1.9% or 70 million tonnes. Average electricity generation costs would be almost the same as in the BAU scenario.

On a global level carbon capture and storage (CCS)[16] may have a significant technical potential according to the IPCC (2005).

16 See section 1.2.4 for a description of the options and obstacles.

Considering that CCS can be expected to be predominantly attractive for newly built large fossil fuel power plants, whereas for the EU presumably only storage in geological formations would be acceptable, the more likely *feasible* potential for the EU reduces significantly. The number of newly built large scale fossil fuel power plants realised between 2005 and 2030 amounts to 300 to 450. However as CCS has probably only sufficiently matured *after* 2020 the remaining number of relevant newly built power plants to which CCS is applicable reduces significantly, approx. 100 ~ 150. The location of these remaining candidate power plants should fit well into a CO_2 logistics system (i.e. pipeline network and selected coal beds and depleted gas fields). Consequently, there may be only some clusters of fossil fuel based power plants involved in CCS. Assuming that 25% of the post 2020 newly built capacity is involved and that capture is below 100% an amount of 70~80 Mt abated CO_2 results. Admittedly this figure could be larger, but the current prospects make it unlikely that in a N+ scenario the application of CCS could cover hundreds of Megatons of CO_2. It is assumed that the investments in CCS are driven by the emission trade prices, not by inclinations to substitute (back to) more coal. Therefore the capacity mix in electricity generation remains unaltered.

For the sake of sufficient contrast between the scenarios the CCS option is only applied in the N+ scenario. In principle CCS can also be fitted to biomass using installations, even though at higher unit-cost. For this reason CCS could also be interesting in other scenarios as a means to achieve even negative CO_2 emission factors for some energy systems (when considering the entire fuel chain).

2.5 Scenario N^{-}: -25% nuclear capacity in 2030 vs. BAU

The N^{-} scenario marks the other end of a range of possible nuclear energy baseline. In this scenario a less favourable development of nuclear energy is assumed. Power plants are assumed to perform less well, with the result that a larger number would be decommissioned earlier than the expected 40 years of lifetime. In addition to this, a greater perception of the risks of nuclear energy, the cost of possible accidents and the mounting costs of finding safe storage facilities for nuclear waste would all combine to increase (economic and political) pressure on plant operators.

In this scenario, no new nuclear power plants are commissioned and built (because of economic reasons and/or a less positive policy towards nuclear energy because of security and waste concerns), and a number of nuclear power plants would not reach a lifetime of 40 years as assumed in the BAU scenario. This would result in a decline of nuclear capacities to 76 GW in 2030.

The gap in electricity generation would be bridged, mainly by higher investment in new gas- and coal fired condensing power plants, by higher load factors of new gas fired power plants as well as by marginally lower electricity consumption (a decrease of about 0.6% in 2030) and a slightly higher penetration of new decentralised CHP and renewable electricity generation.

The N^- scenario is, therefore, more or less the opposite of the N^+ scenario. 44% of the reduced nuclear power generation would be substituted by gas fired electricity generation, a third would come from coal and 11% each from electricity saving and renewable energies. Almost 20% would be delivered by an increased number of new CHP plants. In total, CO_2 emissions in this scenario would be at a level of 72 million tonnes, or 1.9%, more than the BAU scenario by 2030 while generation costs would not differ significantly from the BAU scenario. Some savings, however, would be made due to lower investment into new plants.

Table 2-5: Overview of the N- scenario, changes vs. BAU

Comparison to BAU absolute and % changes	2020 GWh	2020 %	2030 GWh	2030 %
Electricity generation	**-17 197**	**-0.40%**	**-24 528**	**-0.60%**
Nuclear energy	-108 086	-12.20%	-220 382	-26.90%
Renewables *)	8 482	0.90%	25 558	2.10%
Coal and lignite	9 508	1.10%	73 247	6.10%
Natural gas	72 898	6.20%	97 049	9.30%
CHP electricity *)	8 133	0.90%	40 960	3.80%
Electricity generation costs (€/MWh)	-3	-6.60%	-0.37	-0.80%
	Mt	**%**	**Mt**	**%**
CO_2 emissions of power sector	29.1	2.1%**)	82.5	5.8%**)
reduced emissions heat generation	–2.1		-10.5	
Total CO_2 emissions	**27**	**0.7%***)**	**71.9**	**1.9%***)**
*) double counting of biomass CHP; **) relative to power sector emissions; ***) relative to total emissions				

Source: own calculations, Wuppertal Institute

2.6 Energy efficiency (EE) scenario

The energy efficiency (EE) scenario assumes strong policy at EU level as well as within the Member States, targeted at accelerating the rate of increase of energy efficiency in order to reach a level of energy efficiency 50% higher than in the BAU scenario by 2030. This means that energy efficiency (GDP per ktoe primary energy use) would increase by 2.2% per year between 2005 and 2030 – i.e. from 5.6 MEur/ktoe to 10.5 MEur/ktoe. This equates to an increase in energy efficiency at a rate approximately 50% faster vs. the 8.5 MEur/ktoe achieved in the BAU scenario.

In order to achieve this acceleration of energy efficiency improvement, investment in all sectors would have to be redirected to high efficient technology, which would require a comprehensive policy package. A significant share of the energy efficient technology is cost efficient for the customer, especially when introduced in regular reinvestment cycles. In its recent technology perspectives report the IEA reports on a large number of efficiency technologies of which a large share is cost effective for the customers or will become cost effective in the near future. Building envelope measures, heating and cooling technologies and reducing standby losses are listed at costs between 0.1 and 0.3 US ct/kWh (IEA 2006, 144ff). Current analyses of 69 cross cutting energy saving technologies in the residential, commercial and industrial sector resulted in average costs of energy saving of 6.9 ct/kWh for a savings potential of about 27% for Germany by 2015 (Wuppertal Institute 2006c). These figures show that the 22% savings in final energy as assumed in the EE scenario, vs. the BAU scenario, could well be feasible at costs that are lower than the average saving per kWh in the

EE scenario, which increases from 6.2 to 7.5 ct/kWh per kWh saved. However, policy has to deal with the fact that part of the potential is achievable at zero costs, almost 20% at costs below average energy supply costs[17], but the rest at higher costs.

Table 2-6: Overview of the EE scenario, changes vs. BAU

Comparison to BAU absolute and % changes	2020 GWh	2020 %	2030 GWh	2030 %
Electricity generation	**-559 797**	**-14.0%**	**-974 536**	**-22.3%**
Nuclear energy	-167 314	-18.8%	-285 310	-34.8%
Renewables *)	-88	0.0%	-300	0.0%
Coal and lignite	-229 777	-25.6%	-488 059	-40.6%
Natural gas	-147 574	-12.5%	-184 636	-17.6%
CHP electricity *)	-67 286	-7.8%	-72 074	-6.7%
Electricity generation costs (€/MWh)	-2.97	-6.5%	-3.79	-8.4%
	Mt	**%**	**Mt**	**%**
CO_2 emissions of power sector	-295.8	-21.5%	-432.5	-30.6%
*) double counting of biomass CHP				

Source: own calculations, Wuppertal Institute

In the power sector the strong and comprehensive policy mix in relation to energy efficiency would include a fuel switch towards natural gas and an extension of CHP use (in order to compensate for demand reduction due to energy savings) as part of the efficiency strategy (primary energy level). Saved electricity and, to a lesser extent, the expansion of (decentralised) CHP would significantly reduce new condensing capacities of all types, mainly coal, gas and nuclear (nuclear development is assumed to be equivalent to the N^- scenario). Mainly due to the decreased need for investment in new power plants and lower CO_2 costs, electricity generation costs would be between 6.5% and 8.4% lower than in the BAU scenario.

Table 2-7: Overview of the EE Scenario

	2000	2010	2020	2030
Gross Inland Consumption (Mtoe)	1 654	1 721	1 653	1 527
Final Energy Demand Industry (ktoe)	330 062	325 130	324 915	312 683
Final Energy Demand Tertiary (ktoe)	158 975	183 314	182 292	165 435
Final Energy Demand Residential (ktoe)	273 193	282 630	287 420	278 478
Final Energy Demand Transport (ktoe)	325 903	368 630	378 845	361 938
Share of renewable energy forms	6%	8%	11%	15%
Nuclear share in primary energy	15%	15%	11%	9%
Import dependency	47%	49%	58%	60%
Value of energy imports (bln $€_{00}$)	134	250	277	304
Energy costs of end use sectors (bln $€_{00}$)	n.e.	852	908	878
in % of GDP		7,8%	6,6%	5,5%
CO_2 emissions (Mt CO_2)	3 674	3 581	3 396	3 067
CO_2 emissions vs. 1990%	-3%	-5%	-10%	-19%

Source: own calculations, Wuppertal Institute

[17] All prices are calculated without taxes. Including energy taxes or higher CO_2 prices than €25/t would make a larger share of the savings potential cost efficient for the consumers.

No particular emphasis on renewable energies is assumed in this scenario. Therefore, the increase of renewable energies would occur at a rate comparable to the BAU scenario in absolute terms.

Looking at the overall energy consumption, the EE scenario achieves a stabilisation of final energy demand at about the level of the year 2002 by 2030 and a 9% reduction of gross inland (primary energy) consumption. As a consequence of this, renewable energies reach a share of 15% in 2030 and imports of energy may even be slightly reduced. CO_2 emissions decrease by 10% by 2020 vs. 1990 and by 19% by 2030. Energy costs as a share of GDP would be cut by almost a third in this scenario to about 5.1% of GDP by 2030. These costs are substantially lower than in the BAU scenario, allowing for an amount of between 0.5% in 2010 and 1.3% in 2030 of the EU25 GDP to be invested in the energy efficiency strategy (from €50bn to €200bn per year). The external energy bill will remain almost stable in this scenario under the assumed price development.

2.7 Renewable energy (RE) scenario

The renewable energy (RE) scenario describes a restructuring towards a renewable energy system with a target of approaching a renewable energy supply as high as possible by 2030. To achieve such a high share of renewable energy, the scenario is based on an even stronger drive towards energy efficiency than described in the EE scenario. In the RE scenario, the rapid implementation of improvements in energy efficiency is assumed, as described by Lechtenböhmer et al. (2005a/b). This development would lead to an acceleration of 80% of energy efficiency and by 2030 to primary energy efficiency of 11.9 MEur/ktoe for the EU25, which is about 50% higher than in the BAU scenario. Final energy demand would be reduced by 33% and electricity demand by almost 24% in 2030 vs. the BAU scenario. Here efficiency potentials of about 33% final energy savings vs. BAU would be achieved. The lower energy costs vs. BAU allow for investments at average costs of 8.2 ct per kWh energy saved in 2030.

Table 2-8: Overview of the RE scenario, changes vs. BAU

Comparison to BAU	2020		2030	
absolute and % changes	**GWh**	**%**	**GWh**	**%**
Electricity generation	**-593 409**	**-14.8%**	**-1 110 899**	**-25.4%**
Nuclear energy	-167 314	-18.8%	-285 310	-34.8%
Renewables *)	242 785	25.9%	427 424	35.5%
Coal and lignite	-222 923	-24.9%	-939 870	-78.1%
Natural gas	-409 500	-34.7%	-250 519	-23.9%
CHP electricity *)	97 313	11.3%	217 722	20.1%
Electricity generation costs (€/MWh)	-2.4	-5.3%	-7.21	-16.1%
	Mt	**%**	**Mt**	**%**
CO_2 emissions of power sector	-374.2	-27.2%	-812.6	-57.4%
*) double counting of biomass CHP				

Source: own calculations, Wuppertal Institute

Against this background of a strong energy efficiency strategy, the existing mid term renewable energies potential – as assessed by the EU – would be fully exploited by 2030. This means that the EU electricity generation system would be completely restructured during the reinvestment phase over the next decades. By 2030, 50% of the electricity production in the EU25 would come from renewable energy sources, with wind, biomass CHP and hydro delivering the major shares.

Natural gas would increase its contribution to almost a quarter of electricity generation – in decentralised and micro CHP and in modern CGT plants. By this restructuring electricity generation costs would be reduced by about 5% vs. BAU in 2020 and by 16% in 2030. By 2020 lower investment needs due to strong demand reduction are expected to marginally overcompensate for the higher specific costs of new renewable and CHP capacity. After 2020 renewable energies are assumed to be able to deliver electricity at lower costs than conventional plants, enabling about 16% lower generation costs than in the BAU scenario.

For transport fuels it is likely that substantial amounts of revenues from transport fuel taxes would have to be spent in order to enable the development and use of biofuels at competitive (and affordable) prices.

Table 2-9: Overview of the RE Scenario

	2000	2010	2020	2030
Gross Inland Consumption (Mtoe)	1 654	1 707	1 575	1 349
Final Energy Demand Industry (ktoe)	330 062	314 700	305 752	286 389
Final Energy Demand Tertiary (ktoe)	158 975	179 866	162 583	125 515
Final Energy Demand Residential (ktoe)	273 193	272 852	270 313	254 208
Final Energy Demand Transport (ktoe)	325 903	334 823	306 764	252 849
Share of renewable energy forms	6%	12%	20%	31%
Nuclear share in primary energy	15%	15%	12%	10%
Import dependency	47%	47%	50%	49%
Value of energy imports (bln €$_{00}$)	134	231	228	218
Energy costs of end use sectors (bln €$_{00}$)	n.e.	805	795	664
in % of GDP		7,4%	5,8%	4,1%
CO_2 emissions (Mt CO_2)	3 674	3 445	2 880	2 072
CO_2 emissions vs. 1990%	-3%	-9%	-24%	-45%

Source: own calculations, Wuppertal Institute

The realisation of this strategy – apart from the necessity to save 33% final energy vs. BAU – essentially depends on the feasibility of the projected 34% share of fluctuating energies (wind, hydro, solar, tidal and wave) in the electricity system. The question of how to adapt the existing electricity system has been widely studied, for example in a number of analyses for Germany, which have been further analysed by Brischke (2006, 2). Brischke concludes, based on other studies, that for 2050 a share of 58% of renewable energies in the German electricity system would be feasible. However, it would need a restructuring of the grid and the introduction of high voltage direct current connections in order to better balance production and demand over larger distances. In addition, extra capacities of gas fired condensing power plants and, to a limited extent, switching off peak production would also be necessary. In the long run it is expected that innovative storage technologies will enable fluctuating energy systems to self regulate their production, thereby significantly reducing the need for balancing power production.

From the economic point of view, the RE scenario would cut the share of energy costs in GDP by almost half until 2030 and leave between €106bn and €432bn per year for investment into the necessary demand side efficiency technology and renewable heat generation compared to the BAU scenario.

The RE scenario describes a highly ambitious strategy, but this strategy would be capable of delivering on a number of important political targets: ambitious CO_2 emission reductions including fulfilment of the Kyoto targets would be achieved, renewable energy and CHP expansion targets would be realised and import dependency and vulnerability to high energy prices and possible supply shortages would be significantly reduced compared to the BAU scenario.

The dramatic increase of renewable energy sources in the RE scenario would be likely to have significant economic effects outside the energy sector, primarily due to significant changes in land use (and land prices), as well as due to competition for some basic products. In turn, this would predominantly affect agriculture and forestry, but would also have an indirect effect on food processing, paper and building materials industries (see e.g. EEA 2006). The assessment of these effects goes well beyond the assignment of this study; however, in case of further consideration of continental or even global enhanced renewable energy strategies, the assessment of these cross-sector secondary effects is definitely recommended.

2.8 Comparison of scenarios

The following table compares the five scenarios developed for this study with regards to a number of central variables. The overview again gives a picture of the range of possible energy futures illustrated by the scenarios.

Table 2-10: Comparison of the scenarios – results for 2030

Scenario	CO_2 emissions (% Δ 1990)	Primary energy demand (% Δ 1990)	Import dependency	Nuclear share of electricity generation	RES share of PE demand	Energy efficiency growth rate (2000 - 2030)
BAU	+4.7%	+14.6%	64.8%	18.7%	12.2%	1.5%/year
N+ (+CCS)	+1.9%	+16.4%	62.7%	23.6%	12.0%	(<) BAU
N-	+6.6%	+12.2%	66.5%	13.8%	12.4%	(>) BAU
EE	-18.8%	-8.2%	59.8%	15.7%	15.0%	2.2%/year
RE	-45.1%	-20.1%	49.1%	16.4%	31.4%	2.7%/year

Source: own calculations, Wuppertal Institute

In the BAU scenario, the continuation of energy policy trends would already lead to a strong primary energy efficiency increase within the EU25. However, this increase would not be sufficient to compensate growing GDP. As a consequence, primary energy demand would increase by almost 15% and import dependency by more than a third. Due to an increased share of RES and a switch to natural gas, CO_2 emissions would increase by only 1.9% to 6.6%, depending on the policies regarding nuclear power and carbon capture and storage respectively.

On the other hand, the EE and RE scenarios would achieve significant increases in energy efficiency, leading to a decrease in primary energy demand and, together with the achievement of substantial shares of renewable energies, would enable the EU to stabilise import dependency, reduce energy import bills and energy costs and substantially reduce CO_2 emissions.

3 Analysis of policy choices

The energy issues considered in this report interact directly and indirectly with many European policies. These policy areas with wider scope can significantly influence the feasibility of potential pathways for the development of the energy system. With this in mind, the present chapter starts with policy strategies that do not focus exclusively on energy, but that function as framework policies. The following key energy policies will be then touched upon in the sections below:

- Single European Energy Market
- Energy Efficiency
- Renewable Energy
- Energy technology policy

For every policy field a brief discussion on recent trends and explanations – as far as these are relevant for the scenarios – will be given, followed by implications for policy needs in the particular field with regard to the different scenarios.

3.1 Framework policies and driving forces

3.1.1 European climate change policy

As the burning of fossil fuels is a major cause of anthropogenic climate change, energy is a focus of global, as well as of European, climate change policy. The United Nations Framework Convention on Climate Change and its Kyoto Protocol are the most important instruments at international level. However, recently, further international and multilateral actions on energy efficiency and technologies have increasingly been topics for discussion. Additionally, the EU itself has introduced a number of actions to initiate and coordinate Member States' policies on climate change. These are closely linked to energy policy as the use of energy is responsible for about 80% of the EU's GHG emissions.

The EU has declared a target of limiting global warming to a maximum of 2°C average temperature rise above pre-industrial temperatures (EC 2005). Currently, global CO_2 emissions are increasing by 0.5% per year. To limit global warming to +2°C, considerable emission reductions have to take place (EC 2005b).

In 2002 the EU15 ratified the **Kyoto protocol** and agreed to an emission reduction target of 8% by 2012, compared to 1990, with separate targets to meet for each Member State. The ten new Member States have also ratified the Kyoto protocol and hence have their own reduction targets (-6% to 8%), except Cyprus and Malta (EC 2005). In order to meet its obligations under the Kyoto protocol the EU has launched the European Climate Change Programme (ECCP) with the purpose of analysing GHG mitigation potentials and proposing actions for GHG mitigation from energy combustion as well as mitigation of emissions from non-energy and non-combustion sources such as industrial processes, production and use of fluorinated gases, waste management, and agriculture and forestry.

Under the framework of the ECCP many energy related EU directives, like the promotion of electricity from renewable energy, the directive on the promotion of biofuels or the directive to promote CHP have been developed.

The most important cross cutting measure is the **European Emission Trading Scheme** (EU ETS) (Directive 2003/87/EC) (EP 2003). It is designed as a cap and trade system and focuses on the CO_2 emissions of large CO_2 emitting installations. Each Member State has to set up national allocation plans for each trading period, allocating emission allowances to participating companies. With the so-called **'Linking Directive'** (2004/101/EC), the project-based mechanisms CDM (Clean Development Mechanism) and JI (Joint Implementation) of the Kyoto Scheme are linked to the EU ETS. Currently under discussion is the inclusion of civil aviation in the next trading period of the scheme (2008-2012) as well as the addition of all big emitters and economic sectors after 2012 (EC 2006a).

All in all, 15,000 installations (mainly power and heat production, as well as most energy intensive manufacturing industries, with emissions from chemical processes and from non-ferrous metal production as notable exceptions[18]) are covered today by the ETS which accounts for about 45% of the EU's total CO_2 emissions and 30% of its total GHG emissions.

One problem is that emission trading concerns (directly) only about 40% of the required emission reductions by 2010. A further 45% of the emission reductions are to be achieved by other sectors outside ETS, whereas about 15% are left for non-energy related CO_2 and other gases to reduce emissions. However, it will be quite difficult for those sectors not covered by the ETS to make up this reduction deficit (Günther 2004); that is to say in many cases it may cost much more per ton abated CO_2 than in the sectors belonging to EU ETS.

The ECCP also focuses on topics other than energy to combat climate change. An example is the **IPPC Directive** (96/61/EC), concerning integrated pollution prevention and control, which aims to prevent or limit GHG emissions from industrial and agricultural installations by promoting the use of best available technology (BAT). To reduce emissions of biodegradable waste, which account for 3% of GHG emissions, the EU adopted the **Directive on the landfill of waste** (1999/31/EC), in which the Member States are requested to reduce their deposition of biodegradable waste to 35% of the 1995 level by 2016. A relatively new **strategy on the prevention and recycling of waste** (COM (2005) 666 and 667) aims to modernise the EU waste legislation and increase recycling, waste prevention and combustion with energy reclamation.

In order to mitigate the emission of fluorinated greenhouse gases used in air conditioning, refrigeration and various industry processes - which have extremely high global warming potentials - the EU adopted a **proposal of regulation on certain fluorinated greenhouse gases** (COM (2003)492).

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[18] Various member states have included CHP installations which are part of chemical complexes, thereby involving the chemical industry to some extent. The non-ferrous metal industry is very energy intensive (especially for electricity), but emits relatively modest amounts of CO_2 itself.

The proposal wants to improve the monitoring and containment of these gases or, if containment is not possible or the use of these gases is improper, to restrict their use.

First steps to introduce climate policy into agricultural policy have been made. Regulation 795/2004/EC under the **common agricultural policy (CAP)** promotes the production of energy crops, for example for conversion into (transport) biofuels, as well as for electricity and heat production. To prevent water pollution from agricultural waste and fertilisers (especially nitrous oxide NO_x) the **nitrates Directive** (91/676/EEC) came into force in 1991. As N_2O is a powerful greenhouse gas, the nitrates Directive also supports climate change policy. Further possible steps include the introduction of GHG mitigation in best practises, and promoting the use of biowaste (see Lechtenböhmer et al. 2005a/b). The EU does not have a formal common forestry policy, but it is increasingly recognised that European forests also have important potential regarding renewable energy and climate change policy. A recent signal of the increased interest is the EU Forest Action Plan (COM(2006) 302; SEC(2006) 748)). Various Member States already have policies in place e.g. regarding the extension of renewable energy supply from forest based sources. Gasification of forest biomass to produce transport fuel may even constitute an interesting additional alternative for the crop based production of biofuels (Fulton, 2004).

Scenarios and policy choices

With regards to climate policy the scenarios can be divided into two main groups:

- The **BAU and the N+ and N- scenarios** offer mixed prospects on future climate policy. On the one hand, a prolongation of current active climate policy is assumed in these scenarios and will be needed to achieve further increases in energy efficiency and renewable energy generation. On the other hand, there are constraints to climate policy, as the Kyoto target (and the assumed targets for future commitment periods) might be missed by the EU as a whole, unless a very strong strategy is introduced including both emission reductions in the non-energy sectors *and* purchasing emission credits from outside the EU. In the long run, far reaching emission reduction targets will conflict with: (1) increasing energy demand, notably caused by the transport sector, and (2) investment in new coal fired condensing power generation. This will limit the capability of the EU to negotiate strict targets for subsequent commitment periods under the Kyoto Protocol.

  The N+ scenario illustrates that – under these assumptions – the net CO_2 emission reduction potential of nuclear energy is, at about 70 Mt in 2030, quite limited. The same is probably true for CO_2 capture and storage which might provide another 70 Mt – at costs of more than €25/t of CO_2. Both measures would reduce the EU25 energy related CO_2 emissions by 7.2%. If, in addition, extra emphasis were to be put on (equitable) clean technology transfer (CTT), the amount of credits available for purchase would increase, whereas an intensified CTT policy would make it easier to purchase credits. If done fairly, it would make host countries more willing to participate in CTT, as well as improve the EU position in post Kyoto negotiations.

However, in order to achieve emission reductions according to the supposed BAU scenario, mitigation targets of -15% by 2020 and -30% by 2030, more than 500/1,000 Mt of CO_2 credits would have to be purchased and/or generated by over proportional reductions of the emissions of other Kyoto gases by 2020/2030. At an assumed price of €25/t this would mean costs increasing from €12.5bn to €25bn per year, i.e. from 1.2% to 2.3% of the energy cost and from 0.1% to 0.16% of GDP.

Table 3-1: Development of CO_2 emissions

year	2000	2010			2020			2030		
scenario	BAU	BAU	EE	RE	BAU	EE	RE	CS+N+ / BAU	EE	RE
CO_2 emissions (Mt CO_2)										
Total	3 674	3 882	3 581	3 445	3 929	3 396	2 880	3 815/ 3 955	3 067	2 072
Industry	568	577	528	472	595	481	346	570	433	243
Tertiary	245	262	261	251	276	233	189	282	193	121
Residential	452	483	432	418	495	411	369	487	375	303
Transport	970	1 075	1 029	938	1 115	1 032	854	1 093	973	753
Power gener.	1 295	1 362	1 207	1 242	1 333	1 079	1 001	1 284/ 1 424	982	602
Energy Branch	145	124	124	124	114	161	121	100	111	49
% CO_2 compared to 1990										
Total	-3%	3%	-5%	-9%	4%	-10%	-24%	1% / 5%	-19%	-45%
Industry	-19%	-17%	-24%	-32%	-15%	-31%	-50%	-18%	-38%	-65%
Tertiary	-11%	-5%	-5%	-9%	1%	-15%	-31%	3%	-30%	-56%
Residential	-11%	-5%	-15%	-17%	-2%	-19%	-27%	-4%	-26%	-40%
Transport	22%	36%	30%	18%	41%	30%	8%	38%	23%	-5%
Power gener.	-5%	0%	-11%	-9%	-2%	-21%	-27%	5%	-28%	-56%

Source: own table, Wuppertal Institute

The **energy efficiency and the renewable energy scenarios**, however, offer completely different prospects and challenges to climate policy. Kyoto targets are within reach and EU energy policy and climate policy are very much coherent over the whole scenario period. This opens up the opportunity for the EU to pursue an active role in international negotiations. On the other hand, climate policy is needed to deliver significant contributions to the restructuring of the energy system by the use of climate policy targets and instruments (ETS) and by strong support for the policy to foster energy efficiency and renewable energy generation. However, in order to achieve the EE or RE strategy a very strong and active policy is also indispensable, as much greater efforts in energy efficiency are needed, requiring a determined redirection of investment from conventional energy supply and standard energy using technology to high efficient technology and renewable and cogeneration power plants.

The restructuring of the electricity system could be achieved with lower investments than in the BAU or the N+ scenarios – because of lower capacity needs due to electricity savings and, at the end of the period, due to a cost decrease of renewable energy technology (notably wind) which makes renewable energies competitive with other fuels.

However, not only a restructuring of the energy system is needed but also greater investment in energy efficiency and renewable heat generation at the demand side. As stated in chapter 2, in the EE and RE scenarios between 0.5%(EE)/1.0%(RE) in 2010 and 1.3%/2.5% of the EU25 GDP are available for these investments.

Although most of this investment is cost efficient, partly even at zero net costs for the customers, strong policy comprising a mix of all available instruments is needed to implement such a huge and widespread investment and to enlarge the cost efficient share of the potential.

Table 3-2: Climate policy challenges in five scenarios

Policy fields	**Climate policy**		
Scenarios	**External (UNFCCC etc.)**	**Internal**	**Emissions trading scheme**
BAU	In the BAU scenario the EU25 as a whole will miss its Kyoto target (unless substantial emission credits are purchased from abroad). The EU has to oblige Member States to embark on active and broad purchasing programmes and support this by respective support, e.g. framework agreements with Russia, Ukraine and other seller states. Strong actions in favour of CTT and CDM have to be implemented soon. Missing the target might affect the international process on Post 2012 target setting.	Current climate policy as laid down in the national climate programmes will be continued. Policy to mitigate other gases, in particular methane emissions, has to be strengthened and accelerated in order to achieve higher emission reductions in non energy emissions. In the BAU scenario some Member States will achieve their Kyoto commitments (especially among the new Member States and some others). This discrepancy may cause tension within internal climate policy.	The caps of the current scheme – as far as can be currently seen – are generally in line with the BAU scenario. ETS installations will be able to comply with caps. However, in order to fulfil the Kyoto targets the EU should release limits to external purchases in the linking scheme in order to enable companies to purchase rights from abroad. In parallel, caps have to be tightened to achieve real reductions of national/EU emission totals.
N+	See BAU. For the Kyoto target the difference would be minimal. By 2030 the N+ scenario would deliver 70 Mt or 1.7% CO_2 emission reduction vs. BAU. This should be supported by an active promotion of CCS which could provide another 70 Mt of CO_2 emission reduction by 2030 and a strong policy towards CTT and purchasing of emission credits in order for the EU to maintain a leading role in international climate policy.		
N-	See BAU. For the Kyoto period the difference would be marginal. By 2030 CO_2 emissions will be 72 Mt higher than in the BAU scenario. If nuclear capacity were to be reduced this should be combined with an active EE and RE policy in order to mitigate emissions.		

…table continued

EE	The EU25 as a whole has fair prospects of meeting its Kyoto target. EU energy efficiency strategy should be flanked by an ambitious target for the second commitment period of the Kyoto Protocol. Additionally the EU should embed its strict policy for efficiency into an international strategy (e.g. organised as a multilateral agreement / parallel track to the Kyoto Protocol). This would disseminate domestic policy, mitigate the risk of international competition for energy intensive industries, and open up options for EU companies to exploit first haulier advantages.	National climate programmes should be strengthened. Energy efficiency targets and strong measures in achieving these should play a more important role in climate strategy. Compliance control mechanisms for national climate policies have to be enforced. Exchange mechanisms of emission rights between Member States (with surplus or deficit) have to be established. Post 2012 burden sharing has to be established.	Caps of national schemes have to be tightened, beginning with the first commitment period, in order to translate efficiency improvements into national emission reductions. Overlaps and possible interferences with ETS and energy efficiency policy have to be removed (see Lechtenböhmer et al. 2005a/b). Caps have to reflect the effects of efficiency policy. Extension of the ETS to airplane emissions and other sectors can improve efficiency strategy if carefully designed. Introduction of white certificates could introduce efficiency into the ETS if appropriately designed to reflect the differences of the markets.
RE	See EE scenario. In addition to energy efficiency, international renewable energy agreements should be integrated in the “second track”. In the long run the EU will be able to meet even more ambitious targets than in the EE scenario.	Renewable energy strategies have to become mandatory parts of national programmes in addition to energy efficiency and others. Questions of accounting for international exchange of “green” electricity might arise.	The ETS has to reflect policy for renewable energies (as most of it reduces emissions in the ETS sectors by stricter targets).
Numbers/percentages are given for 2030			

Source: own table, Wuppertal Institute

3.1.2 The Lisbon strategy

In March 2000 a special meeting of the European Council in Lisbon decided on a new strategic goal for the next decade, the so-called Lisbon Strategy. Its aim for the EU was “to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion” (European Council 2000). An overall strategy for reaching this goal was decided upon. It should prepare for the transition to a knowledge-based economy and society by better policies for the information society and R&D, as well as by stepping up the process of structural reform for competitiveness and innovation and by completing the internal market. Furthermore, the European social model should be modernised by investing in people and combating social exclusion. Additionally, the healthy economic outlook and favourable growth prospects should be sustained by applying an appropriate macroeconomic policy mix.

The main issues for the realisation of the strategy included a target level for investment in R&D of 3% of GDP, reduction of red tape to promote entrepreneurship, and achieving an employment rate of 70% for men and 60% for women. The Lisbon Strategy contains, in principle, comprehensive – though actually separate – packages of reforms. The European Council decided not to implement any new instrument, but to employ existing guidelines and results of other processes (Luxembourg, Cardiff and Cologne) which were regarded as providing the necessary instruments (EC 2005d).

At the Spring Summit in March 2004 a first interim evaluation of progress was made, showing that the EU was still far away from the goals. Due to the unsatisfactory results of the achievements to date, the EU proposed a new start for the Lisbon Strategy. Before the new start of the Lisbon agenda has been proclaimed, the Commission implemented a High Level Group chaired by Wim Kok to carry out an independent review to identify measures which together form a consistent strategy for the European economies to achieve the Lisbon targets.

The Kok Report was presented in November 2004. It shows that little progress was made in the previous four years, stating that the “disappointing delivery” was due to “an overloaded agenda, poor co-ordination and conflicting priorities”. However, the report puts the main blame on the lack of political will by the Member States (EC 2004b).

In February 2005 the EU Commission decided to put the Lisbon agenda back on track. As the old Lisbon Strategy had too many priorities and was too complex, the key elements of the renewed strategy are a focus on growth and employment, simplification and national ownership via national action plans. Furthermore, it focuses on three priority areas: (1) investment in networks and knowledge (European Growth Initiative); (2) strengthening competitiveness in industry and services by increasing efforts in industrial policy, the services market and environmental technologies; and (3) increasing labour market participation of older people.

As a reaction to the Kok Report the Commission presented a 'Community Lisbon programme' in July 2005, which was meant to complement the national action plans for growth and jobs that the Member States had to finalise by October 2005. However, it did not include new initiatives, but merely grouped existing, or already planned, activities as eight "key measures with a high European value-added[19]" (EC 2005d).

The following two factors have been identified as key drivers of productivity growth and, therefore, as critical factors for ensuring competitiveness:

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[19] These are: supporting knowledge and innovation; reform of state aid policy; simplification of the regulatory framework; completion of the internal market for services; global agreement on the Doha round; removal of obstacles to physical, labour and academic mobility; developing a common approach to economic integration; supporting efforts to deal with the social effects of economic restructuring.

- **Knowledge** (R&D, innovation and education). Amongst others, the EU Commission will promote environmental technologies and energy efficiency, as there is significant potential for economic, environmental and employment synergies.

  Furthermore, measures for improving a strong industrial base will be taken in order to enhance and sustain an economic and technological leadership of Europe.

- The completion of the **internal market** (e.g. in the field of energy) is still a crucial task for Europe in becoming a more attractive place to invest and to work, and to help boost jobs and growth. In order to reach a higher level of growth and competitiveness, reliable electricity and gas services at acceptable prices are regarded as necessary. Both businesses and households should benefit from an efficient energy supply. (EC 2005e).

The Commission emphasised that all measures should be seen as a whole, as they mutually reinforce each other. It is estimated that, once all components have been implemented, the **EU potential growth** rate can be brought close to the 3% objective. Furthermore, employment would be raised by some 6 million jobs by 2010 (EC 2005d).

In the **first annual progress report** on the Lisbon strategy to the 2006 spring European Council the EC (2006b) defined **four priority areas** where further action is needed:

1) Investing in education and research
2) Freeing up SMEs and unlocking business potential
3) Getting people into work
4) Efficient, secure and sustainable energy

The Commission, therefore, took on board one new area, which was previously not part of the Lisbon strategy: the need to define a **common EU energy policy** (EC 2005b). According to the Commission, the main challenge is to **ensure energy availability at competitive prices**. Therefore, attempts should focus on security of supply and development of autonomous resources for avoiding negative economic effects from price shocks or supply interruptions. As energy imports are expected to increase in the coming years (see chapters 1.1 and 2), the need for the EU to speak as one voice in the dialogue with major energy suppliers was identified. Additionally, the importance of energy savings was stressed. By increasing energy efficiency, costs can be saved and investing in new energy efficient technology "will help European industries to maintain and increase their global lead" (EC 2006b). A focus on energy efficiency should be linked to a diversification of energy sources, with a special emphasis on renewable energy. The Commission demands the implementation of adequate measures to realise these objectives without delay. "A partnership between the Member States and the European Union is needed for an integrated approach towards energy" (EC 2006b).

Suggestions for concrete measures include (EC 2006b):

- Strengthening and deepening the internal energy market by:
    - Timely implementation and more effective regulation for reaching the targeted deadline for market opening.

- Promoting more competition in the electricity and gas markets.
  - Greater and better cooperation and integration between the grids and gas pipeline systems of the Member States.
- Exploiting the potential of renewable energy sources, such as biofuels and biomass, and more efficient use of energy.
- A renewable energy sources technology push and demand pull policy at European level for supporting Member States measures.
- Developing a more focused, coherent and integrated approach to ensuring the security of energy supply.

Proposals for implementing these priorities at Member State level are highlighted in the Commission's Green Paper on 'A European Strategy for Sustainable, Competitive and Secure Energy' (EC 2006c).

Scenarios and policy choices

Regarding the character of the Lisbon strategy as a framework strategy, links to different energy futures exist in two directions. The energy strategy can contribute to the Lisbon targets and the realisation of certain parts of the Lisbon agenda can support the development of the energy sector.

The **BAU scenario** (like the N+ and N- scenarios) would probably contribute to the Lisbon strategy by the huge investment needed in conventional energy infrastructures. This might also put pressure on the further development of a single European energy market. Contributions to knowledge and innovation would be limited due to the focus on conventional energy sources. However, renewable energies - in particular wind power - would be developed at a fast rate, thereby requiring innovation and delivering additional job opportunities. A common EU energy policy would, however, be urgently needed in the BAU scenario as a significant increase in import needs would have to be secured and reliable external supply and internal transport and delivery of energy would have to be maintained. Assuming a relatively strong emphasis on clean fossil fuel technology and CO_2 capture and storage in the BAU and N^- scenarios, there would be technology clusters in the EU that would probably also constitute *expanded* export potentials to developing economies such as China and India. However, the BAU and N+ scenario (and to a lesser extent the N-) would result in higher costs of imported energy and higher costs of final energy for the EU economy than the EE and RE scenarios, which might be contradictory to the Lisbon targets.

The **energy efficiency scenario** would be connected to a different investment path, focusing more on decentralised energy efficiency investment: fostering markets for small and medium enterprises, supporting regional labour markets for e.g. refurbishment of buildings and providing technology and know-how development for efficiency technologies. It is assumed that between 0.5% (2010) and 1.3% (2030) of the EU GDP would be invested in these segments rather than in power plants and energy imports. Possibly a tradable white certificate (TWC) system would provide a means for efficiently redirecting the investments. Yet, this would need careful consideration with respect to both the regulatory framework and goal setting, *and* the interaction effects with other energy and climate policies, notably EU-ETS. On the other hand, the scenario would mitigate the need and time pressure for the implementation of a common EU energy policy as import demand would increase more slowly than in the BAU scenario. In addition, the BAU scenario would reduce the vulnerability of the EU economy to energy price shocks and potential energy shortages and, accordingly, potentially deliver an important element to increased competitiveness. Assuming that advanced energy saving technologies, both in industry and buildings, will increasingly require intelligent designs (i.e. using ITC and artificial intelligence), such energy saving technologies can significantly expand the export potentials of any country.

Comparable effects can be expected from the **renewable energy scenario**. Investment in the energy sector would have to be switched, to a large extent, from conventional power plants, where investments would be reduced by about three quarters, to CHP plants and renewable generation where it would have to be increased by about 50%. This restructuring would need substantial innovation, from the discovery of new solutions for different supply problems to the development of renewable energy technology production and energy storage technologies, with the effect of creating new fields for highly skilled new jobs in the EU and opening up potential export markets. On the other hand, the RE scenario would be even more successful in slowing down the growth of energy imports – oil and coal would even show declining absolute imports. It is, therefore, a powerful strategy for defending the EU from future energy market problems. The common EU energy policy would also be needed for the RE scenario but would have a completely modified focus, more targeted at improving domestic renewable energy generation and disseminating renewable energy and energy efficiency strategies. International cooperation would be much easier as pressure on securing ever increasing demand would be much lower than in the BAU scenario.

The geopolitically favourable effect of the EE and RE scenarios on the energy sector can be regarded as a risk reduction benefit (also relevant on a macroeconomic level) which could compensate to some extent for the possible short term higher macroeconomic cost caused by the – generally cost efficient – restructuring costs (in the absence of surprises).

3.1.3 External energy relations

The **import dependency of the European Union** with respect to natural gas and oil is expected to increase dramatically over the next decades. Since the number of large suppliers is limited, this increasing import dependency constitutes an economic risk, notably related to high price volatilities. In addition, many of the large export countries are located in areas with geopolitical risks and, therefore, increased dependency may strengthen geopolitical volatilities which, in turn, may backfire against global and European economic development.

The relevance of actively building stable relationships with external markets is steadily growing. The **Energy Charter Declaration** between the states of the Eurasian continent was already adopted in 1991 and in 1998 the **Energy Charter Treaty** came into force. Its main aim is to further the adoption of common regulatory and economic principles in energy issues.

It thereby aims to "reduce the risks associated with energy-related investments and trade" (Energy Charter Treaty 2006).

The most important issue of the Energy Charter is the establishment of a regulated and transparent third party access to natural gas transmission lines. However, the Treaty has not yet been signed by Russia, the most important energy supplier to the EU, and has, so far, failed to fulfil its role in building and strengthening the European-CIS energy relationship for which it was originally conceived (cp. CIEP 2004).

In addition to the Energy Charter, a discussion about the necessity of a **European External Energy Policy** recently emerged (see above). Two main aspects of such a policy would be well-functioning international energy markets as well as the diversification of energy supply (EU Commission/SG/HR 2006). The EU Commission has already come up with initiatives for supporting such a policy at different levels and has asked the European Council to review the necessity and timing of such schemes. At bilateral level proposals include, for example, working towards a comprehensive agreement with Russia covering all energy products. At regional level the proposal has been made, for example, to extend the EU's internal market and at multilateral level the EU's energy objectives, amongst others, should be fully integrated into its multilateral trade policy and be pursued through the WTO (EU Commission/SG/HR 2006).

Scenarios and policy choices

The current policies on EU external energy markets are mirrored against five different energy scenarios for the EU25 until 2030 in the following table.

The comparison shows that in spite of the general current policy lines, which are important in all scenarios and have still to be developed (securing external energy supply), quite different challenges lie ahead in each scenario.

Table 3-3: External energy market indicators in three scenarios

year	2000	2010			2020			2030		
scenario	**BAU**	**BAU**	**EE**	**RE**	**BAU**	**EE**	**RE**	**BAU**	**EE**	**RE**
Import dependency	47%	55%	49%	47%	64%	58%	50%	65%	60%	49%
solids	31%	55%	37%	41%	58%	33%	32%	66%	34%	30%
oil	82%	84%	85%	84%	93%	92%	91%	94%	93%	90%
natural gas	50%	63%	62%	57%	81%	80%	75%	84%	82%	77%
biomass	0%	0%	0%	20%	0%	0%	20%	0%	0%	20%
Value of energy imports (bln €$_{00}$)	133.8	278.0	293.0	270.0	301.0	277.0	228.0	358.0	304.0	218.0
Energy costs of end use sectors (bln €$_{00}$)	n.e.	943.5	887.3	837.4	1045.5	907.5	795.4	1096.5	878.0	663.8
in % of GDP		8.6%	8.1%	7.6%	7.7%	6.6%	5.8%	6.8%	5.5%	4.1%

Source: own calculations, Wuppertal Institute

In the **BAU scenario** – and in both nuclear scenarios – particular emphasis needs to be put on external energy supply through the establishment of stable political relations and the mobilisation of huge investments – most of all for natural gas. In BAU/N+ the extended efforts to promote clean energy technology transfer in conjunction with a widening use of emission trade (notably EU ETS and CDM) are, to some extent, favourable to global stability but, on the other hand, also need global political stability.

The **energy efficiency scenario** and a fortiori the **renewable energy** scenario significantly relieve the pressure on external supplies to the EU due to decreased imports, while offering additional options to mitigate the worldwide depletion of fossil resources.

Table 3-4: External energy market policy challenges in five scenarios

Policy fields *Scenarios*	**External energy policy**
BAU	Natural gas imports would increase by more than 130% (oil by 26%, coal by 83%). Accordingly, increasing the supply from Russia, Norway, from the Caspian region and the importing of LNG has to be secured. Also links within the MEDA region have to be strengthened. Production and transmission capacities have to be brought on line requiring EU investment in these regions and LNG import and export infrastructure has to be put in place. Increasing international competition from other importing regions (US, S-E-Asia) puts a strong challenge on external energy policies.
N+	As a consequence of higher nuclear electricity generation the increase of coal imports is 16% less (and of gas imports 3% less) than in the BAU scenario. This also mitigates the increase in the external energy bill.
N-	Coal and gas imports would increase more (+13%/+5%) than in the BAU scenario.
EE	International action to accelerate energy efficiency would be needed, particularly with regard to transport (propulsion of cars, trucks and airplanes as well as changes in modal split, spatial planning, etc.) Fossil fuel imports could be stabilised, which represents a reduction of 11% vs. BAU (coal imports -63%, oil imports -9%, gas imports -17% vs. BAU). This would reduce pressure on securing external energy supplies. Policy issues described in the BAU scenario still exist but there would be more time to solve them. International dissemination of strong energy efficiency policy by multilateral agreements and flexible Kyoto instruments could mitigate the speed of resource depletion.
RE	Net imports of energy would be reduced vs. 2000 by about one third (oil by 40%, gas imports increase by 55%, vs. +130% in BAU). The import bill will be almost 40% lower than in the BAU scenario. These achievements substantially reduce the pressure on external energy policies. For oil, emphasis can be laid on disseminating the RE policy to other main consuming regions. Gas imports still increase and infrastructure and access have to be secured, however at a slower pace. Transferring of RE policies and channelling EU investment into energy efficiency and renewable energies in Russia will enable Russia to increase exports to the EU while significantly reducing the speed of developing new fields. For the import of biomass and (in the long run) solar thermal electricity, new partnerships with producing regions (Brazil, Indonesia, Russia, North Africa, etc.) have to be established to set up stable markets and infrastructures and to set sustainability standards for the production of these energies.

Source: own table, Wuppertal Institute

3.2 Energy policy

3.2.1 Single European Energy Market

Owing to different historical developments, each EU Member State had, and often still has, its own energy market. Over the last two decades the EU Commission has attempted to implement a strategy involving the liberalisation of energy markets and the formation of a **Single European Energy Market**. Liberalised EU electricity and gas markets depend on two main factors: 1) an adequate **market structure** fostering competition and transparency, and 2) an adequate technical **network**.

The current EU **Directives concerning common rules for the internal gas and electricity markets** (2003/54/EC and 2003/55/EC) cover the first requirement, whereas the **Directive on security of electricity supply and infrastructure investment** (2005/89/EC) covers the second. Additionally, the recent **Green Paper on a European Strategy for Sustainable, Competitive and Secure Energy** (COM(2006) 105 final) deals with both topics.

3.2.1.1 Market structure and liberalisation of electricity and natural gas markets

The original programmes concerning a single European market did not include the energy sectors in the EU. The first directives on **common rules for the internal gas and electricity market** were adopted in 1996 and 1997, the amendments (2003/54/EC and 2003/55/EC) in 2003. They seek to achieve a full opening of the markets while maintaining high standards of public service and a universal service obligation. Tasks include the dividing of the distribution and transmission sides (unbundling), non-discriminatory transmission tariffs, guaranteed third party access to electricity and natural gas grids including gas storage facilities and common minimum standards of services. Additionally, EU Member States are requested to appoint an independent national regulator. Taken together, both directives establish a common framework. However, Member States must still make further efforts, such as tackling problems with market power as well as links with adjacent markets, such as those for district heating.

The overall target is to open up energy markets by creating an **environment for competition**. There are two landmarks for opening up the EU energy markets: by 1 July 2004, the electricity and gas markets had to be open for all **non-residential gas and electricity customers**. By 1 July 2007 the **residential market** also has to be open to competition. The principal objective of the liberalisation is to achieve a sufficient degree of competition throughout the EU with the aim of enabling lower average prices than those that could be expected in a regulated market.

Although much has been done to create competitive electricity and natural gas markets, the reforms are not yet complete. Many **markets remain largely national** – due, among other reasons, to technical restrictions (see below) – and are dominated by only a few companies, while cross-border mergers lead to new forms of concentration at a European level. EU officials claim that the liberalisation has not progressed far enough (EC 2005c).

European Industry Associations agree with this appraisal and criticise the fact that the liberalisation to date has not led to decreased energy prices (CEFIC 2006, Eurometaux 2005)[20]. Furthermore, there is mounting evidence that the EU ETS has been aggravating exposure to imperfect power markets (Sijm et al, 2006; Grubb, 2006; Fezzi, 2006). The prices of EU ETS permits are, most of the time, more or less fully accounted for in the prices at the wholesale power market, regardless of the actual method of generation. The generators have applied some degree of fuel switching, whereas higher electricity prices will incite some electricity saving. However to date, power companies have shown rather limited interest in extensive investment in new – and in this case carbon free – generation capacity, probably assuming that price elasticity of electricity demand will remain low.

In March 2005, the Commission took Belgium, Germany, Greece, Latvia, Luxembourg and Spain to the EU Court of Justice for **failing to transpose the electricity directive**. According to the Commission, shortcomings in implementation persisted (November 2005) and hence again, in April 2006, the EU Commission took legal action against 17 Member States for insufficient implementation of EU electricity and gas market liberalisation guidelines in national legislation.

3.2.1.2 Technical networks for electricity and natural gas

As a reaction to the power failures that hit Italy, Denmark, Sweden and other EU countries in 2003, the EU Commission proposed a **draft Directive to improve security of electricity supply** and to **boost investment in infrastructure in Europe** (COM(2003) 740). It was part of a **controversial "energy package"**. The electricity industry welcomed the Commission's approach, whereas environmentalists called for alternative ways to deal with supply shortages (WWF 2003, Greenpeace 2003, Friends of the Earth 2003).

On 29 November 2004, the Energy Council adopted a **compromise proposal** that would limit the Commission's and the regulatory authorities' role in the construction of electricity inter-connectors between EU Member States. In December 2005, the Energy Council gave its final approval to the Parliament compromise.

The **Directive on security of electricity supply and infrastructure investment** (2005/89/EC) requires Member States to define standards on the **security of their power networks** and seeks to **increase interconnections between countries** to enable effective competition between businesses in a liberalised electricity market. The rationale behind the Directive is to provide incentives for investment in transmission and distribution networks in a market that is gradually opening up to competition.

Progress concerning interconnection levels between Member States has not been satisfactory, as some Member States are still 'energy islands' and as between others, like France and Spain, additional electricity interconnection would be needed for achieving real competition.

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[20] In order to improve market building, the European Regulators' Group for electricity and gas (ERGEG) intends to create seven regional markets for electricity as well as four markets for gas within the EU25 (ERGEG 2006, 2006a).

A technical barrier, in particular for renewable energy systems, could be the grid capacity. Some national grids are not designed to dispatch on a national scale the energy supply from diverse – often smaller – generation sources (Bechberger, Reiche 2004). Innovative concepts are needed to invest into (possibly new types of) grid enlargements as they are crucial for further renewable energy growth.

3.2.1.3 Scenarios and policy choices

The current policies on a Single European energy market are mirrored against five different energy scenarios for the EU25 until 2030 in the following table.

The comparison shows that in spite of the general current policy lines, which are important in all scenarios and have still to be developed (creation of the legal and technical provisions for a single market), quite different challenges would lie ahead in each scenario.

Table 3-5: Energy market indicators in three scenarios

year	**2000**	**2010**			**2020**			**2030**		
scenario	**BAU**	**BAU**	**EE**	**RE**	**BAU**	**EE**	**RE**	**BAU**	**EE**	**RE**
Primary energy use (Mtoe)	1 654	1 813	1 721	1 707	1 885	1 653	1 575	1 895	1 527	1 349
solids	307	287	244	264	259	197	193	293	182	86
oil	635	669	630	585	670	602	486	640	538	353
natural gas	376	462	454	401	530	483	389	518	444	352
nuklear	238	249	253	253	229	183	183	211	132	132
electricity	2	2	2	2	2	2	2	2	2	2
renewables	97	144	138	202	195	186	322	231	229	424
share of										
RES electr.	14. 7%	18. 0%	19. 1%	20. 5%	23. 4%	27. 2%	34. 6%	27. 6%	35. 5%	50. 1%
CHP elec.	14. 5%	17. 9%	15. 3%	17. 8%	21. 8%	22. 9%	27. 9%	24. 3%	29. 5%	39. 6%

Source: own calculations, Wuppertal Institute

In the **BAU scenario** – and in both nuclear scenarios – current policy trends would have to be pursued and even accelerated. Significant investment would be needed for improvements to gas and electricity networks – about €45bn to €50bn for electricity grid investment including cross border transmission, about €11bn to €14bn for long distance gas transmission, gas storage and LNG terminals (CESI et al. 2005) and about €800bn over the 25 year scenario period for huge replacements in the existing stock of condensing power plants.

The **energy efficiency scenario** and a fortiori the **renewable energy** scenario would present significant new challenges regarding accelerating progress in energy efficiency and restructuring the energy system towards higher shares of renewable energy sources and of CHP in district heating and industry. Grid investments for electricity are expected to be near the upper limit of the above mentioned figures, while those for natural gas will approach the lower end. Investments for new power generation are expected to be 20% lower in the EE scenario than in the BAU scenario and 10% lower in the RE scenario. In the RE scenario the effect of lower capacity is partly offset by the higher cost per kilowatt installed. In addition, investment will be completely different. While even in the BAU scenario investments in new CHP and renewable capacities are projected to overtake investments in fossil and nuclear generation, in the EE scenario the latter will account for only 20% of total investment and in the RE scenario for less than 10%.

Among other instruments (see chapter 3.2.2) a tradable white certificate (TWC) system could provide a means for efficiently redirecting the investments from generation capacity extension to energy efficiency. Yet, this would need careful consideration with respect to both the regulatory framework and goal setting, *and* the interaction effects with other energy and climate policies, notably EU-ETS.

Table 3-6: Investment in new power generation capacities in different scenarios, 2006–2030

	BAU	**N+**	**N-**	**EE**	**RE**
Installed power (MWel) total	763 987	743 163	765 854	611 202	580 114
Nuclear	35 370	48 370	2 194	2 194	2 194
Fossil condensing	298 547	283 381	319 119	185 914	86 025
CHP	188 323	169 666	196 452	181 347	231 840
- fossil	161 229	146 545	167 369	154 253	146 401
- geothermal and biomass *)	27 094	23 121	29 083	27 094	85 439
RES	268 840	264 867	277 172	268 840	345 493
- hydro, wind and solar	192 575	192 575	198 917	192 575	247 352
- geothermal and biomass *)	76 266	72 293	78 254	76 266	98 141
Investment (mill. €) total	795 545	786 069	774 197	638 482	695 029
Nuclear	59 832	81 823	3 712	3 712	3 712
Fossil condensing	226 249	212 866	245 620	126 189	49 421
CHP	199 318	181 233	207 474	198 435	302 246
- fossil	142 603	132 520	146 784	141 720	121 077
- geothermal and biomass *)	56 715	48 713	60 689	56 715	181 170
RES	366 862	358 860	378 080	366 862	520 819
- hydro, wind and solar	238 497	238 497	245 741	238 497	321 106
- geothermal and biomass *)	128 364	120 363	132 339	128 364	199 713
Average investment (€/MWel)	1 041	1 058	1 011	1 045	1 198
Nuclear	1 692	1 692	1 692	1 692	1 692
Fossil condensing	758	751	770	679	574
CHP	1 058	1 068	1 056	1 094	1 304
- fossil	884	904	877	919	827
- geothermal and biomass *)	2 093	2 107	2 087	2 093	2 120
RES	1 365	1 355	1 364	1 365	1 507
- hydro, wind and solar	1 238	1 238	1 235	1 238	1 298
- geothermal and biomass *)	1 683	1 665	1 691	1 683	2 035
*) included in condensing and CHP					

Source: own table, Wuppertal Institute

The evolution in energy market design will clearly affect the progress in energy efficiency and renewable energy use. Changes in energy market design may affect (end-use) prices and, thereby, the basic incentives for energy saving. They may increase or decrease willingness to invest in new capacity (and notably in carbon free capacity, CHP, etc.) and may enhance or attenuate extensions in cross-border transmission capacity (thereby affecting the overall economic/ecologic optimisation of the energy systems). Changes in energy market design may also affect the possibilities of introducing demand side management (DSM) policies, which are, in turn, conducive to energy efficiency efforts.

Table 3-7: Energy market policy challenges in five scenarios

Policy fields / *Scenarios*	Single European energy market	
	Liberalisation	**Infrastructures & networks**
BAU	Further liberalisation may increase competition and reduce prices. Significant efforts to complete the market are still necessary. Regulations for admitting the expanding renewable generation (particularly wind) into the grids are indispensable. Given a lasting prominent significance for emission trade, the interaction effects between emission trade and wholesale power markets merit attention. Sufficient diversity in market parties and power units in all power markets helps to attenuate rent seeking.	Policy to accelerate interconnection of electricity grids has to be continued. As electricity generation is projected to increase by 50% and natural gas consumption by 38% from 2000 to 2030, grids have to be improved and upgraded, especially in the new Member States. Investment into new power generation capacity has to be mobilised by the markets. Grid improvements to connect increasing wind power generation have to be implemented.
N+	Investment for new nuclear power plants has to be secured under liberalised market conditions. Same considerations as in BAU about interaction effects between wholesale power markets and emission trade.	Assuming large size new nuclear units of 1300-1600 MW the main transmission system may need some further reinforcements compared to the already sizeable extensions in BAU.
N-	See BAU	See BAU.
EE	A substantial increase in energy efficiency has to be politically instrumented. This requires the strengthening of instruments such as the energy end-use services directive and the proposed LCP directive to give players in liberalised markets clear incentives to adopt energy efficiency. Regulators should be empowered in order to push for higher efficiency actions by market players. Energy market legislation and rules of energy exchanges should be conducive for the use of demand side management (DSM) and demand side bidding (DSB). Generally, retail energy markets should have pricing structures that are more in line with price signals at the wholesale markets. A level market playing field is needed for energy service companies in order to enable them to compete with energy suppliers. Appropriate provisions for grid connection and power purchasing of CHP and micro CHP, combined with support schemes, are needed. The substantial reductions in GHG emissions *within* the EU dramatically diminish the need for emission trade dramatically and hence largely skip the issue of interaction effects with the wholesale power market.	The need for investment in new condensing power generating capacity, and to some extent in the strengthening of networks, will be reduced. Investment in CHP plants and district heating grids has to be accelerated. Improvement in local networks to adapt to higher percentages of small generators (renewable, micro CHP) will be supported by a 22% lower demand. Natural gas demand from final customers will be 18% lower than in the BAU, accordingly the need for new investment in networks (and partly distribution systems) will be slightly reduced.

…table continued

RE	A complete restructuring of the energy industries has to be instrumented. Priority has to be given to renewable energies. Possible bans or restrictive policies towards new condensing fossil generation may be needed. Schemes internalising external costs into energy prices would be important to support faster market penetration of renewable energies in electricity and heat markets. Actions towards realising a fast efficiency strategy even have to be intensified vs. the EE scenario. Energy market legislation and rules of energy exchanges should be conducive for the use of demand side management (DSM) and demand side bidding (DSB), as well as decentralised power. Generally, retail energy markets should have pricing structures that are more in line with price signals at the wholesale markets. The substantial reductions in GHG emissions *within* the EU dramatically diminish the need for emission trade and hence largely skip the issue of interaction effects with the wholesale power market.	New condensing power plants will hardly be needed, apart from gas fired CCGTs to provide back-up capacity for fluctuating generation. High voltage transmission and HVDC connections have to be expanded as fast as, or faster than, in the BAU scenario and directed more towards transporting wind electricity to consumers. Substantial investment into large scale (offshore wind farms, solar thermal power generation, tidal and wave generation) and small scale decentralised renewable generation has to be mobilised. Expansion of CHP capacities and district heating systems and the improvement of decentralised production have to be supported even more strongly than in the EE scenario. Reduced electricity consumption by 24% and gas consumption by 45% slow down the need for investment in distribution and also transmission grids. Expansion needs for gas storage capacities and import infrastructure (LNG terminals, pipelines) are substantially reduced.

Source: own table, Wuppertal Institute

3.2.2 Energy efficiency

Policy instruments for energy efficiency can be grouped into six main categories. These are (1) the setting of general targets for Member States – as done by the EU for overall energy efficiency, cogeneration, renewable electricity generation and biofuels, (2) fiscal measures – such as taxation of energy and subsidising energy efficiency investments, (3) performance standards for buildings and energy using products, (4) technology procurement – which bundles demand in order to create markets for energy efficient products, (5) energy labelling and (6) information and advice.

Also a tradable white certificate (TWC) system could provide a means for efficiently redirecting the investments from generation capacity extension to energy efficiency. In terms of the above mentioned six categories a TWC system ties in with categories 1, 2 and 6, i.e. an integration of target setting; a white certificate price which replaces fiscal incentives; and informational measures to enable a transparent and accessible energy savings market. Yet, it would need careful consideration regarding both the regulatory framework and goal setting, *and* the interaction effects with other energy and climate policies, notably EU-ETS

Next to a TWC system still sector and product specific policies would be necessary, e.g. regarding new products, services and buildings, since a TWC system typically fits better to the existing stock.

One of the first elements of the EU policy to improve energy efficiency was the **Directive on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances** (92/75/EEC).

In the **1995 white paper "An Energy Policy for the European Union"** (COM(95) 682final) (EC 1995), the European Commission stated that energy efficiency could make a valuable contribution to the reduction of the Community's energy dependency on external sources. As one consequence, in 1997 the EU emphasised another important field: the use of combined heat and power (CHP), which offers substantial potential for increased energy efficiency. In December 1997 the European Council adopted a resolution on a **Community strategy to promote combined heat and power** (98/C 4/01), which sets an overall indicative target of doubling the share of electricity production from CHP to 18% by 2010.

In 2000 the EU intensified its activities in the field of energy efficiency with the **Action Plan to improve Energy Efficiency in the European Community** (COM(2000) 247 final) (EC 2000). The Action Plan estimated a saving potential of 18% by the year 2010 (160 Mtoe or 1 900 TWh) and outlines policies and measures for the realisation of two thirds of this target by 2010 (100 Mtoe or 200 Mt CO_2/year). Furthermore, a doubling of the use of cogeneration by 2010 was proposed, which would lead to additional avoided CO_2 emissions of 65 Mt/year in 2010.

The **Green Paper on Energy Efficiency**, released in June 2005 by the EU Commission, envisaged launching the debate on how the EU could achieve a reduction in its energy consumption by 20% (190 Mtoe) compared to the BAU projections for 2020 on a cost effective basis and, by doing this, limit energy consumption growth to a level of 1520 Mtoe/year in 2020.

The **Directive on Energy end-use Efficiency and Energy Services** (2006/32/EC), adopted in April 2006 by the European Parliament and the Council, sets an indicative target for the EU Member States to achieve overall energy savings of 9% for the ninth year of application of the Directive. Each member state will draw up programmes and measures to improve energy efficiency and progress will be measured as from 1 January 2008.

For 2006 the EU has announced an **Energy Efficiency Action Plan** (not yet released). This action plan will help to realise the saving targets set in the Green Paper. The aim would be the reduction of energy intensity by 1% per year above and beyond business-as-usual trends. The action plan will encompass a variety of actions and measures to be taken by governments at all levels, by industry and by consumers.

In addition to those Directives and action plans already mentioned, the EU focuses on strategies in specific energy policy fields to enhance energy efficiency. Important fields for action are heating and cooling of buildings, electricity use of machines and appliances, energy efficiency of industrial installations, transport efficiency and conversion efficiency with a focus on combined heat and power production (CHP). In the following section, a more detailed look will be taken on **buildings, electric appliances and CHP. Energy efficiency in the transport sector** will be covered in the following section on transport.

3.2.2.1 Energy efficiency in buildings

The Directive on **Energy Performance of Buildings (EPBD)** (2002/91/EC) acknowledges the fact that the building sector is responsible for about 40% of the EU's total primary energy consumption.

What is more, huge savings can be achieved in a cost-effective way, particularly when regular retrofits are combined with energy-saving measures (Ecofys 2005). The buildings directive focuses on the energy efficiency of large existing buildings (larger than 1,000 m^2). It requests that Member States establish minimum efficiency standards for existing buildings that undergo significant renovation. For the EU15 the Directive assumes that the reduction potential of emissions would be 34 Mt/a by the year 2010. Following a study for EURIMA (Ecofys 2004b), if the Directive were to be extended to all houses bigger than 200m^2, the saving could be increased by 69 Mt/a; with the inclusion of the whole European building stock the additional potential in comparison to the Directive increases to 316 Mt/a.

Regarding cooling systems, the Directive proposes measures for regular maintenance of air-conditioners to ensure a minimum standard on energy efficiency. A huge additional potential for efficiency could be tapped by making the combination of reductions in the internal heat loads and improvements in insulation mandatory. Particularly in warm climatic zones the potential for reducing energy use is enormous because the cooling demand can be reduced significantly (Ecofys 2004b).

With regard to heating systems, the European Commission determined the efficiency requirements for new hot water boilers which are fired by liquid or gaseous fuels with an output of no less than 4 kW and no more than 400 kW_{th} with the Council Directive 92/42/EEC. However, these standards have not been updated since the early 1990s and no longer reflect the state of technology. Proposals have been made to introduce a labelling scheme or other policies for heating systems (Iles 2003). The Building Directive focuses on the inspection and the potential replacement of "boilers fired by non-renewable liquid or solid fuel of an effective rated output of 20 kW to 100 kW" (EP 2002). The saving potential through these measures, when applied to the complete residential and non-residential building stock, would increase the emission saving to 82 Mt CO_2/a (Ecofys 2004b).

3.2.2.2 Energy efficiency of electric appliances

Electric appliances are responsible for a significant and increasing share of the EU's electricity consumption. One of the first actions to improve energy efficiency in this field was the **Directive on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances (92/75/EEC)**, which made energy labelling mandatory for an increasing number of appliances. However, since the adoption of the Directive standards have improved significantly for many appliances which led to the need to (regularly) update the efficiency classes[21].

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[21] For Refrigerators e.g. new classes A^+ and A^{++} have been introduced. However, this approach has been criticised for diluting the purpose of the label and for being less effective than merely shifting the existing classes to higher standards.

The Directive on **Eco-design requirements** (2005/32/EC), which was adopted in 2005, provides a comprehensive legislative framework for setting eco-design requirements including energy performance standards for energy using products. It aims at improving the environmental performance and energy efficiency during the life cycle of a product. Currently, studies are being undertaken in order to determine the standards based on the concept of lowest possible life cycle costs of the appliance.

3.2.2.3 Cogeneration

Cogeneration offers a huge, and currently under utilised, energy-saving potential. A first measure to harness this potential was the **Community strategy to promote combined heat and power** (98/C 4/01), which was concluded by the council in 1997 and set an overall indicative target of doubling the share of electricity production from CHP to 18% by 2010. In 2004 the Directive on Cogeneration (EC/2004/8) was adopted which further promotes cogeneration (amending Directive 92/94/EEC) and has to be implemented by 2006 in the Member States.

Its purpose is to put together a harmonised framework in order to maintain investor confidence. The Directive attempts to promote cogeneration through a systematic identification and progressive realisation of the national potential for high efficiency cogeneration by creating a common definition and by removing barriers. It calls upon the Member States to set up stable and supportive regulations according to the definition of cogeneration, the regulations regarding the feed-in of the generated electricity and to create a framework for promoting cogeneration including investment aid, tax exemptions or reductions, green certificates and direct price support schemes.

3.2.2.4 Scenarios and policy choices

The comparison of the current EU policy towards energy efficiency with the three scenarios – BAU, EE and RE – shows some core results.

- The current EU demand side energy efficiency policy will (by definition) be sufficient in many fields to realise the **BAU scenario** as well as the two nuclear scenarios N+ and N-. However, particularly in the transport sector, in electrical appliances and in industry, further action would be needed, e.g. in order to achieve the ACEA agreement. Further action will also be necessary to protract these policies until 2030. On the other hand, the current political targets with respect to energy efficiency, as set out by the Green Paper “Doing more with less” and the Energy end-use Efficiency Directive, will not be achieved in the BAU scenario.
- A much stronger policy for the EU would be needed in order to meet the **energy efficiency** and the **renewable energy scenarios**. This policy would have to implement strong *and* rapid action in order to achieve ambitions efficiency targets close to the technical optimum, introduce further stepwise improvements in the energy efficiency of cars, appliances, buildings and businesses, strengthen technology development and provide substantial financial support and appropriate institutions.

Table 3-8: Energy efficiency indicators for different scenarios

Year	**2000**		**2010**			**2020**			**2030**	
Scenario	**BAU**	**BAU**	**EE**	**RE**	**BAU**	**EE**	**RE**	**BAU**	**EE**	**RE**
Gross Inland Consumption (Mtoe / %vs. BAU)	1 654	1 813	1 721 -5.1%	1 707 -5,8%	1 885	1 653 -12,3%	1 575 -16.5%	1 895	1 527 -19.4%	1 349 - 28.8%
Final Energy Demand (Mtoe)	1 095	1 238	1 160 -6.3%	1 102 -11,0%	1 339	1 173 -12,3%	1 045 -21.9%	1 370	1 119 -18.4%	919 - 32.9%
Energy intensity indicators (1990=100)										
Industry (Energy on Value added)	83.6	77.3	70.5	68,2	66,7	56,6	53.2	58.5	46.6	42.7
Residential (Energy on Private Income)	85.9	80.4	72.9	70,4	70,6	60	56.4	62.5	49.6	45.3
Tertiary (Energy on Value added)	85.4	79.6	78.3	76,8	70,6	61,8	55.1	63.4	47.4	36
Transport (Energy on GDP)	85.4	93	90	76,8	79,3	74,1	55.1	66.9	60.3	36
Primary energy efficiency (MEUR/toe)	5.3	6.0	6.4	6.4	7,2	8,3	8.7	8.5	10.5	11.9
CHP indicator (% of electricity from CHP)	14.5	17.9	15.3	17.8	21,8	22,9	27.9	24.3	29.5	39.6

Source: own calculation, Wuppertal Institute

The evolution in energy market design (see above) will also affect progress in energy efficiency and renewable energy use by affecting end use prices, investment in new and efficient (CHP) generation capacity and the prospects for the introduction of DSM policies.

Table 3-9: Energy efficiency policy challenges in five scenarios

Policy fields	**Energy efficiency**		
Scenarios	**Cross cutting**	**Buildings**	**CHP**
BAU *)	Efficiency of appliances and energy efficiency in industry would need to be tackled in order to achieve the BAU projection.	Current policy might be sufficient to meet the BAU projection (by definition).	Under the BAU scenario the current target of 18% electricity from CHP by 2010 would be (almost) achieved. However, further action could be needed for the time period after 2010 and for the interaction between CHP and the ETS.

…table continued

EE and **RE** (for a broader discussion of policies see e.g. Lechtenböhmer et al. 2005a/b and Wuppertal Institute (2006)	Energy efficiency development has to be significantly increased vs. BAU (+50% growth rate increase in EE, +50% efficiency in 2030 in RE). This needs a comprehensive policy package covering not only energy efficiency policy. Key elements could be • the Directive on energy end-use efficiency and energy services, which could be amended to set mandatory efficiency targets of at least 1% per year; • the Directive on eco-design requirements for energy-using products could be used to regulate strong minimum efficiency standards, e.g. by including the top-runner approach or by including external costs into determination of lowest life-cycle costs; • a new framework Directive on energy labelling, which could introduce dynamic efficiency classes and cover more and more products including cars; Furthermore, the introduction of energy saving funds in all Member States following Danish and British examples and the definition of individual savings targets for energy suppliers under the framework of the energy end-use efficiency as already introduced in the UK, Denmark, Italy, and Flanders. Also the EU CO_2 Emission Trading Scheme should be better combined with energy efficiency policy.	In the building sector national implementation and further revisions of the Directive on the overall energy performance of buildings (see also Bowie & Jahn 2003) in order to achieve tougher mandatory standards for new and renovated houses is a most important policy. This needs to be combined with a strong policy for the expansion of district heating systems, the introduction of micro CHP and renewable energies and improved minimum standards for heating system efficiency. In particular for buildings in the tertiary sector the electricity consumption of the installed equipment has to be included in the regulation schemes. Targeted and well-appointed financial incentive programmes are necessary in order to accelerate renovation and dynamic improvement of dwellings.	Particularly after 2010 cogeneration has to become the major investment area in electricity generation capacity in the EU. This needs: • stronger support for the investments and the technology e.g. by an adequate support of CHP in the ETS, by an amendment of the CHP Directive in order to set (mandatory) targets for further periods (2020 EE: 23%, RE: 28%), by a supportive framework for investment in industrial and municipal CHP plants, by clear rules and conditions for electricity feed-in and stand-by and residual power prices. • For small CHP plants in decentralised district heating systems, e.g. in new residential, commercial or industrial developments, less restrictive planning regulations are important. • A scheme for an accelerated development, technological improvement and market introduction of micro CHP units, comprising e.g. of the inclusion of CHP friendly rules in building codes, soft loans and other subsidy schemes.
Numbers/percentages are given for 2030; *) includes the N+/N- scenarios;			

Source: own table, Wuppertal Institute

3.2.3 Energy efficiency in road transport

The **transport sector** is the fastest growing sector in the EU in terms of final energy demand and CO_2 emissions. Transport accounts for over 30% of total EU final energy consumption. The transport sector also accounts for about 71% of oil consumption and for 21% of GHG emissions in the EU25 (EC 2006a).

Since 1991 there has been a discussion about measures to limit CO_2 emissions from passenger cars in the EU. In 1996, the EU approved a strategy to achieve average CO_2 emissions of newly sold passenger cars of 120g/km in 2010. The strategy is based on three policies: a voluntary agreement with the automobile industry, the promotion of passenger car fuel efficiency by fiscal measures and a fuel economy consumer labelling scheme for cars.

The voluntary agreement between the EU Commission and the European Automobile Manufacturers Association (ACEA) was established in 1998 and is valid for the period from 1998 to 2008 (ACEA 1998). The aim of the so called "ACEA agreement" is to achieve an average reduction of CO_2 emissions from new passenger cars of 25% by 2008 (compared to 1995). This corresponds to a specific emission level of 140g CO_2/km. The additional 20g reduction should be achieved through the labelling of cars and fiscal measures. The ACEA agreement aims to contribute more than 15% of total emissions savings required from the EU under the Kyoto protocol. This means that the agreement could contribute as much as 85 Mt CO_2 to the EU's overall CO_2 emission reduction efforts by 2010 (EC 1998).

The agreement has already yielded some results: The average CO_2 emission per vehicle km decreased from 185g in 1995 to 163g CO_2/km in 2003. However, ACEA members will struggle to reach the target of 140g CO_2/km by 2008 (Wuppertal Institute 2006a; Carter et al. 2005). To reach that target the automobile industry would have to increase their annual reduction rate from the average of 1.8% per year since 1995 to about 2.8% per year. Apart from that, the main reason for the increase in EU15 CO_2 emissions between 1990 and 2003 was growing road transport demand and, with all implemented measures, it is expected that total transport GHG emissions will have risen by 31% in EU25 between 1990 and 2010 (EC 2006b).

The reasons for the persistent increases of emission levels from transport are caused by a continued increase in passenger car ownership (e.g. in many EU countries the share of households with multiple cars is rising), a tendency towards the upgrade of motive power of the average newly bought passenger car, a significant increase in freight traffic (both road and 'short sea'). As regards passenger cars, background factors include, among others, rising incomes, higher job mobility, and urban sprawl. For rising emissions in goods transport, background factors include, among others, the internationalisation of economies, the increase of smaller shipments, and outsourcing of production strategies.

The rapid growth underlines the need for organisational and technological efficiency increases in the transport sector, if overall emission reduction targets are to be met. Therefore, there is a need to encourage car manufacturers to develop more efficient passenger cars, together with the implementation of instruments such as road pricing, fuel taxes or purchase taxes.

A study by the Wuppertal Institute, commissioned by WWF (Lechtenböhmer et al. 2005a/b), indicated that active fiscal policies (e.g. purchase tax differentiation; fuel efficiency incentives for lease cars), regulatory and (spatial) planning activities could achieve a moderate reduction in demand growth on passenger road transport to 1.2% per annum (against 1.3% in the BAU scenario).

Urban and regional planning should aim at the containment of urban sprawl without compromising the quality of life for its citizens, as well as promote optimised logistics and mutual proximity of strongly interacting sectors. This may involve policies regarding appropriate price formation of land use (e.g. the true cost of parking space) and housing. Apart from modal switch from road to rail for goods transport, a switch from road to inland waterways may merit more attention, as the capacity potential is substantial while transport costs are low. Improvements may include well designed container barges, more modal transfer points, cleaner engines and fuels, etc.

Scenarios and policy choices

Most segments of the transport sector (passenger and freight road transport, air transport) show rapidly increasing energy consumption. Combined with the strong dependency of the sector on petroleum fuels this creates significant pressure for political action to be taken in all scenarios.

Table 3-10: Transport sector policy challenges in five scenarios

Policy fields *Scenarios*	**Energy efficiency in transport sector**
BAU *)	Action is needed in order to achieve the target of the ACEA agreement and to make agreements or standards for future periods. Measures to increase freight transport efficiency have to be taken. Transport demand has to be tackled in order to reduce the growing energy consumption of the sector.
EE and **RE** (for a discussion of policies see Lechtenböhmer et al. 2005a/b)	In the RE/EE scenario strong measures in the transport sector are needed: • Achieve 4 litre per 100 km cars (100g CO_2 per vehicle km) as fleet average from 2012 onwards (EE scenario after 2020) at the latest. • Introduce rapid improvements in airplane efficiency. • Reduce growth rates in transport by e.g. improved logistics, demand management in the transportation sector, city tolls etc. • Differentiate vehicle purchase taxes by fuel performance and emissions. • In the EE scenario the same policies and measures are necessary as in the RE scenario. However, a slower success of vehicle efficiency improvement and less active demand measures are assumed.
Numbers/percentages are given for 2030; *) includes the N+/N- scenarios; Biofuels (see 'renewables' section)	

Source: own table, Wuppertal Institute

3.2.4 *Renewable energy*

The most important renewable energy sources (RES) in Europe are biomass, hydro, wind, geothermal, solar and photovoltaics. The EU has set quantitative targets to increase the market share of these energy sources and has taken action in order to achieve the targets in the electricity market, in the transport sector and in heat generation.

Table 3-11: Targets for increasing the share of renewable energy

Source	Target	Timeframe	Sector	Viability
White Paper "Energy for the Future: Renewable Sources of Energy" (COM(97)599 final)	12%	By 2010	Total primary energy supply	Doubts by Green Paper 2006, more optimistic: EREC 2003, EEA 2006
Directive on the promotion of electricity produced from renewable energy (2001/77/EC)	22%	By 2010	Electricity	
Directive on renewable transport fuels (2003/307EC)	2% 5.75%	By 2005 By 2010	Transport fuels	
EREC 2003	20% 50%	By 2020 By 2040	For EU25 Globally	
ITRE: 'on the share of renewable energy in the EU' 2005	20% 25%	By 2020 By 2020 feasible	Renewable energy sources	
WI/WWF 2005b	25%		For EU25	

Source: own compilation

In 2001, the largest sector contributing to RES power generating capacity was **hydro** (91.7 GW), followed by **wind** (17.2 GW), then **biomass** (8.7 Gwe) and, to a lesser extent, **photovoltaics** (PV) and **geothermal** at less than 1 GW. However, in terms of the **annual growth rate** from 1995 to 2001, the highest was wind at 37.9%, then PV at 36.6%, biomass at 6.1%, geothermal at 4.5% and finally hydro at 0.9% (EC 2004).

Between 1995 and 2001 the use of renewable energies in the EU already showed strong growth rates. If these growth rates can be sustained, wind, hydro and photovoltaic electricity generation will reach the targets given in the White Paper.

Table 3-12: Growth rates of renewable electricity generation

Annual growth of installed capacity	**Realised 1995 – 2001**	**Needed 2001 – 2010 for 12% paper target**	**Needed 2010 – 2020 for 20% target**
Wind	37.9%	9.8%	
Hydro	0.9%	1.0%	0.9%
Photovoltaic	36.6%	31.2%	27.8%
Biomass	6.1%	13.4%	1.7%
Geothermal	4.5%	4.9%	

Source: EREC 2003

Whereas data from a recent EEA report (2006a) shows that the EU can potentially produce about 3.5 – 4.5 times the biomass in 2030 than it does today without increasing environmental pressure, the annual growth rate of **biomass energy** would have to more than double in order to reach the 12% target in 2010.

This is a huge challenge and, therefore, the EU is trying to specifically promote this sector and encourage Member States to engage more in this sector. The EU formulated the **Biomass Action Plan** (COM(2005) 628 final) and the **Directive on the promotion of the use of biofuels and other renewable fuels for transport** (2003/30/EC).

The **Biomass Action Plan** should encourage the Member States to promote green electricity more vigorously. The plan estimates that the amount of biomass used in 2010 will be 150 Mtoe (compared to 69 Mtoe in 2003) and that this will not affect domestic food production or demand a significant increase in the intensity (production per unit of space) of agriculture.

The target set by the **biofuels Directive** for 2005 (2% of all transport fuels to be biofuels) has not been met. The reason for this is that it was not mandatory and no EU Member State complied – in part due to reservations regarding the overall efficiency of some of the technologies currently available.

In the short term, it is expected that the greatest potential will come from biowaste (agricultural residues, wet manure, wood processing residues, biodegradable municipal solid waste and black liquor from the pulp and paper industry). In the long term, bioenergy crops from agriculture are expected to provide the largest potential. Since land availability for energy crops in Europe is limited and the energy content of European **energy crops** like rapeseed is lower than that of e.g. soya or palm oil, **import of biomass** would be the only future option to comply with all of the Directives' targets. As the Directives do not require certain standards for biofuel production, some **major impacts on habitats, biodiversity, water supplies and soils** could be the result: A growing EU market for biofuels may provide incentives for over harvesting and the establishment of plantations, leading to an increased intensity of agricultural land. As producer countries are for example Malaysia, Indonesia or the Amazon region, it may also lead to a further destruction of the Rainforest (Biofuelwatch, 2006).

In order to implement the EU wide policy on renewable energies, the Member States have adopted different measures, mainly targeted at the electricity sector. The most relevant are **feed-in tariffs**, **quota or tendering systems**, **tax incentives** and, finally, **green certificates**.

The characteristic of **feed-in tariffs** is purchase obligation by utilities for renewable energy electricity and guaranteed premium prices. **Wind power** in Germany, Denmark and Spain is most successful due to the **feed-in tariffs**. An advantage of this instrument is the **planning security** for investors by guaranteeing the tariff for a certain long term period, as is done by most countries (Bechberger, Reiche 2004).

Quota systems fix a certain amount or share of renewable energy that has to be produced, purchased or bought in a given time period. Quota systems are usually combined with **tradable green certificates** (TGC) to separate the physical power market from the TGC market and to control the compliance of the set quota. A paper by the EU Commission supports this instrument, by stating that the capital return, as well as producer profit, is higher than feed-in laws (COM (2005) 627).

Due to the many different sources and product chains of **biomass,** the support systems in this cluster of technology are not as clear cut as those for wind power.

Denmark has a **feed-in system** which is successful. **Finland** has a **combined tax relief** and **investment support** system which also works well in conjunction with the presence of a large forest industry complex.

For the **biogas** sector both **feed-in tariffs** and **green certificates** are effective in terms of their apparent promotional effect. Denmark, Germany, Greece and Luxembourg use feed-in tariffs while the United Kingdom and Italy use green certificates. Both support systems for all the countries produce higher than the EU average of renewable electricity.

Scenarios and policy choices

The EU would pursue a very active policy to promote renewable energies in all scenarios. As the analysis of the existing policy shows, broad additional activities are indispensable even in the **BAU scenario**. However, in this scenario set targets will be missed and the EU would have to solve the problem of further fostering a supportive framework for renewable energies against a background of possible disappointment.

Table 3-13: Share of renewable Energy in three scenarios

Res Share Values for 2030	in PE	in electricity generation	in CHP generation	in transport fuels	in heat sector
BAU	12%	28%	14%	6%	14%
N+	see above	27%	13%	see above	see above
N-		28%	14%		
EE	15%	36%	15%	7%	11%
RE	31%	50%	35%	26%	20%

Source: own table, Wuppertal Institute

In the **renewable energy scenario** on the other hand, both current targets and ambitious targets for the future (20% in 2020, 35% in 2030) are achievable. However, the scenario also illustrates that these targets require a substantial restructuring of the whole energy system and economy by using the opening window of opportunity presented by the ageing energy system and its subsequent high reinvestment need. It appears that current policy for renewable energy – in spite of its impressive success – is not yet in a position to implement the changes needed for the realisation of this scenario.

Table 3-14: Renewable energy sources policy challenges in five scenarios

Policy fields *Scenarios*	Renewable energy sources				
	Cross cutting	**Renewable Electricity**	**Biofuels**	**Heating and cooling**	**Biomass**
BAU *)	By definition the BAU scenario sketches the effects of a continuation of current policy. This means that the targets set by the EU will not be achieved.	The BAU scenario assumes a strong development of wind energy generation which almost exploits its full potential. For this, stronger policies (feed-in regulations or others) will be needed. Increased support for biomass and sustained support for other renewable sources will be necessary.	Policy to support biofuels will be needed. However, targets will not be met.	Direct use of renewable energy in heating and cooling will remain insignificant in the BAU scenario.	By 2030 about 50% of the domestic biomass potential will be exploited. This needs supporting policies in all Member States.
EE	In absolute terms the EE scenario is equivalent to the BAU scenario. However, policy for RES is embedded in a strong efficiency strategy, which achieves higher market shares of RES but also misses the RES target.	Support for RES generation has to be slightly stronger in a stagnating electricity market, but high reinvestment needs leave sufficient room for RES. Systems targeting market shares (quotas) have to be adapted to the lower demand.	Higher market shares have to be achieved due to lower fuel consumption. This needs higher shares of biofuels in blends and higher numbers of cars using pure biofuels, which can be implemented together with the policy for more efficient cars.	See BAU.	See BAU.

...table continued

RE	The RE scenario more than doubles the growth of renewable energy production while almost fully mitigating energy demand growth. RES reach a share of over 30% (50% in electricity generation). The 12% renewable target for 2010 will be met. This needs a tough and comprehensive policy at EU and MS level. Policies could be binding targets for all MS and for all market segments.	In the RE scenario, the electricity industry has to use the necessary reinvestment of power generation capacity to achieve a complete restructuring. Condensing power plant investment will almost cease, apart from gas fired CGTs. Instead, investment must be made in CHP (biomass and gas fired) and greater renewable capacity. This needs clear political decisions and probably stricter instruments for redirecting investments (such as restrictive permits for new condensing power plants, investment support for new biomass fired CHP, support for market introduction of new renewable technologies, development of offshore wind farms and solar thermal plants. Stronger and wider supporting schemes (feed-in, quotas, certificates etc.) are also needed.	The RE scenario almost achieves the 5% biofuels in 2010 and leads to a 25% share in 2030. This needs strong policy (regulation, voluntary agreements) to substantially increase the biomass shares in mixed fuels (including technical development of motors etc.) and financial incentive schemes to promote market penetration of cars running with pure biofuels. Integrated policies to establish the production capacities also have to be put in place.	Direct biomass use and solar thermal systems will achieve a share of 16% of final energy (without electricity and district heat) in stationary applications. Technologies applicable are solar thermal devices including high temperature and solar cooling as well as biomass fired heating systems and micro CHP systems. This means that specific targets and instruments are needed for this market segment. Possible instruments range from the introduction of RES obligations in building codes, provision of soft loans, combination of RES with building refurbishment, feed-in such as financial support schemes and obligations for businesses.	The EU biomass potential will be almost fully exploited in the RE scenario. This requires the conversion of indicative targets to binding targets, better integration of biowaste use and biomass production into agricultural policy, including the setting of incentives and the promotion of the development of processing infrastructures. Apart from this, sustainability criteria should be developed and implemented to secure environmentally sound production in the EU and in exporting countries.
Numbers/percentages are given for 2030; *) includes the N+/N- scenarios;					

Source: own table, Wuppertal Institute

3.2.5 *Energy research and technology policy*

It is evident that new and innovative energy technologies would have to play a major role in any vision of future energy systems in Europe. Distinct from the policy dimensions depicted above, **energy research and technology policy can be seen as a major enabling and supportive activity** to prepare the ground for achieving the overall policy ambitions. It will be of key importance for

- making a contribution to innovation and economic growth as intended by the Lisbon strategy (cf. 3.1.2)
- achieving the energy and climate policy goals (cf. 3.1.1)
- realising the energy system changes described in the above section

However, it is also clear that research and technology by the Member States and the industry is also highly relevant as its volume surmounts the EU R&T budgets by far.

Since 1984, multi-annual Framework Programmes provide the European Union's main instrument for funding research and development[22]. Overarching the numerous national activities on Member State level the FP instruments help to create a critical mass that is needed for tackling the technological and infrastructural challenges of implementing new energy technologies.

3.2.5.1 *Seventh Framework Programme*

In 2006, the final calls under the 6th FP were executed and the preparations for the **Seventh Framework Programme (FP7)** are under way in order to allow for a timely start in 2007. The FP7 will cover the period of 2007 to 2013. In addition to the non-nuclear activities, a proposal for a **Seventh Framework Programme for the nuclear research and training activities of the European Atomic Energy Community (Euratom)** was also presented on 6 April 2005 as part of the same document as FP7 (Proposals for a Seventh Framework Programme (FP7) for research, 2007-2013, and for a Seventh Framework Programme of the European Atomic Energy Community (Euratom), 2007 to 2011, COM(2005) 119 final).

Among the nine high level themes, energy represents one thematic priority of the FP7. At present, the proposal identifies the following fields of energy research to be addressed by FP7:

- Hydrogen and fuel cells
- Renewable electricity generation
- Renewable fuel production
- Renewables for heating and cooling
- CO_2 capture and storage technologies for zero emission power generation
- Clean coal technologies
- Smart energy networks
- Energy efficiency and savings
- Knowledge for energy policy making

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22 Treaty establishing the European Community (part 3, title XVIII, art. 166, pag.114)

Depending on the decisions made at the end of July 2006 (Council of the European Union 2006a), a budget of €2,300 million is anticipated for the energy related thematic research and development (representing a share of some 7% of the planned total budget of collaborative research of €32,365 million).

Due to the pre-mature state of programme specification, more detailed priorities of the work programme are not yet available. However, to an increasing extent the identification of research issues and the elaboration of tasks and targets take place within collaborative processes with strong involvement of research and industry. Organised as **European Technology Platforms** (described below), these processes help to ensure scientific and industrial relevance of RTD strategies.

3.2.5.2 European Technology Platforms

European Technology Platforms (ETPs) are instruments created by the European Commission as a programme implementation concept (EC 2006g). The platforms aim at bringing together public and private stakeholders in order to define medium to long term research and technological development objectives and to align the research priorities to industry's needs. They cover the whole economic value chain, ensuring that knowledge generated through research is transformed into technologies and processes, and ultimately into marketable products and services.

ETPs focus on areas of significant economic impact and high societal relevance where there is strong public interest and scope for genuine added value through a European level response. Since 2002, 29 European Technology Platforms have been launched, covering a wide range of technological challenges. Most of these have, since their conception, defined their objectives and are reaching the implementation stage. The platforms in the 7th framework programme that are of special relevance to the energy related research are listed below.

- **European Hydrogen and Fuel Cell Technology Platform (HFP):** One key document of the HFP is the strategic research agenda (SRA), identifying six research areas (production, storage and distribution of hydrogen, the stationary, mobile and portable application of fuel cells and socio-economic research). The main goal is to facilitate and accelerate the development and deployment of hydrogen and fuel cell based energy systems and component technologies. As the second pillar, the Deployment Strategy (DS) describes the pathways and challenges to implement a market based transition towards a hydrogen economy in short, mid and long term perspective.
- **European Technology Platform on Photovoltaic (PhotoVoltaic):** The SRA of this platform is more a set of principles, issues, requirements and research areas rather than a guideline for all stakeholders in order to develop their own activities or programmes in the PV research sector. Special focus is put on a continuous development chain, from basic research to industrial manufacturing regarding e.g. materials. A deployment strategy is still to be defined for this platform.

Other ETPs, that may be of importance to the energy sector and provide the possibility of interaction, include the ETP on Sustainable Chemistry, the European Road Transport Research Advisory Council (ERTRAC) and Rail Research Advisory Council, the European Space Technology Platform (ESTP), the Forest Based Sector Technology Platform, and the ETP "Plants for the future". Within the 6th framework programme, the ETP on Industrial

Biotechnology for Sustainable Development (WHITE BIOTECH) has been established.

The ETP process is of a very dynamic nature and covers more and more RTD areas. Apart from these ETPs being included in the second status report of the EU (May 2006), new initiatives have recently been launched (EC 2006g).

- **Zero Emission Fossil Fuel Power Plants Technology Platform (ZEP):** The ZEP was officially launched in December 2005, and it was announced that the SRA would be publicised in spring 2006. In line with the proposed priority for “Near Zero Emission Power Generation” in FP7, the Platform aims at identifying and removing the obstacles to efficient power plants with near zero emissions, thereby reducing the environmental impact of fossil fuel use, particularly coal.
- **Technology Platform for the Electricity Networks of the Future (Smart grid):** The platform has agreed its initial objectives. The launch event and first general assembly took place in April 2006. Integrated research and demonstration projects in electricity networks are envisaged as being key to a successful adoption strategy in the industrial context of an increasingly liberalised and competitive market.
- **European Solar Thermal Technology Platform (ESTTP):** The idea of ESTTP was announced in June 2005 at the 2nd European Solar Thermal Energy Conference estec2005. After one year of preparation, ESTIF (European Solar Thermal Industry Federation) and EUREC Agency (European Renewable Energy Centres Agency) were invited to the official launch at the end of May 2006. Further information is not yet available.
- **European Technology Platform for Biofuels (BIOFRAC):** The BIOFRAC was only launched in June 2006, but a first draft report has already been made. The creation and implementation of the SRA is planned for autumn 2006. The main tasks of this platform are carried out in the four working groups: biomass resources, conversion to biofuel, biofuel distribution and use and context. Interaction takes place with the ETPs of hydrogen and fuel cells, sustainable benefit from renewable forest resources, European road transport advisory council, sustainable chemistry and plant genomics and biotechnology.
- **European Technology Platform on Wind Energy:** The implementation of an ETP for wind energy is currently under discussion. Further information is not yet available.

3.2.5.3 Scenarios and policy choices

With regard to the major technology areas depicted in section 1.2 the intended structure of the FP7 work programme **covers all relevant aspects**. Most of the key technology areas are supported by an ETP that contributes to a market-orientated design of RTD actions.

Moreover, the RTD topics foreseen for FP7 represent **a robust portfolio** that will be needed for implementing any scenario philosophy of the new baseline, energy efficiency and renewable energy scenarios. Due to the pre-mature stage of FP7 budget negotiation, a more differentiated assessment of priorities cannot be undertaken.

The instrument of ETP represents an **important contribution to increase the impact and efficiency of European RTD** through involvement of key players from research and industry into the process of programme shaping. This approach is of particular value when a joint industry effort is needed for establishing new infrastructures (such as in the case of hydrogen) or when new technologies rely on a relatively small number of technology players (such as in the case of solar-thermal electricity).

With regard to the area of energy efficiency, however, a much broader range of technologies and players would need to be addressed. Especially in the field of buildings and urban planning a **dedicated need for integrated approaches** can be identified that bundle high efficient end-use technologies, optimised fossil and renewable energy supply with a strong focus on CHP, and related aspects of integration in energy networks. The FP6 initiative CONCERTO is a promising approach that should be maintained under FP7. Operating on the municipal level CONCERTO projects will apply highly efficient energy saving measures to significantly increase the percentage of renewable energy supplies and integrate the self supply of renewable energies and polygeneration into eco- buildings (EC 2006h).

Table 3-15: Energy market policy challenges in five scenarios

Policy fields *Scenarios*	**Energy technology policy**
BAU	The BAU scenario induces significant investments into advanced fossil power generation and optimisation of networks. These topics are well represented within the draft FP7 programme and supported by the ZEP and Smart Grid ETP. The focus of RES development is on exploitation of wind power. This topic is covered by FP7, too, and supported by the recent ETP on Wind Energy. Major efforts have to be made with regard to accelerating offshore wind power. In addition solarthermal power needs to be introduced into the market on a larger scale by 2030. This challenge is addressed by the ESTTP.
N+	The EURATOM FP7 provides the framework to provide the technology demand for realising higher nuclear electricity generation.
N-	see BAU
EE	Due to the complexity and heterogenity of energy end-uses a broad range of efficiency technologies will be needed to implement the EE scenario. A focal point will be the building sector, together with the related technologies for lighting, heating, ventilation and cooling. A dedicated need for integrated solutions that combine efficiency technologies with options for renewable energy supply to buildings and settlements can be identified (see FP6 CONCERTO). FP7 foresees one thematic priority on efficiency and energy savings. A second focal point is transport, mainly vehicle technology for road transport. Being placed outside the energy part of FP7 the vehicle technologies are addressed by the ETP ERTRAC. It has to be assured that vigorous efforts are undertaken to drastically reduce the energy consumption of road vehicles.
RE	In addition to BAU developments the RE scenario demands more concerted efforts mainly in the field of biofuel use, biomass CHP and renewable heating and cooling technologies, all closely linked to full exploitation of EU biomass potentials. In terms of stationary RES technologies emphasis has to be given to the synergies with efficient building technologies (integrated approaches, see EE scenario). A specific work topic is foreseen under FP7 for renewable heating and cooling. With regard to further exploitation of distributed generation (CHP) grid connection plays a major role. Work under the FP7 topic of smart energy networks and the ETP Smart Grids have to provide solutions to this aspect. In order to increase the share of RES electricity beyond the state of the BAU, RTD under the FP7 topic renewable electricity needs to open up the market opportunities for geothermal electricity (eg. Hot-dry-rock).

Source: own table, Wuppertal Institute

3.3 Analysis of technology areas in the scenario context

The discussion of the various scenario alternatives opens up a spectrum of future energy system settings. Within this context, some technology areas will have to play a prominent role, others are of minor importance or may even lead to counterproductive impacts.

With regard to the technology set introduced in chapter 1.2 some findings on the specific role of the various energy technology areas can be derived.

Energy efficiency in road transport

The transport sector is characterised by lasting growth dynamics and resultant difficulties in reducing GHG emissions. Already in the BAU scenario, a reduction in energy intensity from 85.4 in 2000 to 66.9 in 2030 (-22% or 0.7%/a; 1990=100) is assumed but proves to be considerably insufficient to achieve the policy targets. Stricter efforts are needed, as assumed for the EE and RE scenario, that include for the year 2030 a decline of energy intensity in transport to 60.3 (EE) and 36.0 (RE) respectively. In these cases high efficient technologies in road transport are key to success and would need to be implemented without delay.

Alternative transport fuels (incl. hydrogen)

Increased use of alternative fuels with lower carbon content is one important option to stabilise or even reduce GHG emissions in absolute terms in transport. Under trend conditions the contribution of alternative fuels in the BAU scenario (incl. the two nuclear cases) remains relatively low. An increased share of alternative fuels can be found in the EE and RE scenarios:

- **Biofuels** are of particular importance for the RE scenario as it assumes a far reaching exploitation of biomass potentials in the EU.
- **Hydrogen** as a transport fuel relies on climate friendly primary energy sources. In this regard any large scale deployment of hydrogen requires a massive scale-up of renewable energy sources, in combination with a declining demand for stationary uses. Hence, the hydrogen option will be most compatible with the RE scenario setting. In principle, hydrogen can be generated from carbon-lean power such as advanced coal or nuclear power. In the resulting scenarios (BAU and N+), however, the capacity growth assumed will be needed to satisfy the power need in the electricity sector. Excess capacity for converting electricity into transport fuel will not be available and would require a further expansion of capacities that is not compatible with the scenario definition.

Distributed generation (incl. biomass and stationary fuel cells)

Distributed generation (with a strong focus on (micro) CHP) plays a significant role both in the BAU scenario and in the EE scenario (from 2005-2030 new capacity investment of some 190 GWel for CHP and 76 GWel for biomass and geothermal power). A more important role can be identified in the RE case, where capacity growth amounts to 233 GWel (CHP) and 153 Gwel (biomass/geothermal power). Under both settings however, distributed generation represents a major share of overall capacity expansion in the electricity sector (32% in the BAU/EE case and 40% in the RE case). It can be considered to be a robust option that needs to advance under any conditions, and, therefore, should receive full political support. This includes related efforts to prepare the electricity networks for the integration of higher shares of distributed energy.

Advanced coal power (incl. CCS)

Under BAU conditions coal power retains a dominant role in electricity generation so that a need for advanced power plant concepts and effective CCS solutions emerges.

However, when implementing the EE scenario, and especially the RE scenario, the investment into new capacities of fossil condensing power plants decreases significantly and will be met for the largest part by natural gas.. The relative weight of advanced coal power technology and the CCS option, therefore, strongly depends on the priority given to the full exploitation of renewables such as wind, solar, biomass and geothermal power.

Energy storage – large and small scale

The trend in the energy system is to become more dependent on fluctuating resources. As such, this should already increase the interest in storage. Furthermore, climate change is expected to continue to provoke increases in extreme weather events (droughts, floods, prolonged high air and water temperatures, reduced/re-timed snow melt), which will, in turn, increase the vulnerability of the energy system in terms of fluctuations in actual operating capacity. This makes storage an even more important issue.

In addition to these larger scale supply side concerns, storage can also substantially enhance the use of renewable energies (incl. so-called passive sunlight) in the built-up environment. In the various kinds of so-called zero-energy buildings tested in some Member States, seasonal storage of heat is an important feature.

Wind energy and solar-thermal power generation

Even under BAU conditions the two renewable options, wind and solar-thermal power, are exploited to a large degree – and that is also assumed for the EE and RE scenarios. Taking the relative advanced state of development and the resulting prospects of significant decreasing costs into account, both technologies represent a robust option for any future electricity mix in Europe. It can be concluded, therefore, that both technologies should receive strong political support. In this context, it has to be kept in mind that it will be necessary to prepare the European electricity system for large scale transport of renewable power across the continent.

Nuclear fusion

Due to nuclear fusion being in only early stages of development, this option has not been considered explicitly in the scenario description, but should be highlighted as a kind of follow-up option to be added to the various scenario pathways. According to its technological properties, in this perspective nuclear fusion has to be seen as a large-scale option that would fit well into the BAU scenario, and even better into the derived nuclear expansion scenario N+. However, to a certain degree it could also be integrated into the EE and RE scenarios because both scenarios still retain centralised structures.

From an energy economic perspective, however, a strategic decision is foreseeable that will concentrate efforts either on a prolongation of the nuclear power pathways and a resulting system of safety, waste disposal and decommissioning, or on a shift of priorities to a vigorous exploitation of the energy efficiency and RES potential including the wind, solar, biomass and geothermal options.

4 Conclusion: Policy development needs and upcoming topics

Troubled waters ahead

The overview of the current and projected situation of fossil and nuclear energy sources stresses the fact that has become more and more apparent over the last years: the era of cheap and abundant conventional energy resources is coming to an end. Moreover, this end will possibly arrive sooner than is currently being budgeted for by the European Union (EU) Member States. Maintaining supply will require, on the one hand, significant and timely investment in new and more expensive oil and gas production while, on then other hand, production costs and the concentration of conventional fossil resources in a small number of regions (the Middle East, Russia and the Caspian Sea Region) will significantly increase. Both trends will put upward pressure on world market prices for oil, gas and, to a lesser extent, coal – with potential impacts for economic development and growth. Furthermore, this geographical concentration of oil and gas export potential, combined with newly emerging large energy importing economies (i.e. China, India) can be expected to intensify international competition for market access to the declining resources and, ultimately, may also generate international conflicts.

Distinct from these issues a second challenge has emerged. Climate change requires substantial reductions in global greenhouse gas emissions, which essentially means using less energy and switching to carbon neutral energy carriers.

Both challenges require determined and timely action from the EU and its Member States, as well as from the international community at large. A conventional, albeit advanced, "business as usual" (BAU) strategy is likely to face increasing obstacles when trying to cope adequately with these simultaneous challenges.

Two alternative strategies

The scenarios discussed in chapters 2 and 3 can be grouped into two main types of strategies.

The first type of strategy could be called "*advanced conventional*". This route is described by the BAU scenario combined with the +25% nuclear capacity in 2030 (N+) scenario and specific greenhouse gas (GHG) mitigation options of carbon capture and storage and, particularly, the use of clean technology transfer and other flexible mechanisms to achieve emission reductions outside the EU[23].. Therefore, it represents a more conventional supply side oriented course. The analyses above show that this route would not be merely business as usual. On the contrary, it would require an intensification of the policies for energy efficiency, including cogeneration, and for renewable energies. In addition, nuclear energy would need to have unequivocal support in order to allow for new capacity of 48,000 MW by 2030 to be installed. Climate policy would consist of (1) the support of domestic energy efficiency and renewable energy policy combined with the large scale options of nuclear and carbon capture and storage (CCS) and (2) a strong policy to achieve significant emission reductions abroad by elaborating clean technology transfer mechanisms and emission trade systems.

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[23] It has to be noted that this strategy has not been elaborated to the same extent and is based on less ambitious scenarios than the second strategy, due to the definition of the scenarios which was given for the study.

This strategy would need to be supported by a strong international energy policy securing the substantially increasing energy import flows from abroad. This policy would also have to be strong and credible enough to prevent supply disruptions and sudden price shocks. It would probably require the establishment of stronger relations with the main suppliers (Russia, Northern Africa and the Caspian Sea region) as well as the creation of a common understanding among the large energy importing nations to avoid destructively fierce international competition. In this scenario the EU and its Member States would become more dependent on international relations for tackling climate change as well as for securing energy supply. Furthermore, future costs of investment in the large scale options of nuclear and CCS are not yet known, and there are significant economic and environmental risks associated with this strategy.

The other type of strategy, "*domestic action*" – as described by the energy efficiency and the renewable energy scenarios (EE&RE) –, relies much more on the domestic potential of renewable energy sources and energy efficiency and seems to have the capability to cope adequately with both major challenges, so that the risks emanating from these are significantly lower. This strategy, however, would need more radical and persistent domestic political action in order to speed up progress in energy efficiency and renewable energy supply and to achieve the already agreed (indicative) targets for the expansion of renewable energy supply and cogeneration and the enhancement of energy efficiency. In the context of this type of strategy, international relations could be less strained. Clean technology transfer would still be very welcome and relevant, but would be less burdened by demands emanating from very large scale emission trading required in the BAU scenario. Furthermore, the acceleration of energy innovations in the EU would provide a useful perspective on the lasting export potential of domestic solutions, not least in the framework of clean technology transfer to developing countries. Furthermore, the strategy has the potential to contribute significantly to the Lisbon process by lessening the macroeconomic vulnerability and hence increasing the predictability of the economy.

Both strategies have crucial preconditions which may impose severe challenges to their feasibility.

- The *advanced conventional* strategy crucially relies on the successful implementation of an active foreign energy and technology transfer policy. Strong international competition for energy resources may become an increasing threat for this crucial foreign policy link.

  However, this strategy would be less risky with respect to the management of change inside the domestic European society, since changes tend to be less radical than in alternative scenarios - as long as the increasing energy import flow is secured, investment in large scale technology is accepted and energy price volatilities are not overwhelming. On the other hand it tends to carry more risk with respect to various climate and energy policy objectives, precisely because it would be hard to become more radical should the BAU measures turn out to be insufficient or if environmental degradation, geopolitical turmoil or increase in energy prices and price volatility develop quicker than expected.

- The *domestic action* strategy opens up a perspective of much less strained international relations, allowing for new solutions for global sustainability policy frameworks and for the EU to take a leading role in international climate and energy policy.

However, this strategy would swap, to some extent, the external threats from climate change and geopolitical turmoil for bigger challenges with respect to the management of the more radical changes inside the domestic European society (i.e. within the EU and its Member States). More specifically, this strategy would stand or fall at the successful restructuring of the EU energy system and a good part of the investment decisions, taking into account that today's investment decisions will determine the structure of the energy system for decades to come. This precondition – in spite of being affordable – faces serious challenges from many important actors who would have to be convinced to substantially change their investment decisions and business strategies. Therefore, a well developed and broadly endorsed 'transition management approach' becomes an important ingredient for the successful implementation of this strategy.

Robust policy choices

In spite of these diverging, and at least partly mutually exclusive, strategies the survey of (energy) policy choices in chapter 3 shows a number of policy actions that would be required in any strategy and which would differ only in terms of intensity. Consequently, these policy areas should be given high priority for securing energy supply regardless of the strategy prioritised[24].

The first issue is the enhancing of *demand side energy efficiency,* including cogeneration. All the scenarios discussed in this study assume further significant increases in energy efficiency in all demand sectors. This means that the current policies should be actively implemented at the opportune point in time and that further action should be taken in order to foster the development of efficiency. This is of particular relevance as energy efficiency in principle offers not only the largest, but also the fastest, achievable potential for emission reduction and securing energy supply. Political action is necessary for achieving an active and successful implementation of the Energy end-use Efficiency Directive. The European building stock contains huge untapped potentials for energy saving, but policy instrument portfolios are still either incomplete or internally mismatched, while implementation is often lagging behind decided schedules. Of similar importance is the transport sector, where comprehensive policy packages of technical and non-technical measures are needed and where it is crucial to achieve the emission targets that have already been set and to set new ones for the future. Electricity efficiency could also be improved by a set of measures. The first priority, in conjunction with the implementation of the Energy Services Directive, is the timely setting of tough minimum standards for a large number of appliances using the provisions of the Eco-Design Directive and an update of the Labelling Directive.

The next robust option concerns the *renewable energy sources*. All the scenarios assume high increases in this area as well, particularly in wind power generation and biomass use. What is more, some policies are already partly in place and the current targets on the EU level already correspond to a very ambitious "renewable scenario" (RE scenario), but would need to be supported by stronger policy and expanded by 2020 and 2030.

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24 Carbon capture and storage (CCS) and nuclear power are generally not regarded as long term sustainable solutions. However, under certain conditions and for certain countries they may constitute helpful transitory options with which to some extent 'time can be bought' to develop and test the fundamental solutions adequately. In this respect for example it could be regarded as a robust choice to ensure sufficient R&D effort for assessment of the potential of CCS and its technical prerequisites for a sound use of the option.

Challenges here include gaining greater support for the market introduction of these technologies and spreading the success over the whole of the EU, maintaining technical development and realising technology learning curves in order to make renewable energies a competitive energy carrier. Particular fields of relevance in all scenarios are offshore wind energy, biomass and the use of renewable energies for heating and cooling purposes.

For the overall *energy market,* and taking into account the drive towards enhanced energy efficiency efforts, it is also important that retail pricing of electricity appropriately reflects the scarcity and emission impacts of the wholesale market. In this context demand side management (DSM), demand side bidding (DSB), product differentiation by origin of fuel type, equitable market treatment for decentralised generation and storage facilities, and technical solutions for the creation of virtual power plants deserve more attention. Together, all these institutional and technical innovations also necessitate a change in electricity networks, both with respect to larger variable power sources, such as wind, and with respect to a larger share of small scale generation and storage capacity tied to the distribution networks. In addition, the current inter-connector capacity and its management between EU Member States, and between the EU and neighbouring countries, merits attention in all scenarios.

Robust steps towards a future *EU external* energy and climate *policy* include the fostering of clean development and clean technology transfer, as this would strengthen international relations, partly release demand pressure on energy markets, create additional or strategically needed emission credits and expand markets for renewable and efficiency technologies, which would, in turn, support the domestic development of these technologies.

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Abbreviations

ACEA	Association des Constructeurs Européens d´Automobiles; European Automobile Manufacturers Association
JAMA/KAMA	Japanese and Korean Automobile Manufacturers Associations
BAT	Best Available Technology
BAU	Business as Usual Scenario
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BMWA	Federal ministry for economics and labour
BTL	Biomass to Liquids
CCGT	Combined-Cycle Gas Turbine
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CECED	European Committee of Domestic Equipment Manufacturers
CEFIC	The European Chemical Industry Council
CFL	Compact fluorescent lamps
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CSP	Concentrated solar power
DG TREN	Directorate-General Energy and Transport
DNR	Deutscher NaturschutzRing
DOE	US Department of Energy
DSM	Demand-Side Management
DSB	Demand-Side Bidding
EC	European Commission
ECEEE	European Council for an Energy-Efficient Economy
ECN	Energy research Centre of the Netherlands
EE	Scenario: 50% increase in energy efficiency on a primary energy level versus BAU
EEA	European Environment Agency
EIA	Energy Information Administration
EPBD	Energy Performance of Buildings
ETS	[European Union] Emissions Trading Scheme
EU10	The 10 Member States of the European Union
EU15	The 15 Member States of the European Union since the Year 1995
EU25	The 25 Member States of the European Union since the Year 2004
EWEA	European Wind Energy Association
FAME	Fatty Acid Methyl Ester
GDP	Gross Domestic Product

GHG	Greenhouse Gas
GIF	Generation IV International Forum
GMI	Global Market Initiative for Concentrating Solar Power
H_2O	Water
HEU	Highly Envided Uranium
HVDC	High Voltage Direct Current transmission
ICE	Internal Combustion Engine
ICT	Information & Communication Technology
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPPC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
LCP	Large Combustion Plants
LNG	Liquefied Natural Gas
MCFC	Molten Carbonate Fuel Cell
MEDA	Main programme under the Euro-Mediterranean Partnership
N+	Scenario: +25% nuclear capacity in 2030 versus BAU
N-	Scenario: -25% nuclear capacity in 2030 versus BAU
OECD	Organisation for Economic Cooperation and Development
p.a.	Per Annum / Per Year
PEMFC	Proton Exchange Membrane Fuel Cell
PPO	Pure Plant Oil
PV	Photovoltaic
RE	Scenario: Renewable Energy
R&D	Research and Development
RES	Renewable Energy Sources
RTD	Research and technology development
SOFC	Solid Oxide Fuel Cell
SUV	Sports Utility Vehicle
TWC	tradable white certificate system
U	Uranium
UNFCCC	United Nations Framework Convention on Climate Change
Vs.	Versus
WETO	World energy, technology and climate policy outlook
WI	Wuppertal Institute for Climate Environment Energy
WWF	World Wide Fund for Nature

UNITS

$	US Dollar
€	Euro
/	per (divided by…)
a	Year
bn	Billion = 10^9
bbl	Barrel
ct	Euro Cent
Gb	Giga barrel = 10^9 barrel
Gg	Gigagram = 1 000 t
GJ	Giga Joule
GW	Giga Watt = 10^9 Watt
GW_{el}	Giga Watt (electric power)
GWh	Gigawatt-hours
kt	Kilotonnes = 1 000 t
ktoe	Kilotonnes / Thousand Tonnes of Oil Equivalent
kW	Kilo Watt
kW_{th}	Kilo Watt (thermal power)
kW_{el}	Kilo Watt (electric power)
l	Litre
MEur	Mega Euro (million Euro)
Mt	Megatonnes
Mtoe	Million Tonnes of Oil Equivalent
MW	Megawatt
MWh	Mega Watt Hour
m/s	Metres per second
PJ	Peta Joule
Pkm	Passenger Kilometre
t	Ton
toe	Tonnes of Oil Equivalent
TWh	Terawatt-hours
vkm	Vehicle Kilometre

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