The contribution of renewable energy to a sustainable energy system

Volume 2 in the CASCADE MINTS project

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- Energy research Centre of the Netherlands (ECN) (The Netherlands); coordination/ MARKAL model.
- ICSS/NTUA - E3MLAB (Greece); PRIMES and PROMETHEUS models.
- The International Institute for Applied Systems Analysis (IIASA) (Austria); MESSAGE model
- IPTS (Institute for Prospective Technological Studies), Joint Research Centre, EC (Spain); POLES model.
- Paul Scherrer Institute (PSI) (Switzerland); GMM model.
- The Centre for European Economic Research GmbH (ZEW) (Germany); PACE model.
- The Institute for Energy Economics and the Rational Use of Energy (IER) (Germany); TIMES-EE and NEWAGE-W models.
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- Research Institute of Innovative Technology for the Earth (Japan); DNE21+ model.
- National Institute for Environmental Studies (Japan); AIM model.
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Abstract

This report provides an overview of the main results from the scenarios analysed in the CASCADE MINTS project to assess the role of renewables in solving global and European energy and environmental issues. The main conclusion is that renewable energy can make a substantial contribution to reducing greenhouse gas emissions and improving diversification of the European energy production portfolio, although other technologies will also be needed in order to achieve post Kyoto targets. The report outlines the impacts, costs and benefits of ambitious renewables targets for Europe in the medium term. It also presents lessons learned from taking the global perspective.

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Policy brief

Renewables can contribute significantly to a future sustainable energy system

This policy brief provides an overview of the main results from the scenarios analysed in the CASCADE MINTS project to assess the role of renewables in solving global and European energy and environmental issues. The main conclusion is that renewable energy can make a substantial contribution to reducing greenhouse gas emissions and improving diversification of the European energy production portfolio, although other technologies will also be needed in order to achieve post Kyoto targets. This policy brief outlines the impacts, costs and benefits of ambitious renewables targets for Europe in the medium term. It also presents lessons learned from taking the global perspective.

The brief reflects the consensus among modellers concerning the results presented and the main policy messages. Although all models confirm these messages, there are sometimes significant differences among individual model results, reflecting the different dynamics and assumptions and indicating the impact of uncertainties in the future energy system. The graphs, presented in this paper, show projections from different models, and should be regarded as illustrative of the discussed trends, by no means the only possible paths. The models used in the projections are: PRIMES, PROMETHEUS, MARKAL, MESSAGE, POLES, GMM, PACE, TIMES-EE, NEWAGE-W, NEMESIS, NEMS and DNE21+.

Why renewable energy is needed

In the coming decades, Europe's energy system is facing a number of challenges[1]. Most of these are related to the continuing, worldwide, reliance on fossil fuels, with still a 70-75% contribution to the primary energy mix in 2030. Renewable energy is expected to be a robust way of addressing these challenges by decreasing the share of fossil fuels in Europe's energy mix.

Worldwide a doubling in CO_2 emissions in 2030 compared to 1990
Overall, the CO_2 emissions in 2030 are expected to be approximately twice the level of 1990, the base year of the Kyoto protocol. The largest growth of these emissions is expected to occur in the developing world, in particular in Asia.

CO_2 emissions continue to grow moderately despite climate policy
Although CO_2 emissions in Western Europe show moderate growth as compared to the global trend, it is not on track towards the target agreed under the Kyoto Protocol. Beyond 2012, assuming that some type of climate policy is in place in Europe, reflected in a moderate carbon tax of 10 €/ton CO_2, emissions are expected to continue their growth with ca. 0.4% per year.

Increased dependency on oil from the Middle East, and competition with emerging regions
Europe's dependence on oil from the Middle East is expected to increase up to 85%. As other world regions, such as Asia, also increasingly rely on oil from this region, this may lead to further oil price increases, which will particularly affect the transport sector.

[1] More information on the 'business as usual' trends and developments for Europe can be found in the CASCADE MINTS baseline report on http://www.ecn.nl/library/reports/2004/c04094.

Increased dependency on gas from Russia and Algeria

For natural gas, external dependency will also grow in the next decades. A continuing growth in gas consumption combined with a decrease of gas production in the UK, the Netherlands and Norway, will lead to a higher share of imports, probably still from the two main suppliers Russia and Algeria. Additionally, the accession of the new Member States and their heavy reliance on supplies from Russia increases the risks related to gas supply security. On the other hand, enlargement is expected to reduce the risks associated with transit of gas across the New Member States towards EU-15 countries.

Impacts on carbon emissions and import dependency

In May 2004, the Commission issued a Communication on 'The share of renewable energy in the EU' (European Commission, 2004), in which it 'acknowledges the importance of providing a longer-term perspective, considering in particular the infant nature of the renewable energy industry and the need to ensure sufficient investors' security. Acknowledging the outcome of the currently available feasibility studies, however, the Commission considers it necessary to more thoroughly assess the impacts of renewable energy resources, notably with regard to their global economic effects before deciding on adopting targets beyond 2010 and before taking a position on the 20% target for the share of renewable energy in 2020'. The CASCADE MINTS project aims at contributing to this impact assessment by analyzing the feasibility and consequences of a 20% renewables share in Europe's primary energy consumption in 2020[2].

Emission reduction in 2020 up to 20%

If the share of renewables in Europe increases to (almost) 20%, the share of fossil fuels in Europe reduces roughly from 75% to 65%, which has positive implications for greenhouse gas emissions and security of supply. In 2010, energy-related CO_2 emissions are some 10% lower than in 1990 (according to PRIMES for the EU-25), indicating that Europe's Kyoto target is within range. In 2020, energy related CO_2 emissions are reduced with 9-21% compared to the baseline. The amount of emission reduction depends on the sectoral distribution of the renewables contribution and on which fossil fuels are substituted. These factors differ by model. Although the reduction is substantial, it is not sufficient for post Kyoto targets, and other mitigation measures must also be explored.

Despite the different regional coverage of the models, the indicators in Figure P.1 provide comparable information. It confirms the significant impact of the 20% renewables target for Europe. The trend towards lower CO_2 emissions per unit of GDP is further reinforced. For the CO_2 emissions per capita, an increase is converted into a decrease, at least until 2020.

2 The target is defined according to the Eurostat convention, and would correspond to some 23% in substitution terms.

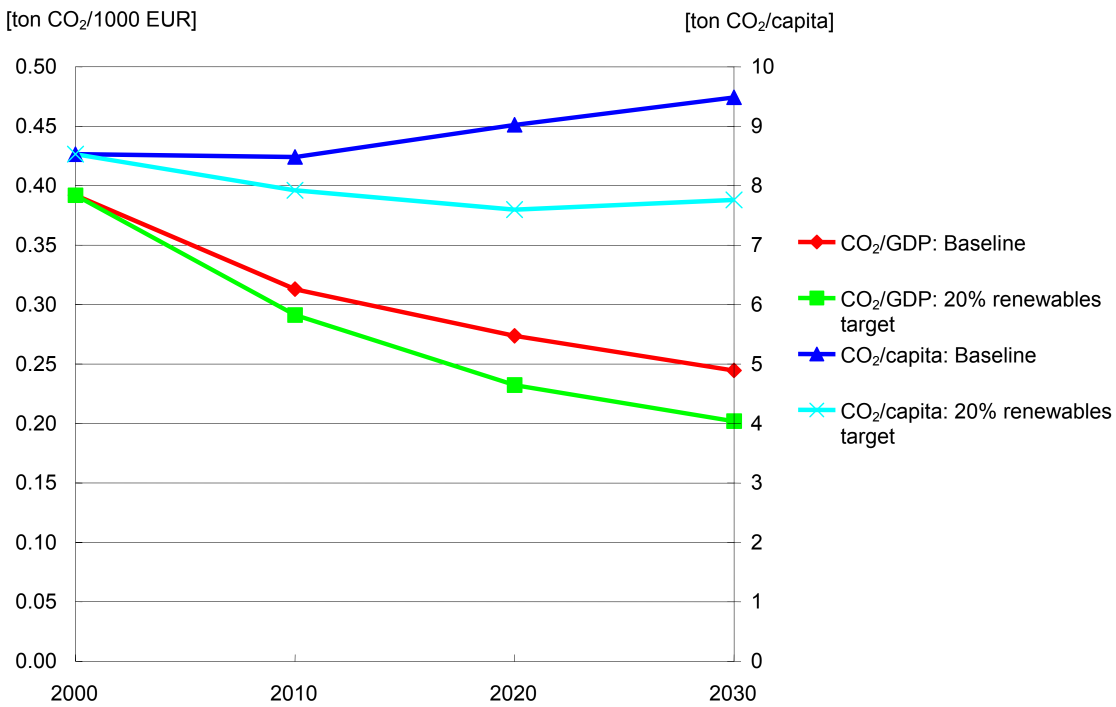

Figure P.1 *Energy-related CO_2 emissions per capita and per GDP in Europe; averaged over results of POLES (EU-30), PRIMES (EU-25) and MARKAL (Western Europe)*

Positive impact on security of supply

As far as supply security is concerned, the impacts are positive, albeit limited. Only in case of large substitution of oil in the transport sector, import dependency is significantly reduced, as one of the models reports on a reduction of import dependency of 14% points. Regarding gas import dependency, the impact is more modest with 2-4% point reduction in 2020 compared to the baseline, which is not sufficient to counter the increasing trend in this indicator. On the other hand, the diversity of Europe's energy mix, as measured by the Shannon indicator[3], improves with 6-8% points to 76%, indicating that adding renewables helps to reduce future risks.

One of the models (PROMETHEUS) is a probabilistic one, which explicitly deals with uncertainties. It has calculated the probability of gas price shocks under the baseline and under a 33% renewables target in the European power sector in 2020. The model finds a lower probability of gas price shocks in the latter case, due to a higher penetration of renewables worldwide, which is in turn due to learning and spillover effects.

Economic impacts

The costs associated with the renewables targets are in the range of 0.5% of (baseline) GDP. In addition, the economic models show that the costs of renewables may lead to higher electricity prices, and to slower economic growth. On the other hand, welfare implications appear to be limited.

Increased penetration of renewables is often expected to lead to employment gains, because renewables energy production is more labour intensive than conventional energy production, and

[3] An indicator often used to measure species diversity in a community. It reflects not only the number of energy carriers present in the fuel mix, but also the relative abundances of different energy carriers.

because it may substitute imported energy. The economic models do not agree on how the renewables target in the power sector may affect employment. One model reports a 1.8% overall increase in employment, while another model projects a 0.15% decrease for Europe. The third economic model is based on the assumption of full employment, but does report a clear shift towards employment in renewable electricity production sectors.

Some considerations should be added on how well employment effects can be evaluated with the economic models used in this project. It may be that the direct gains in employment due to the renewables targets are counterbalanced by job losses in other parts of the economy. This crowding out effect can be due to the scarcity of highly skilled labour or to the fact that the subsidies required for supporting renewable energy replace other subsidies. Therefore, net employment effects are strongly related to the structure of the labour market, wage determination and the differences in productivity in different sectors and types of labour force, and should be assessed by dedicated models that incorporate the structure of the labour markets in the different EU Member States, which is beyond the scope of the project.

How can Europe achieve 20% renewables in 2020?

Under baseline conditions, a 20% share of renewables in Europe’s primary energy consumption in 2020 appears to be an ambitious target. Evidence from different models indicates that approximately 18-19% is achievable by 2020, and that it might require a few years more to arrive at 20%. Other studies (Ragwitz et al, 2004), (Mantzos et al, 2004) suggest that energy efficiency measures that reduce energy demand growth may help to bring the target timely within range.

Allocation over sectors

If renewables sub-targets for different sectors were to be imposed, the analysis shows that the power sector offers most of the technology switching options. Most of the models demonstrate that a share of 33% renewable electricity consumption is achievable in 2020 (incl. large hydro). However, this should be contrasted with the current expectation that the 21% indicative target for 2010 for the EU-25, as stated in the Renewables Directive (2001/77/EC), will only be achieved if several Member States intensify current support policies.

The transport sector is expected to play an important role for various reasons. First, this is also a sector that offers good opportunities for increased penetration of renewables, e.g. biofuels for transportation. Secondly, the penetration of biofuels has a direct impact on the import dependency for oil, and on CO_2 emissions from transportation, which makes the promotion of biofuels a strategic choice for Europe. However, there may be future bottlenecks due to the limited availability of biomass, and the competition for biomass resources that can be applied both for power generation and converted to biofuels.

Contributions from other sectors will also be required to achieve the 20% target. Imposing a carbon cap on the emissions of the industry sector has shown that this sector does not have much room for a more renewable energy supply. The use of biomass in the industry would be possible, but suffers from competition with applications in the transport sector.

A key role for wind and biomass

Although the models show differences in their projections on which technologies will be necessary to achieve the 20% target in 2020, they agree that 40%-50% of the primary renewable supply is based on biomass, and 20-25% comes from wind energy. Figure P.2 illustrates that one of the models projects a substantial share of solar energy, largely due to the implementation of solar thermal water heaters. Although the share of hydropower is also significant, the potential for growth is limited to small installations.

Therefore wind energy and biomass will be the strategic options for achieving Europe's renewables targets towards 2020. Beyond that date, other options such as PV, solar thermal electricity, wave and tidal energy may show some penetration.

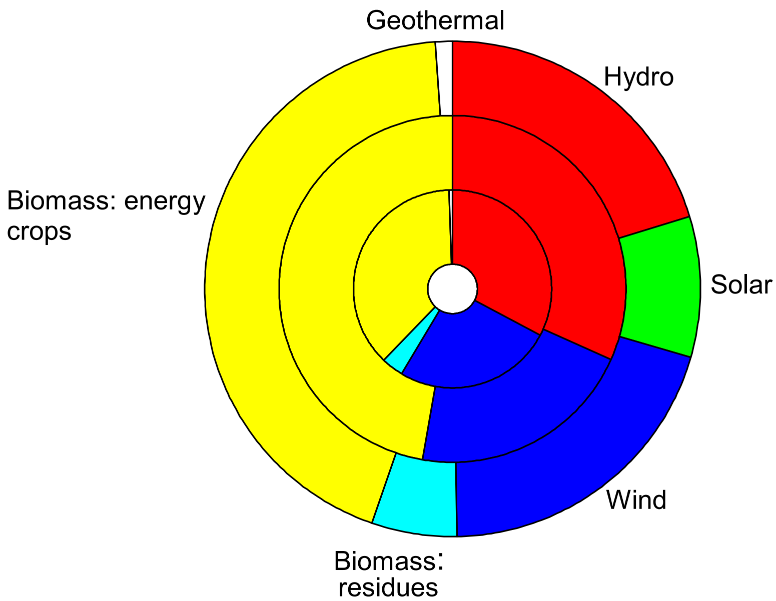

Figure P.2 *Shares of renewable technologies and resources in Europe's primary energy consumption in 2020; from outer to inner circle: PRIMES, POLES and MARKAL*

Biomass: current stagnation needs to be overcome

The European Commission has set targets involving biomass for renewable electricity generation (Directive 2001/77/EC), and for the promotion of biofuels for transport applications by replacing diesel and petrol up to 5.75% by 2010 (Directive 2003/30 EC). The Communication 'The share of renewable energy in the EU' has concluded that the growth of biomass-based electricity stagnates and further efforts are needed in order to achieve the targets set for 2010. The Biomass Action Plan therefore aims at achieving a total biomass accumulated energy production of 130 Mtoe by 2010.

Against this background, the biomass growth path presented in Figure P.3 seems even more ambitious, as it implies a further doubling between 2010 and 2020 required for the 20% target. The amounts of biomass deployed appear to be close to their potentials. Only one of the models (MARKAL) assumes imports of biomass (30% in 2020).

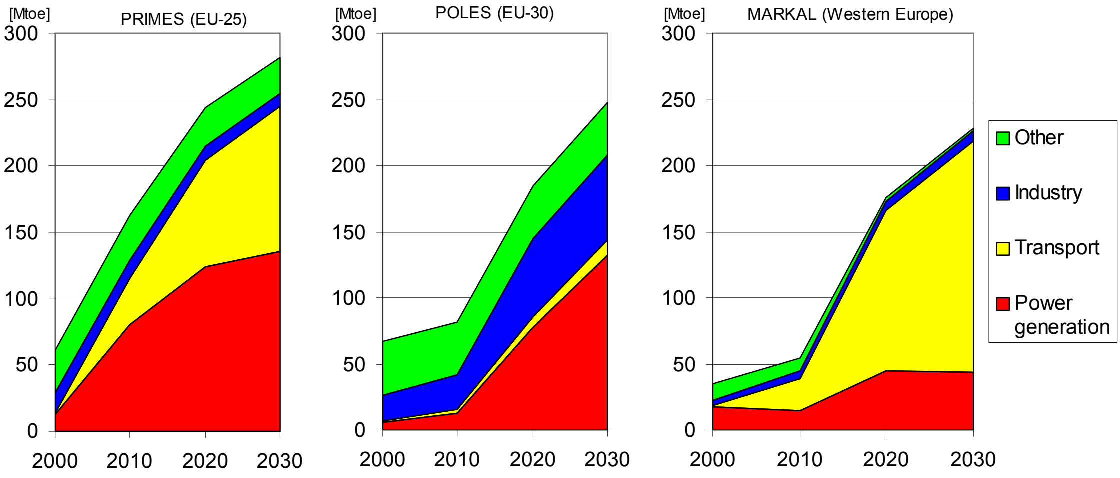

Figure P.3 *Deployment of biomass and waste by sector according to different models*
Note: the sector definitions in POLES are not completely comparable to those in the other models and part of power generation falls in the category 'Other'; EU-30 here excludes Turkey).

Figure P.3 also illustrates the large potential for application in different sectors, particularly for power generation and in the transport sector, but also heating and cogeneration. The prospects by sector differ by model, depending on whether a generic target was set for all renewables (POLES) or whether specific policies targeted at different sectors were implemented. A large penetration of biofuels in the transport sector is only achieved under targeted policies such as taxation of conventional transport fuels, because applications in the power sector seem more cost effective. According to PRIMES and MARKAL, the targets of the Biofuels Directive are more than achieved in 2010, while in 2020, biofuels account for 14-32% of final energy demand in the transport sector, respectively. In MARKAL this is due to an almost complete shift from diesel to biodiesel, which is produced from wood chips. The other models do not specify which processes are used for biofuel production.

Wind energy takes off

Under the 20% target, the amount of wind power production increases significantly, and the target set by the wind industry (EWEA, 2003) of 425 TWh in 2020 for the EU-15 seems within range. The differences in projections for 2020 are large, as illustrated in Figure P.4, while the range is much smaller in 2030, indicating that technical potentials are becoming the limiting factor. In terms of generation capacity, there would be some 100-180 GW wind power installed in Western Europe, increasing to 190-215 GW in 2030. The average 11% share of wind power in total electricity generation is substantial, but generally within dispatchable ranges, although the shares in individual countries could be much higher.

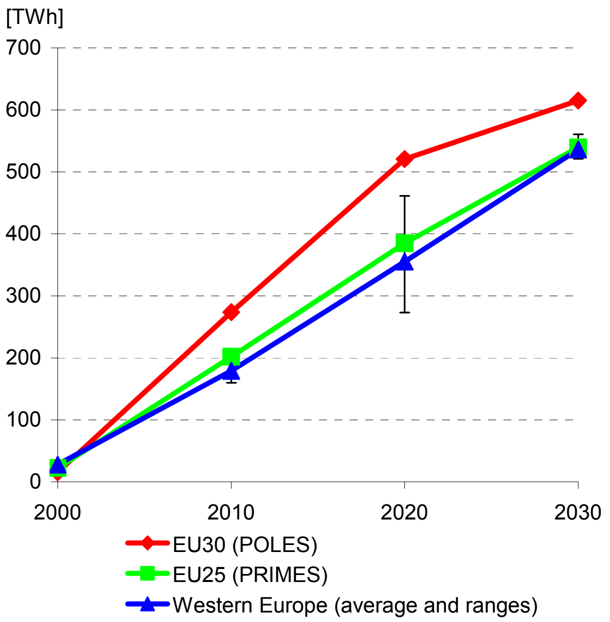

Figure P.4 *Production from wind energy*

Policies to achieve ambitious renewables targets

A variety of policies have been implemented in the different models in order to achieve a high penetration of renewable energy sources. Most of the models have incorporated a separate target for the power sector of 33% renewable electricity consumption, and have reported on the subsidies required for achieving this target as shown in Figure P.5. There seems to be some consensus on a subsidy level up to 40 €/MWh, a level that would be comparable to the electricity commodity price. However, the design of the policy instrument differs, as indicated in the graph, and therefore the support levels are not completely comparable.

Moreover, a well-designed policy should differentiate support instead of providing a flat rate for all technologies, implying that the average subsidy would probably be lower. The TIMES model has compared a scenario of certificate trade in the EU-15 to a scenario where all 15 Member States achieve their targets domestically. Trade leads to cost reductions for most of the countries, whereas expensive technologies, such as PV, experience a larger growth when the targets are met without trade.

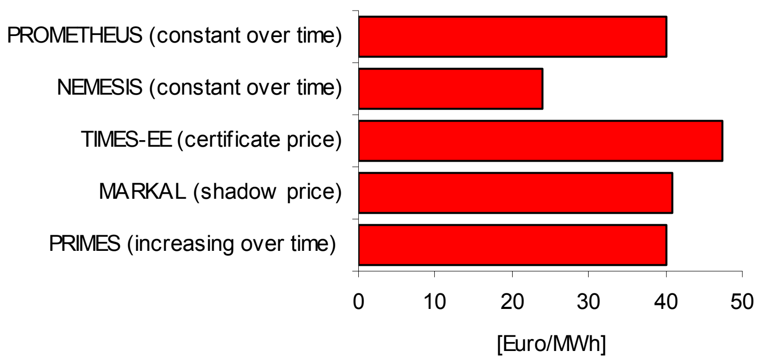

Figure P.5 *Subsidies required for achieving 33% renewable electricity consumption in 2020*

POLES is the only model that has used a generic subsidy for all sectors, and its level of almost 60 €/MWh confirms that the cost of the 20% overall target is higher than that of only the power sector, where this model reaches a 44% renewables share in 2020.

Long term - the global perspective

When extending the focus to the longer term, say until 2050, a restriction of the efforts to the European Union only is unlikely to provide a realistic view on future prospects of renewable energy systems. Therefore, in the study three global models (DNE21+, GGM, and MESSAGE) have been used to analyze the long-term perspective for RES. These models show that when the industrial world takes the lead, global penetration of renewable systems may be achieved for those technologies that show an aptitude for cost decrease.

Penetration of renewables worldwide

Figure P.6 presents the trends for three important options for renewable electricity production. These technologies are presented here, because the models largely differ in what they expect under the modest subsidy scheme of 20 €/MWh implemented in the power sector. The assumption is made that subsidies gradually decrease, so that in 2050 the systems are no longer subsidized. This subsidy scheme reflects a situation where the policy maker is willing to provide a subsidy for market uptake, but is decreasingly willing to support systems that are not entering the market by itself.

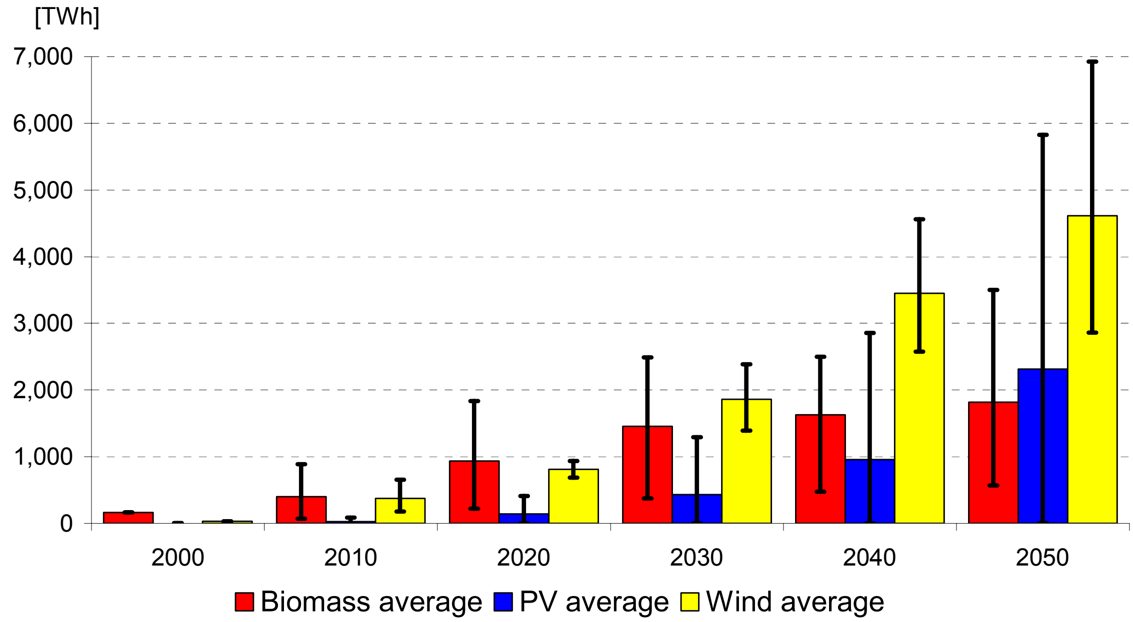

Figure P.6 *Global electricity production from biomass, PV and wind under a subsidy scheme of 20 €/MWh, decreasing to zero in 2050; averages over three models and ranges*
Source: MESSAGE, GMM and DNE21+.

Biomass shows the most limited growth. This is partly due to the fact that biomass resources are also used for other applications, e.g. in the transport sector. Furthermore, the initial increase in application of biomass is annulled by the year 2050 in all models. This indicates that the low and decreasing subsidy level is insufficient to induce a lasting effect on the additional deployment of biomass. Only in the sensitivity scenario assuming subsidies together with learning by doing (LBD), analyzed with GMM, a lasting production increase was realised. This production increase was 3300 TWh in the regions of Asia, Eastern Europe, Former Soviet Union, Latin America, Africa and the Middle East, e.g. outside the OECD for the year 2050.

This result suggests that early learning investments in systems like biomass in regions with large biomass potentials can accelerate introduction of renewable electricity technologies into the market.

For wind power, the GMM model projects the largest growth. Here the subsidy policy induces only limited impact on the technology penetration, since the wind turbines increase the contribution to the power generation mix substantially already in the Baseline, and further increase is limited by the upper bounds imposed on this technology. Most of the capacity is installed in the industrialised world. In the other two models the growth of wind energy in the baseline is more modest, and the relative impact of the subsidy therefore is larger.

For PV, the differences among the model results are extremely large, reflecting the uncertainties on how the costs of this technology will develop. In one of the models (MESSAGE) where it is assumed that R&D spending and direct investment in a broad portfolio of solar technologies has contributed to important reductions of the investment cost for the PV technology, a worldwide production of over 5.000 TWh can be achieved already without additional subsidies. This corresponds to some 1700 GW capacity, which is installed mainly in Asia, Africa and South America, where the potentials are large. On the other hand, there is a model (GMM) with endogenously determined cost reductions due to learning by doing, which expects hardly any penetration of PV under the modest subsidy levels in the current case. This model has calculated that achieving a reduction in production costs down to a level of 50 €/MWh by 2040 requires 'learning investments' (e.g., cumulative undiscounted investment cost), of around 260 10^9 €. This would correspond to a cumulative production of 15.000 TWh in the periods 2040-2050, or an installed capacity of 820 GW by the year 2050.

Learning can enhance effects of subsidies

Within the global perspective, the question arises what is likely to be the most cost-effective way in which Europe may subsidize renewable energy systems. The EU may choose to be initially leading in the stimulation, but this will only be acceptable if taking the lead in the long term will not induce negative side effects, such as decreased competitiveness. Thus, after an initial lead-time, other regions should follow the example, or the need for subsidy should decrease due to increased competitiveness of RES. In the present study, the subsidy scheme assumed follows these assumptions. It is shown that under these discussions the aims of the subsidy scheme are only reached if and when the RES show aptitude for learning, i.e. for cost decrease under increased deployment or research.

To evaluate the effectiveness of subsidy policies in terms of cost and achievable renewable electricity shares, one of the models has analysed an additional 'cap-and-trade' scenario that forces renewable electricity generation to reach a fraction of 35% in 2050. The resulting marginal cost of this renewable electricity amounts 3-6 €ct/kWh in the period 2010-2050, and can be interpreted as certificate prices. While in the subsidy scheme the subsidy is provided equally to each renewable source (with an exception for hydropower), under the renewable target the model finds the least cost solution that defines the supply curve of renewables.

While the three global models mentioned above only allow for the analysis of overall research, development and deployment effects, the stochastic PROMETHEUS model also enables an more particular analysis of either research or deployment stimuli. The framework of such an analysis has been the central theme of several EU-funded research projects, such as the SAPIENT and SAPIENTIA projects[4]. Using PROMETHEUS, a comparison between the effect of direct subsidies and additional R&D spending, shows that the effect of a subsidy of 40 €/MWh is comparable to doubling cumulative R&D investments (corresponding to an additional 48 billion $€_{2000}$) combined with a subsidy of 25 €/MWh.

4 http://www.e3mlab.ntua.gr/sapientia.html.

The R&D-scenario is some 30% more expensive than the direct support scenario. However, when the costs are expressed in terms of avoided CO_2 emissions, the direct support policy is substantially more expensive. This is due primarily to the different nature of the spillover effects of the two policies. The R&D policy enhances the attractiveness of renewables throughout the world, while the direct support policy increases renewable penetration in Europe.

The global versus local effects of the two possible routes sketched above, also point at the need for further analysis. While the direct stimulation is likely to have positive side effects for the RES industry, the increased R&D spending not necessarily has similar beneficial local effects. Other regions, through a spill over of knowledge, may absorb the R&D gains, with possible consequences for European competitiveness.

Efficiency of subsidy schemes

The basic scenario studied here is one where a flat subsidy is provided to RES in the power sector. All of the global models have made additional analyses, using more complex schemes such as differentiated subsidies, international green certificate trade and extending the scheme to other sectors. When looking at the results of such more elaborate schemes, one generally can observe that a flat subsidy rate to all RES is not the most efficient way of increasing the contribution from RES.

Furthermore, one of the models has shown that biomass can play a role in various sectors, and that a stimulus in a particular sector may cause ‘carbon leakage’ to other sectors, due to a shift in application of biomass. In case of applying a subsidy only to renewable electricity generation, the transport sector shows a switch from biomass-based ethanol to fossil-based methanol in transport. Since the biomass resources are limited, it is more attractive to use biomass in the subsidized electricity production than in synthetic fuel production. Both methanol production and use lead to CO_2 emissions. Most of the additional methanol is produced with coal, and emissions from the transport sector may be up to 5% higher than in the baseline in 2050. Therefore, the extension of the subsidy beyond the power sector not only increases the efficiency of the stimulus, but also seems required to reduce CO_2-‘leakage’ between sectors.

CO_2 emissions reductions

To give a more concrete understanding on the effect of the level of the subsidy on the CO_2 emissions, the cumulative emission reductions are calculated for the case where all energy carriers receive subsidies from 1 to 6 €ct/kWh, decreasing over time (Figure P.7).

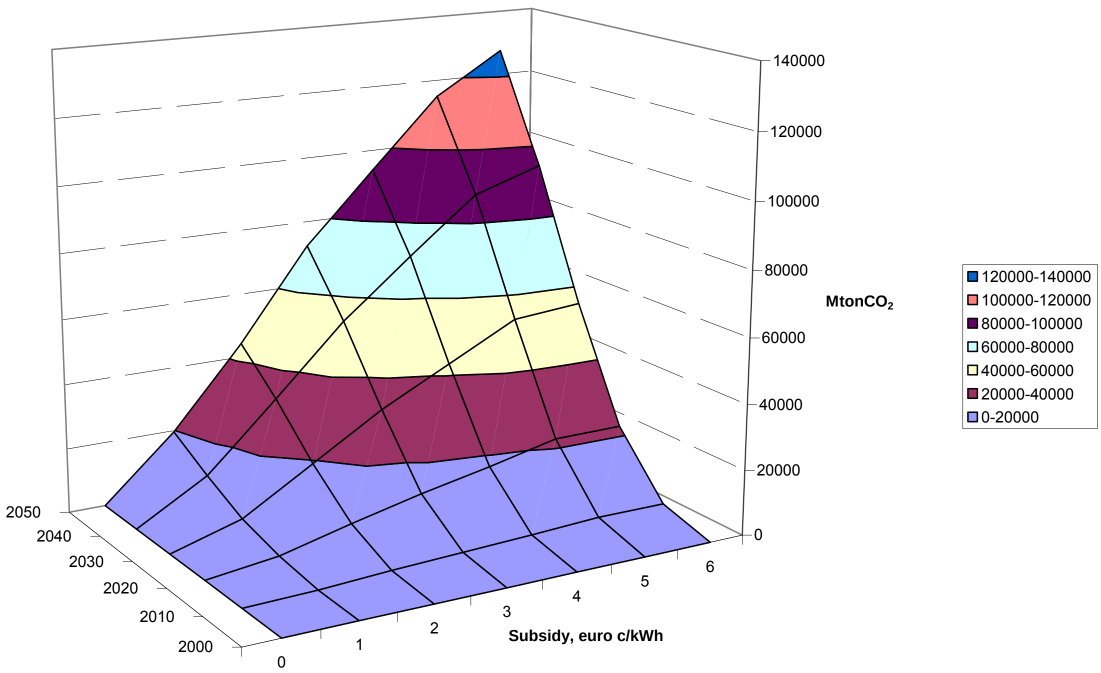

Figure P.7 *Cumulative CO_2 reductions as a function of the subsidy level, renewable energy in all sectors subsidized*
Source: MESSAGE.

As the figure shows, the effect on CO_2 emissions is higher the more ambitious the subsidy scheme is (and this is also the case when only renewables in the power sector are subsidized). However, subsidizing all energy carriers provides much more potential for emission reductions. For example, to reach reductions of 40 Gt CO_2 by the year 2050, an initial subsidy level of 3 €ct/kWh is needed if only electricity is subsidized. An initial subsidy level of approximately 1.8 €ct/kWh would be enough with the overall subsidy scheme (see Figure P.7). Note also that although with the same initial subsidy level the absolute costs of the overall schemes would be higher, the price per ton CO_2, which measures the effectiveness of the policy in terms of emissions reductions, would still be lower. Given the assumptions in the baseline and on the (decreasing) aspiration levels for the subsidies, a reduction of about 140 Gt CO_2 in cumulative emissions may be reached by the year 2050.

Key recommendations

Recently, Europe has shown large ambitions in setting renewables targets. Renewables indeed have the potential to contribute substantially to mitigating climate change options and their indigenous nature improves security of supply. To effectively increase the penetration of renewables up to 20% in 2020, the following recommendations apply:

- The 20% target seems to be within reach provided energy demand reductions are pursued simultaneously.
- Bioenergy is one of the key renewable options because of its large potential and its different possible applications. A strong growth of biomass deployment is required for achieving ambitious renewables and climate targets. Policies in different areas such as energy, agriculture, and environment should be further streamlined in order to overcome current barriers.
- Efforts directed towards the transport sector combine several benefits, because the substitution of oil with biofuels improves both security of supply and reduces carbon emissions.

- Implementation of renewables is currently most straightforward in the power and transport sector, but to achieve further growth towards 2020, applications should involve other end-use sectors. For instance the potential in the building sector, including renewable heating and cooling options, such as solar thermal water heaters or biomass-based district heating should be further exploited.

Furthermore, some lessons on design of subsidies can be drawn.

- For the long-term growth of shares of renewable power generation, the elimination of all subsidies by 2050, as assumed in this case study, is probably not appropriate and may lead to a situation where promising new technologies such as photovoltaics remain locked-out.
- Subsidy schemes should offer differentiated support and stimulate learning effects. It is important to target the subsidies correctly. If only one sector is subsidized, the renewable share in this sector will be high, but there may be ‘carbon leakage’ to other sectors, due to a shift in application of biomass, and the share in primary energy is only mildly affected.
- R&D and demonstration projects can induce spillover effects to the rest of the world and thereby have a higher impact on global emissions reductions.

1. Introduction

1.1 The CASCADE MINTS project

The current report presents results of Part 2 of the CASCADE MINTS project (CMP2). The CASCADE MINTS project is split into two distinct parts:

- Part 1 focuses on modelling, scenario evaluation and detailed analysis of the prospects of the hydrogen economy. It involves extensive development and use of detailed energy models that have received assistance from previous framework Programmes of DG Research. The ultimate aim of this part of the project is to enable perspective analysis of the conditions under which a transition to an energy system dominated by hydrogen is possible.
- Part 2 does not involve significant model development. Its main aim instead is to use a wide range of existing operational energy and energy/economy models in order to build analytical consensus (to the extent that this is possible) concerning the impacts of policies aimed at sustainable energy systems. This part builds on the experience obtained in the ACROPOLIS project (Das et al, 2003), funded by DG Research within the 5th Framework Programme and involves common exercises carried out using a wide variety of models. This part involves modelling teams from both inside and outside the EU. The emphasis is placed on evaluating the effects of policies influencing technological developments.

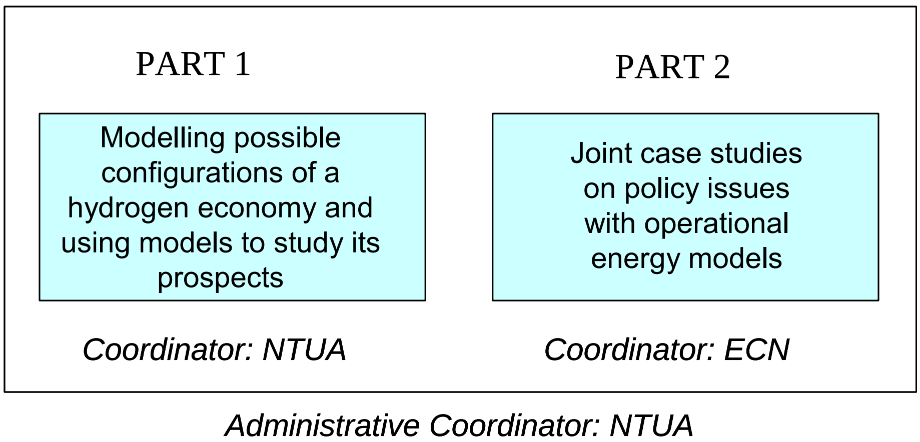

Figure 1.1 *Overview of the CASCADE MINTS project*

Part 2 of the project consists of six work packages. Five of these involve modelling work, and one work package is devoted to reporting and dissemination. In each of the work packages a set of common case studies is analysed with the participating modelling teams. The current report presents results of the second work package on renewables. All work packages are briefly summarised below.

Baseline (WP 2.1)
The report on the first work package, on harmonisation of initial assumptions and evaluating a common baseline projection, has been published separately (Uyterlinde et al, 2004).

Renewable energy (WP 2.2)
Renewable energy sources have the potential to play a much larger role than they presently do. However, targets for steadily increasing the share of renewables prove difficult to achieve. What are the consequences of different targets in 2020?

What is an optimal share for renewables under different CO_2 mitigation and import dependency constraints? Under what conditions and by means of which policy instruments can the 2020 target of a 20% renewable energy share (of primary resources) be reached? What is the related impact on GHG emission reduction and import dependency in 2020 and 2050? What mix of renewable technologies (solar, wind, biomass, geothermal) will be applied in which sectors?

Nuclear energy (WP 2.3)
Nuclear power currently accounts for approximately one-third of the electricity generating capacity in the EU and is therefore a main topic in the current debate concerning security of energy supplies in the EU and the reduction of GHG emissions. Replacement of existing nuclear power plants puts even more stress on both policy issues. Important issues which will shape the future trends in the nuclear sector, are the problems of managing nuclear waste, the economic viability of the new generation of nuclear power plants, the safety of reactors in eastern Europe, in particular Candidate Countries and the policies to combat climate change and improve the security of supply. The main research question that will be addressed is under what conditions and by means of which policy instruments will new nuclear power plants become environmentally and economically feasible? What will be the potential impact of nuclear energy in terms of GHG emission reduction and improving of supply security in 2020 and 2050?

CO_2 capture/storage (WP 2.4)
CO_2 capture and sequestration will always come with an additional cost to any power generation plant. This is true both for the conversion to electricity and the conversion to hydrogen, if hydrogen is used as an energy carrier. CO_2 capture and sequestration will therefore only be applied if future specific or general policies provide the necessary financial incentive. Under what conditions and by means of which policy instruments will CO_2 capture and storage in e.g. old gas and oil fields or aquifers become environmentally and economically feasible? Considering different possible policy strategies to intervene and to stimulate CO_2 capture and storage becoming a mature technology, what is the potential impact of CO_2 capture and storage in terms of GHG emission reduction in 2020 and 2050?

Trade offs and synergies (WP 2.5)
The final work package forms the link between Part 1 and Part 2 of the project. It integrates:
- WP 2.2 (renewable energy)
- WP 2.3 (nuclear energy)
- WP 2.4 (CO_2 capture/storage)
- WP 1.2 (hydrogen).

1.2 Report overview

This report represents the results of WP 2.2 and is structured as follows. Chapter 2 introduces the setup and assumptions behind the scenarios analysed. Next, in Chapter 3, results are presented of all models that have analysed the renewables targets for Europe. Chapter 4 provides a synthesis of the individual model results. In Chapter 5, the world models report on their analysis of the effects of long term subsidies for renewables, while Chapter 6 presents a synthesis based on these results.

2. Assumptions

The analysis in the CASCADE MINTS Renewables case focuses on the policy issues related to the contribution from renewables to the energy system and intends to evaluate the impact of an increased share of renewable energy on the security of supply and on the environment in Europe. In order to benefit most from the 15 different models participating in the project, the policy cases were set up in a flexible way. Different (groups of) models performed different case studies, highlighting different aspects and implications of increasing the role of renewable energy. On the other hand, it is important to ensure a transparent reporting and keep the number of cases or scenarios limited. Therefore two main *clusters* of case studies are used, distinguishing themselves in geographical focus and in time-scale.

2.1 Cluster 1: Medium term (2020) focusing on EU

2.1.1 Post-2010 target setting in the EU

Two different targets have been analysed for the 2020 share of RES in primary energy consumption. The level of these targets is based on a Commission Communication (European Commission, 2004), and discussions at the Renewables Conferences in 2004 in Berlin and Bonn, where a target of 20% of gross inland consumption in 2020 was proposed. The Commission intends to gather more information on the impacts of this target before deciding on long term target setting, a decision probably to be taken in 2007.

The CASCADE MINTS project aims at contributing to this impact assessment by analyzing the feasibility and consequences of the 20% target for 2020 (‘High Target’). It will be compared to ‘Low target’ of a 12% share of renewables in primary energy consumption; this corresponds to the target set in the White Paper ‘Energy for the Future’ (1997) where it was set for 2010, see Table 2.1. The choice of this lower value is motivated from the fact that the targets should be well apart to allow for a meaningful comparison.

The High Target is partly supported by the FORRES 2020 project (Ragwitz et al, 2004) which concludes that 18.6% renewables in primary energy supply in 2020 is feasible under the ‘policy’ scenario, see Table 2.2. It should be noted that this ‘policy scenario’ also includes energy efficiency measures, implying that the high renewables share is possible due to a lower demand projection than the baseline. Cascade Mints Part 2 will attempt to achieve the target relative to the baseline projection.

Table 2.1 *Projections underlying the 2010 target in the White Paper (EU, 1997)*

Table 2

CURRENT AND PROJECTED FUTURE GROSS RENEWABLE ENERGY CONSUMPTION (Mtoe) FOR 2010

	CONSUMPTION IN 1995				PROJECTED CONSUMPTION BY 2010			
TYPE OF ENERGY	Eurostat Convention	% of total	Substitution Principle	% of total	Eurostat Convention	% of total	Substitution Principle	% of total
Total Gross Inland Consumption	1,366		1,409		1,583 (Pre-Kyoto)		1,633	
1. Wind	0.35	0.02	0,9	0.06	6.9	0.44	17.6	1.07
2. Total Hydro	26.4	1.9	67.5	4.8	30.55	1.93	78.1	4.78
2.a. Large (incl. pump storage)	(23.2)		(59.4)		(25.8)		(66)	
2.b. Small	(3.2)		(8.1)		(4.75)		(12.1)	
3. Photovoltaics	0.002	-	0.006	-	0.26	0.02	0.7	0.05
4. Biomass	44.8	3.3	44.8	3.12	135	8.53	135	8.27
5. Geothermal	2.5	0.2	1.2	0.1	5.2	0.33	2.5	0.15
5.a Electric	(2.1)		(0.8)		(4.2)		(1.5)	
5.b Heat (incl. heat pumps)	(0.4)		(0.4)		(1.0)		(1.0)	
6. Solar Thermal Collectors	0.26	0.02	0.26	0.02	4	0.25	4	0.24
Total Renewable Energies	74.3	5.44	114.7	8.1	182	11.5	238.1	14.6
7. Passive Solar					35	2.2	35	2.1

Table 2.2 *Key results FORRES 2020: Analysis of renewable energy's evolution up to 2020 (Ragwitz, 2004) as presented at the Renewables conference in Bonn, June 2, 2004*

Use of RES in heat, electricity generation and transport EU-25

interim results

Electricity [TWh]	2001	2020 BAU	2020 Policy
Wind energy	34	381	448
Hydro power	326	341	349
large-scale	288	296	301
small-scale	38	44	48
Photovoltaic	0,2	0,9	5,2
Solar thermal	0,0	4,2	15,7
Wave & tide	0,0	10,8	36,1
Biomass, biogas, biowaste	37	135	305
Geothermal	6,3	7,5	8,2
TOTAL RES-Electricity	**403**	**881**	**1168**
TOTAL Demand *	2960	4000	3640
Share of Demand	13,6%	22,0%	32,1%

* EU energy outlook 2003

More effective policies in the heat sector (especially for biomass) are feasible than assumed in the Policy Scenario !

Heat [Mtoe]	2001	2020 BAU	2020 Policy
Biomass	47	53	75
Geothermal	1,0	5	18
Solar Thermal	0,5	3	7
TOTAL RES-Heat	**49**	**60**	**100**
TOTAL Demand * **	419	478	478
Share of Demand	11,7%	12,6%	20,8%

Transport [Mtoe]	2001	2020 BAU	2020 Policy ***
TOTAL Biofuels	**1**	**19**	**49**
TOTAL Demand *	279	351	323
Share of Demand	0,41%	5,5%	15,0%

Total primary energy [Mtoe]	2001	2020 BAU	2020 Policy
TOTAL Renewables	**101**	**179**	**316**
		(262)	**(417)**
TOTAL Demand *	**1680**	**1900**	**1700**
Share of Demand	6,0%	9,4%	18,6%
		(13.2%)	(23%)

* EU energy outlook 2003 according to EUROSTAT convention
** No efficiency scenario available ( ) according to substitution principle
*** Processes based on lignocellulosic biomass assumed

2.1.2 Subtargets electricity sector

Some models can provide a least-cost distribution of the overall target over the electricity, heat and transport sector. Other models need to set an intermediate target for renewable electricity consumption. Therefore two reference values are adopted. Note that these are auxiliary values, for those models that do not impose a generic target.

- The FORRES 2020 study reports a share of 32.1% RES-E in gross electricity consumption in the Policy scenario. Therefore, in line with the 20% overall target a subtarget of *33%* is proposed**.** This is the High RES-E subtarget.

- For the Low RES-E subtarget, the *22%* target for RES-E is maintained, which was set for 2010 in the RES-E Directive, analogous to the fact that the 2010 White Paper for 2020 is used as well.

EU targets are defined as a share of gross electricity consumption. This is equal to domestic electricity generation plus net electricity imports. It does not correspond to final demand for electricity. All models apply these targets to the regions that most closely resemble the EU-25. If Norway is included, a correction should be made for the contribution of hydropower.

2.1.3 Definitions

It is important to define clearly how the contribution of renewables (and nuclear) to primary energy production is accounted for. There are two conventions:

- The Eurostat convention based on the direct equivalent methodology, where the direct output from nuclear, solar, wind and hydro is taken (conversion factor = 1).
- The substitution principle where substitution equivalents (e.g., efficiency factors for electricity generation) are used.

As detailed in the box below, IEA uses the direct accounting method, except for geothermal electricity, and nuclear, so it is a mixed approach. Eurostat uses a direct accounting method for all non-fossils. Cascade Mints uses the substitution principle, except for the current report, where the Eurostat convention has been adopted in order to be in line with policy discussions.

Different ways of accounting for non fossil fuels in primary energy production

- *Eurostat:* Production of primary energy comprises energy extracted from natural sources: coal, lignite, crude oil and natural gas. Renewables energy (hydro-, biomass, geothermal, wind and solar energy) as well as nuclear energy are *also considered primary energy sources.* Nuclear heat is accounted for as the heat released during the fission of uranium in a nuclear reactor.
- *IEA:* Total Primary Energy Supply is calculated using the physical energy content methodology. The quantity of geothermal energy entering electricity generation is inferred from the electricity production at geothermal plants assuming an average thermal efficiency of *10 percent*. For solar, wind, tide and wave energy, the quantities entering electricity generation are *equal* to the electrical energy generated. Hydro shows the energy content of the electricity produced in hydro power plants. Hydro output excludes output from pumped storage plants. Nuclear shows the primary heat equivalent of the electricity produced by a nuclear power plant with an average thermal efficiency of 33 percent.
- *Cascade Mints:* Renewable energy sources (hydro, wind, solar, geothermal) are converted to primary use while using a conversion factor of 3 for electricity generated (corresponding to average efficiency of 33%) and 1.1 for heat generated by these fuels (corresponding to an efficiency of 91%). For nuclear energy distinction is made between imported fissile material and domestically reprocessed material from spent fuel (e.g. MOX) (both expressed in equivalent PJ). Again conversion factor 3 for electricity production and conversion factor 1.1 for heat. For hydrogen production from non fossil fuels, with the exception of electricity, use a conversion rate of 2 (equivalent to 50%) and add this amount to the corresponding source in the primary energy production table.

The targets as proposed for the Cascade Mints case studies are defined according to the Eurostat convention, see Table 2.1 and Table 2.2. The 18.6% (according to Eurostat convention) renewables in primary energy supply in 2020 in FORRES 2020 is 23% according to the substitution principle. In the Annexes to the White Paper, the share of 11.5% (Eurostat convention) is reported to be 14.6% according to the substitution principle.

Although the reference in policy discussions is the Eurostat convention, the Commission also acknowledges that the use of the substitution approach would have several advantages. It would give a more balanced reflection of the contribution of different forms of renewable energy, reflect the objectives of renewable energy policy in terms of substitutions for the use of fossil fuels and thus reducing CO_2 emissions and improving security of supply and allow a clearer comparison between the effects of renewable energy and energy efficiency measures.

2.2 Cluster 2: Long term (2050) World

This cluster provides the long-term global perspective complementary to the European case. It is important to focus on the role of Europe within the world context. It has been decided not to set a target for 2050 beforehand, because of large differences in the baseline results between different models (see Uyterlinde et al, 2004). Instead it is proposed to introduce policy instruments (subsidies) and see what happens looking at the role of renewables. The subsidy levels should decrease towards the time horizon, in order not to give the impression that renewables will continue to require financial support until 2050. Next, a sensitivity analysis will give an idea of the attainability of different targets on the time horizon of 2050.

2.2.1 Subsidy scheme

The following subsidy scheme is proposed for the global models participating in the renewable case study of part two of CASCADE MINTS:

- A subsidy of 2 €ct/kWh for the renewable electricity produced, starting from 2010 for the industrial countries. Subsidy diminishes linearly reaching zero in the year 2050.
- Developing countries join the scheme in 2020 and have then the same subsidy as the industrial countries do between the years 2020 and 2050.
- Large scale hydro is not subsidized. Only, for those global models, where small hydro plants are not explicitly modelled, the subsidy will be limited to maximum one third of total hydropower generation (33.33% of total generated hydro electricity can be subsidised). Similarly, only 1/3 of total hydro-power generation will be allowed for trade of ‘green certificates’.

To enable cross model comparison, the central case is run with all global models. In addition to the central case, teams may perform sensitivity runs with different subsidy levels.

3. European models

3.1 PRIMES

3.1.1 Introduction

In the context of the two RES cases examined, additional runs have been performed to estimate the subsidies required to achieve the renewable targets for EU-25 share of RES in primary energy consumption set to:

- 20% for the year 2020 for the 'High target scenario',
- 12% for the year 2020 for the 'Low target scenario'.

In both cases, it is assumed that additional incentives are provided to both energy consumers and energy producers so that the targets from renewable energy sources to gross national energy consumption by 2020 are reached.

Further penetration of renewable energy forms on the *demand side* is achieved through promotional policies for the use of biomass and waste in industry and the use of solar thermal panels for water heating purposes in services and households. This case also assumes the implementation of the biofuels Directive, adopted in May 2003 that sets indicative shares for biofuels in petrol and diesel for transportation purposes of 2% in 2005 and almost 6% in 2010, and the introduction of additional policies in this direction.

On the *supply side* targets are achieved through support schemes that provide subsidies for electricity generation from renewable energy sources. However, these payments on account of higher costs due to more renewables deployment are passed on to the consumers through increased electricity prices (i.e. the electricity tariffs, paid by all electricity consumers, increase to reflect the higher costs of greater renewables deployment). The subsidies (in €/MWh) introduced are:

Subsidies in high and low target scenarios

[€/MWh]	High target scenario	Low target scenario
2000	0	0
2005	0	0
2010	20	0
2015	30	15
2020	40	18
2025	45	28
2030	50	32

In the High target scenario case examined, with the above subsidies a 34% RES-E/gross electricity production for EU25 in 2020 is achieved. In the same way, in the 'Low target' case examined, with the above subsidies a 27.1% RES-E/gross electricity production for EU25 in 2020 is achieved.

3.1.2 Results

Primary energy consumption

As can be seen in Table 3.1 primary energy demand in the EU-25 energy system for renewable energy forms in the 'Low target' scenario increases by some 77 Mtoe (or +46%) from baseline levels in 2020. In the 'High target' scenario, this increase reaches 163 Mtoe (or +97%) in 2020 from baseline levels. In both scenarios examined, the increase occurs mainly to the detriment of solid fuels (-10.6% and -17.7% respectively from Baseline levels for the two cases examined) while the decline is less pronounced as regards primary consumption of other energy forms. In both cases overall primary energy needs are projected to exhibit a slight increase on top of Baseline levels (+0.7% and +0.8% respectively in 2020) as a result of the higher exploitation of biomass in the EU-25 energy system with lower production efficiency in the power generation sector.

Table 3.1 *Evolution of primary energy needs in the EU-25 energy system*

	[Mtoe]				Change from baseline [%]		
	2000	2010	2020	2030	2010	2020	2030
Low Target case							
Solid Fuels	303.2	216.4	171.0	169.7	0.0	-10.6	-15.0
Liquid Fuels	635.6	644.8	642.6	630.0	0.0	-2.8	-5.0
Natural Gas	376.0	506.8	587.8	630.7	0.0	-3.8	-5.2
Nuclear	237.7	245.3	210.5	183.4	0.0	-1.3	-5.5
Renewable energy forms	96.1	139.5	244.8	308.6	0.0	46.2	63.5
Total	1651	1755	1859	1925	0.0	0.7	0.6
EU-15	1453	1552	1634	1690	0.0	0.8	0.5
NMS	198	203	225	234	0.0	0.3	1.6
High Target case							
Solid Fuels	303.2	199.5	157.2	159.5	-7.8	-17.7	-20.2
Liquid Fuels	635.6	613.2	601.7	585.5	-4.9	-9.0	-11.7
Natural Gas	376.0	486.3	573.2	615.9	-4.0	-6.2	-7.4
Nuclear	237.7	245.3	196.2	166.0	0.0	-8.0	-14.5
Renewable energy forms	96.1	225.8	330.3	394.2	61.9	97.2	108.9
Total	1651	1772	1861	1923	1.0	0.8	0.5
EU-15	1453	1567	1635	1687	1.0	0.8	0.3
NMS	198	205	226	236	1.0	0.8	2.3

Source: PRIMES.

Table 3.2 illustrates the changes of primary energy needs by fuel in absolute terms under the two cases examined. It is interesting to note that in both cases the bulk of the increase in the use of renewable energy forms occurs for biomass/waste, whereas the contribution of intermittent renewable energy sources, such as hydro, wind and solar energy, is less pronounced. The wide range of potential use of biomass/waste in the EU-25 energy system, including power generation, steam generation in industry and production of biofuels, is the main driver for this result. It is also interesting to note that, whereas in percentage terms the most pronounced decline is projected for solid fuels, in absolute terms the decline is rather uniform for all fossil fuels in the 'Low target' scenario while in the 'High target' scenario it becomes increasingly important as regards the use of natural gas.

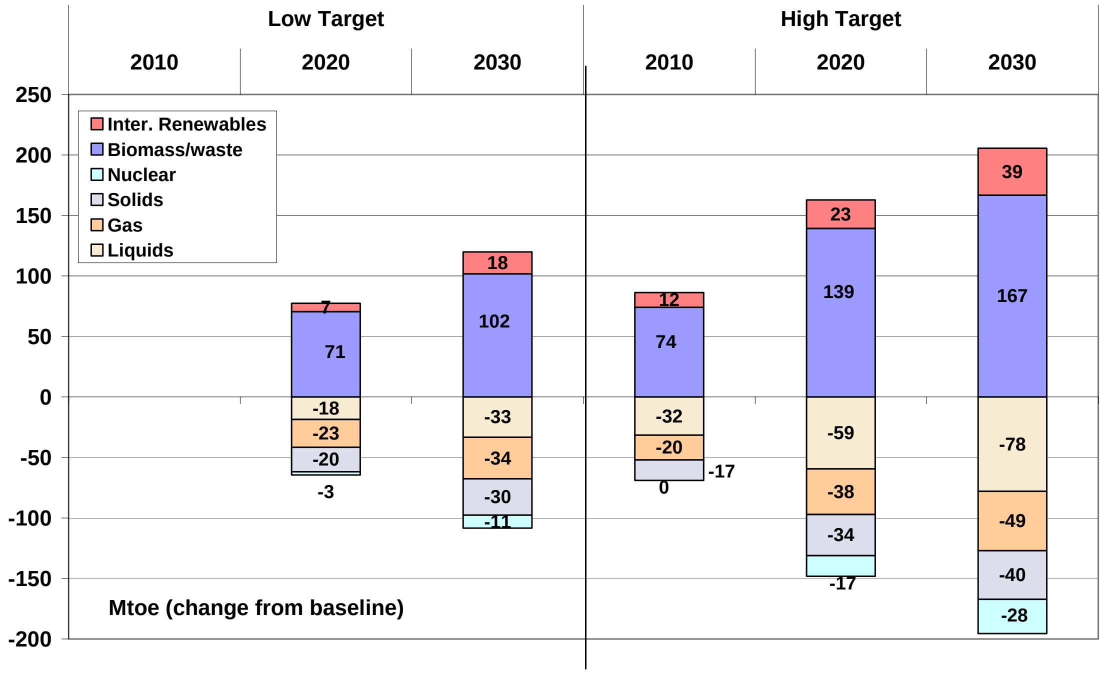

Figure 3.1 *Changes of primary energy needs in the EU-25 energy system*
Source: PRIMES.

Share of renewables
Under the 'Low target' case assumptions, the share of renewable energy forms in primary energy needs of the EU-25 energy system reaches 13.7% in 2020 (see Table 3.2). An even more pronounced growth, is projected in the 'High target' case; renewable energy sources share reaches 18.3% in 2020 (21% in 2030).[5]

Table 3.2 *Share of renewable energy forms in primary energy needs of the EU-25 energy system*

	Primary energy needs [%]				Points change from baseline [%]		
	2000	2010	2020	2030	2010	2020	2030
Low Target	6.1	8.4	13.7	16.4	0.40	4.58	6.53
High Target	6.1	13.5	18.3	20.9	5.50	9.27	11.00

Source: PRIMES.

Final energy demand
Compared to baseline scenario, no significant changes are expected to occur in final energy demand in the EU-25. In the 'High target' scenario, in 2020, final energy demand decreases by some 3 Mtoe, while in the 'Low target' scenario final energy demand is projected to remain at baseline levels (see Table 3.3).

[5] It should be noted that in the 'High target' scenario the achievement of the 20% target of renewables in primary energy needs cannot be fully achieved in 2020 in the absence of policies and measures towards improving energy intensity in the demand side.

Table 3.3 *Final energy demand in the EU-25 energy system*

	[Mtoe]				Change from baseline [%]		
	2000	2010	2020	2030	2010	2020	2030
Low Target case							
Industry	309.1	334.7	360.4	381.5	0.0	-0.1	-0.2
Tertiary	154.2	168.4	189.1	212.6	0.0	-0.2	-0.4
Households	279.1	304.5	323.5	333.3	0.0	-0.1	-0.3
Transport	332.0	384.3	420.0	441.1	0.0	0.0	0.0
Total	1074	1192	1293	1369	0.0	-0.1	-0.2
EU-15	955	1062	1143	1207	0.0	-0.1	-0.2
NMS	119	130	150	162	0.0	-0.1	-0.2
High Target case							
Industry	309.1	334.9	360.1	380.8	0.1	-0.2	-0.4
Tertiary	154.2	168.1	188.3	211.8	-0.2	-0.6	-0.8
Households	279.1	304.1	323.0	333.8	-0.1	-0.3	-0.1
Transport	332.0	384.4	420.0	441.2	0.0	0.0	0.0
Total	1074	1191	1291	1368	0.0	-0.2	-0.3
EU-15	955	1061	1142	1206	0.0	-0.2	-0.3
NMS	119	130	150	161	-0.1	-0.3	-0.3

Source: PRIMES.

A significant change occurring in the demand side but not illustrated in Figure 3.2 concerns the higher use of biofuels as an ingredient of gasoline and diesel oil (i.e. as the fuel is available in the pump).

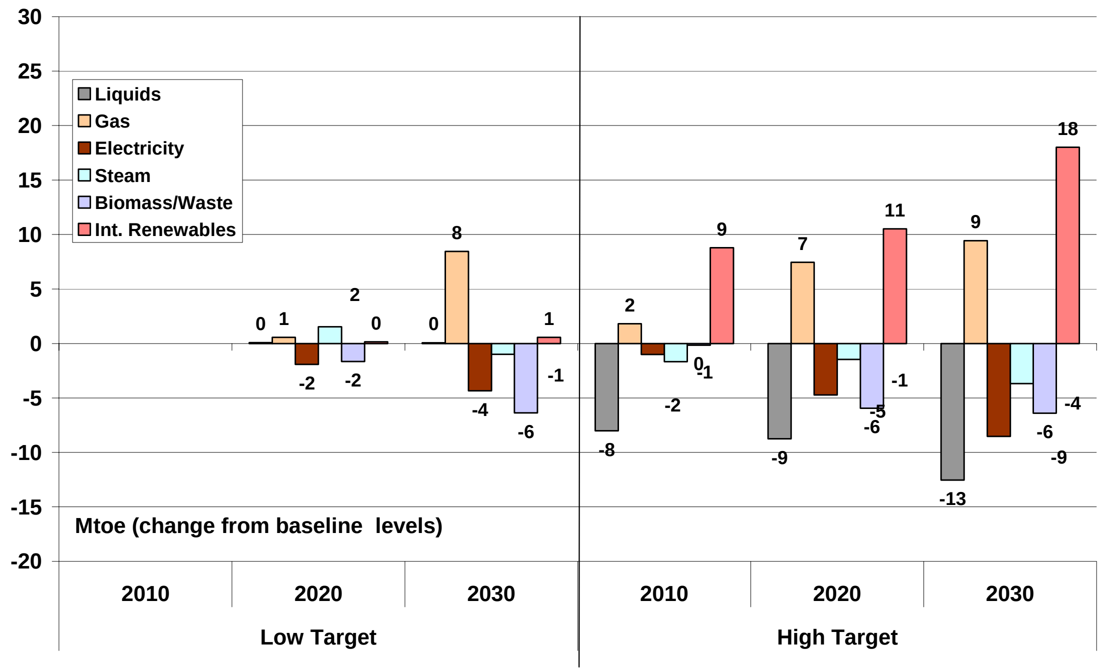

Figure 3.2 *Changes of final energy demand by fuel in the EU-25 energy system*
Source: PRIMES.

As can be seen in Table 3.4 the targets set in the Directive proposed by the European Commission for biofuels in 2010 are more than achieved in the 'High target' scenario, whereas in the 'Low target' scenario the share of biofuels in gasoline and diesel demand in 2010 is just 2.3%. In the 'High target' case, a 14.3% share of biofuels in total final energy demand of the transport sector in 2020 (or 17.1% share of biofuels in gasoline and 17.3% share in diesel oil) is achieved. Similarly, in the 'Low target' scenario,a 7.1% share of biofuels in total final energy demand of the transport sector in 2020 (or 8.4% share of biofuels in gasoline and 8.7% share in diesel oil) is achieved.

Table 3.4 *Biofuels share in the transport sector*

[%]		2000	2010	2020	2030
Low Target	In gasoline and diesel demand	0.17	2.27	8.57	14.24
	In total final energy demand	0.14	1.90	7.10	11.62
High Target	In gasoline and diesel demand	0.17	7.98	17.25	22.45
	In total final energy demand	0.14	6.68	14.29	18.31

Source: PRIMES.

Electricity and steam generation

Significant changes are also projected to occur in the electricity and steam generation sector under the two different renewable cases examined (see Figure 3.3). In the 'Low target' case, renewable energy forms increase their market share to the detriment of gas and solid fuels. In 2020, a much more pronounced growth is projected for biomass/waste in replacement of solid fuels and to a less extent of natural gas. In 2030, intermittent renewable energy forms gain significant market share and solid fuels exhibit, besides natural gas, also a strong decline. The share of renewable energy forms in electricity generation reaches 27.3% in 2020 (including waste) and 32.9% in 2030, i.e. an increase of 7.3 and 12 percentage points in 2020 and 2030 compared to baseline respectively.

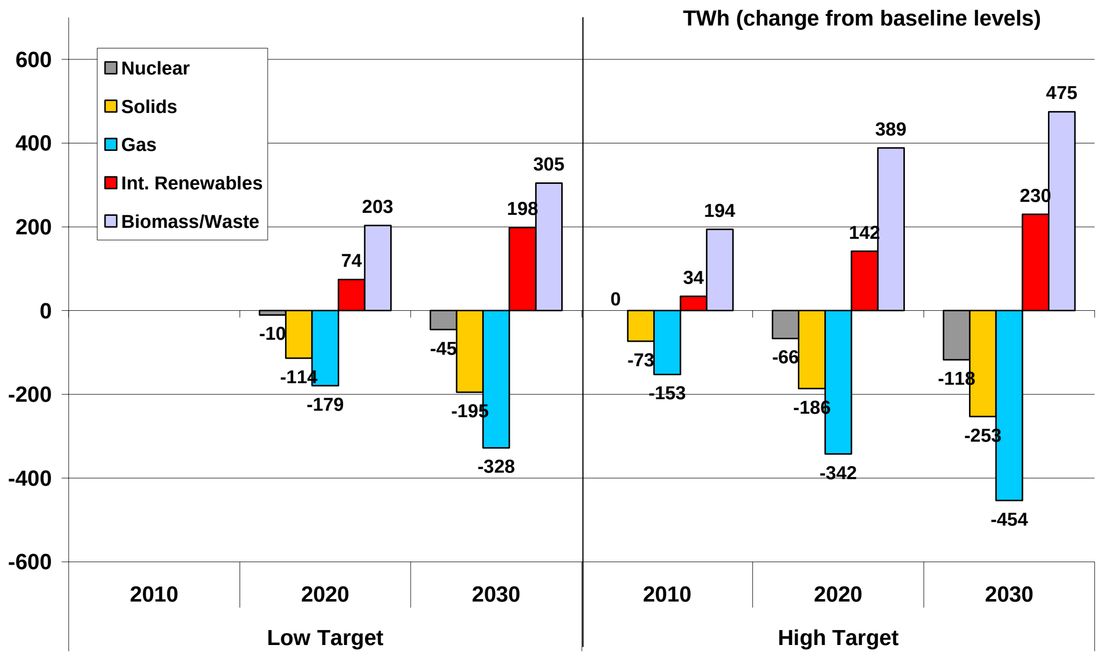

Figure 3.3 *Changes in electricity generation in the EU-25 energy system*
Source: PRIMES.

In the ‘High target’ scenario, penetration of renewable energy sources in the electricity and steam generation of EU-25 is even more pronounced. The share of renewable energy forms in electricity generation reaches 34% in 2020 (including waste) and 38% in 2030.

In 2020, among thermal technologies, the technology that is most favoured in the context of both scenarios examined are open cycle units and especially monovalent biomass- waste units (using biomass and waste as input fuels) as they are found to be the most cost effective option for the further exploitation of biomass and waste in the power generation sector. Clean coal and lignite plants as well as solar photovoltaic plants are projected to increase notably in the ‘High target’ scenario. On the other hand, the technologies that lose in terms of competitiveness in both cases examined are gas turbines combined cycle plants as well as supercritical polyvalent units.

Changes in the structure of electricity generation by fuel are also reflected in investment choices of power generators (see Figure 3.4).

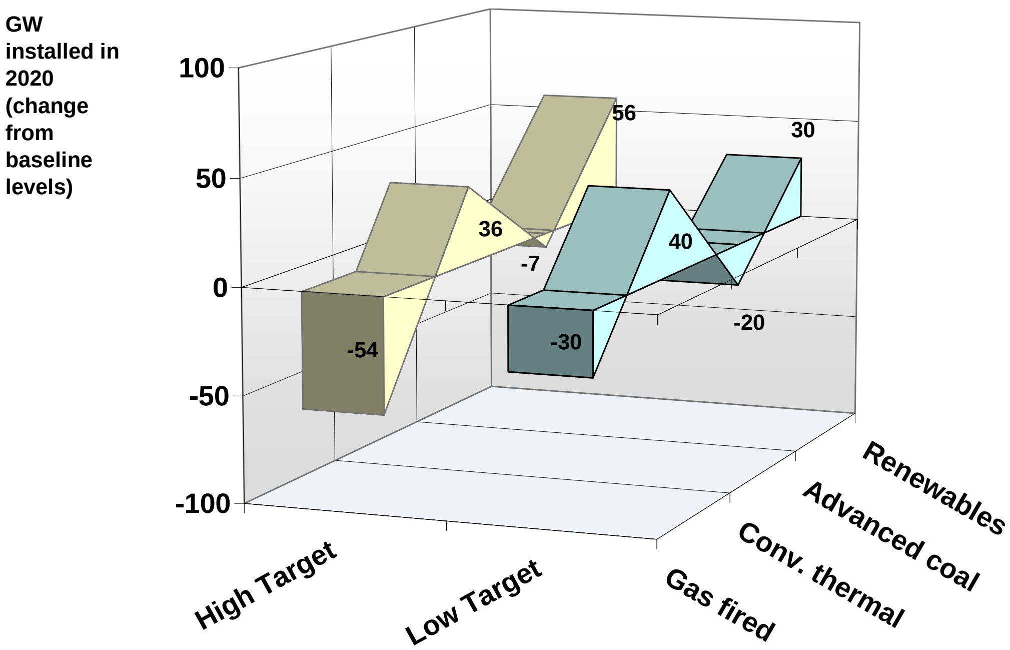

Figure 3.4 *Changes of installed generation electricity capacity in the EU-25 in 2020*
Source: PRIMES.

3.1.3 Consequences of a large share of renewables

CO_2 emissions
As expected, the evolution of CO_2 emissions in the EU-25 energy system is also strongly affected by the introduction of promoting policies for renewable energy forms in both cases examined (see Table 3.5).

CO_2 emissions under the ‘Low target’ case assumptions are projected at -5% compared to baseline levels in 2020. In the ‘High target’ case, the corresponding decrease in CO_2 emissions is 11% from baseline levels.

Table 3.5 *Evolution of CO_2 emissions in the EU-25 energy system*

	[Mt of CO_2]				Change from baseline [%]			Index (1990=100)			
	2000	2010	2020	2030	2010	2020	2030	2000	2010	2020	2030
Low Target	3665	3619	3603	3659	0.0	-5.0	-7.6	97.2	96.0	95.6	97.1
High Target	3665	3410	3393	3451	-5.8	-10.6	-12.8	97.2	90.5	90.0	91.5

Source: PRIMES.

The supply side is the main driver for this reduction (see Figure 3.5). In the 'Low target' scenario, CO_2 emission reduction in the supply side accounts for some 73% of total reduction (compared to baseline levels), whereas in the 'High target' case the corresponding reduction is some 58%. As overall primary energy needs are projected to exhibit a small increase on top of Baseline levels in both cases examined, implying a worsening of energy intensity for the EU25 energy system, it is clear that the projected CO_2 emission reduction is the result of changes in the fuel mix towards the use of less carbon intensive energy forms both in the demand and the supply side.

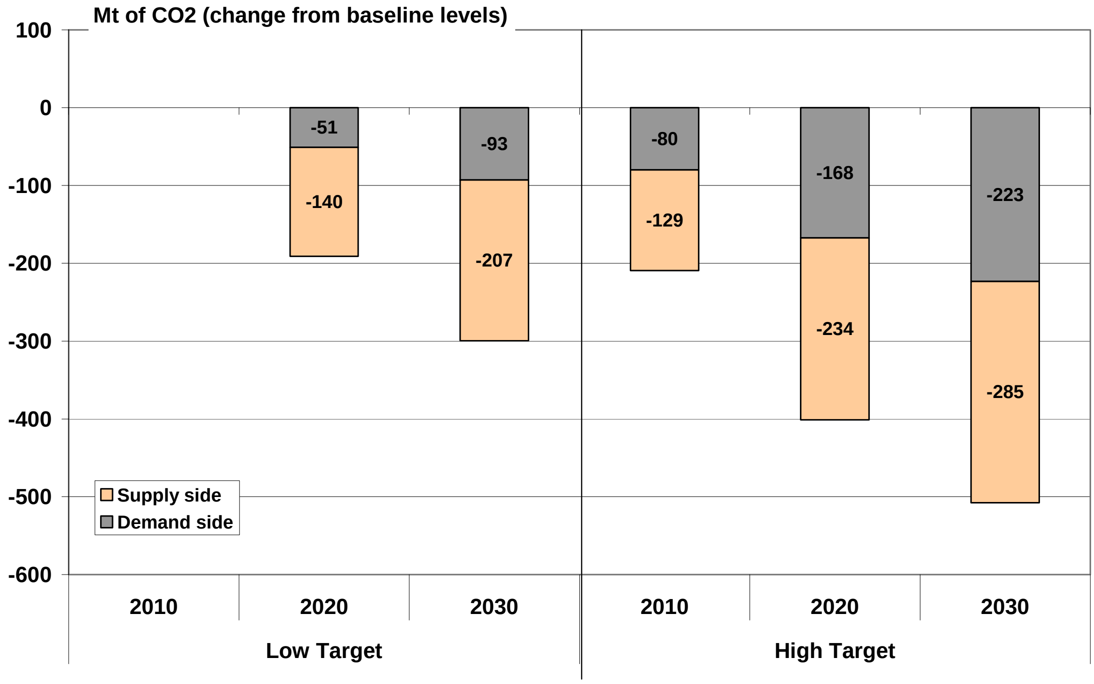

Figure 3.5 *Changes in CO_2 emissions*
Source: PRIMES.

Promoting policies on renewable energy forms lead, also, to an improvement of import dependency for the EU-25 energy system (see Figure 3.6). By 2020, under 'Low target' case assumptions, import dependency exhibits a decline of 3.1 percentage points compared to baseline levels, whereas under the 'High target' scenario assumptions the corresponding decrease more than doubles reaching 6.3%.

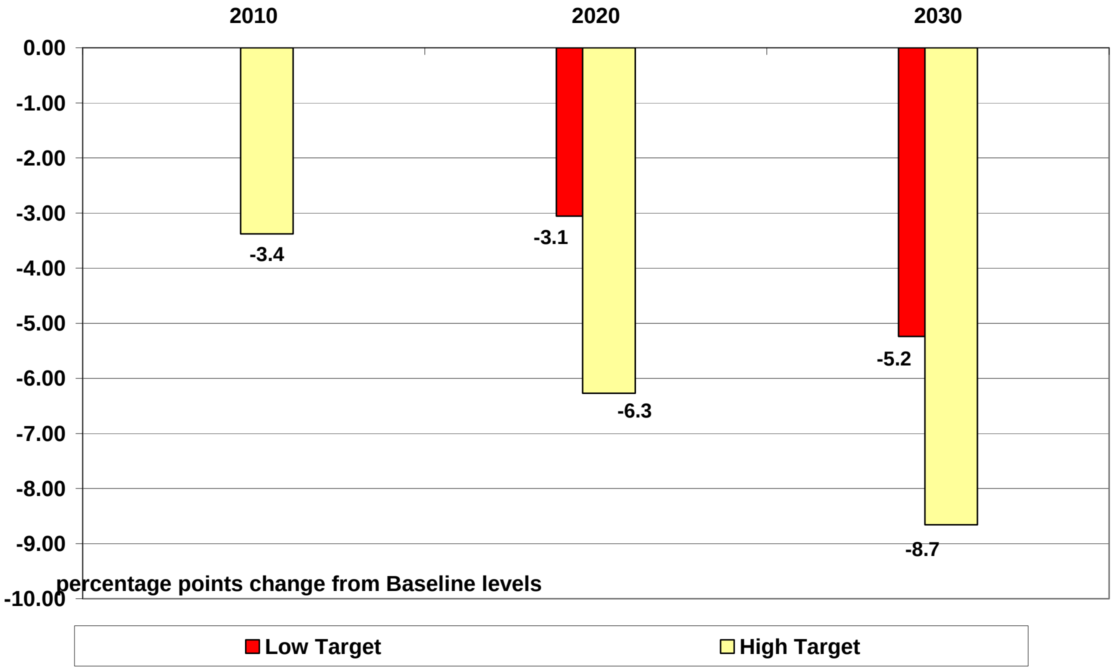

Figure 3.6 *Changes in import dependency in the EU-25*
Source: PRIMES.

The introduction of both targets as regards the share of renewable energy forms in total electricity production has significant impacts also for the cost of electricity production (see Table 3.6). In the 'Low target' case, total system cost does not exhibit a significant increase and in 2020 reaches up to 1.4% more compared to Baseline scenario conditions, whereas the corresponding cost in the 'High target' case increases by almost 5%.

Table 3.6 *System costs in power generation*

		Mln €$_{2000}$				Change from baseline		
		2000	2010	2020	2030	2010	2020	2030
Low Target	Total system cost	210	268	284	342	0.0	1.4	2.9
	Total investment (undiscounted) supply side	86	126	181	239	0.0	21.6	18.3
High Target	Total system cost	210	273	294	353	1.6	4.8	6.1
	Total investment (undiscounted) supply side	86	161	201	243	27.8	30.5	15.4

Source: PRIMES.

3.1.4 Conclusions and recommendations

From the analysis performed it can be concluded that the role of promoting policies on renewable energy forms, both in the EU-15 but also in New member states, is of great importance, as they lead to a significant relaxation of environmental pressures for the EU-25 energy system.

Despite the introduction of strong promoting policies for renewable energy forms, both in the demand and the supply side, and the achievement of desired share of electricity generation from renewable energy forms (33%) in the EU-25 energy system, the share of renewables in gross inland consumption remains below the desired target in the 'High target scenario' (18.3% in 2020 compared to a target of 20%).

This result clearly reflects the need for additional policies towards improving energy efficiency in the EU-25 if high shares of renewable energy forms are to be achieved as available options, especially in the demand side, are highly exploited.

In the 'Low target scenario' the share of renewable energy forms in 2020 reaches at 13.7%. This overachievement of the target of 12% is largely due to the higher share of renewables in the power generation sector (27.3% compared to 22% required).

3.2 MARKAL Western Europe

3.2.1 Introduction

In the Renewable energy sources (RES) policy case study, two targets are considered for the contribution of RES to the energy system. First, an ambitious target of 20% contribution in 2020 to the primary energy supply is considered, based on recent discussions regarding the future ambition level of the European Union. Secondly, for comparison, a more modest contribution of 12%, also in 2020, is considered. In the analysis, the low target case is mostly used as an indication of the effect of relaxing the ambitions of the high target case. Thus, detailed comparisons are generally made between the high target case and the baseline, while the comparison between the three scenarios is restricted to more general observations.

High target

The high target case has been set up as follows. The first step to achieve a share of 20% renewables in primary energy consumption from 2020 onwards, was to implement the sub-target of 33% renewable energy in the electricity consumption. In MARKAL this can be done in a direct way, by imposing a lower bound to the share of renewables in total electricity production. As MARKAL uses a region larger than the EU-15, the contribution of Norway, Iceland and Switzerland has to be considered. Particularly the inclusion of Norway facilitates the achievement of the renewables targets, because the electricity produced in Norway is almost completely based on hydropower. Because of this, the electricity produced by Norway is disregarded for the overall electricity consumption target. It is likely that Norway will also have a positive influence on the overall share of renewables in primary consumption. However, since we do not know how Norway's energy mix will develop in the future, Norway cannot be excluded from the target of 20% renewables in primary energy consumption. This implies that the large share of hydropower in Norway does not contribute to the RES-E target in Europe, while the other sectors, such as transport, have to contribute to the overall target in a way similar to the other Western European countries.

To achieve the overall target of 20% renewables in primary energy consumption, additional policy instruments had to be implemented in other sectors. Since the transport sector is the most energy intensive sector per value added and moreover because it has possibilities to change to biofuels, the first policy measures have been introduced for transport. An indirect tax of €100 per ton CO_2 on standard diesel and gasoline, corresponding with € 0.25 per liter, is charged for 2020. The tax is gradually introduced by imposing a tax on gasoline and diesel of € 0.13 in 2010. After 2020 the tax increases further to € 0.33 in 2050.

The industry sector is also a large consumer of energy. However, for many industrial sectors, a switch to renewables is hard to make. Since we do not want to prejudice specific energy carriers and specific industries, taxes on particular fuels are not implemented. Therefore another policy instrument in the form of a carbon cap on the emissions of the industry from 2010 has been introduced. This cap can be interpreted as an emission trade system. The cap requires a decrease of 125 Mton in 2010 with respect to the 1990 level. In absolute terms, the level of the cap decreases to 200 Mton CO_2 in 2050.

Low target
The low target has been set up rather similar to the high target case. The starting point for reaching the 12% RES-share in the primary energy production is the sub-target of 22% renewable energy in the electricity consumption. Again, this can be done by imposing a lower bound to the share of renewables in total electricity production. In contrast to the 33% sub target, the constraint on the power sector is already quite helpful in approaching the overall target. Therefore, a more relaxed tax is introduced for gasoline and diesel in the transport sector, and no target has been set for industry. The tax is half that of the high target, thus starting at € 0.07 in 2010, gradually increasing to a final level of € 0.17 in 2050.

Potentials
As background information to the results, Table 3.7 provides the potentials of the main renewable energy sources. All potentials are technical potentials in 2050, except where stated otherwise.

Table 3.7 *Potentials of renewable energy sources used in MARKAL Western Europe*

Technology class	[GW]	*Remarks*
Wind, onshore	136	
Wind, offshore	148	
Solar PV	248	With regional detail
Geothermal for electricity	1.6	Potential already completely exploited in baseline
Water, including tidal	298.8	
Biomass in electricity sector	585	

Accounting system
The contribution from renewable energy sources to primary energy consumption is a quantity that a priori is not well defined, particularly for sources such as wind and solar energy. The same problem also holds for nuclear energy. Unlike the case for fossil fuels, where the energy content of the source is quite clear, for these types of energy sources an accounting system has to be chosen.

In the Cascade Mints project, initially a substitution principle has been used for the accounting of the contribution from wind, nuclear, and the like. In this system, the contribution from such sources is accounted for in primary energy consumption as the amount of fossil fuels it replaces, using some average efficiency. Here an efficiency of 33% has been used, so that 1 PJ of electricity generated with such a source is counted as resulting from 3 PJ of primary energy use.

In setting the targets for the share of renewable energy systems, the European Union generally used a different accounting system, namely that of Eurostat, which facilitates the comparison of targets to European statistics. In this accounting framework, the contribution from energy sources such as wind, solar, and nuclear is taken to be equal to the energy extracted from this source. Thus, 1 PJ of electricity generated with such a sources is counted as resulting from 1 PJ of primary energy use.

As may be clear, the definition of targets in terms of the Eurostat convention requires that the discussion of the target should also be based on this convention, particularly when discussing in how far the target is reached. For this reason, an additional indicator was developed, that gives the contribution from RES to the primary energy consumption according to the Eurostat convention.

In other discussions, we maintain our original choice of accounting scheme, namely the substitution principle.

In the Eurostat norm, replacing for example an oil fired power plant by a wind turbine will result in a substantial lowering of the primary energy consumption. However, there is no change in the actual use of energy, in the sense that the demand for useful energy does not change. Nevertheless, when viewing the energy system from the primary energy demand, it is as though there has been substantial efficiency improvement in the system. We believe that this gives an inaccurate view of what is actually happening in the energy system.

3.2.2 Results

Primary energy consumption

As a result of implementing the policies described in the introduction, the low target appears to be feasible, whereas the high target proves to be too ambitious, if only by a narrow margin. Whereas the low target is readily reached, as the renewable sources contribute over 12% by 2020, only a 19% share of renewables in the total primary energy consumption is achieved in 2020 for the high target. In the long run, the policies seem to be more effective. For 2050, the contribution of renewables to the total primary energy consumption will even be up to a third, with the high target, and over 22% for the low target. The high levels reached are due to the assumed strengthening of the policies.

Just like in the Baseline scenario, the total primary energy consumption in the Low and High target case will increase till 2020. Whereas increase of primary energy consumption in the Low target case is very similar to the increase in the Baseline, primary consumption stabilizes after 2020 in case of the high target, as can be seen from Figure 3.7. For a large part, the stabilization in the High target case is due to the use of the Eurostat convention for accounting for the contribution from non-fossil energy sources, as explained in the introduction. However, also higher costs of renewables, compared to the fossil fuels in the baseline, resulting in a drive towards increased efficiency, explain some of the difference.

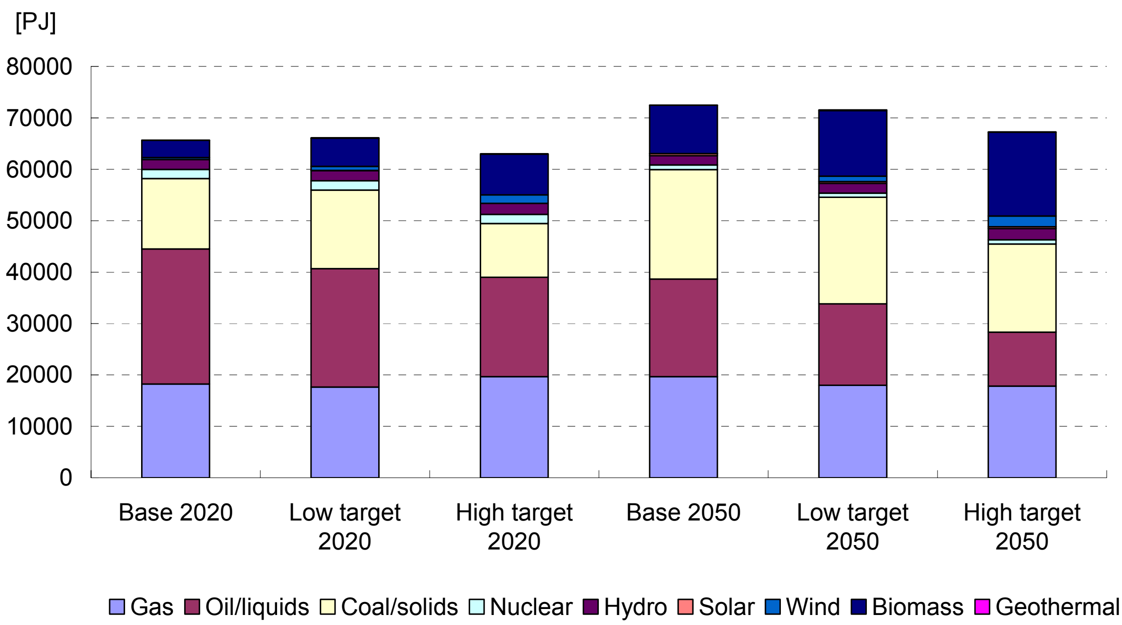

Figure 3.7 *Primary energy consumption in the Baseline and in the two RES policy cases (Eurostat convention)*

The three most important renewable energy sources remain biomass, hydropower and wind. The largest growth as compared to the Baseline is shown by biomass. In 2020 the primary energy consumption of biomass will be between 1.6 and 2.4 times higher than in the Baseline, for the low and high target, respectively.

The difference between the three cases becomes smaller towards 2050, as even in the Baseline the use of biomass starts to pick up. However, in absolute terms the growth of the contribution from biomass between 2000 and 2050 ranges between a factor 2.75 for the Baseline up to as much as 4.5 for the High target case.

For hydropower, the difference between the policy cases and the Baseline is substantially smaller. The setting of the target turns out to be decisive: whereas the difference between the Low target case and the baseline remains some 5%, this difference is doubled for the High target case, from 10% in 2020 to 20% in 2050. Finally, the amount of energy from wind expands significantly. This increase of renewables is at the expense of mainly coal and oil. The primary energy consumption of gas does not change a lot on an overall scale, but it is fluctuating more. The amount of nuclear energy is nearly the same in both scenarios.

Electricity consumption

As a result of the sub-target for electricity consumption, 22% or 33% of the electricity consumption in 2020 and beyond will be produced by renewable energy sources, depending on the target. In the Baseline the RES-E share was almost 9% in 2020 and 17% in 2050. This increase of renewables goes together with a decrease of electricity produced by coal and gas plants. The amount of gas decreases with a quarter. Electricity production by oil and nuclear power plants stays the same in absolute terms.

The Low target case furthermore shows a remarkable shift towards coal in the power generation mix. This is explained by the combination of increased final electricity demand and increased competition for biomass from application in the transport sector. Furthermore, the commercial, residential and industry sector consume more natural gas than in the baseline. This case illustrates that policies should be balanced over different sectors in order to avoid leakage effects.

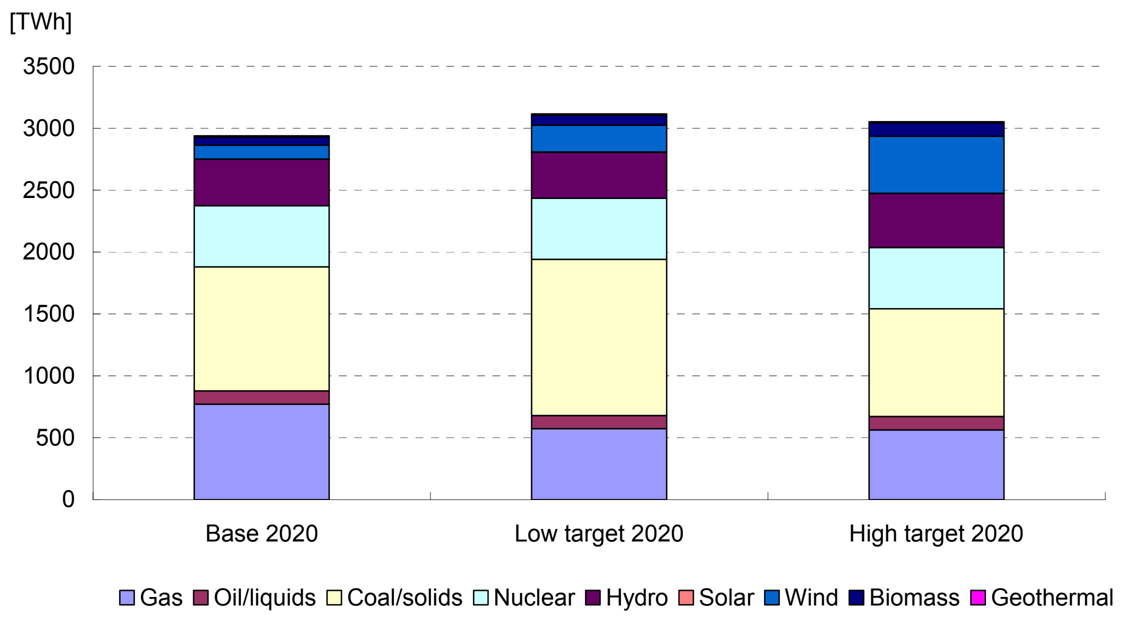

Figure 3.8 *The electricity generation mix in 2020 in the Base and the two policy cases*

The uses of geothermal heat and solar PV are hardly influenced by the introduction of policies considered here. For the former of these, this is mostly the result of technical and physical bounds. For PV, the restrictions remain more of an economical nature, as systems are too expensive to provide a competitive alternative.

The increase of renewables in the electricity consumption therefore is largely due to increases in the application of biomass and wind power systems.

In 2020, the latter shows a doubling for the Low target case when compared to the baseline, and even a quadrupling for the High target. By 2050, the contribution from wind in the Baseline has decreased, making the difference even more pronounced. Table 3.8 shows the contributions of onshore wind and offshore wind respectively.

Table 3.8 *Wind power installed capacities in the different RES policy cases*

[GW]	2000	2020			2050		
		Base	Low	High	Base	Low	High
Onshore	6.8	42.5	86.1	161.2	7.2	118.5	199.9
Offshore	0.0	1.0	1.0	15.4	0.0	0	19.3

Final energy demand by sector

This section will present the implications of the renewables policy cases for the different end-use sectors. Since we have applied a tax on diesel and gasoline for transport and put a cap on CO_2 emissions in the industry, it is clear that in these sectors the implemented policies have the highest impact. But also for the agricultural sector consequences of the measures can be seen. The impact for the residential and commercial sector is minimal. It is noteworthy that all applications of renewables in end-use sectors are based on biomass.

Transport sector

The tax on standard/regular diesel and gasoline causes a substitution of these fuels by more 'green' fuels. Since biodiesel is cheaper than the alternatives of gasoline, the share of diesel passenger cars is much larger than in the Baseline. Moreover, diesel cars are more efficient and so the total energy consumption of the transport sector decreases. Gasoline is mainly substituted by ethanol and methanol, where methanol is produced from coal and gas. The other vehicles were already almost all diesel driven in the Baseline. An interesting point is that inland ships consuming hydrogen replace diesel inland ships. For the Low target case, the tax being substantially lower implies less severe reactions to it. Nevertheless, the qualitative conclusions are the same for the two cases.

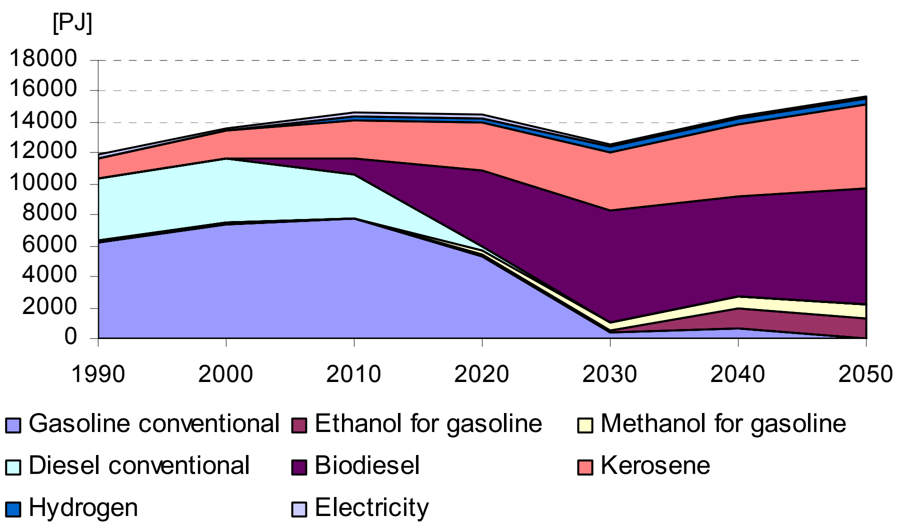

Figure 3.9 *Fuel demand in the transport sector - High target scenario (note that diesel includes diesel for agricultural vehicles, and that methanol is not produced from biomass)*

Industry
The cap on CO_2 emissions in the industry that is introduced in the High target case intensifies the decrease of total final energy consumption in this sector[6]. In 2020, the cap induces a shift from solid and gaseous (fossil) fuels to electricity, steam and heat from various sources, and hydrogen. Beyond 2020, particularly hydrogen gains importance. The reaction of industry to the measures in the Low target case is small. The only noticeable effect, due to competition for biomass products and higher electricity costs, is a small decrease of final energy demand. This is an indication that the sector moves towards more efficient technologies in response to these policies. Nevertheless, the sector specific cap, reinforced by the higher electricity costs and competition for biomass products, shows a small decrease of final energy demand.

Agricultural sector
After 2010 the final energy demand of the agricultural sector increases relative to the Baseline in the High target case. This is due to the higher demand for biomass (energy crops), implying an increase in the amount of energy required for producing this biomass. On the other hand, the own consumption of biomass in the agriculture sector will decrease in this case. This decrease and the growth of the total energy demand were compensated by an increase of gaseous and liquid fuels. In the Low target case, the increase in final energy demand is less distinct.

Biomass
It is clear that biomass is expected to play a key role in achieving a higher share of renewables in the European energy mix. As a consequence, the availability and costs of biomass resources become very important[7]. The different policies have various effects on the applications of biomass. In the Baseline scenario, 60% of the biomass is allocated to the electricity sector in 2020. Industrial boilers and the residential sector mainly use the rest. Between 2020 and 2030 the usage of biomass grows with 3% each year, after 2030 biomass has an annual growth of 1.5%. The growth of the total biomass consumption is due to an increase of the use of biomass for electricity production and the substantial growth of ethanol applications in gasoline. The application of biomass in the electricity, residential and agricultural sector consists mainly of wood chips. The industrial boilers use straw.

When only the RES-E target is imposed, but no additional measures in other sectors are taken, a large growth of biomass consumption between 2010 and 2020 is visible. The aggregated biomass consumption in 2020 is 1.5 times higher than in the Baseline.

In the High target scenario, where besides the 33% RES-E target also a cap on the CO_2 emissions in the industry and a tax on regular gasoline and diesel are required, the picture of the biomass use changes completely. This is illustrated in Figure 3.10. Already in 2010 the use of biomass in the transport sector is 25 times higher than in the Baseline. Between 2010 and 2020 the biomass consumption expands enormously, particularly by the use of biofuels in transport vehicles, where an annual growth of 17% leads to more than 5000 PJ in 2020. Also the amount of biomass for electricity production grows between 2010 and 2020, although to a lesser extent than when no tax is charged on fossil transport fuels.

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6 In the baseline, the decrease of final energy consumption in industry is due to the expected replacement of energy intensive processes in Europe by processes with a higher added value.

7 Biomass data used in MARKAL have been collected in the EU-funded BRED project. Gielen, D.J.; Bos, A.J.M.; Feber, M.A.P.C. de; Gerlagh, T. 'Biomass for greenhouse gas emission reduction task 8: optimal emission reduction strategies for Western Europe' ECN-C--00-001 (October 2000).

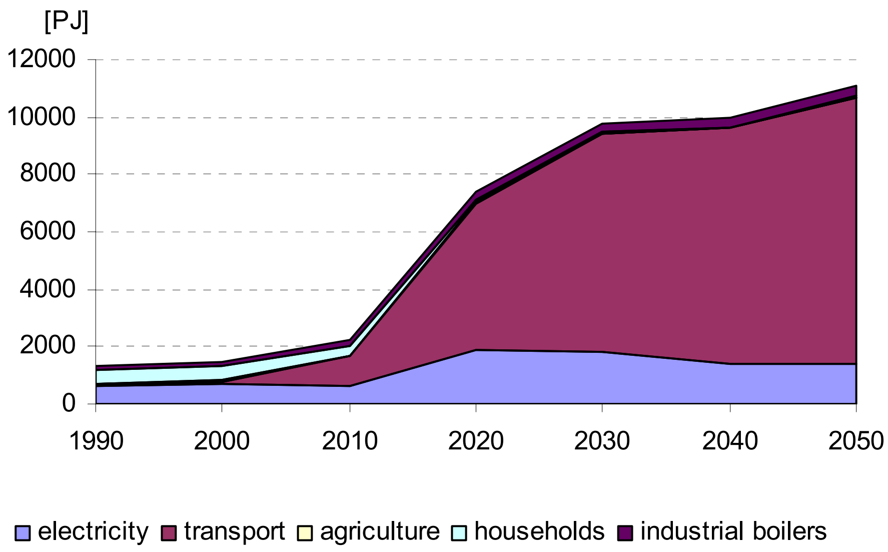

Figure 3.10 *Biomass consumption in several sectors in the High target scenario*

The large increase of biomass in the transport sector is mainly because more and more biodiesel is used. This biodiesel is produced from wood chips and so the consumption of wood in the agricultural and residential sector will decline to an assumed minimum because less expensive fuels are available. Since industrial boilers use straw, the consumption of biomass in the industry remains the same as in the baseline. After 2020 the biomass consumption in the transport sectors increases further, albeit to a lesser extent. The biomass will be so expensive in 2040 and 2050 (more than 8 €/GJ for imported wood chips) that the use of biomass for electricity production decreases and even will be less than in the Baseline.

Not all biomass used is produced in Western Europe. In 2020, 30% of the biomass consumption is imported, consisting mainly of residual wood (60%) and forestry thinnings (40%). The biomass from within Europe consists of fiber chips (50%), straw (27%), landfill gas (16%), and some cellulosic products. Both domestic production and imports continue to grow beyond 2020. In 2050, 60% of biomass consumption is produced within Western Europe, and 40% is imported.

3.2.3 Consequences of a large share of renewables

Costs of achieving renewables targets

In 2020, total system costs increase with 4% compared to the baseline. Total investment in the electricity sector almost doubles in the year 2020, compared to the baseline, due to, among others, investment in a new hydropower plant. In the power sector, the additional costs of enforcing the 33% RES-E target amounts to 4.1 €ct/kWh, which can be interpreted as the subsidy (feed-in tariff) level required for reaching the target.

CO_2 emissions

The underlying motivation for the measures described in 3.2.1 is the reduction of emissions of greenhouse gasses (GHG), particularly CO_2. In the case study described here, the policies aimed at reaching this objective are directed towards a higher penetration of renewable energy sources, in the hope that these will replace fossil fuels. In this paragraph, the effects of the policies on the emissions of GHG are discussed.

As described in the introduction, the policies considered here are aimed at specific sectors. It is to be expected that the impact will be most clearly seen in the emissions by those sectors. As furthermore the sectors contributing most to the CO_2 emissions are those three for which policies are defined, plus the combined residential/commercial sector, the analysis is restricted to these four sectors; the other sectors (agriculture, non-energy conversion and non-energy use in industry) are aggregated into a fifth class denoted by 'other' below.

The power sector

The CO_2 emissions from the power sector are shown in
Figure 3.11 for the baseline scenario and for the RES policy cases. Most striking is the increase in the low target case, observed for most periods, and the little difference between the baseline and the high target case. This seems contradictory to the growing contribution from renewable energy sources (RES), rising to 22% or 33% in 2020 and beyond. In both cases the emissions show a substantial increase between 2000 to 2050, of the order of 30-50%. The higher emission level in 2020 and 2050 in the low target case, compared to the baseline, is due to the higher share of coal in the power generation mix (see also Figure 3.8).

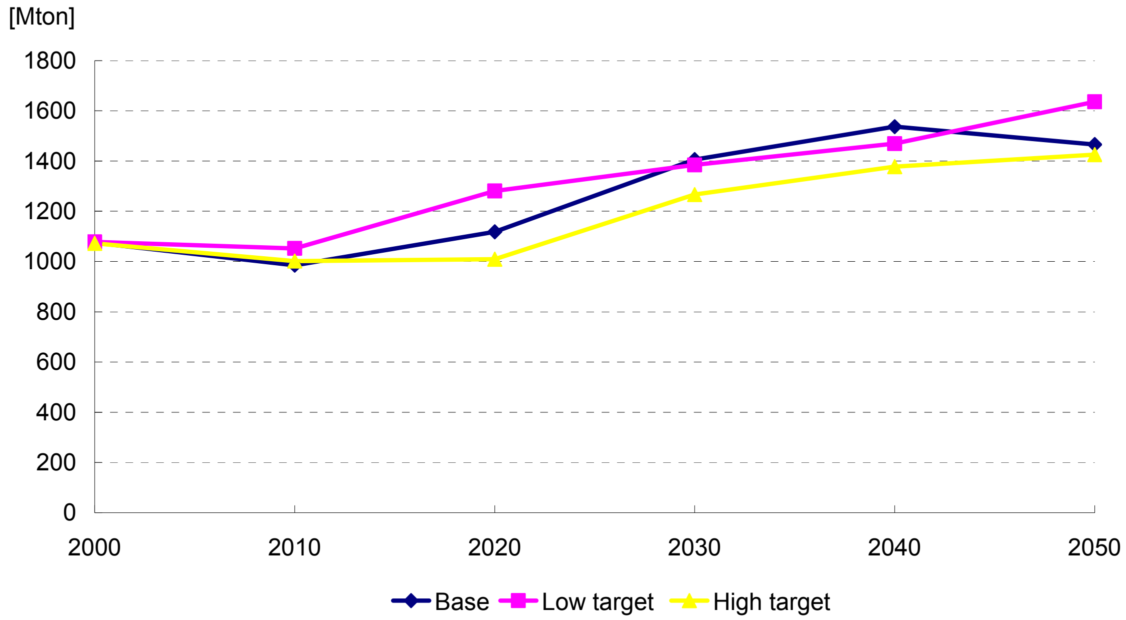

Figure 3.11 *CO_2 emissions from the power sector, in the baseline scenario and in the two RES policy cases*

It is worthwhile to compare the rise in emissions to the growing demand in electricity. Whereas in the baseline the growth in electricity demand between 2000 and 2050 is a little over 33%, in the RES policy case this growth is almost 40% when applying a high target, and again a little over 33% for the low target. Thus, in the High target case the carbon intensity in the power sector is roughly constant, it is *increasing* in both the baseline scenario and the Low target case. Thus, RES policies may have a beneficial impact on CO_2 emissions in the power sector, but whether this indeed is the case depends strongly on the level of the targets. For low levels of targets, RES is likely to replace more expensive conventional capacity, such as gas-fired power plants.

Industry

For the High target case, the CO_2 emissions by industry in themselves are not interesting, as the policy implemented for this sector is a straightforward emission cap. The emissions simply follow this cap, leading to a reduction of approximately 75% by 2050 to a level of 200 Mton CO_2.

In this case, the marginal cost or shadow price of the emission constraint is more interesting, as it gives information on the costs of an additional incremental reduction. These rise from some € 10 per ton CO_2 at the onset of the emission cap up to a maximum of a little over € 200 per ton CO_2 in 2040. In general, one can say the shadow price of the emission cap is approximately one order-of-magnitude higher than the generic implementation of the limited climate policy in the base case. For the Low target case, the emissions are noteworthy, as they show an increase when compared to the baseline. This is mostly due to a shift from gas to coal and residual fuel oil. At the same time, the use of CO_2-capture in industry decreases.

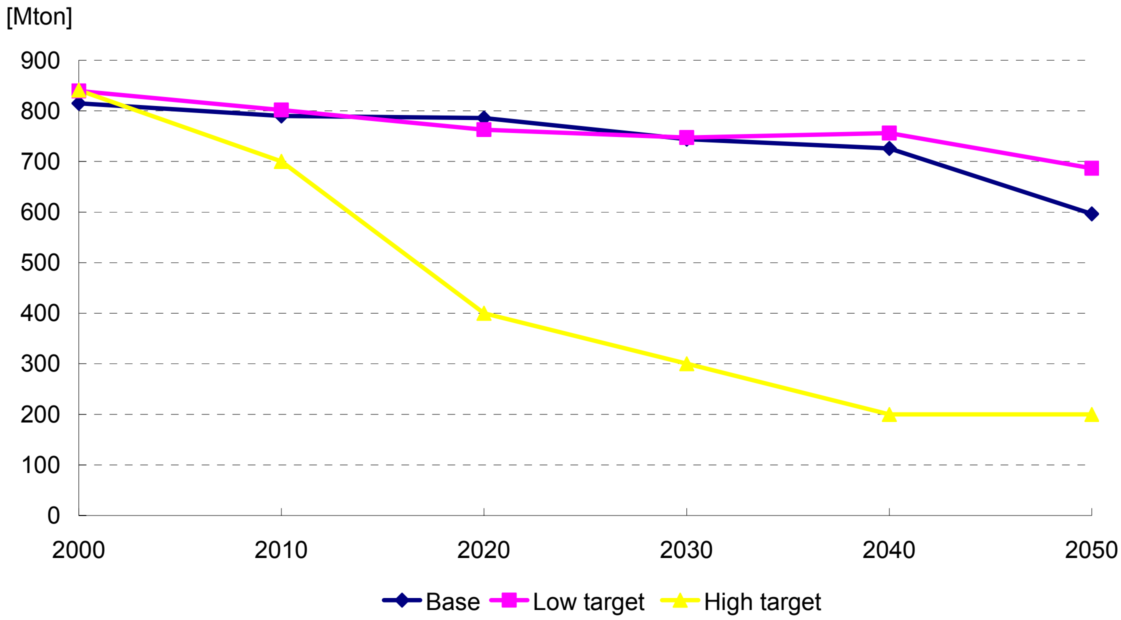

Figure 3.12 *CO_2 emissions from industry, in the baseline scenario and in the two RES policy cases*

The transport sector

The third sector of interest in the context of our RES policy cases is the transport sector. Here, a tax is levied on the traditional fuels (gasoline and diesel), creating opportunities for alternative fuels. The policy turns out to be primarily aimed at the large-scale introduction of biomass options, as both electric vehicles and fuel cell vehicles are too expensive to be competitive. The decrease in the emissions by the transport sector as shown in Figure 3.13 indicates that the policy is effective, particularly when the emissions are compared to the baseline scenario. For a large part, the emission reduction in the passenger cars segment is accomplished by replacing gasoline cars by cars running on bio diesel. Second and third best options for reduction are ethanol and methanol cars, respectively. It is furthermore interesting to notice that halving the tax as implemented in the Low target case results in roughly halving the emission reduction, particularly in the long run. However, for more robust statements on the relation between the tax level and the emission reduction, a more thorough study is needed.

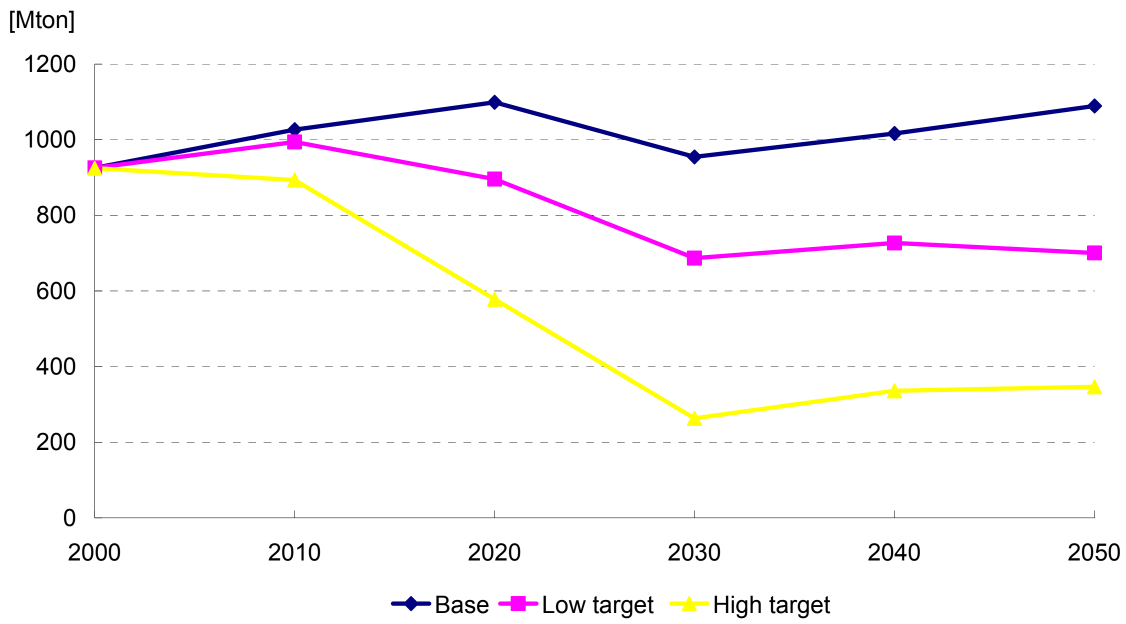

Figure 3.13 *CO_2 emissions from the transport sector, for the baseline scenario and for the RES policy case*

There is some use of hydrogen in the transport sector, the most surprising aspect not being that it used at all, but the purpose for which it IS used: for inland ships rather than for passenger cars. Furthermore, the use of hydrogen actually shows a drawback of the policy as formulated here, as at present it should be considered as a non-renewable option. The MARKAL model has no direct production option for hydrogen using renewable sources. The exception could be electrolysis, in case the electricity used comes from renewable sources, but presently there is no option in the model to force the use of electricity from renewable sources, and it appears to be produced mainly from natural gas without CO_2 capture. Thus, the introduction of taxes on diesel and gasoline stimulates the use of non-renewable hydrogen in inland shipping.

Other sectors
For the remaining sectors, no policies are specified, but they may nevertheless show a response to the framework presented here. Particularly, one might expect increased emissions for sectors not directly penalized for using fossil fuels. As becomes clear from Figure 3.14 there are some effects, but these are of limited importance for the emission levels. The emissions from residential and commercial increase slightly, as the increased demand for biofuels cause a replacement of these fuels by fossils. The impact is more pronounced in the category others, where emissions increase up to 33% in some periods for the High target case. It is a clear sign for strong competition for cheap renewable resources, having the most severe impact in the non-energy uses in the conversion sector.

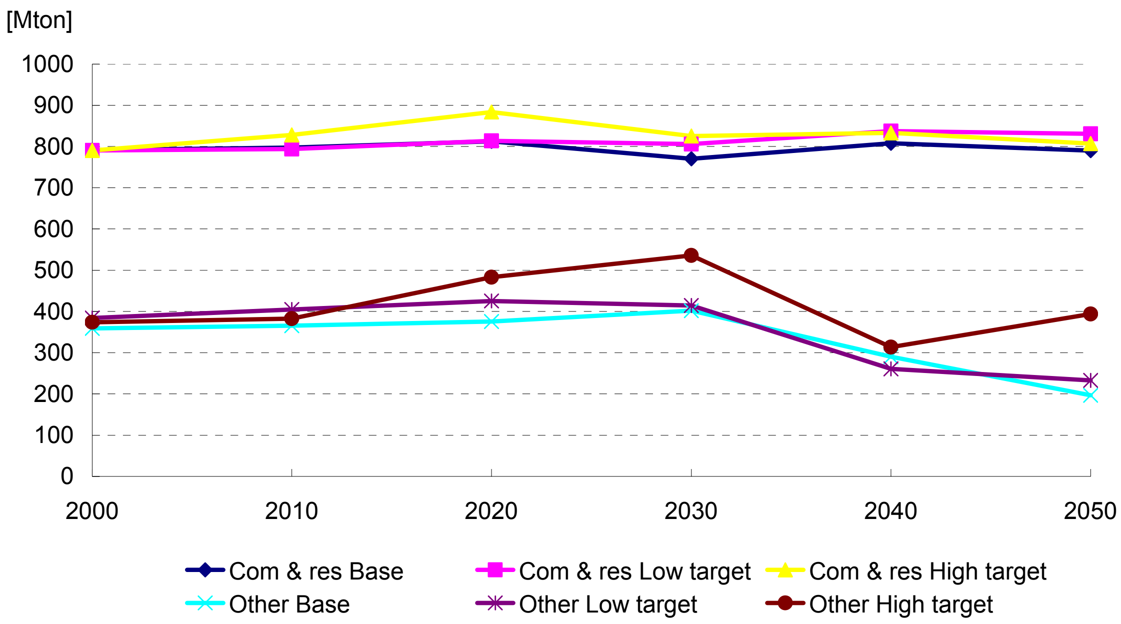

Figure 3.14 *CO_2 emissions for the sectors without explicit policy measures, in the baseline scenario and in the two RES policy cases*

Overall picture: RES policies decrease emissions, but at what cost?

From the previous sectoral discussions, an overall picture emerges that policies aimed at introducing renewable energy systems will lead to emission reductions if and when sufficient sectors are targeted. The sum of sectoral emissions is given in Figure 3.15 where energy- and process-related CO_2 emissions in the baseline scenario are compared to the emissions in the RES policy case. The RES policies induce an emission reduction of approximately 1000 Mton CO_2, or some 25%, by 2050.

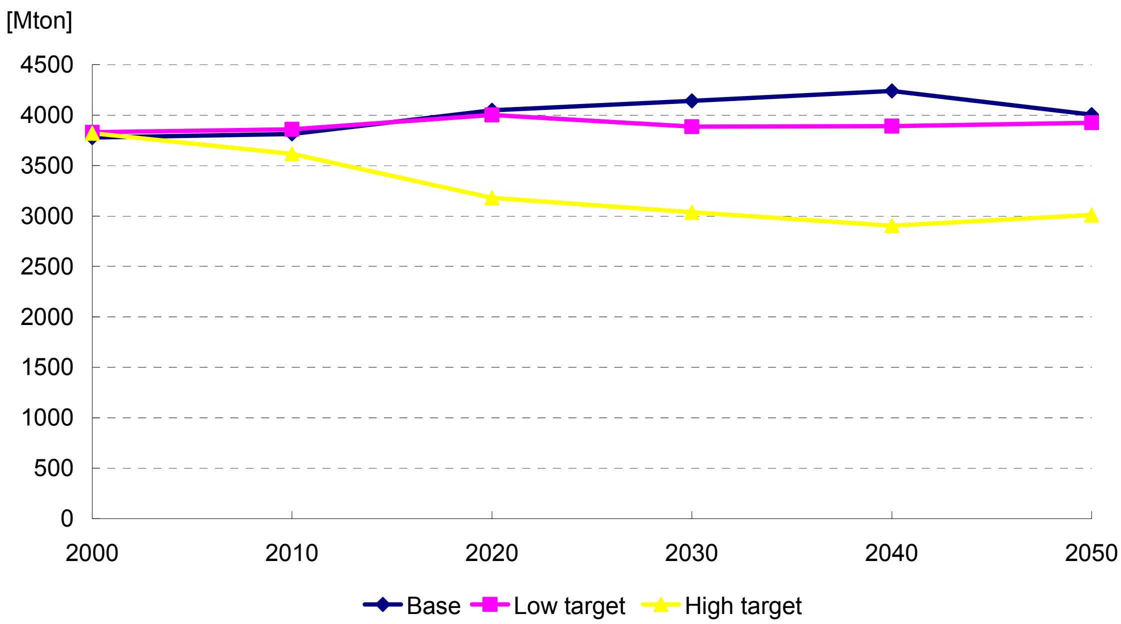

Figure 3.15 *Energy- and process-related CO_2 emissions in the baseline scenario and in the two RES policy cases*

Security of supply
A high share of renewables has a positive impact on Europe's dependency on imported fuels. This is more due to a decreased import dependency for oil, than for natural gas. In the long run, the overall import dependency will continue to grow both in the baseline and the high target case. This is mainly due to a continuing decrease in domestic oil and gas production. Furthermore, coal production in Western Europe is not competitive. The Low target case indicates that there is need for some minimal level of targets to ensure long-term improvement in import dependency.

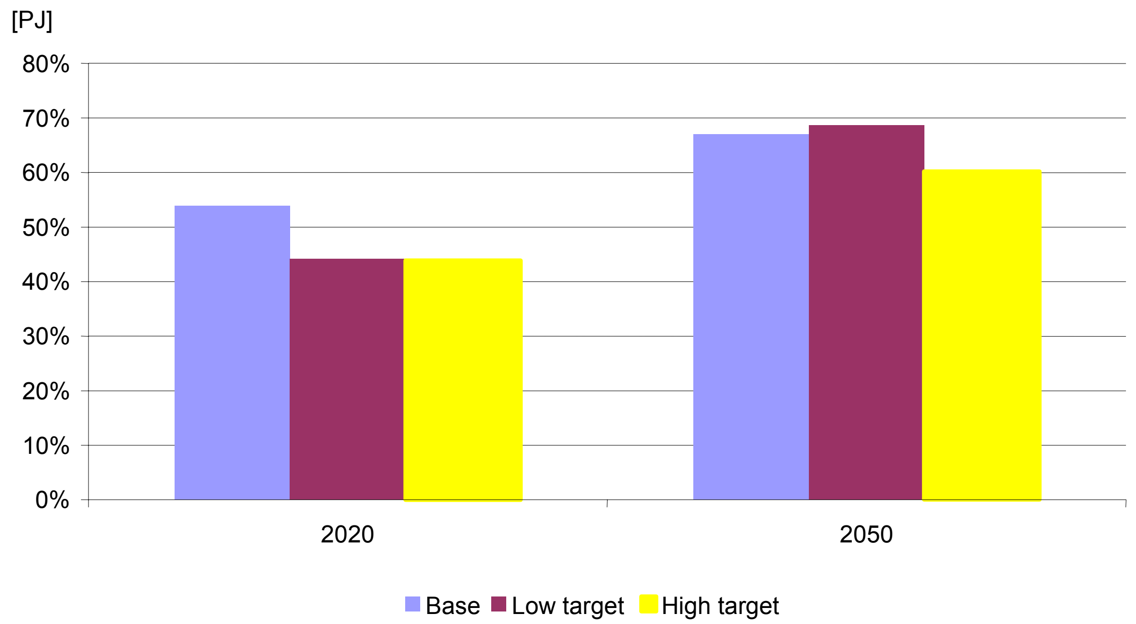

Figure 3.16 *Share of net import in primary energy consumption in baseline and the two RES policy cases*

Similarly, Europe's energy system becomes more diverse due to the increased share of renewables. The Shannon diversity index reflects the variety and the balance in Europe's portfolio of sources for primary energy consumption, as explained in the Baseline report. A decreasing diversity index is to be interpreted as a situation in which there is an increasing reliance on only a few energy sources. In the baseline, the Shannon diversity index has a value of 68% in 2020. It improves to 75% for the High target renewables case, and 72% for the Low target case. In the years beyond 2020, the diversity index remains more or less stable at the 2020 level in all scenarios.

3.2.4 Conclusions and recommendations

The process of implementing the high target scenario into the MARKAL model has shown that 20% renewables in primary energy consumption in 2020 is an ambitious target. Despite a 33% share of renewables in electricity generation, and an almost complete shift from diesel to biodiesel in the transport sector, the overall share of renewables in primary consumption does only achieve 19%. A higher penetration may be possible, but this implies higher efforts in the electricity and transport sectors. In the power sector, a higher share of RES-E will give rise to additional problems related to the intermittent character of many renewable sources. In the transport sector, the consumption of kerosene for domestic aviation (not for international) might be subject to additional policies.

The way in which the contribution from RES is accounted for in the primary energy consumption is essential, as it is used for defining the target. For example, the 33% contribution of RES in electricity production is reduced to roughly13% of the primary energy consumed by the power sector, when calculated according to the Eurostat norm. This norm furthermore puts uneven emphasis on the use of biomass, as unlike other RES it replaces fossil fuels on a one-to-one basis. Finally, this norm results in a decrease of primary energy consumption as the contribution from (non-biomass) RES increases, i.e. use of RES is interpreted as conservation, instead of a shift to different sources. All in all, when all renewables are to be treated on equal footing and a clear interpretation of results is desirable, it is advisable to use a substitution principle.

Imposing a carbon cap on the emissions of the industry sector has shown that this sector does not have much room for a more renewable energy supply. The use of biomass in the industry would be possible, but suffers from competition with applications in the transport sector. The present and expected technological options show other ways of reducing emissions than increasing the contribution of renewable energy.

In achieving the high target, biomass plays a crucial role, notably in the transport sector, where an annual growth of 17% is observed in 2010-2020. Biomass is also one of the major options for renewable electricity generation, where it grows with a factor 2.5. The overall consumption of biomass grows with a factor 5 in 2000-2020. The availability of biomass is not a bottleneck, because 30-40% of total consumption is imported from outside Western Europe, but the costs do impose limitations to its use.

It is also shown that a low RES target of 12% in 2020 is easily reached, using a obligatory 22% share of RES in the power sector, and introducing a tax on conventional (fossil) fuels in the transport sector. However, this does not necessarily lead to the fulfilment of the underlying objectives, such as reduction of CO_2 emissions or improvements in Security of Supply, as the present analysis shows. On the other hand, comparison of the results for the power sector and of the transport sector indicate that tax policies can be quite useful in reaching targets.

A high penetration of renewables comes at a cost. Compared to the baseline, total system costs increase with 4%, while total primary energy consumption remains at a somewhat lower level. Achieving 33% electricity from renewable energy sources in 2020 requires a subsidy equivalent to approximately 4 € c/kWh. This is slightly lower than e.g. most feed-in premiums paid by EU Member States.

On the other hand, the high penetration of renewables has a number of clear benefits. Europe’s security of supply increases, because it replaces imported fossil fuels, and contributes to a higher diversification. The RES policies induce an emission reduction of approximately 1000 Mton CO_2, or some 25%, by 2050. The case of the low target shows that such effects occur only when the ambition level is sufficiently high.

3.3 POLES

3.3.1 Introduction

The present version of the POLES model has a separate module dedicated to the new and renewable technologies in order to represent, by means of a technology dynamics approach the development and the diffusion of these technologies. The module identifies twelve generic technologies, which can have a significant contribution in the long-term development of the energy systems.

According to the POLES RES case definition, seven renewable technologies receive subsidies to promote their development in order to reach the low and high RES targets. These technologies are the following:

- small hydro,
- wind power plants for network electricity production according to wind resources (three on-shore and one off-shore category),
- decentralized building integrated PV systems with network connection,
- PV systems for decentralised rural electrification,
- low temperature solar system in the residential sector,
- biofuels, conventional technologies (woodfuels, electricity from wastes, biofuels),
- biomass gasification for electricity production.

For the POLES runs the overall share of RES in primary energy consumption was set as the objective function, which means that no separated target was used for electricity generation from RES. These targets are: 12% for the Low target case in 2020 and 20% in the High target case in 2020. The RES share in electricity generation is endogenously determined by the model as the consequence of reaching the total target. It has to be noted, that the geothermal energy is not included in POLES and heat production from renewable sources is only partially modelled, and this deficiency has some impact on the model results.

To increase the renewable share, an extra subsidy was given to the above mentioned technologies, which should be regarded as the subsidy exceeding the level of the already existing one (already included in the reference runs). This financial incentive is uniform for all technologies and maintained during the whole modelling period. This solution mirrors the view, that investments in renewable technologies require long-term commitment, considering the relatively high investments costs.

The available technology potentials for each technology and region existing in the model database have been reviewed and updated with the latest available information (Enguídanos, et al, 2002; Hoogwijk, 2004; Kavalov, et al, 2003; Nikolau, et al, 2003). For some technologies (wind offshore, biomass (including biofuels)), the review included the entire techno-economic characterization in the EU30 region.

The coverage of the subsidy is EU30, including all the present EU member states, plus Romania, Bulgaria, the former Jugoslavian countries, Norway and Switzerland, according to the scenario definition of Cascade-Mint and the POLES regional split.[8]

3.3.2 Results

Primary energy consumption

Using the subsidy scheme described above, both the Low and High RES scenario targets were reached, 12% and 20% in 2020 respectively. The increased renewable share has only a small effect on the total energy consumption for both scenarios. The increase in renewables is mainly at the expense of coal, but oil, natural gas and nuclear have reduced shares in the RES scenarios as well.

[8] This means that the scenario variable values should be compared to the reference values set on the same geographical coverage.

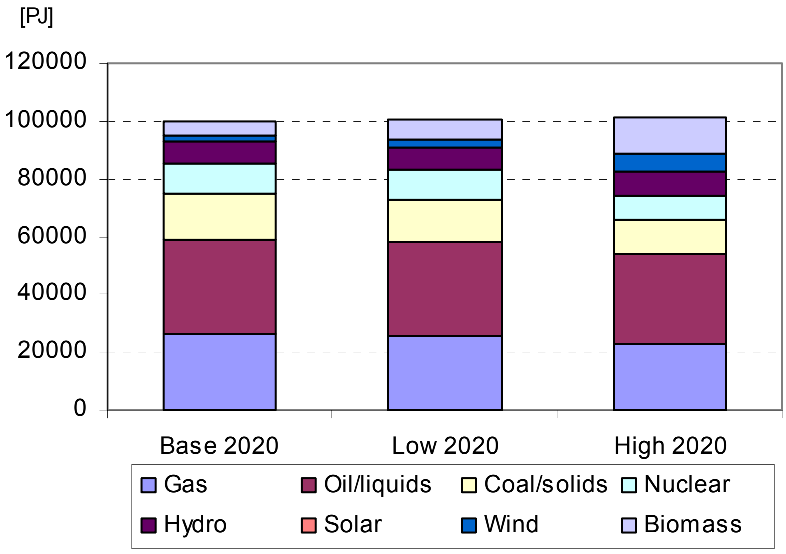

Figure 3.17 *Primary energy consumption in Baseline and RES Low and High target scenarios*

The most significant renewable sources are biomass, hydro and wind. Biomass is the most important renewable resource, representing 40-48% of the total renewable energy supply. Due to the subsidy it could reach 8-11% yearly growth rate in the 2000-2020 period compared to the 5% in the reference. Wind energy exhibits an even higher growth rate, reaching 17% in the same period, however with much lower base year values. Hydro has a significant share as well in both of the scenarios - but a limited (around 1%) growth rate in the small hydro category that indicates that its potential is almost saturated in Europe.

Electricity consumption

The scenarios presented here did not assume the separate target of 33% share of renewables in electricity generation (22% for the Low target case). As it is a result of the model simulation, it significantly differs from the target values. The renewable electricity share reaches 27% in the Low target case in 2020 and 44% in 2020 in the High target case. This indicates, that the electricity share target seem to be less demanding according to our model. On the other hand, some features of POLES - specifically that the geothermal energy is not included, and heat production from renewable sources is only partially modelled - suggest that one has to treat these shares with some caution. To reach the target, the technologies and resources (available in the model) have been forced to grow even faster than in the case when they would be included in the model.[9]

All the fossil fuels and the nuclear have reduced shares in electricity production. Interestingly, the natural gas based capacities also face significant slowdown compared to the dynamic evolution in the reference case.

[9] E.g. according to the FORRES (2002) study, the contribution of geothermal and the heat ration could reach 2% of RES by 2020. [5]

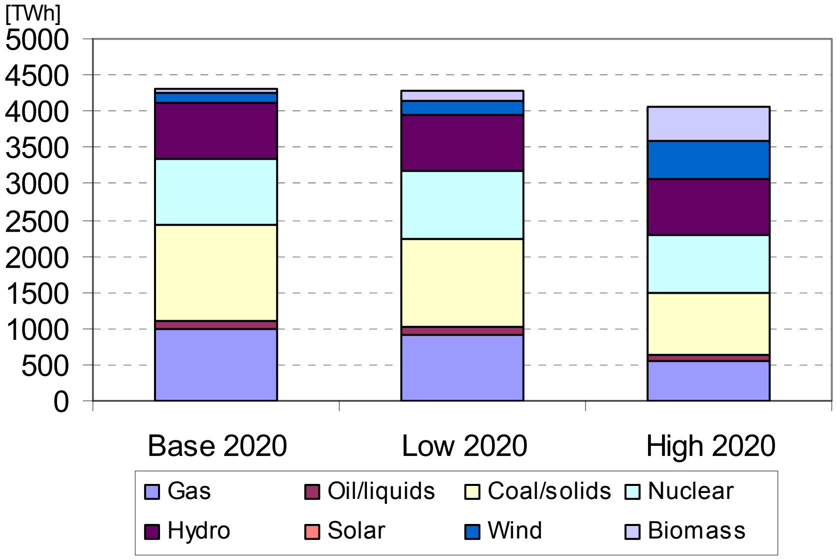

Figure 3.18 *The electricity generation mix in the Baseline and RES Low and High target case*

Wind and biomass electricity generation absorb the bulk of the renewable growth. In the High target case already 12% of electricity is generated from wind, mainly from on-shore sources (the cost gap between on-shore and off-shore is expected to be relatively significant). Biomass also shows dynamic growth approaching to the ratio of wind electricity generation in the High target case. Hydro cannot increase its electricity generation significantly, the minor increase is coming from the small hydro generators. Solar applications appear rapidly, but its expansion is still insufficient to reach any considerable share in electricity generation for the time horizon considered.

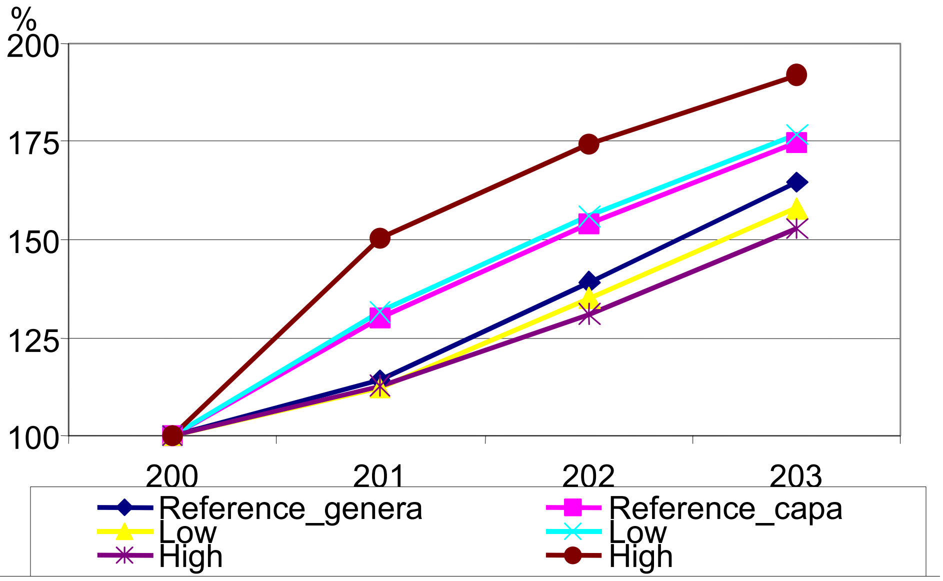

Figure 3.19 *Total electricity generation and capacity in the Reference and RES scenarios*

Figure 3.19 shows the growth rates of the total electricity generated and the capacity extensions in the baseline and in the two RES cases (Low and High target) in percentage terms. With higher renewable shares the total capacity has to increase even further, as the availability factor of these new capacities are smaller. This drives the average utilisation rate down, a further signal for an electricity price increase.

The wind electricity generation shows the highest growth rate amongst the renewable energy sources. Already in the baseline the average yearly growth rate is 17% in the EU30 region in 2000-2020, which increases to over 20% in the two policy scenarios. The highest growth rate is in the Rest of Central Europe region (Romania, Bulgaria and the former Yugoslavian countries), but this is mainly due to the low baseline values. The 'big' five, namely Germany, France, UK, Spain and Italy give the bulk of the wind energy even in 2020, which amounts to between 55 to 59% of the EU30 and 72-81% of the EU15, depending on the scenario. The share of wind electricity generation is still under 13% in the High target case in 2020, which means a still manageable ratio in the dispatching in general. However in some countries it could represent a ratio as high as 26%, as in the case of Denmark in 2020.

The other, even more important source of renewable is the biomass, however the bulk is used for the conventional heat production rather than electricity generation in the EU30 at the beginning of the simulation period. By 2020 this type of use loses share and with the renewable subsidy in place the integrated biomass gasification and combined cycle technology becomes the leading technology for biomass energy. The effect of the subsidy is significant on the growth rates of biomass energy use. The 5% average growth rate for the EU30 is increased to 8% and 12% in the Low and High target case respectively. For the EU15 these figures are slightly lower.[10]

3.3.3 Consequences of a large share of renewables

Costs of achieving renewables targets

POLES - being a simulation model - does not give indication on the total system cost. The best indicator to used as a proxy is the extra subsidy level required by the system to reach the target renewable level. In the Low target case the subsidy required was 0.9 €ct/kWh, while in the high target case it increases to 5.8 €ct/kWh. This latter value indicates the extremely high costs of the policy, as this subsidy is already in the range of the base-load electricity price.

The yearly subsidisation of the renewables amounts to less than 0.1% of the GDP ($€_{2000}$ in PPP) for the Low target case in 2020 and 0.48% in 2020 for the High target case. This latter value reveals the high financial burden of such a policy. However these figures are merely indicative figures, as in POLES - being an energy sector model - this subsidy is an exogenous transfer, therefore the total economic impact and the full interaction amongst the agents cannot be modelled.

CO_2 emissions and security of supply

Both scenarios have significant effect on CO_2 emissions. The Low target case reduces emissions by 3% by 2020, while the High target case has CO_2 emissions 14% lower than in the reference case. Most of this emission reduction is taking place in the power generation sector, followed by the industrial sectors, while the emissions from the transport sector are relatively stable. It should be noted that both in the reference and the RES scenarios a 10 €/tCO_2 carbon value was applied for the EU member states after 2012. As it is present in the reference run, the difference showed in Figure 3.20 is due to the introduced renewable subsidy only.

[10] One has to bear in mind, that the target of 20% renewable share means an average 6% growth rate for renewables for Europe using the FORRES study figures. Considering that hydro already reached its potential, this figure increases to 8-9% for the rest of the renewables. This is the 'target' growth rate to which one has to compare the growth rates of the individual energy sources (e.g. wind, biomass).

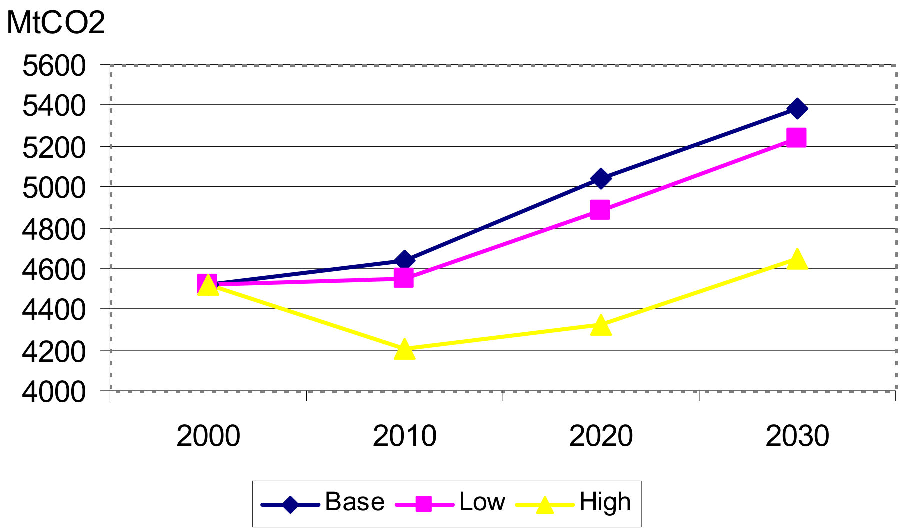

Figure 3.20 *CO_2 emissions in the Baseline and RES scenarios*

The policy scenario has advantageous effects both on the security of supply and energy diversity indicators of Europe. Considering the primary energy consumption, the total fossil fuel import of the EU30 is projected to be 61% in 2020, while it reduces to 49% in the High target case, and to 59% in the Low target scenario case.

The Shannon index[11] including energy dependency also confirms the advantageous effect of the renewable policies.

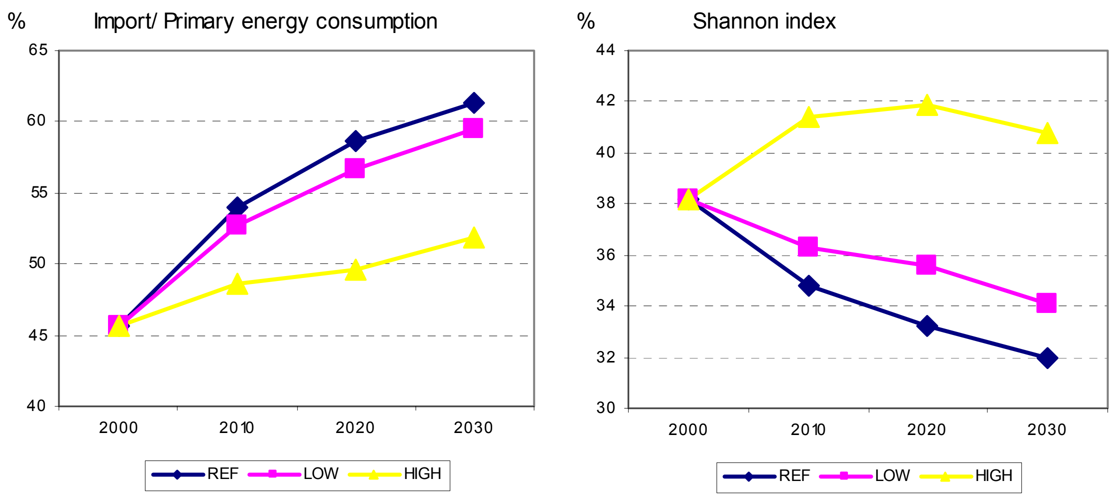

Figure 3.21 *Share of import in primary energy consumption, Shannon index including import dependency (with 11 carriers)*

[11] The Shannon index in Cascade-Mint is defined as:

$$\left(\sum_i (-X_i / PEC_{total}) * \ln(X_i / PEC_{total})\right) / -\ln(1/N_{Xi})$$

where *Xi*: energy consumption by fuel type, PEC_{total}: Primary Energy Consumption, N_{Xi} : number of energy carrier considered.

3.3.4 Conclusions and recommendations

The runs with POLES on the RES scenarios show that the goal to reach 20% renewable share in the primary energy consumption by 2020 could be a very ambitious target for Europe. In order to reach it a relatively expensive subsidy scheme has to be set up, both with a large coverage and a high level of subsidy. In the model the subsidy level is in the range of the base-load electricity cost (5.8 €ct/kWh for the High target and 0.9 €ct for the Low target case). Additionally, the scheme has to cover not only all type of renewables (biomass, wind, solar and small hydro) and has to be extended to a long time horizon. Without continuous and foreseeable subsidisation of the renewable technologies, their economic disadvantages would prevent them from getting closer to their technical potentials. The lagged 'learning' effect would prevent these technologies from gaining higher market shares. Furthermore in many cases the fact that they are close to their technical potential means increasing marginal costs (e.g. land availability, lower quality wind areas) indicated by the sharply increasing subsidy level.

The RES-subsidization schemes have their unquestionable advantages as well. As the Shannon index and the import dependency indexes show, the policy helps to improve the diversity of energy sources and at the same time significantly reduces the deteriorating trend of the energy import dependency in Europe. It helps to reach climate targets as well, the case studies show carbon emission reductions in the range of the Kyoto commitments.

The main effects, according to these POLES analysis, take place in the power sector, where most of the fuel and technology switching options are available (wind, biomass gasification etc.). This is also reflected in the resulting renewable shares in electricity generation, where POLES projects significantly higher shares than was set in the original scenario sub-target. Amongst the fuels biomass is the most important option to reach higher renewable shares. Although some other sources show higher growth rates (e.g. wind), the more than 40% contribution of biomass makes it a vital renewable energy source. In the High target case biomass grows with a factor of 3.8 between 2000-2030, but the data also indicates a certain slow-down in its progress after 2020. The wind energy keeps its dynamic evolution even after 2020, most probably due to the still available off-shore potentials.

The analysis of the global impacts of an EU renewable scheme was not the objective of the case study. However the energy prices of the model indicate that an isolated EU action has no significant price signals. Only in the case of natural gas one can observe a small reduction in the producer price in the European market.

In general, the evaluation of the effectiveness of the RES-subsidization schemes would require further analysis. First because the cost-effectiveness can only be assessed in comparison with other policy instruments (e.g. with a carbon constraint case) arriving to similar effects (emission reduction, security of supply). Secondly, as the scheme requires significant financial transfers between sectors of the economy, its full impact should be assessed with general equilibrium models as well.

3.4 TIMES-EE

3.4.1 Introduction

For the electricity supply industry different options are at the disposal for the reduction of CO_2 emissions of the EU-15, such as electricity saving measures, the intensified use of renewable energies, the development of the combined heat and power (CHP) production, the power station modernization and/or the new power station construction and emissions trading. The development of the renewable energies is an avowed target of national governments and the European

Union. In Table 3.9 the national targets of the electricity generation from renewable energy sources are presented for the year 2010 together with their projection for future years.

Table 3.9 *National indicative targets (Renewables Directive) of the gross electricity consumption from renewable energy sources in the year 2010 and projections until 2030*

	1995	*2010*	*2020*	*2025*	*2030*
Austria	71.8	78.1	87	91	91
Belgium/Luxemburg	3.7	6	15	19	23
Denmark	6.8	29	32	33.5	35
Finland	24.9	31.5	38.5	41.5	48.5
France	14.6	21	30	34	38
Germany	5.1	12.5	20	25	32
Greece	9.7	20	29	33	37
Ireland	5.5	13.2	22	26	30
Italy	19.45	25	34	38	42
Netherlands	2.3	9	14	18	22
Portugal	26.8	39	48.4	52.4	56.4
Spain	15.1	29.4	38	42	46
Sweden	49.4	60	63	73	77
United Kingdom	2.8	10	20	24	28

The projection contains both national targets already existing and an updating of the renewable targets of the European Union with the same rate of growth as between the year 1995 and the target value of the year 2010. In the case of countries such as Austria with a target of 78.5% for the year 2010 an updating would correspond to a portion of the renewable energies of the net electricity generation until 2030 of 96.5%. Since this portion exceeds the domestic potentials, the level was selected in such a way that all renewable potentials up to those of photovoltaics would be used. For photovoltaics a smaller increase was updated according to the development within the last years. The scenario with implementation of the national targets in the individual countries (RES_NAT) is compared to a scenario, in which a certain portion of the electricity production from renewable energies is reached (RES_EU15) for the entire EU. In this case, the implicit assumption of an open and well functioning market for green certificates is made, and the portion reached in each country is not a default but a distinct result of the scenario calculation. For both scenarios the policy assumption is that the total amount of subsidies for renewable electricity generation (feed-in tariffs, investment contributions, and reduced interest rates) is at the same level as in the reference scenario. The additional share of renewables will be achieved by a quota which triggers a national or EU15 certificate system.

For the analysis and evaluation of the different options an integrated view with a model of the European electricity market takes place. Basis of the model of the European electricity sector is the in the context of the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA) co developed is the model generator TIMES, developed in the context of the ETSAP at the IER Stuttgart. The electricity systems model TIMES-EE is a technical-oriented model, which illustrates (in the context of the current analysis) the electricity markets of the member states of the EU-15 in detail including the CHP plants for the period of 2000 to 2030. In order to simulate the economical behaviour of the enterprises, a real discount rate of 5% is subordinated, with which the investments have to amortize. For the consideration of the electricity exchange relations and the possibilities of joint implementation projects and/or the emission trade additionally the four neighbouring states Switzerland, Czech Republic, Poland and Norway are included in the model. As goal criterion it is assumed that in the sense of a complete competition on the European electricity market the costs summed over the entire modelled region are to be minimized. As a result of coupling the different regions an interregional competition structure arises. This leads to an electricity exchange in the system whenever the marginal costs of covering a certain load segment at a certain time are larger than the sum of the costs of the transmission and the transmission losses expressed in monetary value.

The different basic conditions of the different regions are seized on the basis regionally differentiated indicators, such as fuel prices, potentials of renewable sources of energy and region specific load curves for different customer groups (households, trade, energy-intensive and energy-extensive industry, agriculture, traffic). In addition to energy flows and other important parameters the energy-related greenhouse gas missions are also included in the model Thus, it is possible to investigate possibilities of emissions trading for the European electricity market.

3.4.2 Results

The electricity production from renewable energy sources rises in the reference scenario (REF) from 17.3% in the year 2000 to 21.3% in 2030 (see Figure 3.22). Thus, the absolute contribution grows from 430.2 TWh to 585.0 TWh. Their portion increases as expected more clearly with the set ratios for the portion of the renewable energies of the electricity production (RES_NAT resp. RES_EU15). Thereby the absolute portion of the fossil and nuclear electricity production reduces in equal parts. On European level the development of renewable energies takes place substantially via the intensified electricity production from wind energy and bio-energies (included in the category ‘others’ in the figure).

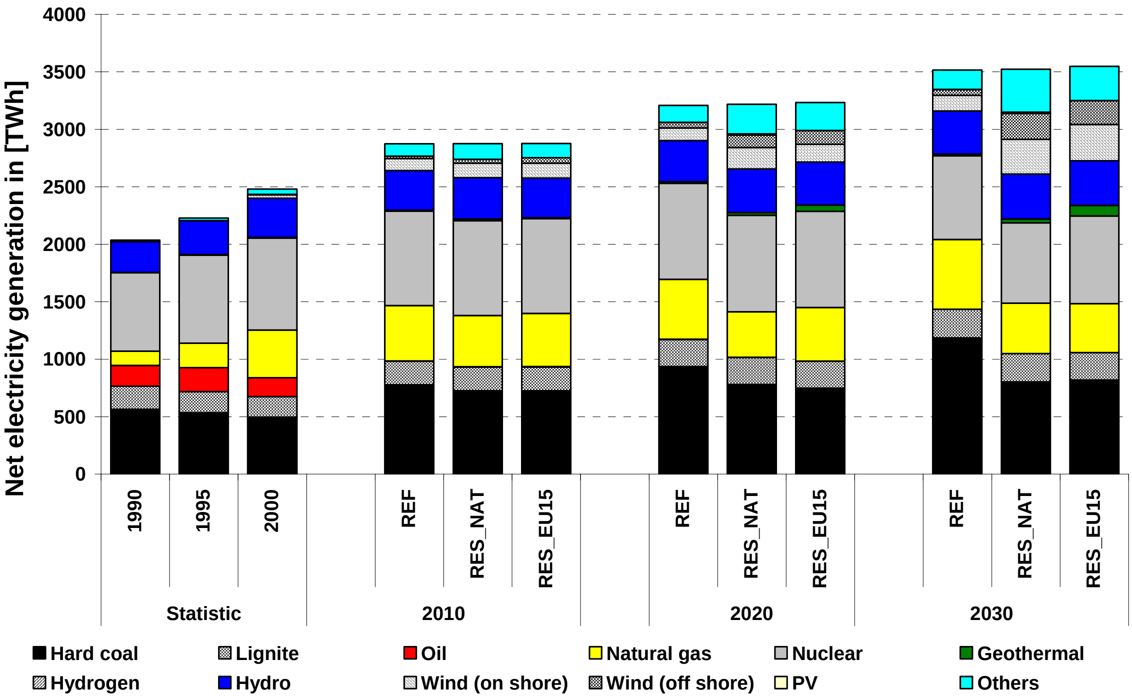

Figure 3.22 *Net electricity generation in the EU-15 by energy carriers in different cases*

The net generation capacity (see Figure 3.23) development follows the increased electricity production quantities. Since the availabilities of the renewable energies (especially those of wind energy and photovoltaics) are smaller than those of fossil electricity production techniques, a far higher installed capacity is necessary. This capacity rise in the reference scenario (REF) is determined by the future development of the electricity demand. In the scenarios with the target for the renewable energies (RES_NAT resp. RES_EU15) 189 GW wind capacity are installed in the year 2030. Until 2020 the share of off shore wind power in the scenario RES_NAT with national targets will be higher than in the scenario RES_EU15. The installed capacity of photovoltaics amounts to 20.2 GW in the year 2030. According to that the total power station capacity installed in the European Union is significantly higher in these scenarios.

The electricity production by hydro power will be by given national targets approximately 5 to 15 TWh higher in the case of EU 15 targets. Especially countries like France and Austria need to build up higher capacities of small hydro to fulfil the quota. On the other hand, biomass from energy crops or forest wood will be used in these countries and additionally in Germany, the Netherlands, Spain and Sweden to fulfil the quote. Additional cheaper biomass sources from Finland, UK, Ireland and Greece will be used in the EU15 scenario.

In particular the use of geothermal energy in organic ranking cycle power plants in Italy, Germany and Belgium will increase until 2030 in the RES_EU15 scenario in compared to the scenario RES_NAT.

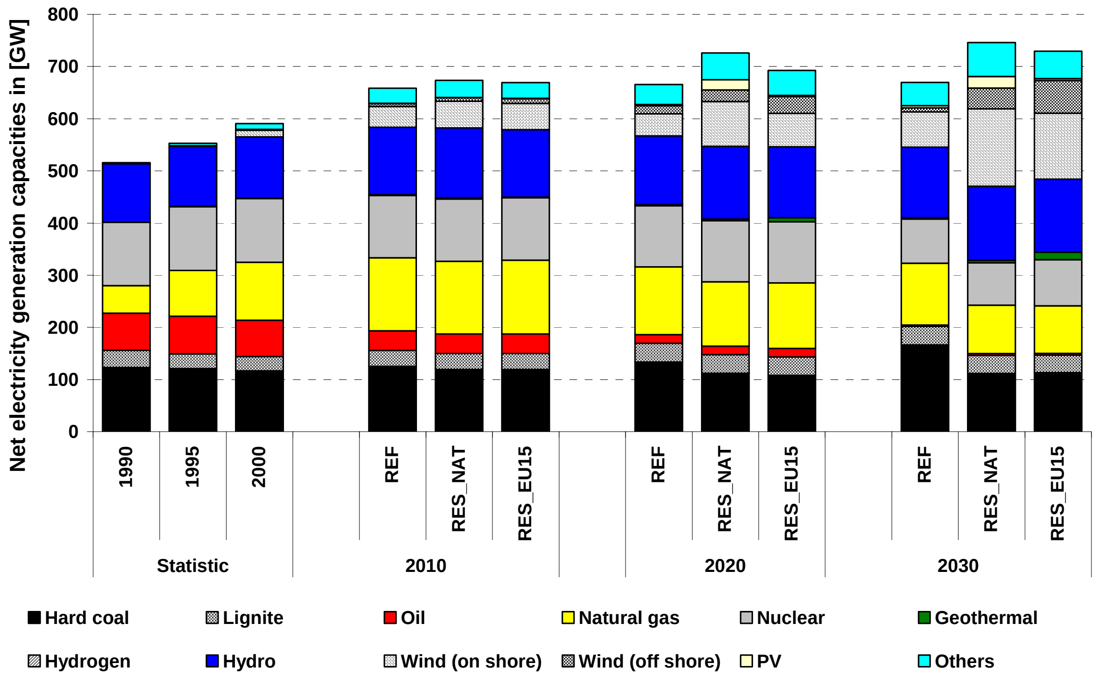

Figure 3.23 *Installed net capacity in the EU-15 by energy carriers in different cases*

3.4.3 Consequences of a large share of renewables

With a portion of the renewable energies of approximately 19.6% the EU-15 without using special additional political measures in the reference scenario (REF) will miss the target to produce 21% electricity in the year 2010 from renewable energies (see Figure 3.24). This target is still not expected to be achieved in the reference scenario in the year 2030. Here portions of the potentials are economical for electricity production from biomass, since at the same time the prices for fossil fuels reach a relative peak.

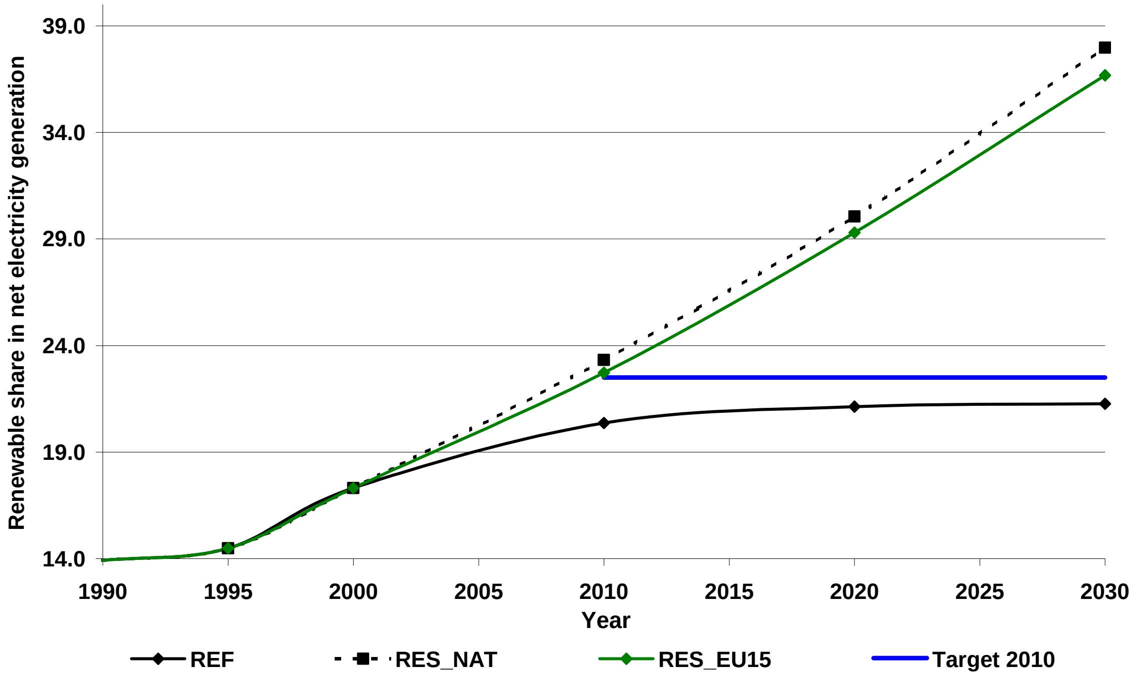

Figure 3.24 *Portion of the electricity production from renewable energies of the entire net electricity generation in the different cases*

In the case of converted national targets for the share of renewables within the electricity production (RES_NAT) in the year 2010 the target of the EU-15 is exceeded by approximately 1.5%-points. Therefore the growth of the electricity demand in combination with the aim of fulfilling the national targets is not compatible with the overall target for the EU-15.

For the different countries there are large differences in the marginal costs for the electricity production from renewable energies in the scenario with national targets (RES_NAT) due to the differently ambitious targets and the national diverging potentials for renewable energies (see Table 3.10). In certain countries, such as Germany, Portugal, Ireland, the Netherlands, Denmark and United Kingdom, the certificate prices for green electricity will be 'zero' for the year 2010, since in these countries the national targets will already be achieved with the today valid legal regulations and/or the granted subsidies, whose continuance was presupposed for the reference scenario. On the other hand extremely high certificate prices appear in Finland, Austria, France, Spain and Italy, where a large share of renewable potentials has already been exhausted. In these countries, reaching the targets will require measures, such as energy crops as fuel, small hydroelectric power plants or wind energy plants at locations with small to middle wind velocities.

Table 3.10 *Prices for green certificates in the different countries and in the different years*

	AT	BG	DK	DE	ES	FI	FR	GR	IR	IT	NL	PT	SE	UK	RES_EU15
2010	75.3	22.8	0.0	0.0	77.0	69.7	67.6	0.0	0.0	85.5	0.0	0.0	47.4	0.0	19.3
2020	44.9	60.6	0.0	60.8	57.5	39.1	63.4	0.0	17.5	54.1	17.6	48.0	52.4	49.6	47.5
2025	44.9	52.3	0.0	52.4	54.3	43.5	58.6	0.0	44.2	44.6	44.4	43.7	55.2	47.3	48.5
2030	46.2	49.3	0.0	50.3	55.0	47.5	55.4	38.9	42.1	34.5	50.1	48.9	47.6	48.0	48.9

With the exception of Denmark (DK), which can fulfil the ratio without a repeated additional expenditure to 2030, the price for green certificates varies in the range from approximately 40 to 65 €/MWh. In contrast to this a uniform certificate price of 48 €/MWh is the result in the scenario with a common objective for the entire EU-15 (RES_EU15).

The base value of the CO_2 emissions for 1990 of the EU-15, which was determined by means of the model calculations and in alignment with the available statistics to the fuel inventory, amounts has been determined, amounts to 1030.8 Mio. t for the modelled range of the electricity and district heating production. The regarding CO_2 emissions from electricity and district heating production for the reference scenario (REF) sum up to 1003.5 Mio. t in the year 2010. This is around 2.7% lower than in the year 1990 (see Figure 3.25). Therefore the considered Kyoto reduction target of the year 2010 (-9.4%) is not reached in the reference scenario.

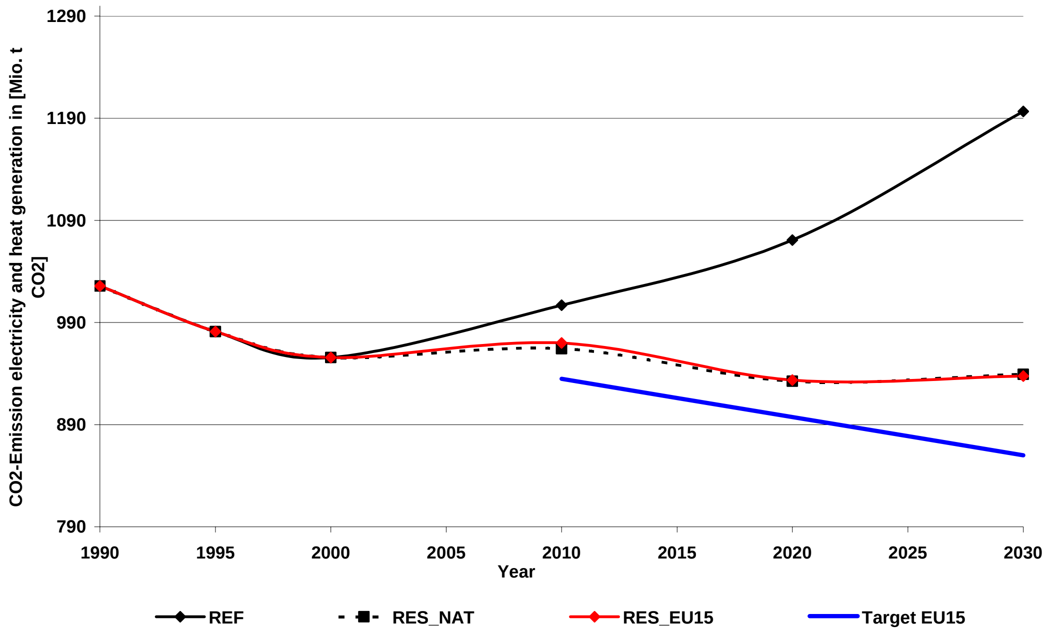

Figure 3.25 *CO_2 emissions of the electricity production in different cases*

In the scenarios where the indicative targets for the electricity consumption from renewable energies in 2010 are achieved, (RES_NAT resp. RES_EU15) the overall emission reduction exceeds the mitigation target for the electricity and district heating production resulting from the translation of the national emission reduction targets. Thus, by intensifying the use of renewable energies through imposing binding targets (quota obligations), the CO_2 emissions in the EU-15 in the year 2010 are lowered by approximately 43 Mio. t compared to the reference case. The emissions stay in a range between 960 and 930 Mio. t till 2030 in the renewable scenario. This leads to a 30 to 60 Mio. t increase above the Kyoto target transferred to the electricity and district heating production.

3.4.4 Conclusions and recommendations

The analysis of the national targets regarding the portion of the renewable energies of the electricity consumption showed the fact that the sum of the national formulated and converted targets exceeds the target formulated for the entire EU-15. The ratios from EU Renewables Directive 2001/77/EC and their updating do not consider the national situation concerning availability and costs of the different renewable sources and technologies and the differences in the growth in electricity consumption in the different countries.

A comparison of national and EU 15 prices for green certificates identifies the differences of targets and cost efficient renewable potentials for electricity generation.

The target for a given national or EU15 quota of 33% in 2020 will only be reached, when it is possible to double the wind power generation and the use of biomass. In order to achieve this significant increase the wind offshore technology will have to reach its technical maturity concerning the supply system and its integration into the electrical grid. On the other hand, technologies for biomass and biogas power plants are already established on the market but the use of large amounts of biomass will require an advanced logistic structure.

The additional burden for fulfilling the renewable targets within the European countries varies between 20 and 85 €/MWh in the year 2010. The analysis of the development until 2030 has been carried out additionally with a continuation of the targets for the renewable energies. If no substantial cost reduction of the techniques to the electricity production from renewable energies will be realized within this time horizon, a significant increase in the costs to the final consumers and/or to the entire electricity production would be the result. A common European solution appears more favourably due to similar reductions of the CO_2 emissions with lower costs. Additional sensitivity analyses have shown that efficiency improvement of existing power plants and the increasing share of natural gas power plants instead of coal fired power plant are measures to fulfil the Kyoto target and beyond.

3.5 PROMETHEUS

3.5.1 Methodology

In the context of the renewables case for CASCADE MINTS project PROMETHEUS focused on the electricity sector, which is represented in detail inside the model. The main model results were the distributions of the share of renewables in gross electricity consumption in OECD Europe for the year 2020 by examining different policies (subsidies and R&D) for promoting the renewables. The probabilities for achieving the two proposed RES-E targets were also calculated. However, these targets of 33% and 22% were set higher, 37% and 28% respectively, because of the inclusion of Norway and Turkey into the geographical coverage of Europe. The new target levels were based on PRIMES calculations.

The sensitivity analyses that examined for the CASCADE MINTS renewables case study were:

- ☑ No new policy: PROMETHEUS ‘baseline’. The baseline assumes that all existing subsidies and supports remain constant in real terms throughout the forecast horizon.
- ☑ Introducing additional subsidy of 1 €ct_{2000}/kWh.
- ☑ Introducing additional subsidy of 2 €ct_{2000}/kWh.
- ☑ Introducing additional subsidy of 3 €ct_{2000}/kWh.
- ☑ Introducing additional subsidy of 4 €ct_{2000}/kWh.
- ☑ Doubling cumulative R&D investments on renewables technologies (~48 Billion $€_{2000}$ in addition).
- ☑ Combined policy: Doubling cumulative R&D investments and introducing additional subsidy of 2.5 €ct_{2000}/kWh.

In all analyses climate policy was applied, as described in the PROMETHEUS ‘baseline’ (Uyterlinde et al, 2004). All RES supporting policies were assumed to be independent of the outcomes. This implies that for some extreme cases, where renewables become cost-effective through non-policy factors, there is clearly excessive RES support.

For each one of the above cases the presentation focuses on:

- ☑ Distributions of the international fuel prices (oil, gas and coal).
- ☑ Distributions of the capital costs of the renewables technologies (Hydro, Wind, Biomass).
- ☑ Distributions of the share of each power generation technology in gross electricity consumption for the 3 PROMETHEUS regions: OECD Europe, Rest of OECD, and Rest of the World.
- ☑ Distribution of the share of renewables in gross electricity consumption.

3.5.2 Analysis of the results

PROMETHEUS incorporates endogenous learning-by-doing and learning-by-researching, which affect the capital costs of the renewable technologies. By introducing subsidies the installed capacity of RES in Europe increases affecting the capital costs of renewables worldwide via the learing-by-doing mechanism. In a similar way, the introduction of more R&D is taken into account by the learning-by-researching mechanism which results in lower capital costs worldwide. Thus, the penetration of renewables in electricity production is not only higher in Europe but also in the other world regions. This change of the technology mix in electricity production worldwide affects the share of fossil fuels in power generation, resulting in lower international prices for gas and coal.

Table 3.11 summarizes the results of the renewable support policies examined in PROMETHEUS.

Table 3.11 *Aggregate results of renewable support policies in 2020*

Case study	No new policy				Introducing additional subsidy 1 cent Euro00/KWh			
	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability
RES-E share (EUROPE) (%)	20.6	5.16	14.4	30.9	24.0	7.24	15.2	38.1
RES-E share (Rest of OECD) (%)	18.2	4.18	12.7	26.0	18.3	4.24	12.7	26.1
RES-E share (Rest of the world) (%)	17.7	7.31	10.8	34.3	17.9	7.40	10.8	34.6
Capital Costs (Euro00/KW)								
Large Hydro	2823	10.3	2806	2839	2823	10.3	2806	2839
Small Hydro	2142	143.1	1906	2385	2142	143.1	1905	2384
Wind	869	141.7	647	1109	844	138.9	635	1093
Biomass	1887	220.1	1501	2220	1865	226.8	1466	2208
International fuel prices								
Oil (Euro00/bl)	29.7	7.0	19.7	42.2	29.7	7.0	19.7	42.1
Gas (Euro00/toe)	156.2	43.6	97.0	241.8	155.5	43.4	96.9	240.2
Coal (Euro00/tn)	32.7	6.1	23.8	43.2	32.6	6.1	23.8	42.9

Case study	Introducing additional subsidy 2 cents Euro00/KWh				Introducing additional subsidy 3 cents Euro00/KWh			
	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability
RES-E share (EUROPE) (%)	28.0	8.37	16.2	41.8	32.8	8.43	17.5	44.9
RES-E share (Rest of OECD) (%)	18.4	4.27	12.8	26.1	18.5	4.30	12.8	26.3
RES-E share (Rest of the world) (%)	18.0	7.48	10.9	34.9	18.2	7.58	10.9	35.4
Capital Costs (Euro00/KW)								
Large Hydro	2824	10.2	2806	2839	2824	10.1	2807	2839
Small Hydro	2141	143.1	1905	2384	2141	143.2	1904	2382
Wind	819	133.7	626	1060	795	125.0	620	1023
Biomass	1846	234.4	1434	2203	1831	242.0	1409	2202
International fuel prices								
Oil (Euro00/bl)	29.7	7.0	19.7	42.1	29.7	7.0	19.7	42.1
Gas (Euro00/toe)	154.9	43.2	96.6	239.1	154.1	43.0	95.6	238.0
Coal (Euro00/tn)	32.5	6.0	23.6	42.7	32.3	6.0	23.5	42.5

Case study	Introducing additional subsidy 4 cents Euro00/KWh				Introducing R&D on RES Doubling cummulative R&D			
	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability
RES-E share (EUROPE) (%)	36.9	7.33	20.8	47.4	24.4	6.74	15.8	37.4
RES-E share (Rest of OECD) (%)	18.6	4.32	12.9	26.5	21.9	5.74	13.8	31.6
RES-E share (Rest of the world) (%)	18.3	7.64	10.9	35.7	21.6	10.17	11.4	43.4
Capital Costs (Euro00/KW)								
Large Hydro	2824	10.0	2807	2839	2823	10.3	2805	2839
Small Hydro	2140	143.3	1904	2380	1859	196.5	1547	2195
Wind	777	116.0	616	1005	743	110.0	578	943
Biomass	1826	249.1	1392	2198	1651	225.2	1276	2022
International fuel prices								
Oil (Euro00/bl)	29.7	7.0	19.7	42.1	29.7	7.0	19.7	42.1
Gas (Euro00/toe)	153.5	42.8	95.0	237.4	152.1	42.4	93.6	234.4
Coal (Euro00/tn)	32.1	6.0	23.4	42.2	31.7	5.9	23.1	41.9

Case study	Combined policy Doubling cummulative R&D and introducing additional subsidy of 2.5cents Euro00/KWh			
	mean	s.d.	Value to be exceeded with 95% Probability	Value to be exceeded with 5% Probability
RES-E share (EUROPE) (%)	36.0	7.54	20.9	46.9
RES-E share (Rest of OECD) (%)	22.1	5.78	13.9	31.8
RES-E share (Rest of the world) (%)	21.8	10.23	11.5	43.6
Capital Costs (Euro00/KW)				
Large Hydro	2824	10.1	2807	2840
Small Hydro	1858	196.9	1547	2196
Wind	719	101.0	574	901
Biomass	1628	235.4	1239	2014
International fuel prices				
Oil (Euro00/bl)	29.7	7.0	19.6	42.0
Gas (Euro00/toe)	150.3	41.9	92.6	232.7
Coal (Euro00/tn)	31.3	5.8	22.8	41.4

Wind turbines take advantage of the policies introduced and increase their share in the electricity production substantially in OECD Europe (especially in policies with strong intensity (subsidies of 3 €ct_{2000}/kWh and above, as well as in the combined policy) they receive the highest share among all other options). Wind turbines also increase their share in the other world regions, because of the spill over effect. Hydroelectric energy increases its share mainly because of the contribution of small hydro, since the large hydro potential in Europe has almost been reached by now. Finally the biomass share is also increased.

Regarding the probability of achieving the target of 37%, the policy of introducing an additional subsidy of 4€ct_{2000}/kWh gave almost the same results as the combined policy. The mean value of both policies was 37% and 36% respectively (see Figure 3.26).

The distribution of the share of renewables displays high positive skewness (higher density for small values but a larger upward range) in the no new policy or weak policy cases. As policy intensifies, skewness becomes markedly negative under the impact of saturation effects. (see Figure 3.26).

On inspection of the cumulative distribution graph (Figure 3.27), it can be concluded that the probability of meeting both the renewable targets (28% and 37%) in the 1 €ct/kWh support policy and the R&D on renewables policy is about equivalent, i.e. 29% for the weaker target and 8% for the ambitious one. The R&D scenario implies a certain (non-stochastic) cost of 47.6 billion $€_{2000}$ while the direct support policy has a mean cost of 36.7 billion $€_{2000}$ (costs for the support scenarios are measured in terms of discounted expenditures on the support schemes). The probability that the direct support policy costs more than the R&D policy is around 23%. The relative merits of the two types of policies are reversed if the object is CO_2 abatement rather than adherence to a particular renewable target. In these cases the mean cost in terms of CO_2 avoided is much higher in the direct support policy (133 $€_{2000}$/tnCO_2 avoided versus 16.5 $€_{2000}$/tnCO_2 avoided). This is due primarily to the different nature of the spillover effects of the two policies.

The R&D policy enhances the attractiveness of renewables throughout the world, while the direct support policy increases renewable penetration in Europe and indirectly reduces fossil fuel costs for the rest of the world.

Looking at the CO_2 effectiveness of the stronger policies it is worth-noting that the combined case (doubling R&D spending on renewables and introducing 2.5 $€_{2000}$/kWh direct support) compared to its almost equivalent (in terms of achieving the target) case of 4 $€_{2000}$/kWh direct support policy is much cheaper on average (30.6 $€_{2000}$/tCO_2 avoided compared to 81 $€_{2000}$/tCO_2 avoided) and has a lower standard deviation (even as a percentage of the mean) and much smaller positive skewness. The smaller mean is widely attributable to the spillovers as mentioned above. The lower variability on the other hand is attributable to the hedging characteristics implied by a combined rather than a concentrated action.

PROMETHEUS is capable of security of supply analysis in that it can measure impacts in terms of changes in probability of an adverse event. The usual supply concerns relate to both oil price and gas price shocks. Given the low penetration of oil in the power generation sector (especially in Europe) PROMETHEUS was used to only address the question of security of gas supply, since gas is projected to take a substantial share in power generation in the next two decades. The measure of security retained was the highest increase in imported gas prices over any 3-year period to the year 2030. Table 3.12 shows the probability that the highest increase in gas price will exceed certain thresholds.

Table 3.12 *Security of supply probabilities referring to the maximum increase of the gas price in any 3-year period between 2005 and 2020*

	Probability that the highest increase in gas price in any 3-year period will exceed the level of	
[%]	50 $€_{2000}$/toe	100 $€_{2000}$/toe
No policy	64.1	9.9
Combined policy	58.0	7.6

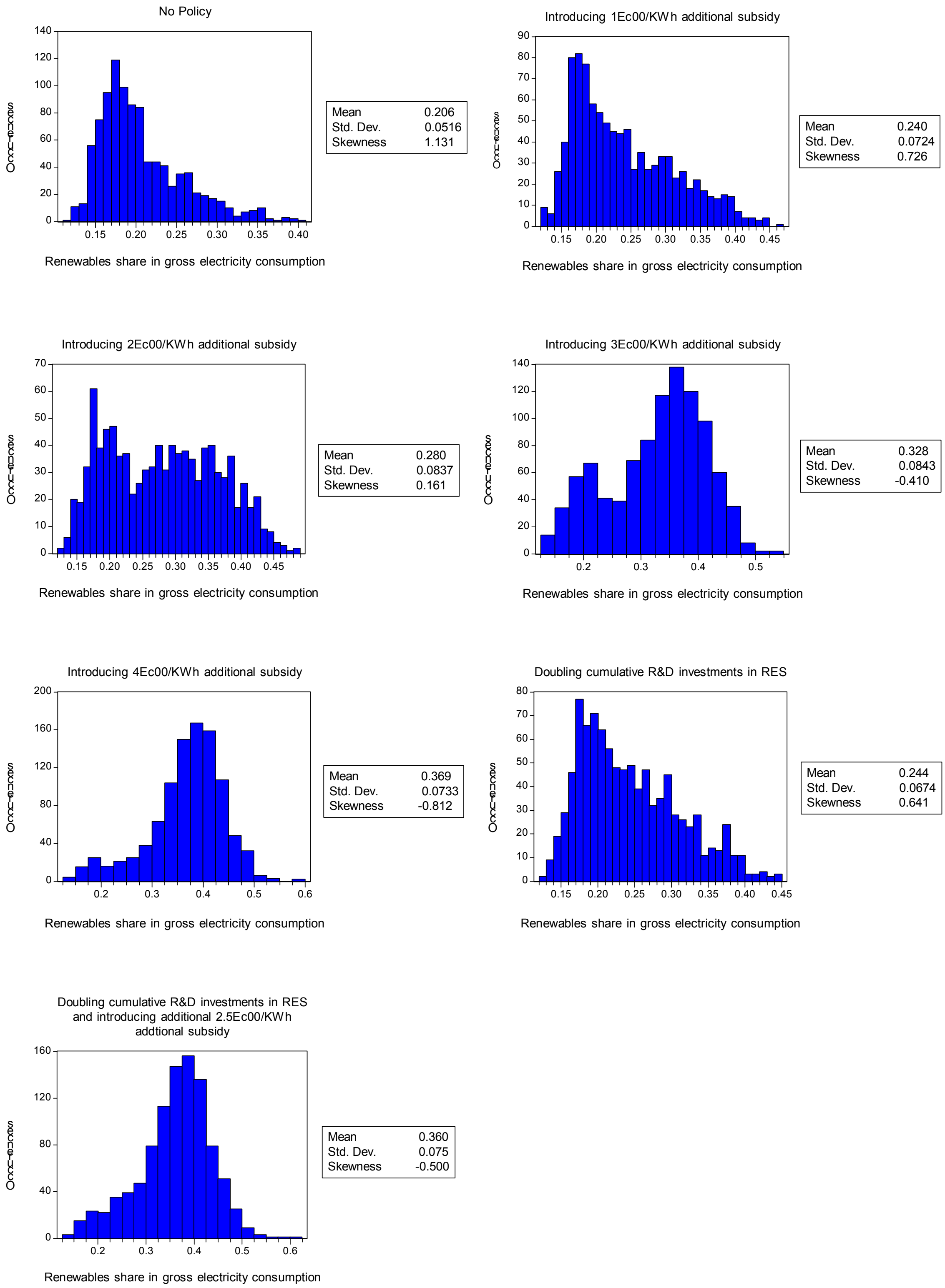

Figure 3.26 *The distribution of RES-E share in the examined renewable support polices*

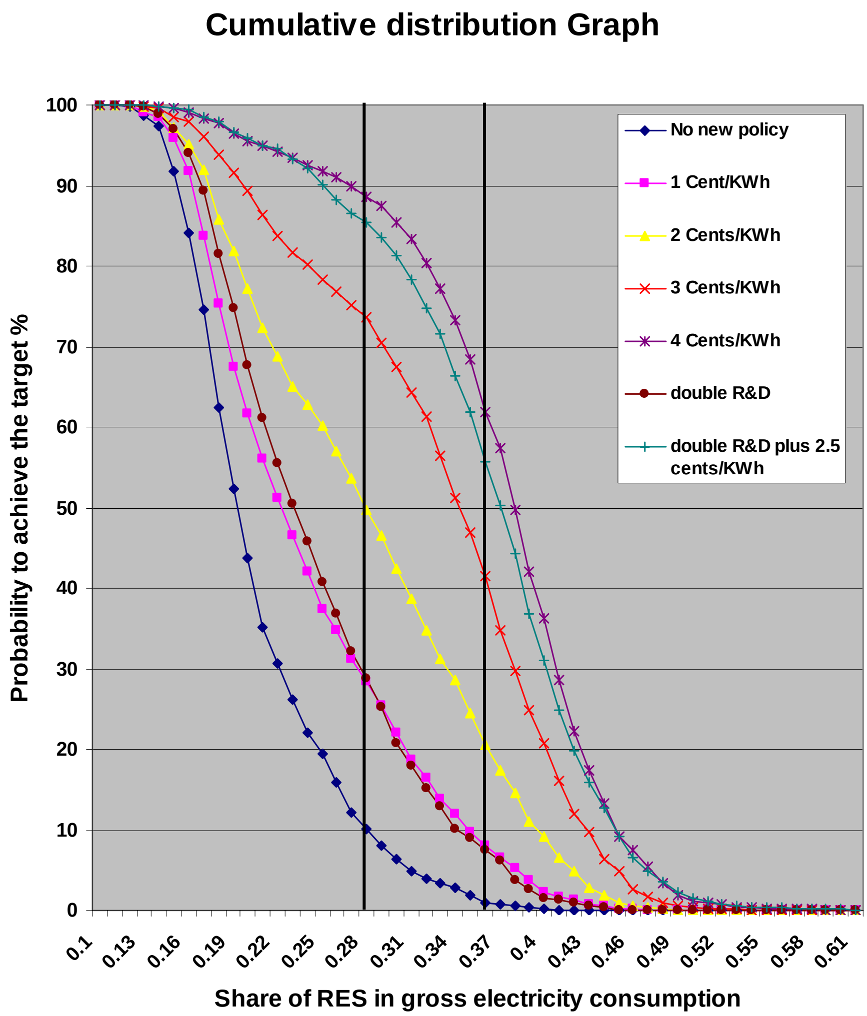

Figure 3.27 *Probability to achieve various shares of renewables under the examined renewable support policies*

3.6 NEMESIS

3.6.1 Introduction

The targets on renewable share were introduced for electricity sector only, since in NEMESIS there is no other major source of renewable, as biofuels. The targets, set as RES in gross electricity consumption (RES-E), were levied respectively to 22% and 33% for 2020 in the 'low' and 'high' cases, under 21% in the baseline. It was imposed for EU-15 only and, taking account Norway, it implies targets of respectively 26% and 36% for RES-E in 2020 for EU-15 plus Norway, this last country producing its electricity nearly exclusively from renewable sources. The policy scenarios have been implemented in NEMESIS as follows. Subsidies were introduced for renewable technologies in order to meet the targets. In the Low target policy, the subsidy was set to 1.0 €ct_{2000}/kWh and it was applied from 2015 to 2020 only, the target being spontaneously reached before 2015. In the High target case, the subsidy was set to 2.4 €ct_{2000}/kWh and it was applied from 2005 to 2020. The subsidy was passed to consumer prices, by adding it to the prices proportionally to renewable share in gross electricity production. The policies considered are consequently analogous to the introduction of Green Certificates in the electricity sector. Here we will comment only the results for EU-15 plus Norway.

3.6.2 Results

Consequences for other energy sources

The introduction of a subsidy on renewable modifies strongly the contribution of the different energy sources in primary energy production in the high case, with in 2020 a fall of 8.11% for gas, of 9.51% for coal and solids and a sharp rise for renewables (+10.34% for wind, + 31.98% for geothermal and + 30.95% for biomass).

Table 3.13 *Difference in primary energy production in the High target RES policy cases with respect to the baseline*

[%]	2010	2020
Gas	-3.31	-8.11
Coal/solids	-1.33	-9.51
Hydro	5.09	10.34
Wind	77.31	89.80
Geothermal	1.98	31.98
Biomass (energy crops)	4.40	30.95

Primary energy consumption

As expected in the High target scenario, 33% of electricity consumption is produced in 2020 by renewable based power generation. The impact on primary energy consumption of the development of renewable energy sources are firstly a strong reduction for gas (-8.1% in the High target case and -0.9% in the Low case) and coal/solids (-9.51% in the High target case and -1.9% in the Low case) consumption. The growth of renewable energy consumption come mostly from hydro power, from bio mass (energy crops), from wind and to a lesser extent from solar. The contribution of renewable sources to total energy consumption reaches in 2020 7% for hydro power, 4.1% for biomass and only 3.3% for wind.

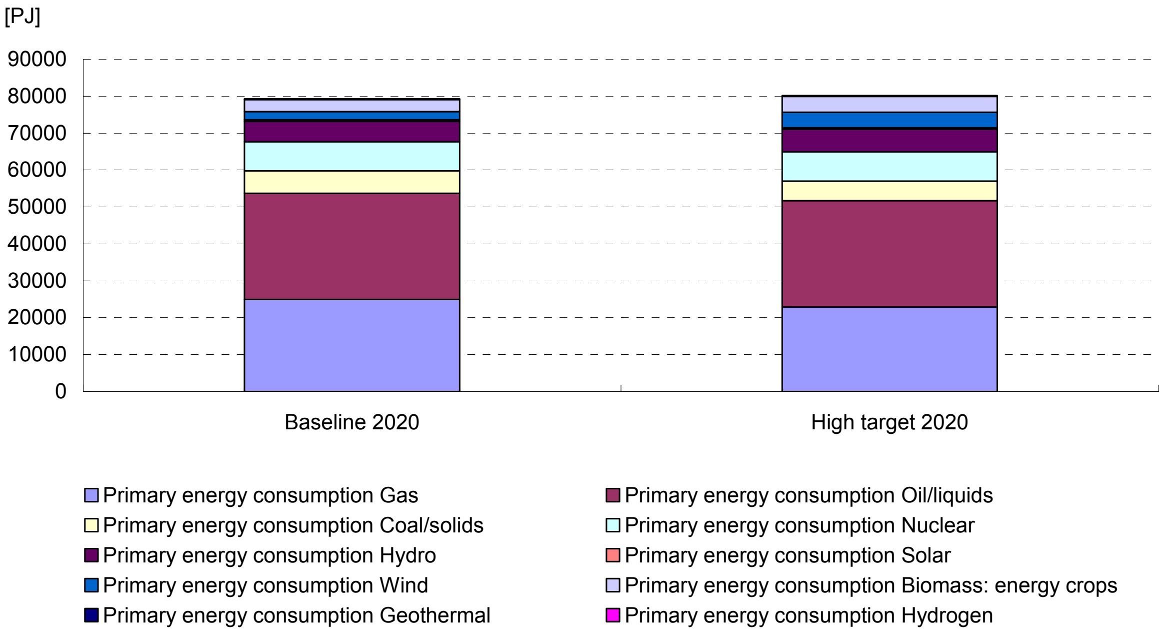

Figure 3.28 *Primary energy consumption in Baseline and High target scenario in 2020*

Electricity consumption and production

By comparing the baseline and the High target scenario, it can be seen that by raising the renewable energy share, the electricity production decreases slightly.

Gross electricity generation produced from gas declines by almost 25% and by almost 18% for coal/solids. The shares of nuclear and of oil/liquids in electricity production remain constant. Electricity generation based on hydro power dominates the increase in renewable sources with half of the RE generation. The rise in renewable energy results also in an increased penetration of wind and biomass in electricity generation (respectively with an 89.8% and 98.5% increase in 2020 in the High target case).

Final energy demand by sector
The final energy demand by sector decreases in average by about -0.23% in 2020 in the High target scenario with respect to the baseline. This variation of final energy demand takes into account the direct effect of the 2.1% fall of electricity demand; which concerns all sectors. This impact on final energy demand reflects the direct effect of the energy prices rise on factor substitutions and on the general level of economic activity.

The magnitude of the effect however can differ, depending mainly on the importance of energy costs in total production cost. The sector with the biggest decline is industry with a decrease in electricity demand about -3% in the High target case. Others sectors see a lower impact on their energy demand as a consequence of implementing renewable energies. The results show that the demand for renewable energies increases at the expense of gas and coal/solids.

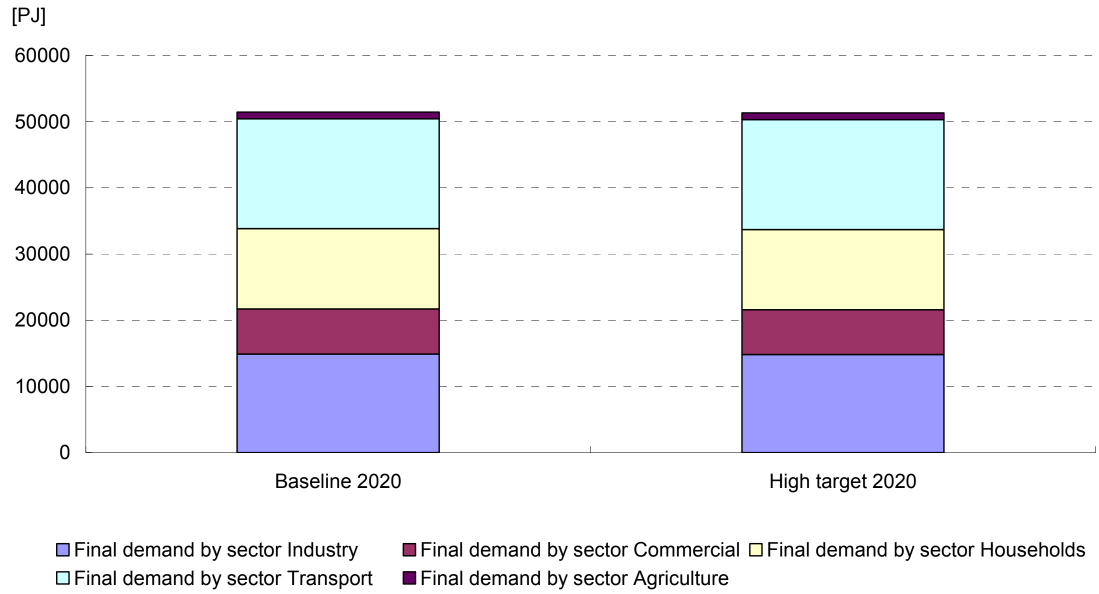

Figure 3.29 *Final energy demand by sectors in Baseline and High target scenario in 2020*

3.6.3 Consequences of a large share of renewables

CO_2 emissions
Increasing the use of renewable in power generation results in a substantial decrease of total CO_2 emission in EU-15 plus Norway. The design of this policy promotes electricity from renewable energy sources and consequently reduces the contributions of gas and coal to electricity production. In turn, it provokes a decrease of respectively 0.6% and 4.5% for GHG emissions (Mt CO_2 equivalents) in the low and high cases. Then, the market penetration of RES-E contributes to meet climate change targets for reduction of GHG emissions.

Table 3.14 *Difference in CO_2 emission in the RES policy cases from the baseline in 2020*

Emissions	Low target scenario [%]	High target scenario [%]
CO_2 total from energy only	-0.72	-5.12
CO_2 from power sector	-2.87	-20.23
CO_2 from (other) conservation	-0.24	-2.03
CO_2 from industry	0.09	0.47
CO_2 from residential, commercial and service	0.04	0.25

CO_2 emissions reduce in the power generation sector (-20% in the high scenario case) and from (other) conservation sources whereas they increase slightly in industry, residential, commercial and services sectors.

Security of supply

In the situation characterised by a large share of imported gas, oil/liquids and coal/solids, the deployment of renewable sources imply a higher degree of security of supply in Europe. In 2010 comparing the High Target scenario to the baseline, the net imports of primary energy decrease of 8.1% for gas and of 13.1% for coal/solids whereas they remain constant from oil/liquids sources. Then, the net imports of primary energy are reduced by 4.3% in the High target case.

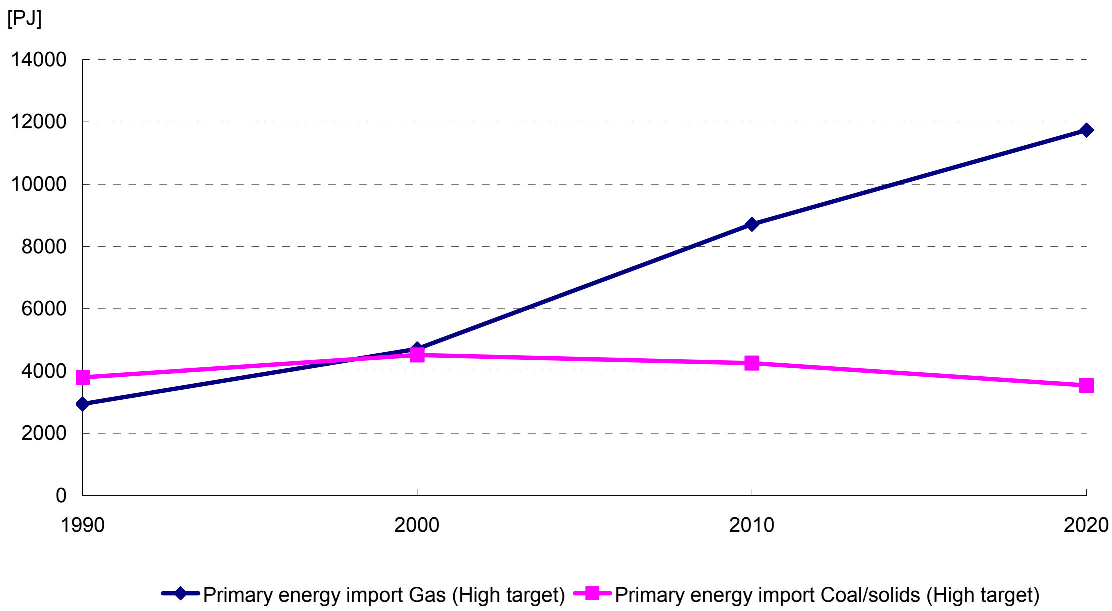

Figure 3.30 *Primary energy import from gas and coal/solids in the High target scenario in 2020*

The RES scheme leads gradually to a significant increase in security of supply. The increase in RES supply in 2020 compared to the baseline, in the High target case, origins mostly from wind (+89.9%), from geothermal (+32%) and from energy crops biomass (+31%). Hence the Shannon diversity index, commonly used to determine the import dependency of an energy system of a defined region, is increasing in 2020 from 67.8% in the baseline to 70.2% in the High renewable target. This means that the reliance on only few primary energy sources is decreasing.

Effects on employment and economic growth
The introduction of renewable energy target has a negative impact on European macroeconomic indicators. The European GDP decreases by about 0.2% at the end of the simulation in the high case scenario. This policy has a large inflationary impact as the energy prices increase of about 4.4% in 2020 with respect to the baseline. The rise in the energy prices has a direct effect on the price index of GDP, which rises by 0.83% in 2020.

Table 3.15 *Macroeconomics effects in the RES policy cases from in 2020 (difference from the baseline)*

[%]	Low target scenario	High target scenario
GDP	-0.027	-0.18
Price index on GDP	0.21	0.83
Private consumption	-0.02	-0.18
Real wage	-0.02	-0.14
Employment	-0.03	-0.15

The increase of consumer price, by lowering households' disposal income, induces a fall in private consumption in Europe. The nominal wage rate follows the rise of consumption price in a slightly weaker proportion, for the reason that energy represent an important proportion of households' final consumption; real wages reduce consequently of about 0.14%. The drop of employment level in Europe (-0.15%) is explained mainly by competitivity losses.

International competitiveness of Europe
The prices increase has a negative impact on competitiveness in Europe, resulting in a rise of 0.11% for imports and a fall of 0.28% for exports. The decrease of imports is inferior to the decrease of exports in reason of the reduction of European GDP.

Table 3.16 *International competitiveness effects in the RES policy in 2020 (difference from the baseline)*

[%]	Low target scenario	High target scenario
Export	-0.07	-0.28
Import	0.05	0.11
Terms of trade	0.04	0.12

3.6.4 Conclusion and recommendations

In the long run, the penetration of renewable energy sources will most certainly affect European economies. The High target policy seems to have greater impacts both on environmental/energy scheme and on macroeconomics values. In all scenarios the increase of renewable sources goes together with a decreased use of gas and coal/solids. This leads to a substantial reduction of GHG emissions and contributes importantly to security of energy supply. However, macroeconomics indicators are worsening and accompanying measures should be designed in order to reduce the macroeconomic cost of the policy for Europe, by lowering for example labour or investment costs.

3.7 PACE

3.7.1 Introduction

The Renewables Case study of the Cascade Mints project investigates the economic and environmental effects of achieving a share of 20% renewables in primary energy consumption in Europe from the year 2020 onwards. Our objective is to provide quantitative insights into this policy issue based on an extended version of the PACE computable general equilibrium (CGE) model for Europe (EU-15). The model features a bottom-up description of power generation technologies for the electricity sector using detailed engineering data. The various electricity generation technologies are characterized by their specific cost structure, physical capacity constraints and the output shares in the benchmark equilibrium (i.e. the baseline or business-as-usual evolution until 2020). There are no endogenous learning technologies in PACE.

For an economic assessment of energy policy interference, the marginal costs of existing power plants as well as the full cost of backup technologies are crucial. Benchmark technology cost shares for the different technologies in Europe are calculated within a dynamic investment approach based on techno-economic data from IKARUS (KFA, 1994). Table 3.17 provides a summary of the derived cost shares across technologies at the EU level.

For the current analysis, we have adopted a dynamic-recursive approach where dynamics are driven by the savings behavior of households under myopic expectations. In line with empirical evidence, the fraction of income devoted to savings is assumed to be constant (*marginal propensity to save*). Total investment then equals the endogenous level of savings. The composition and allocation of investment goods across sectors is determined by profit-maximizing behavior, i.e. investment is allocated to sectors and technologies with the highest returns to capital. This formulation still permits de-investment in technologies as soon as new vintage capital does not offset depreciation. In the dynamic-recursive specification, the time path for the economy is a set of connected equilibria where the current period's savings (investment) provide new vintage capital for the next period. Sector and technology specific capital stocks are updated as an intermediate calculation between periods taking into account new vintage investment and depreciation.

Table 3.17 *Representative technologies and benchmark technology cost shares for Europe*

Representative technologies		Coal	Oil	Gas	Material	Labor	Capital
HCO	Hard coal	30.8	–	–	13.7	8.9	46.5
SCO	Soft coal	35.8	–	–	17.8	3.9	42.4
OEL	Fuel oil	–	33.1		12.4	2.2	52.3
NGS	Natural gas	–	–	32.6	10.5	2.4	54.5
NUC	Nuclear	–	–	–	17.9	4.7	77.5
BIO	Biomass	–	–	–	57.1	5.5	37.5
WND	Wind	–	–	–	–	15.9	84.1
HYD	Hydro	–	–	–	–	8.4	91.6
SOL	Solar	–	–	–	–	11.4	892.9

The dynamic-recursive model is calibrated to the European Commission’s (European Commission, 1999) business-as-usual assumptions on non-uniform growth rates for GDP as well as projections on fossil fuel production and use (the latter determining the carbon emissions). Autonomous energy efficiency improvement (AEEI) factors are employed which scale energy demand functions in order to match GDP forecasts with the energy production and consumption projections. To align the European Commission’s projections on the baseline activity levels of the various power generation technologies up to 2020, we introduce technology-specific endogenous taxes and subsidies. The latter work as a tangible proxy for a variety of market regulation approaches in place within the various EU Member States. Furthermore, a few technologies (NUC, SCO, HYD) are fixed by explicit exogenous policy restrictions or natural capacity constraints.

In our analysis, we examine a renewables phase-in scenario where the EU mandates a linear increase of electricity production from renewable energy sources between 2005 and 2020 starting from business-as-usual (BAU) levels in 2005 up to 30% in 2020. Thereby, we have translated the renewables target for primary energy consumption into a target for the share of renewables in total electricity production as the current PACE version only provides a detailed bottom-up representation of electricity production. Our translated target of 30% for the share of renewables in total electricity production for 2020 is in line with results of the former EU-project Admire Rebus on EU renewables policies. The administered increase in electricity production from renewable energy sources is achieved by (uniform) endogenous subsidies on renewable technologies (in our case: BIO, WND, SOL).

3.7.2 Results

Electricity production and technology mix

Figure 3.31 visualizes the level and technology supply structure of electricity production between the years 2000 and 2020 under ‘Business as Usual’ (*BAU*) for Europe.

[Index 2000 = 1]

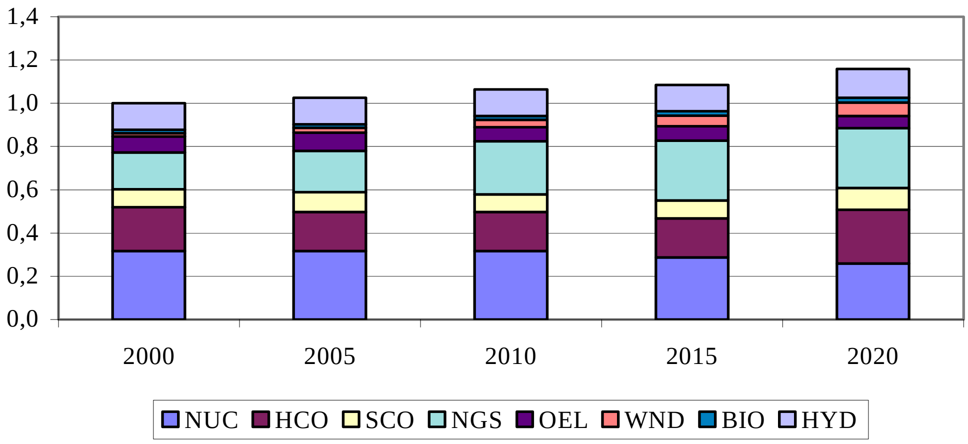

Figure 3.31 *Electricity production by supply technology under ‘Business as Usual’ (BAU)*

Electricity production increases by roughly 16%. Under *BAU*, Europe’s electricity generation is predominantly based on nuclear power, hard coal and natural gas. Between 2000 and 2020 electricity production from oil decreases by about 25%, nuclear power decreases - due to exogenous phase-out constraints - by about 18%, coal production is increased by about 22%, natural gas by more than 60%. With respect to renewables, there is a large increase in electricity supply from wind (almost 360%) and also to a lesser extent from biomass (31%). Hydropower production increases only slightly by 9%. The *BAU* share of renewable energy in electricity consumption increases from 15.3% in 2000 to 18.8% in 2020. For the baseline calibration of PACE we employ endogenous taxes and subsidies to ensure the *BAU* projections by the European Commission with respect to the production levels of the various electricity production technologies. These endogenous taxes and subsidies reflect the regulatory framework for power production across EU member countries.

In the high target case, renewable energy technologies are uniformly subsidized by the government such that the target of 30% renewable energy in electricity production is achieved. The effect of the renewable quota on the level and mix of electricity production is shown in Figure 3.32. Due to the subsidies on renewable energy, total electricity produced by the different electricity supply technologies increases by almost 5% vis-à-vis the *BAU* level (if subsidies were to be financed by a price mark-up on overall electricity production sales - as is the case e.g. in Germany - electricity prices may go up and production may fall). As of 2020, electricity production from hard coal and natural gas is roughly 14% below *BAU* levels, power generation from natural gas declines by 14.5% and by 10.2% for oil. Wind and biomass increase by more than 170%. By assumption, nuclear, soft coal and hydro power production remain unchanged in absolute terms.

[Index 2000 = 1]

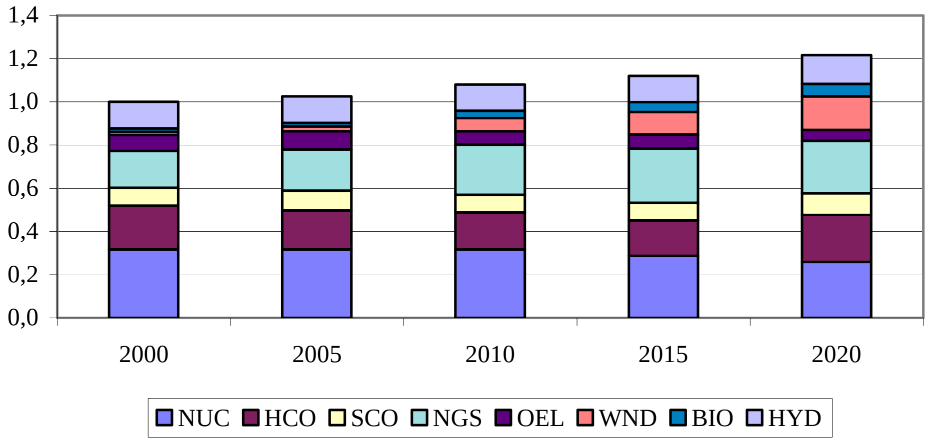

Figure 3.32 *Electricity production by supply technologies with renewable quota*

The implied changes in the technology shares over time are summarized in Table 3.18. The production shares of the fixed technologies decrease slightly after 2010 due to the increase in electricity production for the renewables scenario. The increase in electricity production from renewable sources results in a reduction of market shares for hard coal and natural gas. The market share of hard coal in 2020 decrease from 21.5% under *BAU* to about 17% for the renewables case. The share of natural gas in 2020 declines from nearly 24% under *BAU* to roughly 19% under the renewable quota. The share of wind in electricity production increases from around 5% to 14%, the share of biomass from 2.0% to more than 5%.

Table 3.18 *Production shares for representative technologies in electricity generation under business-as-usual (scenario: BAU) and renewables phase-in (scenario: REN)*

		2000	2005	2010	2015	2020
BAU	NUC	31.6	30.8	29.7	26.5	22.3
	HCO	20.4	17.7	17.0	16.7	21.5
	SCO	8.2	8.9	7.7	7.6	8.7
	NGS	17.1	18.7	23.1	25.6	23.9
	OEL	7.5	8.2	6.1	6.0	4.8
	WND	1.3	2.1	3.1	4.5	5.3
	BIO	1.7	1.7	1.8	2.0	2.0
	HYD	12.2	11.9	11.4	11.2	11.5
REN	NUC	31.6	30.8	29.2	25.5	21.1
	HCO	20.4	17.7	15.8	14.3	17.3
	SCO	8.2	8.9	7.6	7.3	8.2
	NGS	17.1	18.7	21.3	21.9	19.3
	OEL	7.5	8.2	5.7	5.8	4.1
	WND	1.3	2.1	5.9	10.0	14.0
	BIO	1.7	1.7	3.3	4.4	5.2
	HYD	12.2	11.9	11.2	10.8	10.8

Electricity production costs, electricity prices and electricity demand

The quota on renewable electricity production is achieved through an endogenous uniform subsidy on renewable electricity production technologies. Given its large cost disadvantage, solar technology does not break even until 2020 and thus remains inactive also for the renewables scenario.

The uniform ad-valorem subsidy on power production from wind and biomass amounts to 8.5% in 2010, 11.3% in 2015 and 13.7% in 2020 of the technology-specific electricity production costs. Overall these lump-sum subsidies exert a downward pressure on electricity prices as compared to *BAU*. In 2020 electricity prices decrease by 2.3% versus *BAU*. Not surprisingly, the decrease in electricity prices triggers an increase in electricity demand: In 2020, electricity demand increases by 0.7% vis-à-vis *BAU*. Electricity supply increases by more than 2% in 2020 vis-à-vis *BAU*. Accordingly the imports of electricity are reduced by almost 6% until 2020. Table 3.19 summarizes these results.

Table 3.19 *Electricity price, demand, supply and imports*

		2010	2015	2020
Subsidy rate	[%]	8.5	11.3	13.7
Electricity price	[% vs. *BAU*]	-0.9	-1.7	-2.3
Electricity demand	[% vs. *BAU*]	0.3	0.6	0.7
Electricity supply	[% vs. *BAU*]	0.8	1.6	2.1
Electricity import	[% vs. *BAU*]	-2.1	-4.4	-5.8

3.7.3 Consequences of a large share of renewables

Welfare

The welfare implications of the phase-in scenario are measured in Hicksian equivalent variation in income (HEV). Overall welfare losses for Europe are relatively modest ranging from -0.03% in 2010 up to -0.08% in 2020. Obviously, the magnitude of welfare losses is closely related to the stringency of the renewable quota associated with the premature phase-in of renewables.

Employment

Given persistently high unemployment rates in OECD countries, employment impacts of environmental or energy regulation constitute an important policy dimension. If policy initiatives are likely to worsen unemployment, their political feasibility may substantially decrease. On the other hand, positive labor market effects can greatly promote acceptance of environmental or policy interference. It is often argued, that the promotion of renewables generates employment gains. The reason is that (i) renewable energy production is more labour intensive than conventional energy and (ii) renewable energy production uses less imported goods and services. However, subsidies to enlarge the share of renewables in electricity production have to be financed through taxes on other activities or replace subsidies for other activities which will lead to employment losses in other sectors. This crowding out effect may reduce or even over-compensate the employment gains in renewable energy technologies. Some studies found that the net effect of renewable energy promotion is positive (see, e.g., Ecotec, 2002), while other found a negative overall employment effect from renewable subsidization (see, e.g., Pfaffenberger et al., 2003 for Germany).

Model-based analysis of the unemployment impacts of policy interference requires first and foremost the formal treatment of labour markets as imperfectly competitive resulting in persistent unemployment. To date, even though labour market effects of policy interference have become a key interest to decision makers, little work has been done to incorporate unemployment features within the applied general equilibrium framework. One simple approach consists in the replacement of the competitive labour market of the neoclassical standard model with a 'wage curve' (Blanchflower and Oswald 1994). The wage curve reflects empirical evidence on the inverse relationship between the level of wages and the rate of unemployment. In such a model, the wage curve, together with labour demand, determines the level of involuntary unemployment. A recent example is provided in Böhringer et al. (2003). The wage curve constitutes a convenient short-cut to incorporate unemployment, but it lacks an explicit micro-foundation. This makes it impossible to analyse how specific policy measures affect the wage setting mechanism. Another, much more involved way to deal with unemployment is to look into the 'black box' of the wage curve and explicitly model the wage-setting process. Examples are the efficiency-wage model provided by Hutton and Ruocco (1999), MIMIC, a detailed model of the Dutch labour market (Bovenberg et al., 2000), where wage determination is based on collective bargaining between firms and trade unions, or PACE-L (Böhringer et al., 2005), where the German labour market is represented by explicit wage negotiations at the sectoral level.

Applied models that incorporate imperfectly competitive labour markets are typically phrased as single-country models. The reason is that the sources of unemployment are typically due to country-specific institutional labour market restrictions. As to the EU where labor market institutions of Member States may vary substantially, an appropriate modelling of unemployment would require country-specific sub-modules for each Member State. This is clearly beyond the scope of the Cascade-Mints project/modelling exercise. Against this background, we run PACE-EU as a full employment model, so layoffs in one sector are balanced by increases in employment in other sectors. The model framework is static, so it maintains a long term perspective and does not quantify the adjustment costs associated with moving workers from one sector to another. Table 3.20 provides a summary of changes in employment levels in the different European sectors. In the electricity production sector, employment in renewable technologies biomass and wind increase substantially against BaU. Conventional technologies like hard coal, oil and natural gas suffer large employment losses. Fossil fuel production sectors are only slightly negatively affected through the promotion of renewable electricity supply. Given our full employment model, net employment gains in the electricity production sector are fully crowded out by reductions in employment in the two macroeconomic sectors 'Energy-intensive industries' and 'Rest of Economy'. Since these sectors are large in absolute terms, the associated percentage reductions look rather small.

Table 3.20 *Changes in employment levels in the different sectors (% vs BaU)*

	Sector	Technology	2010	2015	2020
COL	Coal		-0.005	-0.012	-0.013
OIL	Oil		-0.070	0.047	-0.059
CRU	Crude oil		-0.037	-0.075	-0.105
GAS	Gas		-0.005	-0.017	-0.015
HCO	Electricity production	Hard coal	-5.683	-11.011	-14.465
SCO	Electricity production	Soft coal	0	0	0
OEL	Electricity production	Fuel oil	-5.636	-0.514	-10.189
NGS	Electricity production	Natural gas	-6.036	-11.056	-14.530
NUC	Electricity production	Nuclear	0	0	0
BIO	Electricity production	Biomass	91.800	131.512	178.877
WND	Electricity production	Wind	91.323	130.548	177.106
HYD	Electricity production	Hydro	0	0	0
EIS	Energy-intensive sector		-0.013	-0.023	-0.043
Y	Rest of economy		-0.012	-0.023	-0.035

Carbon emissions

The mandated increase of renewable energy in electricity production decreases carbon emissions in Europe as compared to *BAU* because carbon-free green technologies replace in part electricity from fossil fuel based technologies. However, part of the decarbonization is offset in absolute emission terms since electricity production increases due to the implicit subsidization of electricity. Overall, carbon emissions in Europe decrease by 1.0% in 2010, 1.7% in 2015 and 2.6% in 2020 vis-à-vis *BAU*.

3.7.4 Conclusions and recommendations

We have investigated the economic and environmental implications of a phase-in of renewable energy in electricity production in Europe. Our quantitative results show that a phase-in of renewables imposes induces relatively small adjustment costs to the European economy. From a climate policy perspective, an accelerated electricity production from renewable energy provides ancillary benefits as carbon-free renewable technologies will replace to some extent fossil fuel technologies - however, part of the technology substitution effect may be offset by increased electricity production depending on the concrete choice of the subsidization scheme.

3.8 NEWAGE-W

3.8.1 Introduction

Increasing the share of renewable energy sources (RES) is considered to be one of the instruments to face environmental issues in Europe. The share of RES in primary energy consumption to be achieved from 2020 on is 20%. Up to the year 2010, 12% is to be reached. With regard to the electricity sector only, these targets can be devided into sub-targets of 22% in 2010 and 33% in 2020 of renewable energy share in electricity production. Table 3.21 presents the RES market shares within Western Europe (WEU) including Norway, Iceland, Switzerland and Turkey, and five other world regions for the year 2000, as reported in the World Energy Outlook 2002.

Table 3.21 *Market shares of energy carriers for electricity generation in the year 2000*

[%]	NAM	WEU	REF	PAO	ASA	ALM
Coal	48.33	29.80	22.91	31.28	61.35	14.87
Oil	3.04	5.63	5.53	12.18	7.90	23.59
Gas	14.40	16.06	34.30	20.75	9.52	23.33
Nuclear	18.94	29.01	17.18	24.21	6.31	1.79
Biomass	1.65	1.58	0.20	1.43	0.14	0.79
Wind	0.13	0.70	0.00	0.00	0.07	0.00
Geothermal	0.33	0.19	0.00	0.45	0.48	0.42
Solar	0.02	0.00	0.00	0.00	0.00	0.00
Hydro[1]	13.17	17.04	19.88	9.70	14.22	35.21
Sum	100.00	100.00	100.00	100.00	100.00	100.00

[1] TIDE/WAVE/HYDRO.

Renewable energy in the electricity production in Western Europe is approximately 19.5% including 178 TWh of hydropower in Norway and Switzerland. Due to the regional mapping in NEWAGE-W used for this renewable case study, RES targets must be applied to the WEU region (see Table 3.22). Because of the above-average amount of hydropower covering nearly 100% of the Norwegian and 56% of the Swiss electricity supply, one has to take RES production in Norway and Switzerland into consideration in order to determine the renewables share in the EU-15 of 13% in the year 2000. However, for the group of Norway, Iceland, Switzerland and Turkey, an increase of the renewable energy share comparable to the EU-15 targets is assumed.

Table 3.22 *Regions in NEWAGE-W*

Region		Countries within Region
NAM	North America	USA and Canada
PAO	Pacific OECD	Japan, Australia and New Zealand
WEU	Western Europe	Western Europe (EU-15 + Norway, Switzerland, Iceland and Turkey)
REF	Countries undergoing Economic Reform	Central and Eastern Europe, Newly Independent States, Former Soviet Union
ASA	Asia Region	Centrally planned Asia and China, South Asia, Other Pacific Asia
ALM	Africa and Latin America	Middle East and North Africa, Sub-Saharan Africa, Latin America and the Caribbean

To analyse the impact of an increased RES share in the EU-15, the computable general equilibrium model NEWAGE-W is used. Within the analytical framework of a general equilibrium model it is possible to cover the major interregional and intersectoral effects, which are caused by a specific policy. The drawback most of the top-down models face is the missing technology representation. The production possibilities are described on a sectoral level founded on input-output data and estimated elasticities of substitution. For analysing an energy economic scenario related to a specific technology, the model has to be adjusted accordingly.

For the renewables case study the representation of the electricity sector within NEWAGE-W was extended. By implementing a sub-sector in the electricity production function, the share of RES in each region can be modeled explicitly. To capture technology-specific parameters of the different renewable energy supply options, cost data were considered. Together with information about market shares of the different generation technologies based on the GMM[12] data, the value shares of each factor input could be calculated. The elasticity of substitution in the electricity sub-sector is assumed to be lower than inf., i.e. electricity from renewable energy sources

[12] GMM is a model of the world energy system, also used in the CASCADE-MINTS project. GMM is operated by the Paul Scherrer Institute in Switzerland.

is an imperfect substitute for conventional electricity production. To assume RES as an imperfect substitute is due to the requirement of a back-up system based on fossil fuels to cover fluctuating wind or solar energy supply.

Using data on fixed costs like investment and variable costs for sectoral intermediate and labor input, it is possible to identify sectoral flows from each sector involved in the electricity supply chain. The evaluation of the data can be illustrated based on the example for electricity production from biomass. Nearly all of the sectoral factor input for electricity production from biomass is provided by agriculture and forestry. The entire value stream from agriculture and forestry to the electricity sector goes into renewables, whereas nothing is provided to conventional electricity supply. In contrast to agriculture and forestry, the interconnection between industry, services and the electricity sector is not that obvious. Sectoral inputs are divided into renewable and conventional electricity production. The sectors that were taken into account to capture the major input structure for renewable energy are machinery, manufactures and equipment, metal products, construction, electricity and services.

Within the analysed RES scenario, the share of renewable electricity generation in WEU that is to be achieved is 22% in 2010, 33% in 2020 and 40% in 2030, respectively. These targets are implemented in NEWAGE-W by a quota on renewable electricity production as a single action in WEU, corresponding to the increasing market shares. According to that, inputs to the RES electricity sub-sector were increased over time, taking a specific elasticity of substitution into account. The model results of the RES scenario regarding effects on GDP, sectoral output changes and changes in output prices, and CO_2 emission are described in the following sections.

3.8.2 Results

With an increased share of renewable energy sources for electricity generation, the gross domestic product (GDP) in Western Europe decreases by approximately 46 bil. $€_{2000}$, i.e. 0.3% compared to the baseline scenario in 2010. The GDP loss amounts to 137 bil. $€_{2000}$ (0.8%) in 2020 and 325 bil. $€_{2000}$ (1.7%) for the year 2030 (see Figure 3.33). The RES quota, which is implemented to guarantee a minimum deployment of renewables in the electricity sector, leads to rising generation costs. Electricity production from fossil fuels is partly substituted by relative cost-intensive generation from wind, hydro, biomass and solar.

The environmental impact of a greater penetration of renewables in Western Europe leads to a decrease in CO_2 emissions, as is expected. The quantity of CO_2 emissions, which could be avoided is approximately 27.3 mln. t of CO_2 in 2010, 68.3 mln. t in 2020 and 117.2 mln. t in 2030, respectively (see Figure 3.33). Due to the fact that the RES quota is applied to the electricity production sector only, one can relate the CO_2 mitigation to a substitution of fossil fuels in electricity generation. Comparing the changes in overall fossil fuel consumption, one can observe that the demand for coal and for gas is going down, whereas there is a small increase in oil demand. Figure 3.34 shows the changes in coal, gas and oil demand in Western Europe, due to a higher penetration of RES compared to the baseline scenario.

The significant decrease in coal demand of approximately 5% in 2010, 11% in 2020 and 19% in 2030, respectively, is mainly caused by the substitution of factor input for electricity generation. As opposed to the strong reduction in coal demand, a more slightly decrease of gas use can be observed. Gas is not as much substituted by renewable energy sources, whereby gas is an input factor in other industrial sectors which are not affected by the RES quota. In contrast to coal and gas, oil usage is going up, when RES is deployed further. The different impact on the various energy carriers are induced by the multiple usage of coal, gas and oil within the economic system as well as the assumed elasticities of substitutions within the nested productions functions.

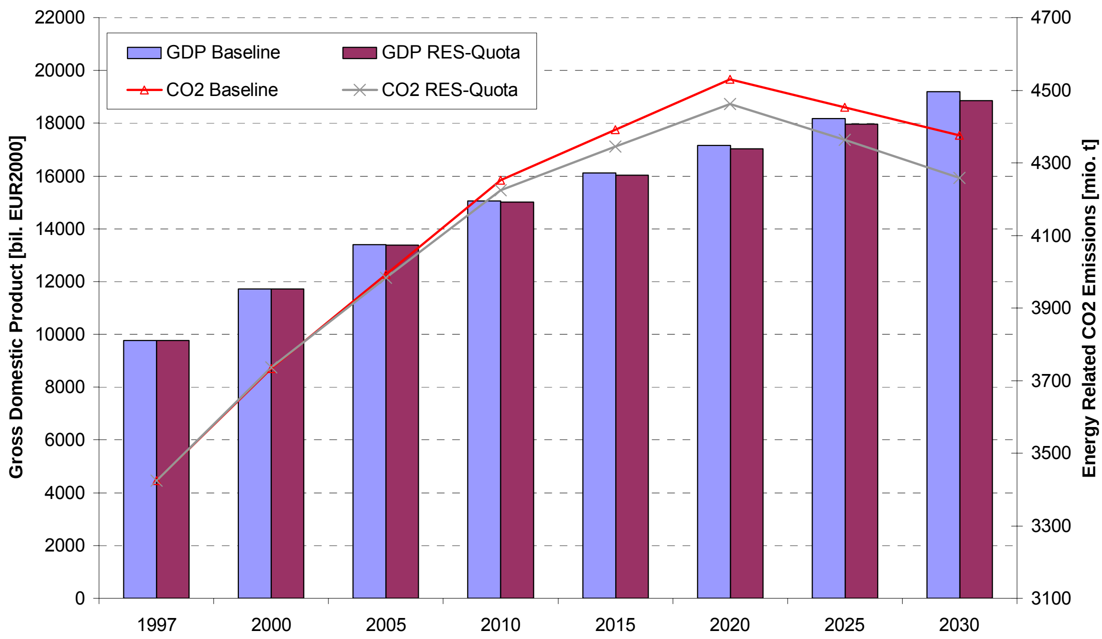

Figure 3.33 *GDP and CO_2 emissions in the baseline and the RES scenario in WEU*

Considering sectoral changes in the production process beyond fossil fuels, it can be observed that the sectoral output is slightly increasing in the sectors, mainly supplying inputs to the RES sub-sector. Figure 3.35 presents the reallocation of sectoral production. One can easily see that the main changes in output are related to the fossil fuel production sectors. Due to the fact that the intermediate inputs to the RES sub-sector for electricity generation come from machinery, building and construction, metal products and services, some changes in these industries could be observed as well (see Figure 3.35).

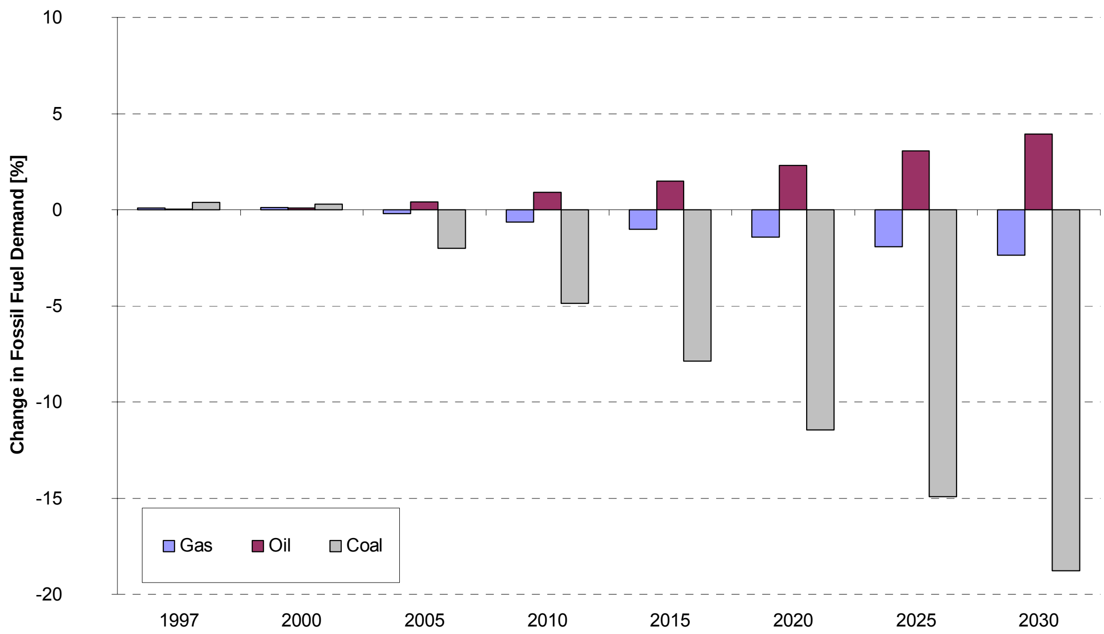

Figure 3.34 *Change in overall fossil fuel demand in WEU, RES case compared to baseline*

The little impact on the output values for some of the sectors which provide intermediate inputs for the RES production, e.g. Machinery or Building is induced by the relative low share for RES inputs of the overall output of these sectors. Other economic effects which are caused by the loss of GDP and higher costs for electricity generation superimpose the intermediate value flows between the RES sub-sector and the rest of the economy.

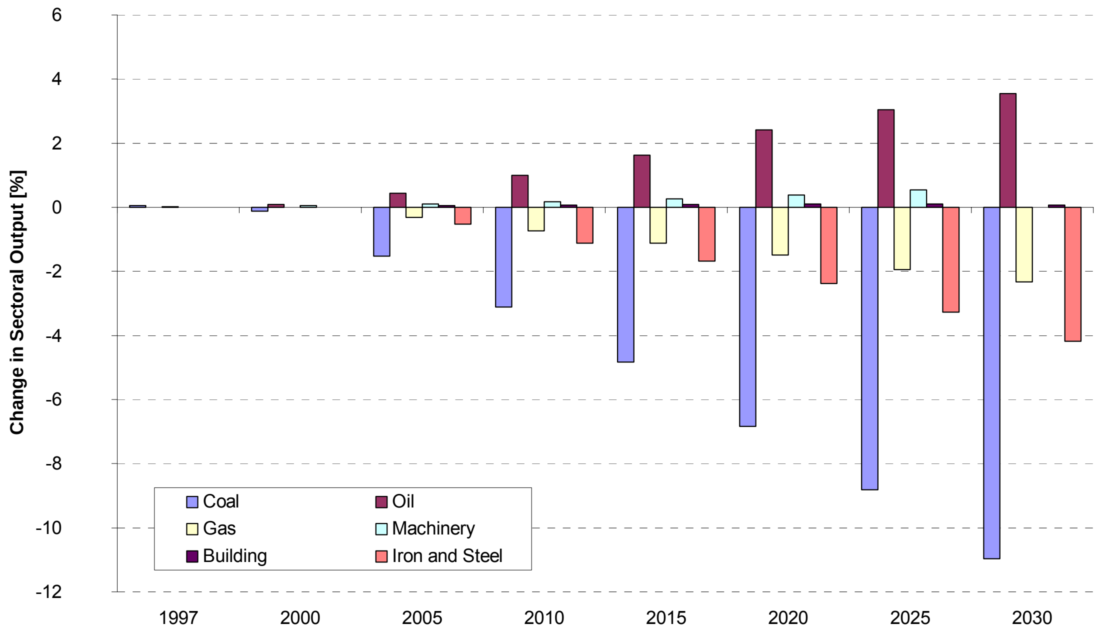

Figure 3.35 *Change in output value for selected sectors in WEU, RES case compared to baseline*

The significant decrease in coal demand for electricity production lowers the output of the coal sector. The increasing electricity generation costs in WEU result in disadvantages for energy intensive industries like iron and steel production. Closely related to the negative impact of higher intermediate factor inputs are the changes in output prices for various production sectors.

3.8.3 Consequences of a large share of renewables

The introduction of a RES quota to increase the penetration of renewable energy sources in the EU-15 (WEU) results in higher electricity production costs. As energy becomes more expensive in the production process, one can observe a negative impact on output and sectoral prices. Figure 3.36 shows the change in the output price in the electricity sector. The electricity price increases in the RES scenario by approximately 11% in 2010 compared to the baseline scenario. In the year 2020 the price lies 25% above the baseline and in 2030 about 47% above the reference, respectively. Figure 3.37 presents some selected sectors which strongly depend on energy inputs like iron and steel, chemicals, and paper and pulp.

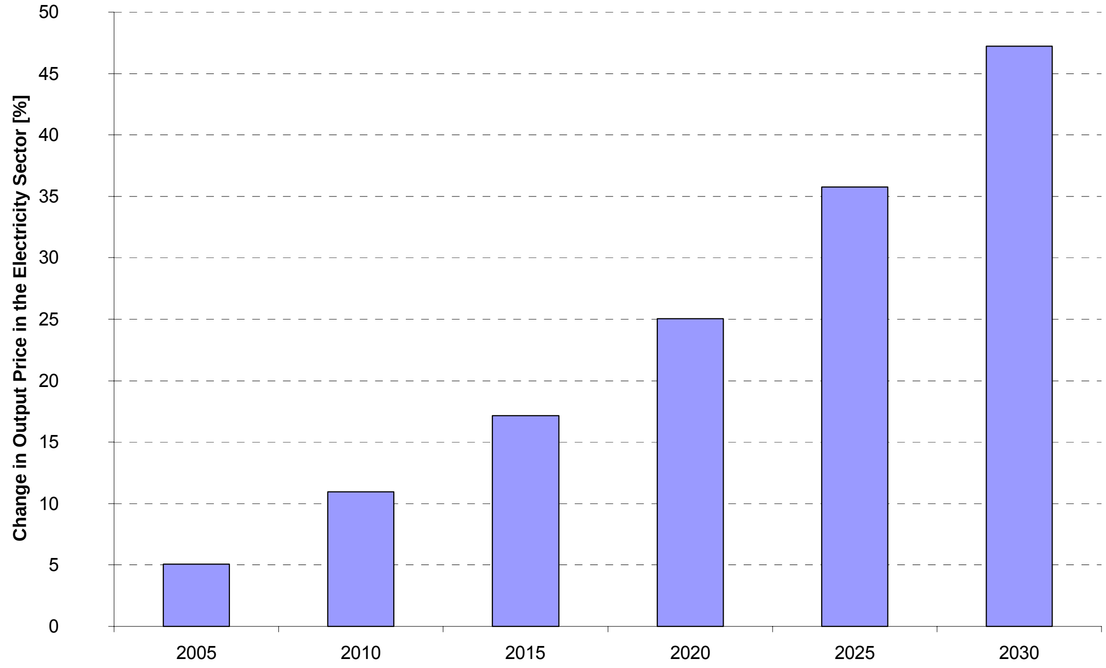

Figure 3.36 *Change in output price in electricity sector, RES case compared to baseline*

Higher cost of intermediate energy inputs results in rising output prices of the related sector itself. Compared to the significant increase of the electricity price, the rise of output prices in the related sectors is much slighter. One can observe an increase of 0.22% in the year 2010 for the chemical production sector and of 0.54% in iron and steel production. The Output prices rise up to 1.43% (chemicals) and 2.22% (iron and steel) in the year 2030 above the reference case. The increase of sectoral output prices and the related reallocations of factor inputs in Western Europe is one reason for the decrease in GDP that can be can be observed up to 2030.

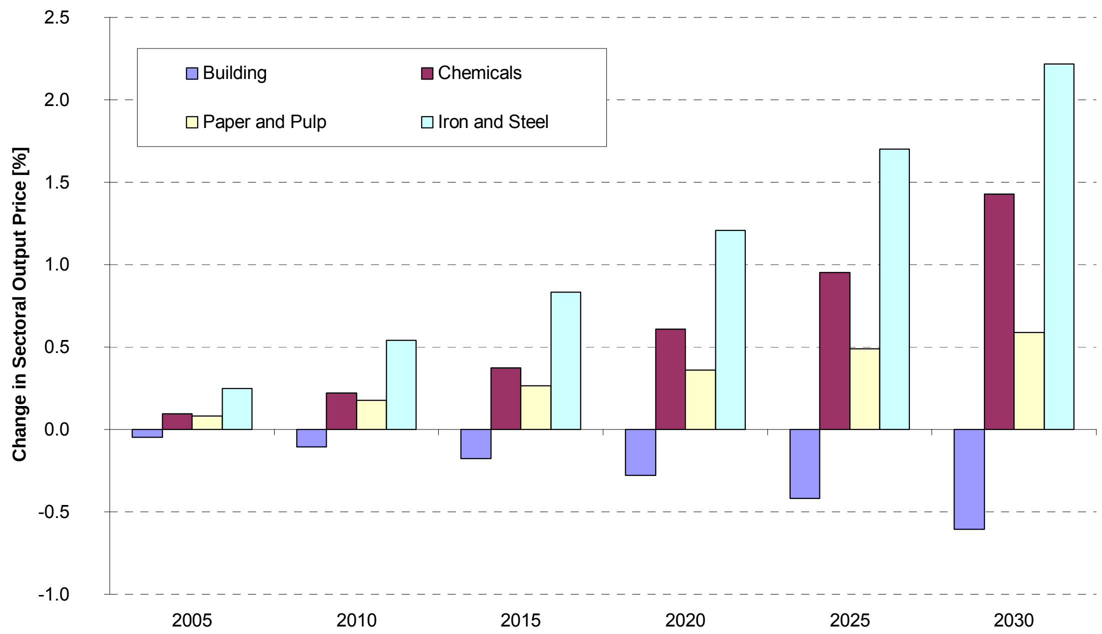

Figure 3.37 *Change in output price in selected sectors, RES case compared to baseline*

Beyond the environmental and economic effects within the region aspiring to achieve a specific target, interregional spillover effects might be induced. By implementing a policy instrument like a quota to ensure a minimum share of renewables of primary energy supply or electricity production, reallocation within the economies facing the policy leads to interregional effects. In the analysed RES case, one can observe increasing oil imports to Western Europe, whereas gas and coal imports decrease slightly. The negative impact on the european GDP also has implications for neighbouring regions.

Figure 3.38 presents the changes in GDP and CO_2 emissions for the three regions Western Europe (WEU), North America (NAM) and the Countries undergoing Economic Reform (REF), due to an strong deployment of renewables in the WEU. The GDP losses faced by NAM and REF lie between 0.01% and 0.02% for the years 2010, 2020 and 2030, respectively. A observed GDP loss in Western Europe of 0.31%, 0.80% and 1.70% is not followed by a comparable GDP decrease in neighbouring regions.

Focusing on environmental spillovers, similar results can be observed. A CO_2 emission reduction within Western Europe of 0.3% in 2010, 0.8% in 2020 and 1.7% in 2030 in comparison to the reference case does not result in CO_2 reductions in NAM or REF to that extent. Due to leakage effects, small increases of CO_2 emissions in REF can be observed.

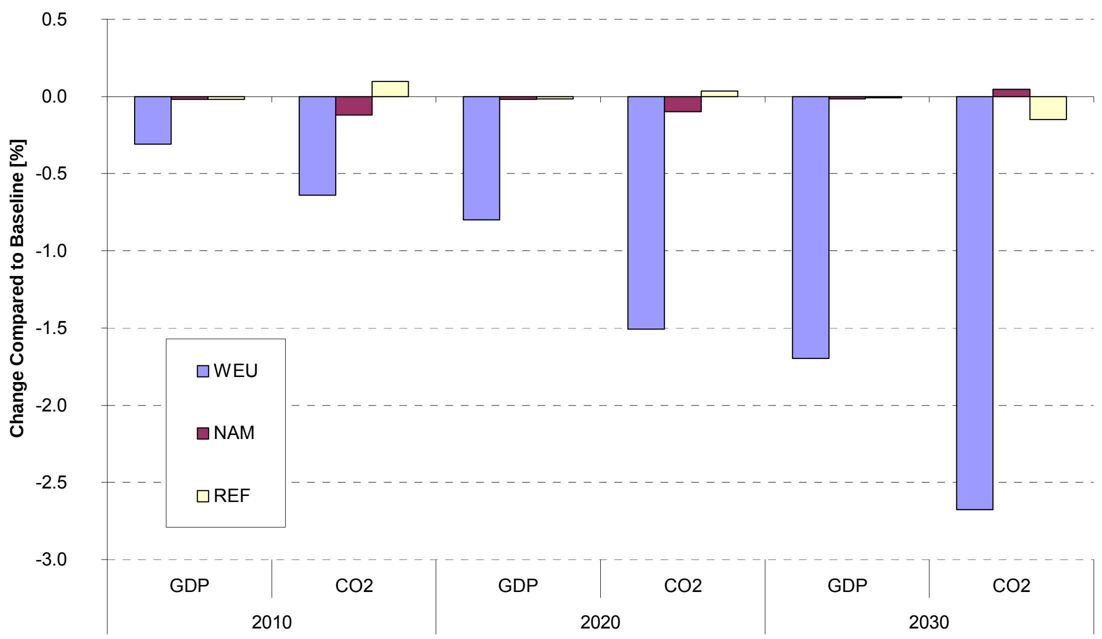

Figure 3.38 *Change in GDP and CO_2 emissions in selected regions, RES case compared to baseline*

Beside the energy and environmental related effects reflected by changes in the regional coal, oil and gas demand and CO_2 emissions on the one hand, and the economic impacts like the changes in GDP or output prices in various sectors on the other hand, effects on employment due to an increased share of RES could be expected.

As a basic principle, each policy instrument which changes the structures of intermediate inputs due to changes in the sectoral production structures, the output prices, or, as a consequence, the growth of GDP has an impact on employment. For analysing the impacts of a specific policy on the labour market, one has to take various effects into account.

The increased deployment of renewable energy sources for electricity production is associated with an increased supply of intermediate inputs for the electricity sector. These increases are caused by a growth of investment and production activity in the RES sub-sector. Due to a stronger investment and production, the input of labour as an primary production factor is increased as well. In these premises, the effect on employment should be positive. Analogous to the positive investment and production effects within the electricity sector, the opposite impact could be caused within other production sectors which provide e.g. fossil fuel inputs for electricity production (see Figure 3.35). The magnitude of the potential negative impact on employment depends on the specific input shares and elasticities of substitution.

Another effect that should be considered is related to the feedback of rising sectoral prices (see Figure 3.36 and Figure 3.37). Due to the strong growth of RES electricity production an increase of electricity prices could be observed. As electricity is an intermediate input factor for all other production sectors in the economy, this price increase could have negative effects on the economic performance and employment. The loss in GDP itself is another evident cause for effects on the labour market. A significant loss in GDP or a strong increase in sectoral output prices due to a specific policy would compensate much of the potential positive impact on employment caused by the investment and production effect. Beside the national-oriented labour market effects, one has to take the international spillover effects into account as well. Increasing prices could cause a decrease in exports, which then could have a negative impact on production and employment itself. A lower GDP e.g. in WEU could be associated with lower GDP in other regions, due to a strong interconnection among the economies.

The analysis of the impact on employment due to a specific energy policy instrument has to take into account all the feedback and spillover effects mentioned above. Within the traditional applied general equilibrium analysis, one can capture all these effects in a closed theoretical framework. Within NEWAGE-W the different sub-effects of employment impacts are covered in principle. The problem for analyzing labour market effects within a CGE model like NEWAGE-W[13] is the lack of labour market specification. Within a traditional CGE model the labour market is treated like any other commodity market, i.e. a fully competitive labour market is assumed. The differentiated labour market structures like imperfect competition, different levels of labour skills, lower bounds for wage levels or trade union power are not covered. As a consequence of the assumption on competition, the regional markets for the primary production factors like labour is cleared in each economic situation. There is no involuntary unemployment due to free prices, i.e. wages.

Keeping these aspects in mind, the impact on employment due to an increased share of renewable energy sources for electricity production calculated with NEWAGE-W could be documented by changes in labour input to production within the WEU to 2030. The demand for labour within the sectors that provide intermediate inputs for the RES sub-sector increases. One can observe that the labour demand in the sectors Building, Machinery, and Services is rising, whereas the demand for labour within Coal or Iron and Steel sectors is decreasing. Labour demand in the chemical production sector, which is an input factor for nuclear electricity production within the electricity sector, is decreasing as well on a very low level.

It can be concluded that compared with the increase in labour demand for sectoral production from the year 2000 to 2030 of approximately 48.0% in Western Europe, the additional increase due to a rising share of RES of less than 1.8% in 2030 is negligible. The overall positive effect up to the year 2030 could be led back to the continuous increase of RES and the positive investment and production effects. The negative price, GDP and trade effects seem to be compensated by these effects. Beside this, the costs for an increased RES share in electricity production and the loss in GDP that is caused by this policy have to be taken into account.

[13] In the version, used for CASCADE-MINTS. The IER is working on a model extension to capture the labour market specifications within NEWAGE-W on a more sophisticated level.

For a comprehensive analysis of the employment effects, a more sophisticated modeling approach of the labour market specifications within NEWAGE-W is needed. Energy and environmental policy instruments should not be deployed as instruments in labour market policy.

3.8.4 Conclusions and recommendations

The implementation of the RES scenario within NEWAGE-W shows that the resulting CO_2 reduction causes loss in GDP for Western Europe of about 1.7% up to 2030. Using a quota system, i.e. setting a minimum share of renewable energy sources for electricity generation, results in increased output prices, mainly in the electricity sector itself. Due to the economic interrelations among the production sectors, the rise in energy prices induces a negative impact on other sectors' output and prices, respectively.

Loss of sectoral output or GDP in neighbouring countries or regions could cause negative feedback to the regions where the policy instruments are applied. To lower negative impact on individual region, a multilateral proceeding were appropriate. A instrument like an emissions trading system or tradable green certificates on a global level, might help to avoid negative economic effects. Beside the possibilities to enhance the efficiency of a RES quota by implementing an international trading system, the inclusion of all sectors within the economy is advisable.

3.9 NEMS (US)

3.9.1 Introduction

Renewable technologies in the United States, Europe and Japan have been supported for over thirty years with R&D investments and, for some technologies like wind and solar, with tax credits or other subsidies. Support for such programs has almost always been motivated by combinations of interest in reducing energy import dependence, reducing damaging environmental emissions, and saving some of the depletable high-quality resources like natural gas for future generations. Underlying these obvious goals has been the hope that by providing moderate-term subsidies, these technologies would eventually become economic and not require further government support. To date, such subsidies in the United States have largely failed to produce economic grid-connected renewable generation technologies except in niche markets, even though the technologies have often met or exceeded their program goals, because the competing technologies have also improved and fuel prices have remained relatively low until recently.

The renewable portfolio generation policies evaluated for this case study are the 12, 20 and 25 percent non-hydro electric renewable portfolio standards. A typical renewable portfolio standard (RPS) requires that a share of the power sold must come from qualifying renewable facilities.[14] Companies that generate power from qualifying renewable facilities are issued credits that they can hold for their own use or sell to others. To meet the RPS requirement, each individual electricity seller must hold credits - issued to qualifying renewable facilities or purchased from others - equal to the share required in each year. For example, a supplier of 10 TWh of retail electricity sales in a year with a 10-percent RPS requirement would have to hold 1 TWh of renewable credits. In a competitive market, the price of renewable credits would increase to the level needed to meet the RPS requirement. The RPS provides a subsidy to renewable generators (from nuclear, coal, natural gas, oil and hydro-electric generators) to make them competitive with other resource options while allowing the market to determine the most economical renewable options to develop.

[14] For this analysis, all non-hydropower renewable electricity generation qualifies.

For all of the RPS cases, these targets are assumed to be achieved gradually between 2008 and 2020 and then remain constant thereafter. Moreover, it is assumed that there is no price limit to the renewable credit price - unusual for any of the legislative proposals in the U.S. Congress.

While a handful of RPS bills have been proposed in the United States Congress over the past five years, ranging from 10 percent to 20 percent and sometimes coupled with other proposals to reduce emissions such as nitrogen, sulphur dioxide, carbon dioxide and mercury, none have garnered enough support to be passed.

Finally, this analysis implements the renewable portfolio standards within the National Energy Modeling System (NEMS)[15] developed by the Energy Information Administration of the U.S. Department of Energy. NEMS was used to develop the *Annual Energy Outlook 2005*[16] *(AEO2005)* reference case. This analysis compares the energy consumption, production, carbon dioxide emissions, and electricity generation capacity decisions of the RPS cases with the *AEO2005* reference case. As a short-hand reference, we may also refer to the 12 percent RPS standard case as RPS 12, the 20 percent RPS standard case as RPS 20, etc.

Key Assumptions of the Analysis

- Technologies and consumer preferences are those assumed for the reference case of the *AEO2005.*[17]
- GDP growth rate in the *AEO2005* reference case is slightly higher than in *AEO2004* with a greater shift toward service industries.
- No maximum national renewable constraint was imposed; adoption of generation technologies in the U.S. market is based on the economic choices and the ability of a technology to serve electricity demand.
- World crude oil prices are higher than AEO2004, much higher in the early forecast years and about $ 3 per barrel (2003 $) higher in 2025.[18]
- Qualifying renewable generation facilities in the United States were assumed to be those that use renewable energy sources and generate electricity but are not conventional hydropower.

3.9.2 Results

While three RPS cases have been simulated using NEMS and the results are shown for all cases, the discussion focuses on the RPS20 case. The primary impact of the RPS cases is to increase renewable-generated electricity and thereby lower some of the new coal-based and natural gas-based capacity additions and generation that would otherwise have been built and generated in the reference case. When the proposed RPS policy requirement is imposed, new renewable capacity is selected on an economic basis, based on the cost and performance characteristics of the generation choices. The direct impact of such policies is to affect the mix of generation technologies chosen and retired and the quantities of fuels used for electricity generation. Such choices affect not only electricity prices but also the prices of fuels used to meet the electricity demand. Under the most extreme case analyzed for the U.S. market, the 25 percent RPS requirement makes some of the nuclear generation plants with the highest operating and maintenance costs become uneconomic and are retired toward the end of the time horizon.

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15 Energy Information Administration, *The National Energy Modeling System: An Overview 2003*, DOE/EIA-0581(2003) (Washington, DC, March 2003), web site www.eia.doe.gov/oiaf/aeo/overview/index.html.

16 Energy Information Administration, *Annual Energy Outlook 2005*, DOE/EIA-0383(2005) (Washington, DC, February 2005), web site www.eia.doe.gov/oiaf/aeo/index.html.

17 http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2005).pdf.

18 While world crude oil prices are likely to be higher than those posited in *AEO2005* through 2010, U.S. oil consumption for generation is very small and the change in oil prices does not have significant impacts on the results of the RPS cases examined.

Fossil fuel primary energy consumption and prices

In the RPS20 case, fossil fuel consumption (Table 3.23 and Figure 3.39) in 2020 is expected to be about 7.1 percent lower than the *AEO2005* reference case - down from 115.4 EJ to 107.3 EJ. For electricity generation in 2020, fossil fuel consumption is about 16.8 percent lower than the reference case - from 38.4 EJ to 31.9 EJ. Natural gas consumption for electricity generation declines the most in percentage terms in the RPS20 case (28.5 percent) while coal use for power generation declines by 20.3 percent relative to the reference case.

Impacts on the Electricity Sector

The penetration of renewable generation technologies that are induced by an RPS policy reduces the construction of the more efficient gas combined cycle and conventional and advanced coal gasification generation technologies that would have been built in the reference case, thereby reducing the overall stock efficiency of fossil-fueled electricity generation plants. In 2020, the RPS20 case is projected to build about 34.9 GW less combined cycle, 13.7 GW fewer gas turbines, and 24.8 GW fewer new advanced coal units; renewable generation capacity is projected to increase by about 144.6 GW, much of which is intermittent wind capacity (about 80.2 GW above the reference case) (Figure 3.40).

Table 3.23 *Summary of RPS Cases for 2020 and 2025*

		2020				2025			
	2003	Reference	RPS12	RPS20	RPS25	Reference	RPS12	RPS20	RPS25
Average Delivered Fuel Prices (2003$ per million Btu)									
Coal	1.30	1.27	1.10	1.18	1.19	1.32	1.28	1.22	1.21
Petroleum	10.51	10.29	10.3	10.32	10.31	10.66	10.67	10.67	10.68
Natural Gas	6.86	6.3	6	5.66	5.62	6.59	6.44	6.41	6.31
Electricity	21.74	21.11	21.02	21.29	23.14	21.38	21.35	21.91	22.69
Fossil Energy Consumption (EX)	89.06	115.42	111.03	107.26	104.98	122.89	118.32	114.16	111.75
Coal	23.98	28.80	25.32	23.40	22.44	32.19	28.79	26.73	24.51
Petroleum	41.28	54.17	54.02	53.89	53.69	57.47	57.32	57.10	57.05
Natural Gas	23.80	32.45	31.68	29.97	28.85	33.23	32.22	30.34	30.19
Total Primary Consumption (EX)	103.72	132.63	134.22	135.06	134.43	140.66	141.82	142.77	142.98
Electricity Generation (Bkwh)	3649	5011	5008	4989	4878	5432	5415	5383	5283
Coal	1949.9	2473.6	2139.6	1952.2	1863.2	2869.4	2523.4	2299.4	2070.3
Petroleum	112.6	131.2	120.3	110.7	103.2	135.2	127.4	113.7	113.2
Natural Gas	555.9	1233.9	1082.4	829.1	670.8	1234	1070.2	782.7	714.1
Nuclear	763.7	830.2	830.2	830.2	779	830.2	830.2	830.2	765
Renewables	323.4	415.6	907.7	1338.8	1533.8	434.2	935.1	1427.8	1690.8
CO2 Emissions (million metric tons)	5789	7520	7165	6898	6750	8062	7704	7414	7211
Renewable Credit Price (2003 cents/kwh)	NA	NA	1.9	3.7	7.5	NA	1.4	2.6	3.8
Capacity Additions (2005-) Gigawatts									
Coal	NA	31.8	17.4	7	3.3	85.4	48.9	21.1	9.1
NGCC	NA	44.2	24.5	9.3	4.2	56.8	34.5	11	7.5
Gas Turbine	NA	47.4	53.3	33.7	23.3	69.9	71	63.7	62.7
Renewable Capacity	NA	4	67.6	148.6	205.4	7.7	95	187	235.8

Bkwh = Billion killowatthours
Run Sources: aeo2005.d102004a, eurps12.d112204b, eurps20.d112204a, eurps25.d112304a.

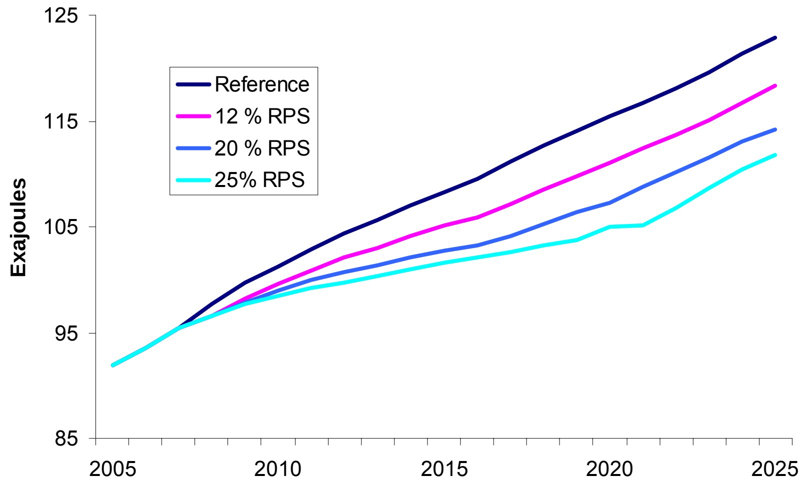


Figure 3.39 *Fossil Fuel Consumption, Four Cases*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

The RPS electricity production is expected to be slightly lower in 2020 than the reference case (about 22 TWh or 0.4 percent) because of the higher electricity prices that result from the RPS (Figure 3). However, electricity generation from non-hydro electric renewables increases from about 107 TWh in the reference case in 2020 to about 1031 TWh in the RPS20 case. Total renewable generation, including hydropower in 2020 is 1339 BkW (Figure 3.42). The primary contributors to non-hydro renewable generation in the RPS case in 2020 are expected to be biomass generation from both dedicated plants and co-firing with coal (about 617 TWh), wind systems (about 325 TWh) and geothermal (about 73 TWh).

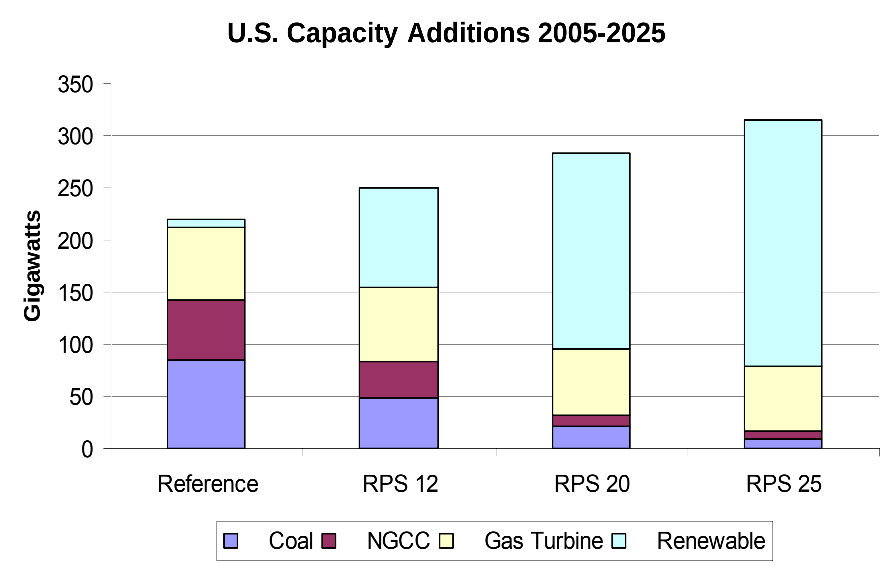


Figure 3.40 *Capacity Additions, 2005 - 2025*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

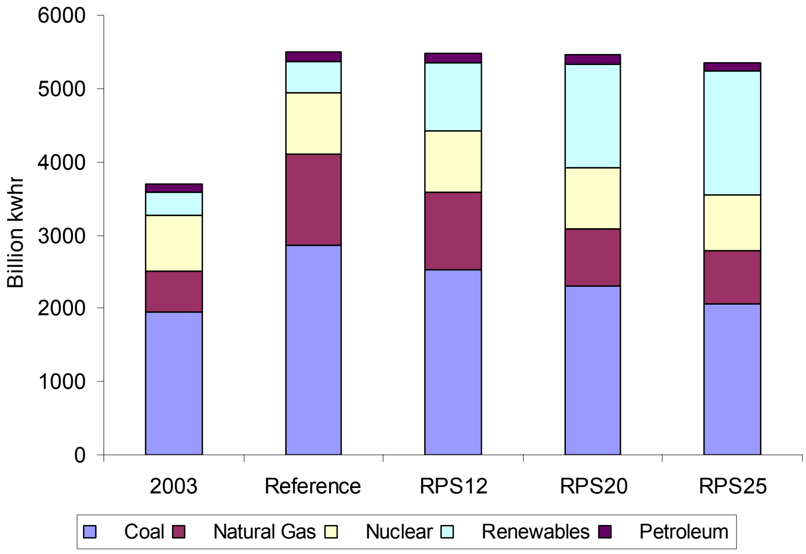


Figure 3.41 *U.S. Electricity Generated by Fuel in 2025*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

The displacement of some natural gas and coal for electricity generation lowers the demand for these fuels and hence the delivered prices to all consumers. For electricity, however, the lower delivered natural gas and coal prices to utilities means that the renewable credit prices had to rise high enough to make renewable capacity economic to meet the RPS20 standard. Consequently, by 2020 the average price of electricity to all consumers in the RPS20 case is slightly higher than the reference case. By contrast, the RPS25 indicates that the U.S. market will find it considerably more difficult and expensive to achieve a 25 percent RPS than the 20 percent RPS as indicated by Figure 3.43.

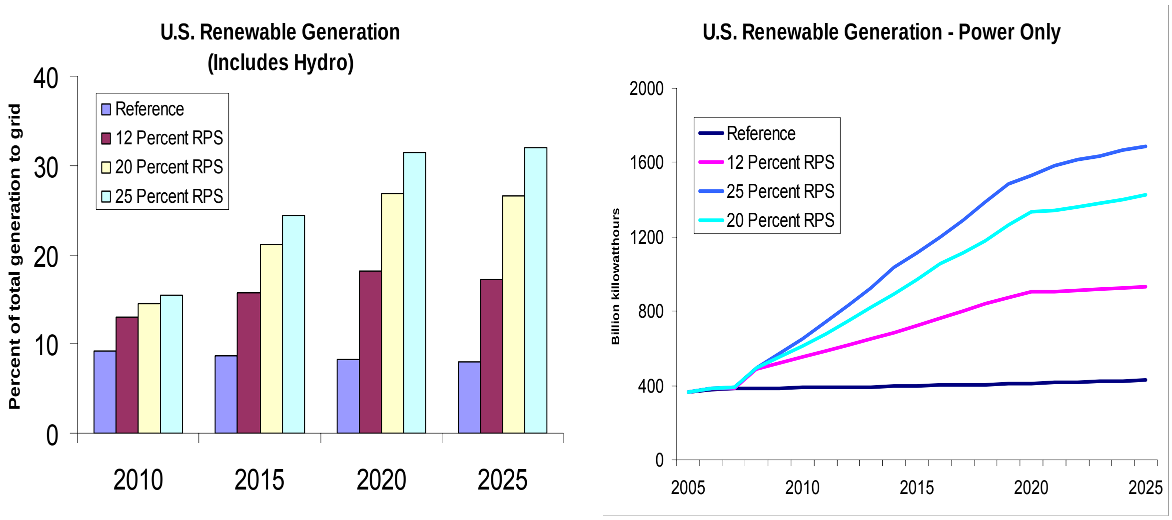


Figure 3.42 *Total Renewable Generation and the Renewable Share of All Generation for the Grid*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

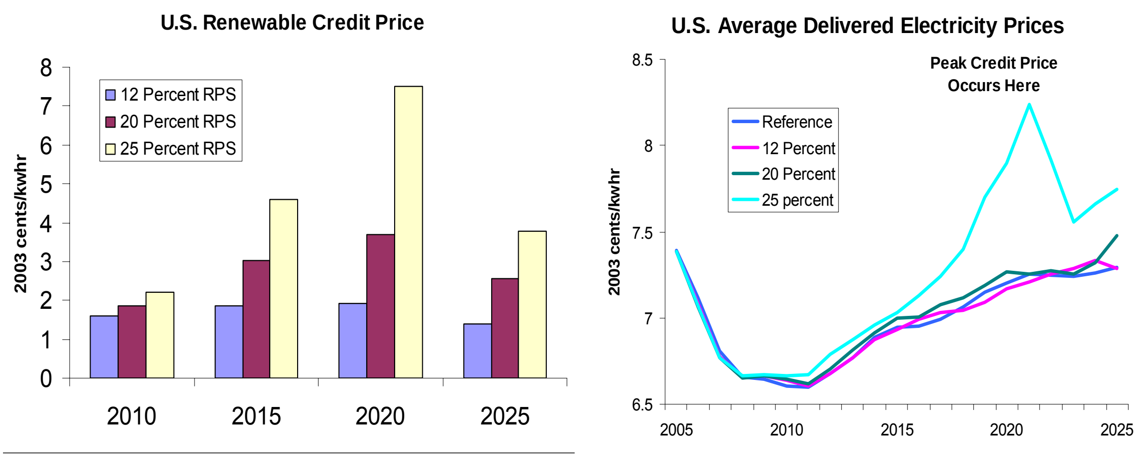


Figure 3.43 *Credit Prices and Average Delivered Electricity Prices for Four Cases*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

Costs of the 20 percent renewable portfolio standard policy
Imposition of a renewable portfolio standard on the U.S. generation markets is projected to have a relatively mild adverse affect on delivered electricity prices but a significant cost to the electricity industry. Electricity prices in 2020 in the RPS case are projected to be less than 1 percent higher than the reference case as a result of the costs that were added to electricity prices to conform to the RPS standard (Figure 3.43, Figure 3.44 and Table 3.23). The reduction in natural gas prices in the RPS case in 2020 relative to the reference case mitigates against the price increases that would otherwise have occurred because of the renewable credit prices paid and the additional capital invested in renewable generation technologies. However, the cost to the electricity industry over the next 17 years is expected to rise in constant 2003 dollars, reaching $ 16.8 billion in 2020 and $ 34 billion in 2025 (Figure 3.44) in the RPS20 case.

As the industry ratchets up its usage of renewables to 20 percent by 2020, significant issues emerge regarding the ability of the U.S. renewable resources to continue to expand as evidenced by the rising renewable credit prices and the slowing expansion rate of wind and geothermal capacity. For example, geothermal resources are projected to have utilized almost 50 percent of all remotely competitive sites, although another 10 GW of additional capacity are possible at significantly inferior and costlier sites. Wind expansion in 2020 begins to be limited by the amounts of cost competitive wind resources remaining in regions that are sufficiently close to demand and transmission centers to allow further expansion. Although wind capacity is projected to reach 91 GW by 2020 under a 20 percent RPS, expansion beyond 150 GW is likely to be very expensive, based on economic considerations alone. Limits to the market potential for wind generation seem to be based as much on aesthetic considerations and land-values as it is on economic and engineering considerations. The rapid growth of biomass generation is likely to be eventually limited by the competition between agricultural uses and the generation of an energy feedstock for biomass power generators. Further, dedicated biomass gasification plants must be built within a 50 mile radius of their resources to be cost effective, otherwise transportation costs are likely to make biomass generation very expensive (raise renewable credit prices).

Finally, any new programs that aggressively promotes the development and use of biofuels in U.S. energy markets, such as ethanol, methanol and biodiesel are likely to make compliance with all of the electricity-based RPS standards much harder and more expensive because of the competition for the biofuel feedstock and the competition with the other uses for agricultural lands.

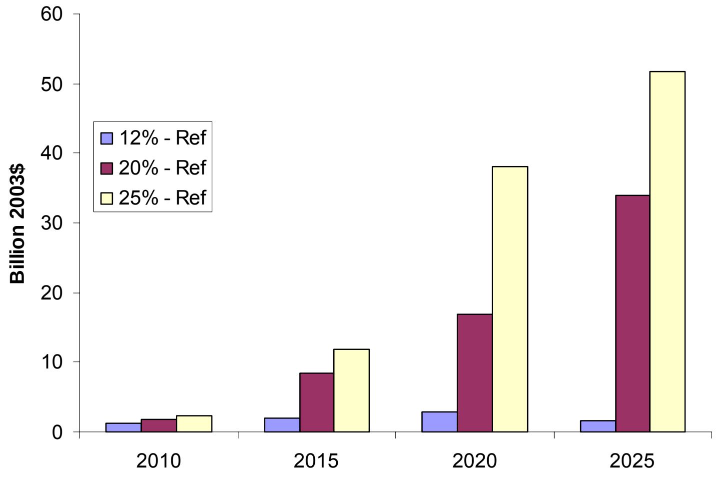


Figure 3.44 *Change from Reference of U.S. Electricity Resource Costs for RPS Cases*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

CO_2 emissions
NEMS projects only carbon dioxide emissions on a system-wide basis for the U.S. In 2020, carbon emissions are projected to be about 8.3 percent lower in the RPS20 case compared to the *AEO2005* reference case (see Figure 3.45). However, carbon emissions from electricity generation are over 21 percent lower in the 20 percent RPS case than in the reference case thanks to meeting the 20 percent RPS target in 2020. More than 77 percent of the carbon dioxide reductions in the generation sector are due to reductions in coal-fired generation.

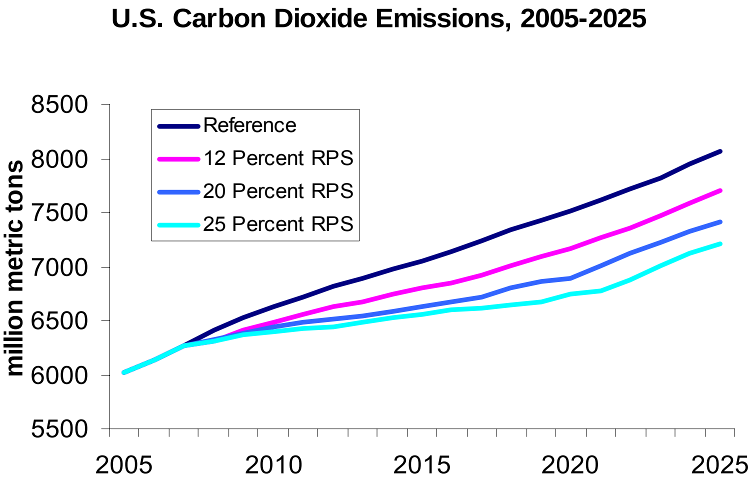


Figure 3.45 *Carbon Dioxide Emissions in Four Cases*
Sources: Energy Information Administration runs. aeo2005.d102004b, eurps12.d112204a, eurps20.d112204b, eurps25d112304a.

3.9.3 Conclusions

The various electricity portfolio standards proposed are not ‘win-win’ policies for all segments of the U.S. energy markets, particularly for the power generation sector. The direct energy cost impacts of the RPSs, up to about 20 percent, do not appreciably change average delivered electricity prices and generally decrease end-use natural gas prices, making this policy attractive to most consumers. However, the RPS policies can add substantial costs to the power industry and therefore adversely affect shareholder wealth. Moreover, coal producers and regions with a very high percentage of coal-based generation are likely to be unhappy with such a development since it could well imply some job losses for the coal-based industries.

From a renewable resource feasibility perspective, NEMS does not model the competition for land and its alternative applications for food, lumber and leisure. Wind resources are theoretically known but their actual accessibility and associated costs have not been reliably estimated. The levels of capacity of wind and biomass generation projected in the RPS20 and RPS25 cases imply large paradigm changes for the United States power sector and rapid change will undoubtedly idle capacity which otherwise would have been profitable to employ. Consequently, the levels of biomass and wind-based electricity generation are highly uncertain and depend as much on technological progress and economic developments as on public acceptance of such technologies at such high levels.

4. Synthesis: Impacts of 2020 renewables targets for Europe

Two different targets have been analysed for the 2020 share of RES in primary energy consumption. The level of these targets is based on recent discussions within the European Union and at the Renewables Conferences in 2004 in Berlin and Bonn. In April 2004, the European Parliament considered the recommendations of the Berlin Conference. It urged the Commission and the Council to start a political process of setting ambitious, time tabled targets for increasing the share of renewable energy in final energy consumption, addressing the medium and long-term time frame in advance of the Renewables Conference in Bonn, and called upon the Commission and the Council to make the efforts necessary to reach a target of 20% for the contribution by renewable energy to domestic energy consumption in the EU by 2020.

In May 2004, the Commission issued a Communication on 'The share of renewable energy in the EU' (European Commission, 2004), in which it 'acknowledges the importance of providing a longer-term perspective, considering in particular the infant nature of the renewable energy industry and the need to ensure sufficient investors' security. Acknowledging the outcome of the currently available feasibility studies, however, the Commission considers it necessary to more thoroughly assess the impacts of RES resources, notably with regard to their global economic effects before deciding on adopting targets beyond 2010 and before taking a position on the abovementioned 20% target for the share of renewable energy in 2020'. The CASCADE MINTS project aims at contributing to this impact assessment by analyzing the feasibility and consequences of the 20% target for 2020 ('High Target'). It will be compared to 'Low target' of a 12% share of renewables in primary energy consumption; this corresponds to the target set in the White Paper 'Energy for the Future' (1997) where it was set for 2010[19].

4.1 A variety of subsidy schemes implemented

In Table 4.1 an overview is provided of the policies and subsidy schemes applied in different models to achieve the renewables targets. Depending on the structure of the model, roughly two approaches for implementing targets are possible. The first is to impose the target and to evaluate the consequences (required subsidies) and/or technological developments. The second approach is to introduce policies (subsidies, R&D, other...) and to evaluate what it takes to achieve the target. Table 4.1 shows examples of both approaches, and also illustrates that different models applied the policies to different regions. Not all models are capable of including this overall target, some have therefore only looked at a sub-target of 33% RES-E in gross electricity consumption.

In this chapter we will first discuss PRIMES, POLES and MARKAL, that have evaluated the overall target. Next, in Section 4.3, we will focus on the power sector, and present results from the other models involved in this case study.

[19] The 'low target' of 12% has been reported on in Chapter 1 for individual models.

Table 4.1 *Policy assumptions by model and by sector; high target case*

	Region to which policy applied	Power sector	Transport sector	Other sectors
POLES	EU-30[20]	20% Primary consumption target in 2020 (leading to a 44% RES-E share in electricity consumption); requiring a subsidy of 5.8 €ct/kWh, starting in 2005 and constant over time		
PRIMES	EU-25	Subsidies for RES-E; 2 €ct/kWh in 2010; 4 €ct/kWh in 2020	Implementation of Biofuels Directive (target 5.75% in 2010)	Promotion of biomass and waste in industry; use of solar thermal water heating in buildings
MARKAL	EU-15, Norway, Switzerland, Iceland	33% Electricity consumption target in 2020 (corrected for contribution Norway)	Tax on diesel and gasoline (€ 0.25 per liter in 2020)	Carbon cap of 700 Mton CO_2 in industry
TIMES-EE	EU-15	National targets in the EU-15; resulting in 33% in 2020; certificate price of 4.8 €ct/kWh		
NEMESIS	EU-15, Norway	Constant subsidy RES-E production: 2.4 €ct/kWh (2005-2020) leading to 33% RES-E share (36% incl. Norway)		
PROMETHEUS		Constant subsidy of 4 €ct/kWh (2005-2030) required for 33% target; comparable to doubling cumulative R&D investments & a subsidy of 2.5 €ct/kWh		
NEWAGE-W	EU-15, Norway, Switzerland, Iceland, Turkey	33% Target in 2020		
PACE	EU-15	30% Target in 2020		
NEMS	US	25% and 20% Targets (Renewables Portfolio Standard)		

4.2 Achieving 20% renewables in Europe in 2020

Figure 4.1 shows the development of the share of renewable energy in Europe for the three models that have evaluated the overall target. It should be noted that the three models cover different regions, ranging from Western Europe (MARKAL) through EU-25 (PRIMES) to a region encompassing 30 countries in Europe (POLES), but not entirely overlapping the EU-25, because the Baltic states are not included. The 20% target appears to be ambitious, as only POLES achieves it in 2020, and does so by including Norway with a large hydropower share. The reasons for the apparent ambition level of the target differ by model, but are related to the possibilities within different sectors to switch to renewables, and the time required for such shifts.

20 EU-25, excluding Baltic states, but including Norway, Switzerland, Turkey, Romania, Bulgaria, Ex-Yugoslavia, Iceland and Albania.

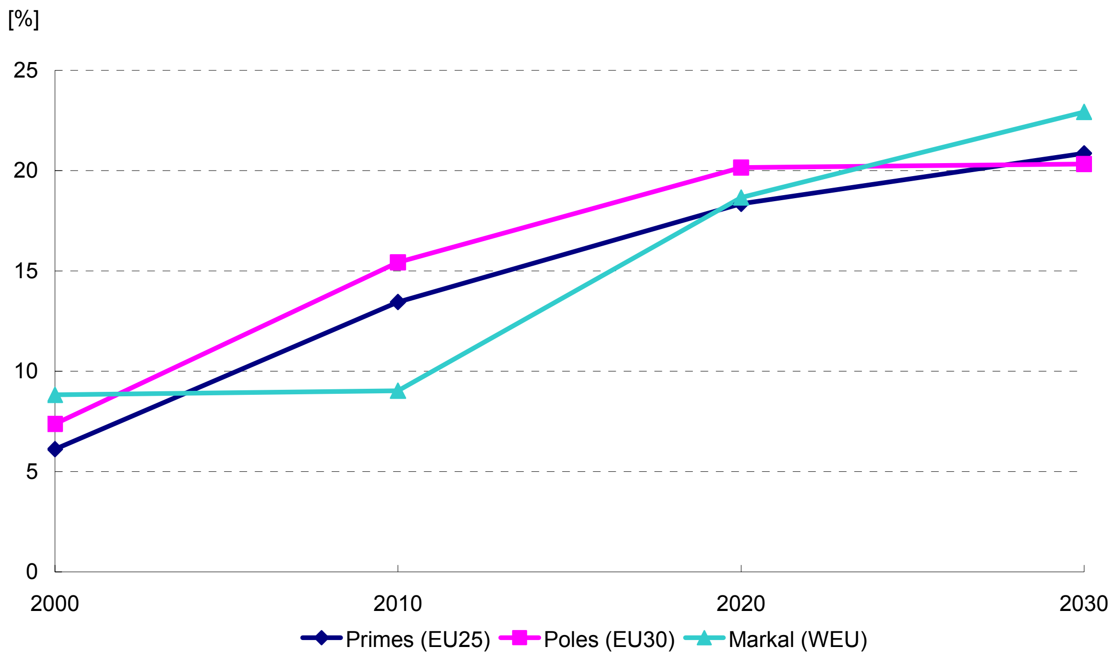


Figure 4.1 *Contribution of RES to primary consumption (Eurostat convention)*

In MARKAL, the overall share of renewables in primary consumption does only reach 18.6% in 2020. This share, applicable to Western Europe, is based on contributions of different sectors as follows.

- In the power sector, a 33% contribution of electricity from renewable sources is achieved in 2020, excluding the contribution of Norwegian hydropower. This requires a subsidy of 4.1 €ct/kWh[21]. Although the model would be capable of achieving a higher RES-E share in 2020, it is questionable whether this would be realistic, given the current expectations that in 2010, only some 19% RES-E might be reached instead of the 22% target (European Commission, 2004). Moreover, a higher share of RES-E might require advanced technical solutions to problems related to the intermittent character of many renewable sources.
- In the transport sector, the targets of the Biofuels Directive are more than achieved in 2010, and in 2020 an almost complete shift from diesel to biodiesel is established by imposing a tax on regular diesel and gasoline. This leads to a 32% share of biofuels in the final energy demand in the transport sector in 2020. Towards 2030, this share can increase further due to a replacement of gasoline with bio-ethanol, and a further growth in diesel driven cars. This is the main reason for the further growth of the overall RES share to 23% in 2030, as shown in Figure 4.1.
- Imposing a carbon cap on the emissions of the industry sector has shown that this sector does not have much room for a more renewable energy supply. The use of biomass in the industry would be possible, but suffers from competition with applications in the transport sector. The present and expected technological options show other ways of reducing emissions, namely a shift from solid and gaseous (fossil) fuels to electricity, steam and heat, and hydrogen rather than increasing the contribution of renewable energy.

These results show that substantially higher contributions from the power sector, the transport sector and the industry seem unlikely. Therefore, to achieve the 20% target, applications in other end-use sectors should be explored, such as renewable heating in buildings (solar thermal water heaters or biomass-based district heating).

[21] In the model this is the shadow price of the constraint related to the 33% target.

The results of PRIMES for the EU-25 show a share of 18.3% in Europe's primary energy consumption in 2020, comparable to MARKAL, but reached in a different way.

- In the power sector, again the 33% subtarget for renewable electricity is achieved, and requires a subsidy of 4 €ct/kWh, comparable to what was found by MARKAL. However, the composition of the renewable technology mix for electricity generation differs in that far more biomass is deployed (40% versus 10% in MARKAL, see the next section).
- Related to this, the transport sector deploys a relatively smaller amount of biomass for biofuels. PRIMES achieves a 14% share of biofuels in total final energy demand of the transport sector in 2020 (or a 17% share of biofuels in gasoline and 17% share in gasoline and in diesel oil).
- Further penetration of renewables on the demand side is achieved through promotional policies for the use of biomass and waste in industry and the use of solar thermal panels for water heating purposes in services and households. In 2020, the options on the demand side are highly exploited.

Finally, POLES shows a completely different distribution of the overall 20% target over the different sectors. In the POLES model this distribution is endogenously determined, whereas the other models have taken the 33% RES-E subtarget as a starting point. The renewable electricity share reaches 44% in 2020, although this is somewhat easier because it includes the contribution of Norwegian hydropower. It is remarkable that POLES projects a far lower share of biofuels than the other two models. Given the endogenous allocation over the sectors, this indicates that biomass applications in the power sector are cheaper than in the transport sector. On the other hand, the fact that in POLES geothermal energy is not included, and heat production from renewable sources is only partially modelled, suggests that more could be achieved in the heat sector.[22]

4.2.1 A crucial role for biomass

The three models that have evaluated the overall target give some insights into the competition of different biomass applications. Figure 4.2 presents the contribution of renewables to the primary energy consumption; showing that over 40% of the primary renewable supply is based on biomass, and 20-25% comes from wind. Furthermore it is noteworthy that in PRIMES a significant contribution of solar power is projected, mainly due to the implementation of promotional policies for solar thermal water heaters. On the other hand, PRIMES shows a lower penetration of wind energy, presumably due to lower potentials, or higher costs than in the other models. The POLES and MARKAL models show a larger share of hydropower than PRIMES. This difference is already visible in the year 2000, and mainly due to the inclusion of Norway, and, for POLES, Turkey. The potential for growth in hydropower is limited to small installations. The role of wind and other renewable electricity generation technologies will be further discussed in comparison with other models that have focused on the power sector.

[22] E.g. according to the FORRES (2002) study, the contribution of geothermal and the heat ration could reach 2% of RES by 2020. [5]

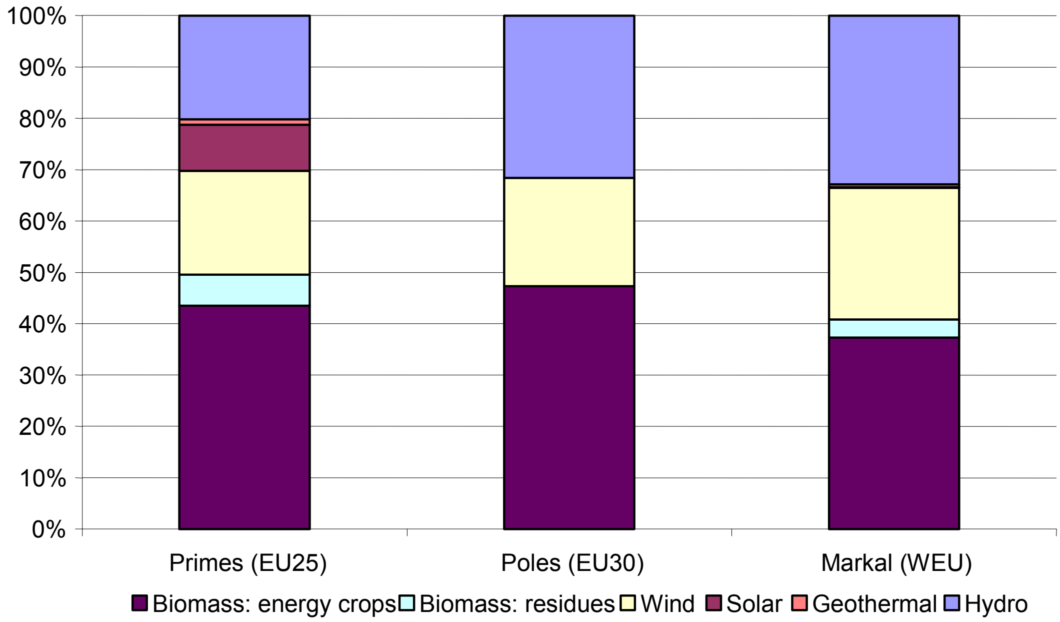


Figure 4.2 *Composition of the primary mix of renewables in the high target case; year 2020*

The amount of biomass deployed in 2020 ranges from 7.9 EJ (MARKAL) to 10.2 EJ (PRIMES) to 12.6 EJ in POLES. These differences are larger than can be explained from differences in regional coverage, taking into account that according to PRIMES, the EU-15 uses 9 EJ biomass, so only 1.2 EJ can be attributed to New Member States. Figure 4.3 shows the sectoral distribution of the biomass usage in different models. The differences among the models can be explained from a combination of how the policies were designed (see Table 4.1) and relative costs differences among renewable technologies. MARKAL shows by far the largest biomass deployment in the transport sector, due to a high tax on regular fuels. PRIMES allocates more biomass to the power sector, some 50%. POLES expects only a very modest contribution of biofuels in 2020, indicating that application in the power sector is less expensive. By 2020 the integrated biomass gasification and combined cycle technology becomes leading for biomass. POLES is the only model that expects a large growth in biomass heating applications in industry (*Conventional burning for heat*) in the years 2000-2020, whereas the more modest shares in MARKAL and PRIMES are comparable, albeit increasing with 70% in MARKAL due to the carbon cap in industry, and decreasing with 40% according to PRIMES. The category ‘other’ encompasses the residential, services, agricultural and district heating sectors, but is not completely comparable among models.

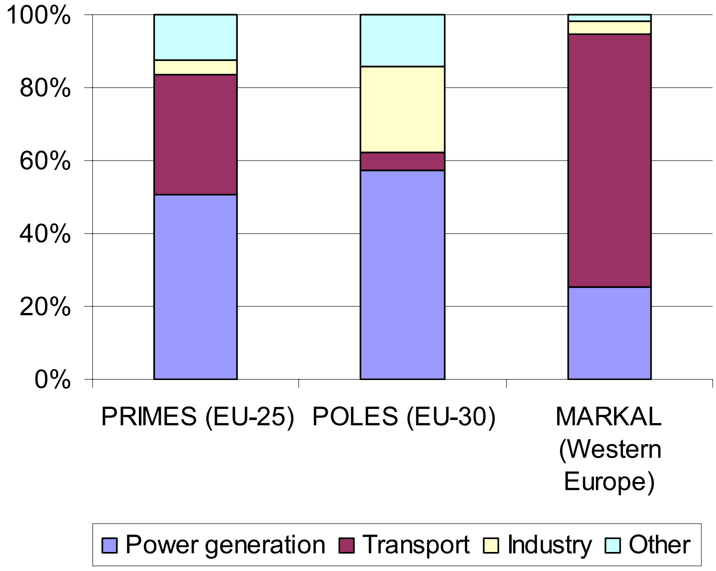


Figure 4.3 *Biomass deployment by sector in 2020; high target case*
Note: For reasons of comparability, the POLES data excludes Turkey in this graph.

According to MARKAL, not all of the biomass used is produced in Western Europe. In 2020, 30% of the biomass consumption is imported, consisting mainly of residual wood (60%) and forestry thinning (40%). The biomass from within Europe consists of fiber chips (50%), straw (27%), landfill gas (16%), and some cellulosic products. Both domestic production and imports continue to grow beyond 2020. On the other hand, PRIMES and POLES assume that all biomass is domestically produced in each country. Given the fact that PRIMES shows a larger amount of biomass usage than MARKAL, these potentials are to a large extent deployed. Here it should be noted that domestic biomass is constrained in MARKAL due to competition over land use with agricultural products. If the EU would change its agricultural subsidising policy, domestic biomass production could increase considerably.

4.2.2 The share of fossil fuels in Europe is reduced from 75% to 65%

Figure 4.4 illustrates a clear impact of the 20% target on fuel mix for the primary consumption in Europe. All three models show that a larger penetration of renewables is at the expense of fossil fuels and nuclear power. However, the distribution of these effects shows a mixed picture, due to the differing policies applied to different sectors (see Table 4.1), the different regional coverage, and the already different fuel mixes in the baseline. The PRIMES model shows the largest reduction in nuclear power (11%), while oil and gas reduce both some 8%. PRIMES had already a relatively large share of RES in the baseline and therefore shows a smaller difference than the other two models. For MARKAL, due to the strong policies in the transport sector, the contribution of oil is strongly reduced by 26%, while the use of coal for electricity production decreases significantly by 24%. Finally, POLES also shows a large reduction of solids for power production (28%) and natural gas (14%).

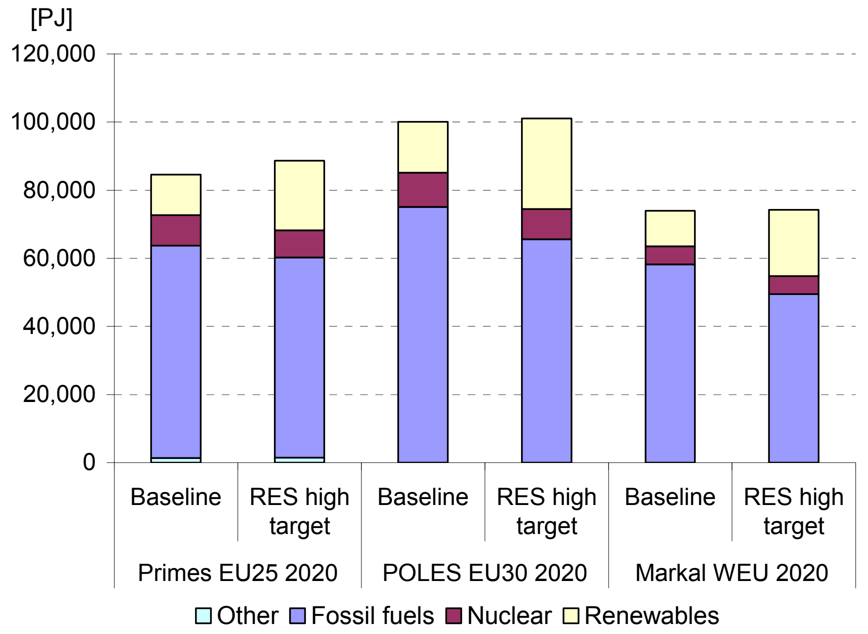


Figure 4.4 *Primary energy mix in baseline compared to the High renewables target*
Note: Primary consumption of renewables in this graph has been calculated according to the substitution principle. However, if the Eurostat convention was used, the only difference would be a lower amount of RES.

4.3 Achieving 33% renewable electricity in 2020

As shown in Table 4.1, several models have only examined the effects of a target for renewable electricity[23]. Although the 33% target is quite ambitious compared to the 14% realisation in 2000 (in the EU-15), it should be noted that it corresponds to some 12-13% in primary terms, which is significantly lower than the 20% target discussed above. Moreover, models that only impose a target on the power sector may encounter fewer restrictions on the availability of biomass than models that include the biofuels targets for the transport sector.

Figure 4.5 shows the contributions of different RES-E technologies. Again, wind and biomass will be crucial for achieving the high target in the power sector. Wind energy shows the largest growth (up to 17% in electricity consumption), while small hydro and biomass also grow substantially. Wind turbines also increase their share in the other world regions, because the increased penetration in Europe induces cost decreases due to learning, that spill over to the rest of the world.

[23] POLES results are not discussed in this section but rather in 4.2, as the 44% RES-E share is not comparable to the 33% target considered by other models.

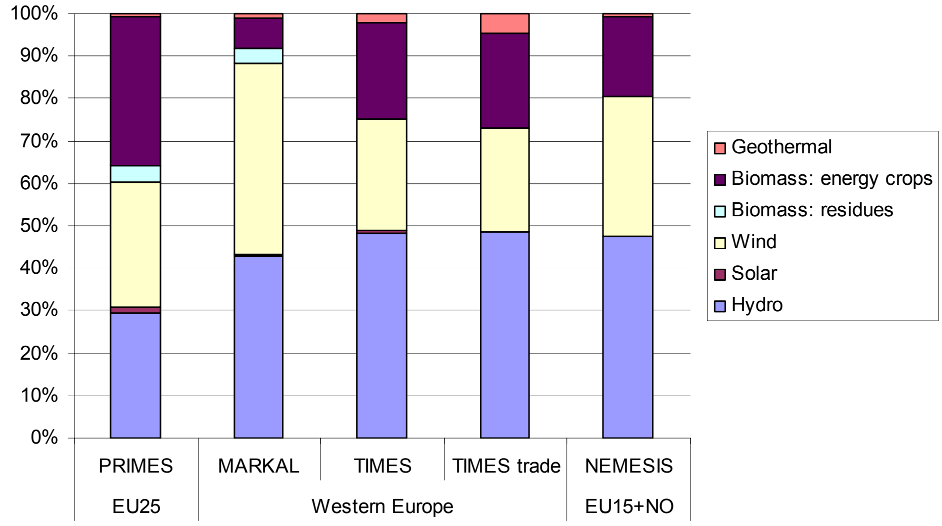


Figure 4.5 *Technology mix for power generation from renewables in 2020; high target case*

As illustrated in Figure 4.6, the projections of the amount of wind power production differ largely among the models. TIMES and PRIMES are on the lower end, while MARKAL is the only model that approximately projects the target set by the wind industry (EWEA, 2003) of 425 TWh in 2020, for the EU-15. MARKAL reports on installed capacities of 161 GW on-shore wind and 15 GW off-shore wind, whereas the EWEA target would encompass some 70 GW off-shore wind. The average 11% share of wind power in total generation is significant, ranging from 8% (TIMES, certificate trading scenario) to 15% (MARKAL) but generally within dis-patchable ranges, although the shares in individual countries could be much higher, such as 26% in Denmark, according to POLES.

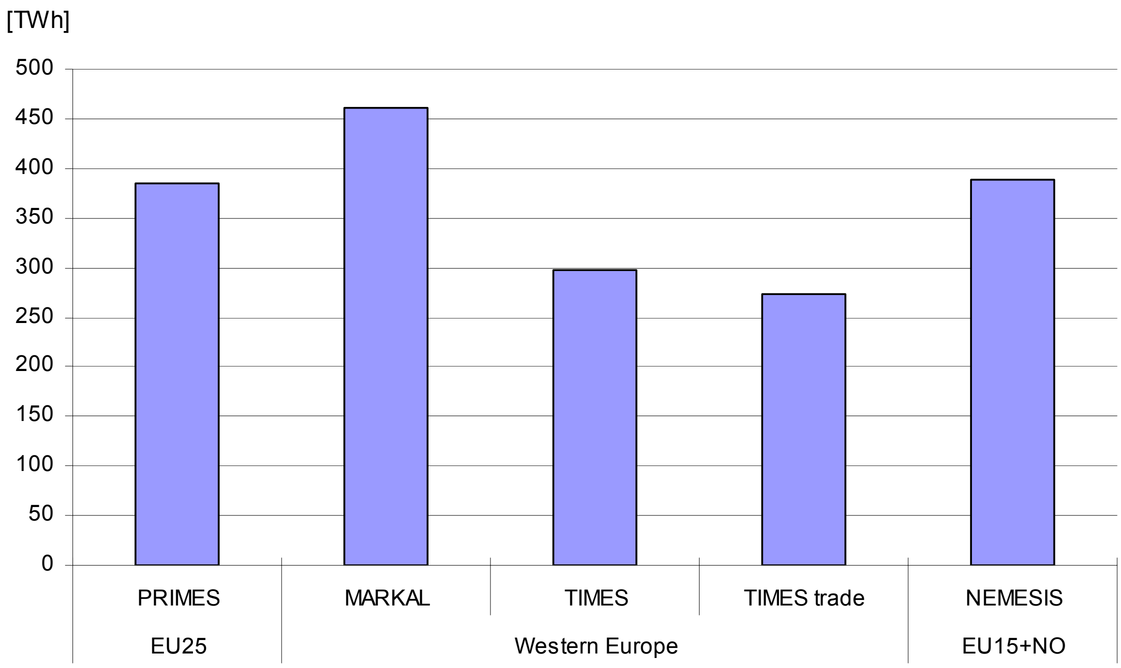


Figure 4.6 *Electricity production from wind in 2020, high target case*

As regards hydro, the potential for growth is generally limited to small scale installations. Still, PRIMES, MARKAL and NEMESIS project some 15-20% growth in 2000-2020, while TIMES expects 3% at most.

A model not represented in these figures is PROMETHEUS. This is a stochastic model and therefore contributes to the analysis of sensitivities and uncertainties of achieving a high share of renewables in the power sector. It finds that with a subsidy of 4 €ct/kWh, the probability of reaching the 33% RES-E target is 63%. Almost the same result can be achieved by a combined policy of doubling cumulative R&D investments and introducing an additional subsidy of 2.5 €ct/kWh.

4.4 Costs and benefits for Europe

4.4.1 Costs

The costs incurred for stimulating renewables in Europe are significant. MARKAL and POLES report an increase in total energy system costs corresponding to 0.6% and 0.5% of GDP in 2020, respectively.

From the overview in Table 4.1, it was already clear that the type and design of subsidy schemes differs largely among the models. Still, there are indications from several models that achieving the 33% renewable electricity target will require some 4 €ct/kWh subsidy in 2020. Of course a flat rate subsidy is not the most effective support scheme, as also demonstrated in the scenarios run by the world models (see Chapter 5). Therefore this support level should be interpreted as a measure of the maximal costs of the 33% RES-E target. POLES is the only model that has used a generic subsidy for all sectors, and the level of almost 6 €ct/kWh illustrates that the cost of the 20% overall target is higher than that of the power sector.

The PROMETHEUS model has been used to compare the effect of direct subsidies to additional R&D spending, and concludes that with a comparable effect, the R&D-scenario is some 30% more expensive than the direct support scenario. However, when the costs are expressed in terms of avoided CO_2 emissions, the direct support policy is substantially more expensive (almost a factor 8). This is due primarily to the different nature of the spillover effects of the two policies. The R&D policy enhances the attractiveness of renewables throughout the world, while the direct support policy increases renewable penetration in Europe and indirectly reduces fossil fuel costs for the rest of the world.

4.4.2 Substantial CO_2 emissions reduction

The increased penetration of renewables has a positive impact on CO_2 emissions reduction. For the models that have aimed at the overall target of 20% renewables in primary consumption, reductions range from 9-21%, see Table 4.2.

Table 4.2 *CO_2 emissions reduction in 2010 and 2020 compared to the baseline*

[%]	2010	2020
POLES EU30	-9	-14
PRIMES EU25	-5	- 9
MARKAL WEU	-5	-21

In the period 2000-2020, the implementation of the 20% target leads to a decreasing trend in CO_2 emissions, as shown in Figure 4.7. In 2010, energy-related CO_2 emissions are some 10% lower than in 1990 (according to PRIMES for the EU-25), indicating that Europe's Kyoto target is within range. Beyond 2020, PRIMES projects almost a stabilisation of emissions, MARKAL a further decrease, and POLES an increase.

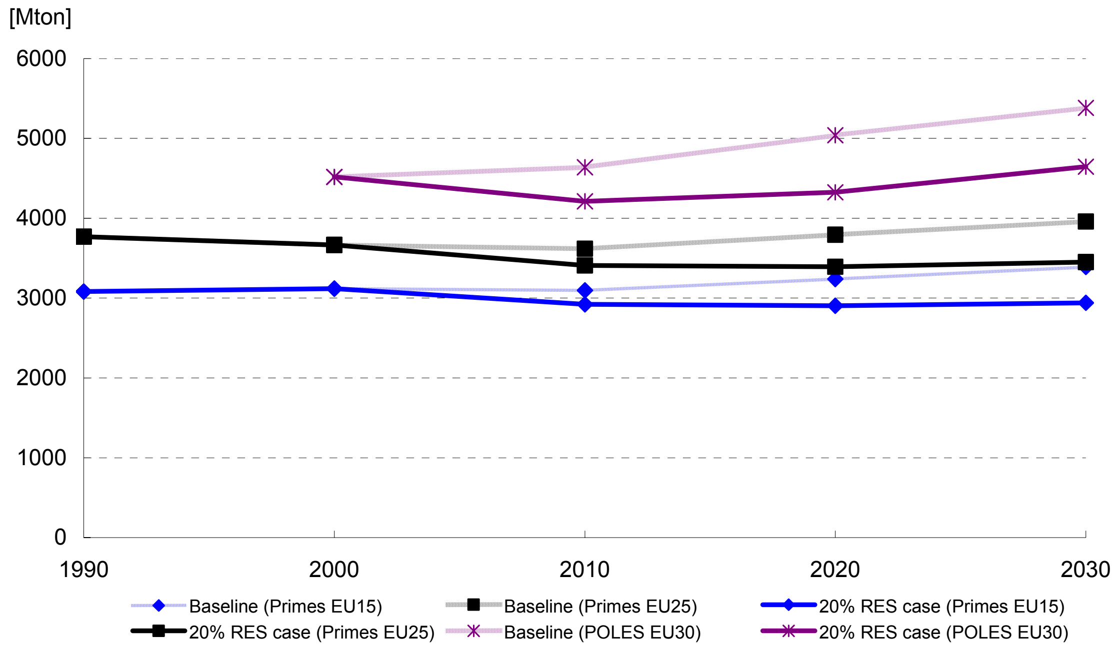


Figure 4.7 *Emission trends in baseline and high renewables target case*

Furthermore, in line with the differences in sectoral allocation of the renewables penetration, discussed in 4.2, the emission reductions also differ by sector and by model, as illustrated in Figure 4.8. For POLES, most reduction takes place in power sector, some in industry, but emissions are stable in transport sector. This is explained by the low penetration of biofuels, according to this model. Similarly, the shares of the transport sector emission reductions for MARKAL and PRIMES correspond to their higher expectations of biofuels.

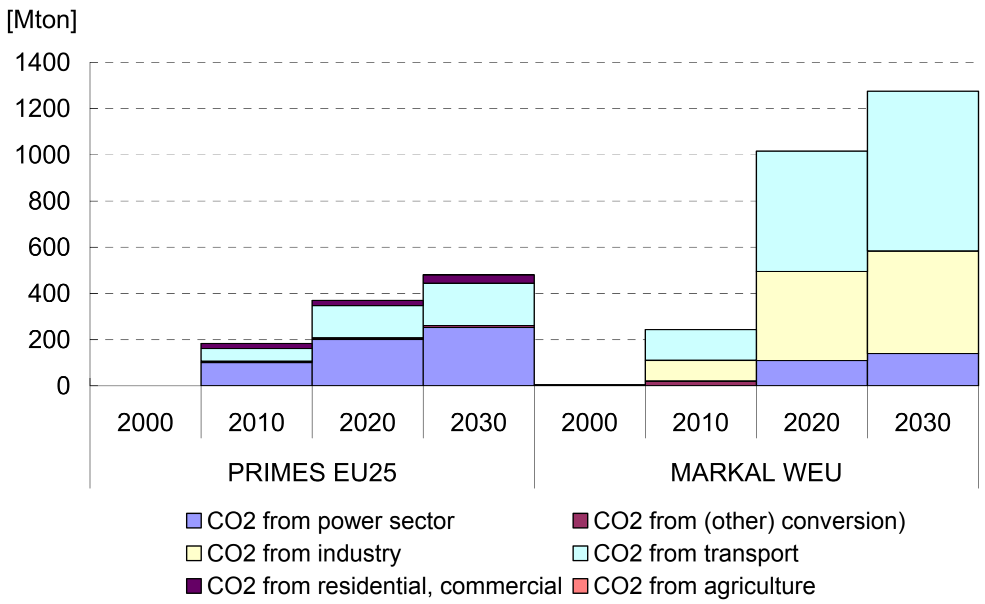


Figure 4.8 *Sectoral distribution of emissions reductions*

4.4.3 Security of supply

The increased penetration of renewables leads to less import dependency, because of the indigenous character of renewable energy sources. The largest impact is reported by MARKAL, and concerns a 14% point reduction in dependency of oil imports compared to the baseline. This is related to the large share of biofuels in the transport sector. Regarding gas import dependency, the impact is more modest with 2-4% point reduction in 2020 compared to the baseline, which is not sufficient to counter the increasing trend in this indicator. PRIMES shows the weakest effects on security of supply, due to the fact that renewables substitute more nuclear than oil and gas.

The diversity of Europe's energy mix, as measured by the Shannon indicator, improves with 6-8% points to 76%.

The PROMETHEUS model gives some complementary information, as it has calculated the probability of gas price shocks under the baseline and under the renewables target in the power sector. The model finds a lower probability of gas price shocks in the renewables case (applying a combined policy of 2.5 €ct/kWh and doubling cumulative R&D investment). This is due to a higher penetration of renewables worldwide, which is in turn due to learning and spillover effects.

Table 4.3 *Probability of gas price shocks under the baseline ('no policy) and under the renewables target in the power sector ('combined policy')*

	Probability that the highest increase in gas price in any 3-year period will exceed the level of	
[%]	50 $€_{2000}$/toe	100 $€_{2000}$/toe
No policy	64.1	9.9
Combined policy	58.0	7.6

4.4.4 Impacts on economic growth, welfare and employment

First, it should be noted that the economic models NEMESIS, PACE and NEWAGE-W have all focused on the power sector target, and therefore the economic impacts reported by these models are obviously weaker than when the 20% target in primary terms would have been considered.

Economic growth and welfare

In the models PACE, NEWAGE and NEMESIS, different implementations of the subsidy scheme for renewables have been chosen, and therefore these models report different impacts on economic growth and welfare.

- In PACE, the subsidy scheme for wind, biomass and PV is designed in such a way that electricity prices decrease, inducing in turn a higher demand for electricity. The welfare implications of the renewables scenario are measured in Hicksian equivalent variation in income (HEV). Overall welfare losses for Europe are relatively modest ranging from -0.03% in 2010 up to -0.08% in 2020.
- In NEWAGE-W a quota on renewable electricity production was implemented as a single action in Western Europe, leading to rising electricity generation costs. Electricity production from fossil fuels is partly substituted by relative cost-intensive generation from wind, hydro, biomass and solar. This causes electricity price increases of up to 25% in 2020, compared to the baseline (11% in 2010). The rise of output prices in energy intensive sectors is limited; the output prices rise up to 1.43% (chemicals) and 2.22% (iron and steel) in the year 2030 above the reference case. The increase of sectoral output prices and the related reallocations of factor inputs in Western Europe is reason for a weaker GDP growth, 0.8% less than in the baseline in 2020.

- In NEMESIS, a subsidy of 2.4 €ct_{2000}/kWh was applied from 2005 to 2020. The subsidy was passed to consumer prices, by adding it to the prices proportionally to the renewable share in gross electricity production. This has a weak negative impact on European macro-economic indicators. In 2020, GDP is appr. 0.2% lower than in the baseline. This policy has a large inflationary impact as the energy prices increase about 4.4% in 2020 with respect to the baseline. The rise in the energy prices has a direct effect on the price index of GDP, which rises by 0.83% in 2020. This induces a decrease in private consumption (0.18%). NEMESIS reports a negative impact on competitiveness of Europe; due to the higher price level, imports increase and exports decrease.

Employment effects

Increased penetration of renewables is often expected to lead to employment gains, because renewables energy production is more labour intensive than conventional energy production, and because it may substitute imported energy. The economic models do report on employment effects, but add some considerations on how well these effects can be evaluated with these types of models. It may be that the direct gains in employment due to the renewables targets are counterbalanced by job losses in other parts of the economy. This *crowding out* effect can be due to the scarcity of highly skilled labour or to the fact that the subsidies required for supporting renewable energy replace other subsidies. Therefore, net employment effects are strongly related to the structure of the labour market, wage determination and the differences in productivity in different sectors and types of labour force.

Moreover, increasing electricity prices, due to a higher RES share may result in slower GDP growth. A significant loss in GDP or a strong increase in sectoral output prices due to a specific policy would compensate much of the potential positive impact on employment caused by the investment and production effect. Finally, beside the national-oriented labour market effects, one has to take the international spillover effects into account as well. Increasing prices could cause a decrease in exports, which then could have a negative impact on production and employment itself.

As a consequence, the analysis of employment effects requires dedicated models that take these factors into account. In addition, labour market institutions vary substantially among EU Member States, and the models used in CASCADE MINTS are not particularly designed for the purpose of analysis of unemployment impacts.

- PACE is a full employment model, so layoffs in one sector are balanced by increases in employment in other sectors. The model framework is static, so it maintains a long-term perspective and does not quantify the adjustment costs associated with moving workers from one sector to another. The changes in employment levels in the different European sectors are small. In the electricity production sector, employment in renewable technologies biomass and wind increase substantially compared to the baseline, up to 180% in 2020. Conventional technologies like hard coal, oil and natural gas suffer large employment losses. Fossil fuel production sectors are only slightly negatively affected through the promotion of renewable electricity supply. As a result of the full employment assumption in the model, net employment gains in the electricity production sector are fully crowded out by reductions in employment in the two macroeconomic sectors ‘Energy-intensive industries’ and ‘Rest of Economy’. Since these sectors are large in absolute terms, the associated percentage reductions look rather small.
- NEWAGE-W reports on only a 1.8% overall increase in employment due to the RES-E target, as compared to the baseline. The overall positive effect up to the year 2030 could be led back to the continuous increase of RES and the positive investment and production effects. The negative price, GDP and trade effects seem to be compensated by these effects.
- NEMESIS: The increase of consumer price, by lowering households’ disposal income, induces a fall in private consumption in Europe. The nominal wage rate follows the rise of consumption price in a slightly weaker proportion, for the reason that energy represent an important proportion of households’ final consumption; real wages reduce consequently of

about 0.14%. The drop of employment level in Europe (-0.15%) is explained mainly by competitivity losses.

Other spillover effects
PROMETHEUS incorporates endogenous learning-by-doing and learning-by-researching, which affect the capital costs of the renewable technologies. By introducing subsidies the installed capacity of RES in Europe increases affecting the capital costs of renewables worldwide via the learning-by-doing mechanism. In a similar way, the introduction of more R&D is taken into account by the learning-by-researching mechanism, which results in lower capital costs worldwide. Thus, the penetration of renewables in electricity production is not only higher in Europe but also in the other world regions. This change of the technology mix in electricity production worldwide affects the share of fossil fuels in power generation, resulting in lower international prices for gas and coal. The effect on the gas price is also shown by POLES.

Environmental spillovers are limited; NEWAGE-W reports on small increases of CO_2 emissions in REF (Countries undergoing Economic Reform) due to leakage effects. The negative impact on the Western European GDP also has implications for neighbouring regions, although these are very small - between 0.01% and 0.02% for North America (NAM) and Countries undergoing Economic Reform (REF), compared to 0.3% - 0.8% for Western Europe.

4.5 Conclusions

Under baseline conditions, a 20% share of renewables in Europe's primary energy consumption in 2020 appears to be an ambitious target. Evidence from different models indicates that approximately 18-19% is achievable by 2020, and that it might require a few years more to arrive at 20%. Other studies (Ragwitz et al, 2004), (Mantzos et al, 2004) suggest that energy efficiency measures that reduce energy demand growth may help to bring the target within range.

If renewables sub targets for different sectors were to be imposed, the analysis shows that the power sector offers most of the technology switching options. Most of the models demonstrate that a share of 33% renewables in electricity consumption is achievable in 2020, although this should be contrasted with the current expectation that the 22% indicative target for 2010, as stated in the Renewables Directive, will only be achieved if several Member States intensify current support policies.

For various reasons, the transport sector is expected to play a key role. First, this is also a sector that offers good opportunities for increased penetration of renewables, e.g. biofuels for transportation. Secondly, the penetration of biofuels has a direct impact on the import dependency for oil, and on CO_2 emissions from transportation, which makes the promotion of biofuels a strategic choice for Europe. However, there may be future bottlenecks due to the limited availability of biomass, and the competition for biomass resources that can be applied both for power generation and converted to biofuels.

If the share of renewables in Europe increases to (almost) 20%, the share of fossil fuels in Europe reduces roughly from 75% to 65%, which has positive implications for greenhouse gas emissions and security of supply. In 2020, energy related CO_2 emissions are reduced with 9-21% compared to the baseline. The amount of emission reduction depends on sectoral distribution of the renewables contribution and on which fossil fuels are substituted. And although the reduction is substantial, it is not sufficient for post Kyoto targets, and other mitigation measures must also be explored. As far as supply security is concerned, the impacts are limited. Import dependency is only significantly reduced in case of large substitution of oil in the transport sector. On the other hand, the diversity of Europe's fuel mix increases, indicating that adding renewables helps to reduce future risks.

Finally, the annual costs associated with the renewables targets are in the range of 0.5% of (baseline) GDP, which is substantial. In addition, the economic models show that the costs of renewables may lead to higher electricity prices, and to slower economic growth. On the other hand, welfare implications appear to be limited. The models do not agree on how the renewables target may affect employment, but they do point out that employment gains in one sector, e.g. renewables in the power sector, may be at the expense of other sectors. The order of magnitude of the effects depends on the structure of the labour markets in the different EU MS, which is beyond the scope of the project. There is no sufficient evidence to conclude on a correlation between net employment and increased deployment of renewables.

5. World models

5.1 MESSAGE

This study analyses the effect of subsidies for renewable energy technologies in order to accelerate their deployment and contribution to the global energy supply[24]. As our baseline we adopt the assumptions of the MESSAGE-B2 scenario given in the first CASCADE-MINTS report on baselines (Uyterlinde et al, 2004).

We distinguish between two main schemes according to the energy sectors where the subsidy is implemented. The first scheme assumes that subsidies are paid just for renewable power generation in the electricity sector. This scheme is compared to a subsidy regime where the full portfolio of renewable supply technologies is subject to subsidies. For each scheme we focus on a central case characterized by an initial subsidy of 2 €ct/kWh. In addition, a sensitivity analysis is performed for each scheme, looking into the implication of alternative subsidy levels (ranging between 1 to 6 €ct/kWh).

Our central case for the electricity sector, ELEC2, is defined as follows. A subsidy of 0.02 $€_{2000}$/kWh is given to renewable electricity production, starting in 2010 for the industrial countries. Note that just the power production is subsidized and not the capacity buildup. This subsidy diminishes linearly until reaching zero in 2050 (Figure 5.1). The developing countries join the subsidy scheme in 2020, adopting the same level for the subsidy as the industrial countries at that point in time. In this study we define biomass-fired power plants, solar PV and thermal power plants, small hydro power plants, geothermal power plants and wind power as renewable methods of electricity production. Large scale hydro power plants are not subsidized.

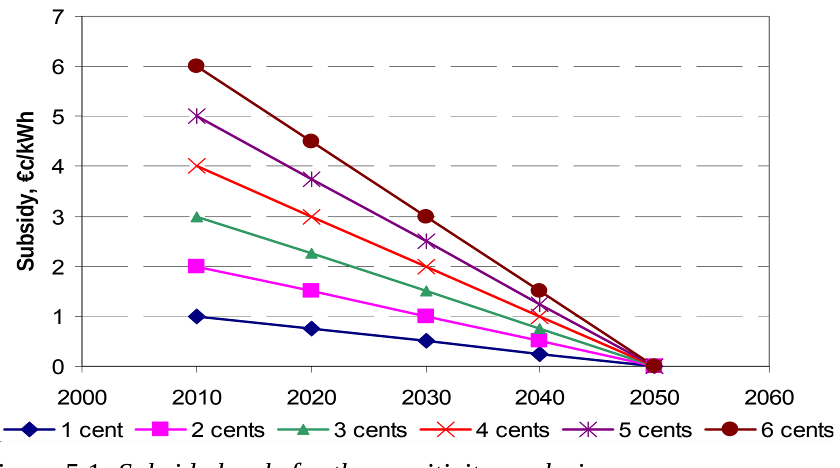


Figure 5.1 *Subsidy levels for the sensitivity analysis*

The second central case represents an extension of the first case to the full set of renewable technologies for energy production being subsidized. The main additional cluster of technologies that are subject to subsidies are the renewable production of hydrogen, ethanol, biogas and heat. We call this case 'ALL2'.

[24] This paper reports on work of the International Institute for Applied Systems Analysis and has received only limited review. Views or opinions expressed in this report do not necessarily represent those of the Institute, its National Member Organizations, or other organizations sponsoring the work.

The level of the subsidy for these energy carriers is defined relative to the subsidy in the electricity sector, i.e., 80% for hydrogen, 31.5% for ethanol and biogas and 20% for heat. The technologies added in this scheme to the previously mentioned technologies are solar and biomass based hydrogen production, heat production with biomass or solar energy and biogas or liquid fuels (ethanol) production from biomass.

As mentioned above, we alter the level of the initial subsidy from 0.01 €$_{2000}$/kWh to 0.06 €$_{2000}$/kWh and carry out a sensitivity analysis for both main subsidy schemes. In sum we develop a set of 12 alternative scenarios referred to later in this report as ELEC1 to ELEC6 and ALL1 to ALL6. For the development of the subsidies in the alternative cases over time, see Figure 5.1.

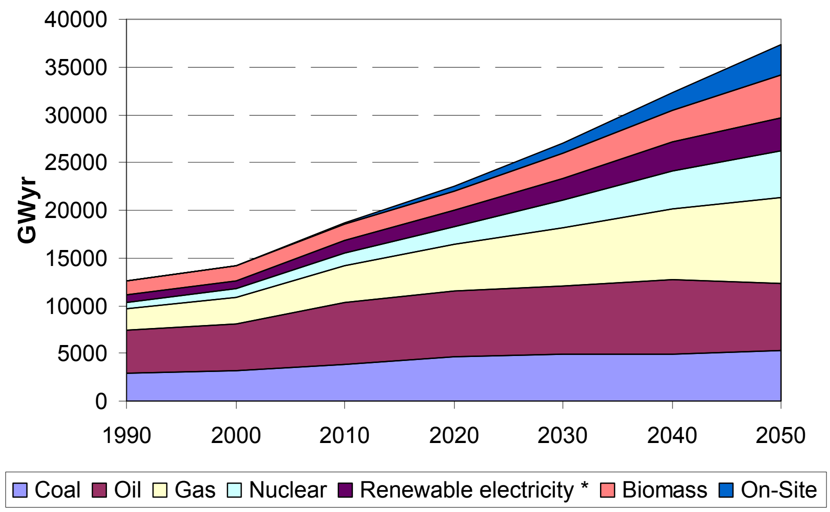
The impact of the central subsidy cases on the diffusion of renewable energy as well as the effectiveness of the schemes in terms of costs and CO_2 emissions are discussed in Section 2. Section 3 presents the main results of the sensitivity analysis, and Section 4 concludes.

5.1.1 Central Subsidy Scenarios

Primary energy consumption

When a 2 cent subsidy is applied to the electricity production as described above, the share of renewables in primary energy rises from the 2000 value of 17.4% to 22.1% in 2030. In the baseline scenario this share was 20.3%. The share of renewables further increases reaching 29.8% in 2050, but since the baseline already had a 29.2% share of renewables, the change compared to the baseline can be considered quite modest.

The development of the primary energy mix for ELEC2 is presented in Figure 5.2. The differences compared to the baseline are more apparent in 2030 than in 2050. In 2030 the consumption of biomass is 11.1% higher than in the baseline. Other renewable energy sources (excluding on-site production) have an 8.4% higher consumption compared to the baseline. In absolute numbers, coal experiences the steepest decline in consumption, when compared to the baseline. However, in percentages nuclear energy is getting replaced nearly as much, 4.2% against 4.4% for coal. In 2050 the differences compared to the baseline become smaller and the consumption of biomass is actually lower, and the use of coal higher, in the subsidy case than in the baseline. The reason for this convergence is the diminishing subsidy, which is finally phased out in 2050.



* Renewable electricity includes wind, hydro, solar and geothermal

Figure 5.2 *Primary energy mix, 2 €ct/kWh subsidy for electricity production*

Extending the subsidy scheme to include other energy carriers (ALL2) results in a higher penetration of renewables in primary energy (Figure 5.3). With this subsidy scheme the share of renewables in primary energy is 22.9% in 2030 and 30.5% in 2050. Biomass is also in this scenario the energy source with the largest increase in activity, 19.7% compared to the baseline in 2030. Also in this scenario coal is the fuel getting replaced the most, 7.3%. The same convergence to the baseline that was observed with the first subsidy case in the year 2050 is happening also with this case, although not quite as strongly. The consumption of biomass is 4.5% higher in 2050 when compared with the baseline and coal use is 2.7% below the baseline.

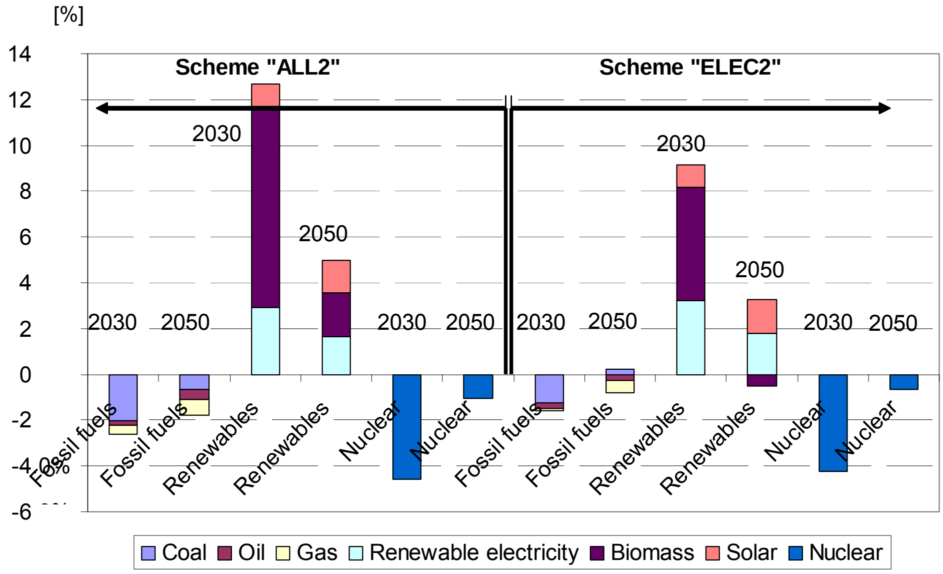


Figure 5.3 *Difference in primary energy consumption between the subsidy cases (ELEC2, ALL2) and the baseline*

Electricity production

Since the first subsidy case (ELEC2) is directed only to the power sector, it comes as no surprise that the effect on the share of renewables is more evident within the power sector than in primary energy. In the baseline scenario the share of renewables was 21.6% in 2030 and 23.8% in 2050. These numbers increase to 27.3% and 28.2%, respectively. The most important contribution to this increase comes again from biomass: in 2030 the production of electricity from biomass is 88.8% higher in ELEC2 than in the baseline. On-site production with solar energy also experiences rather steep increase, 21.9%. The amount of electricity produced with gas and coal fired power plants is approximately 8% lower in ELEC2 than in the baseline. Unlike with primary energy, no strong convergence with the baseline is observed within the power sector and the above mentioned trends hold true to 2050 as well. Figure 5.4 shows the electricity production mix and Figure 5.5 presents the differences between the production in the subsidy case and in the baseline in 2030 and 2050.

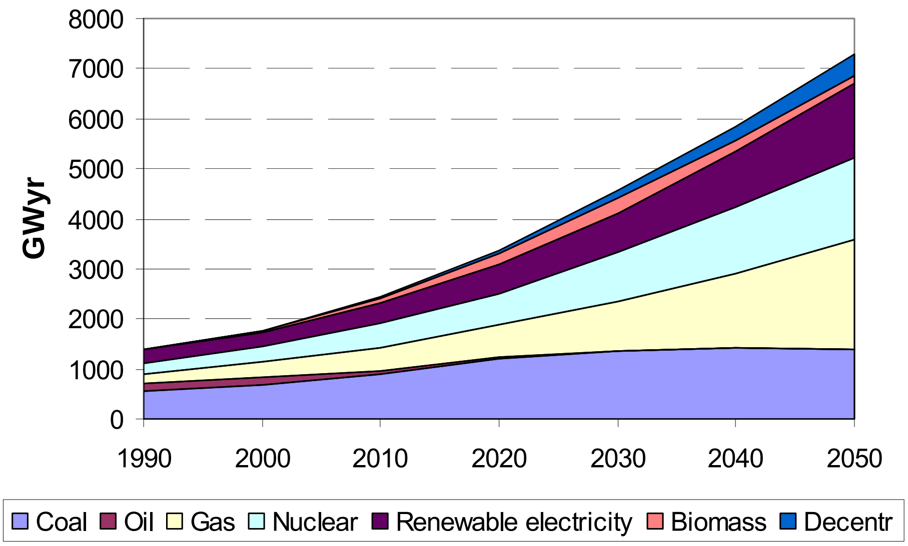


Figure 5.4 *Electricity production mix, subsidy for renewable electricity production only (ELEC2)*

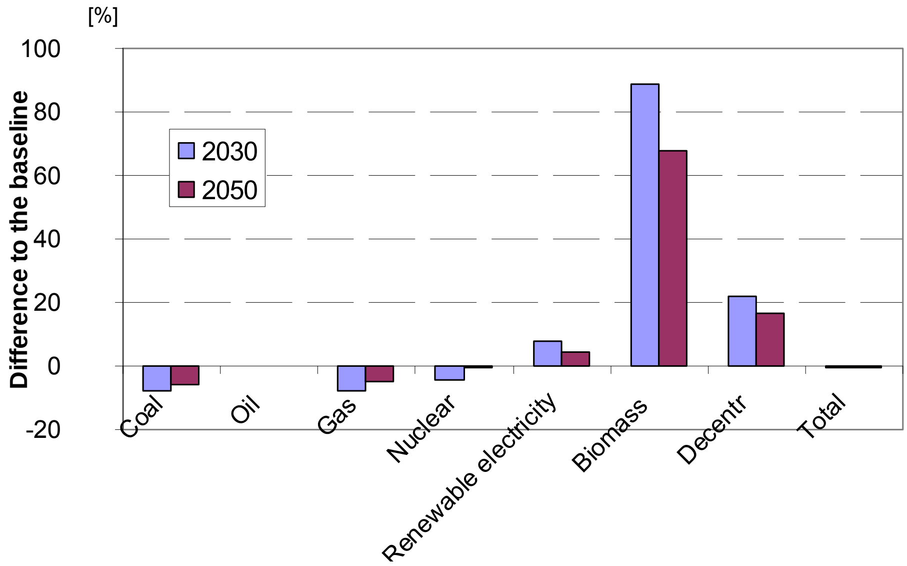


Figure 5.5 *Difference in electricity production between the baseline and the subsidy case, subsidy for electricity only (ELEC2)*

As can be seen from Figure 5.6, changes in the electricity generation sector of the scenario where other energy carriers are also subsidized (ALL2) follow similar trends, i.e., a pronounced shift from fossil generation to biomass and decentralized renewables can be observed. The sudden increase in electricity produced with oil is not as dramatic as it seems, since it is only a sign of a slightly delayed phasing out of these plants. This phasing out happens already in the baseline, but with the ALL2 scheme the phasing out starts one period later than in ELEC2 and the baseline. After this delay the phasing out progresses so rapidly in ALL2 that by 2040 the baseline, ALL2 and ELEC2 all have again the same amount of production from oil-fired power plants.

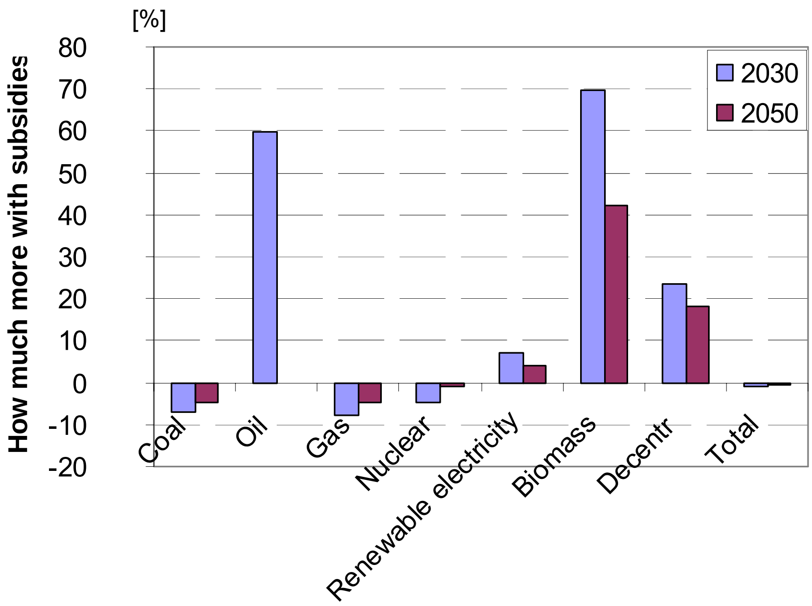


Figure 5.6 *Difference in electricity production between the baseline and the subsidy case, subsidy for all energy carriers*

CO_2 emissions and the costs of mitigation

One of the main motivations to encourage renewable energy is to reduce CO_2 emissions. No additional policies are included in our scenarios and therefore the changes in emissions follow from the given subsidies alone.

Figure 5.7 shows the total annual reductions of energy related CO_2 emissions (bars) for both subsidy schemes presented as well as the reductions achieved only in the power sector (lines). As can be seen from the figure, in the ALL2 scenario leads to considerably higher emissions cut-backs than the ELEC2 scenario. This trend is particularly pronounced during the last two periods. The lower reductions for the last period are mostly explained by the phase out of the subsidy.

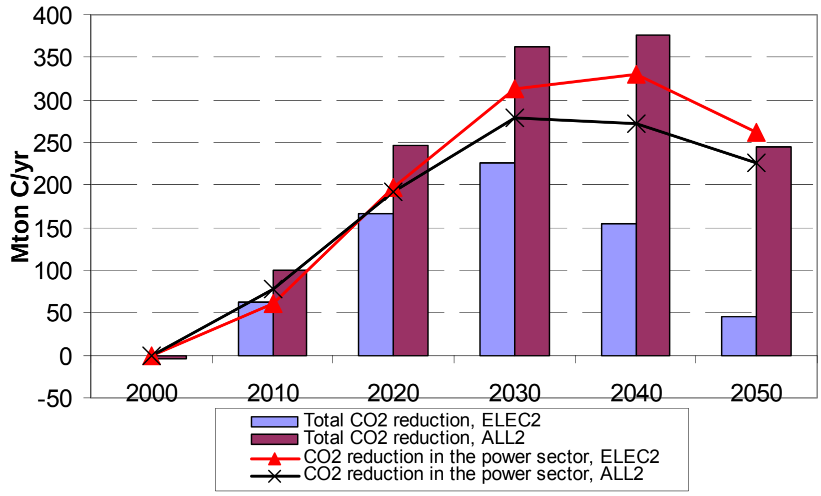


Figure 5.7 *Annual mitigation of CO_2*

Another interesting observation can be made concerning the relationship between total emission reductions and the reductions that were realized in the power sector alone. With the case where only electricity production is subsidized (ELEC2), the reductions from the power sector are higher than the total annual energy related reductions from 2020 onwards, indicating that the emissions from other sectors have been increasing quite strongly. The difference grows and is especially pronounced during the last two periods.

The culprit for the carbon leak is the transport sector. In 2030 emissions from the transport sector are 1.5% higher than in the baseline and by 2050 this difference is already 5%. The cumulative difference in emissions from 2000 until 2050 is 1.5%. This difference can be attributed almost solely to a switch from biomass-based ethanol to fossil-based methanol in transport. Since the biomass resources are limited, it is more attractive to use biomass in the subsidized electricity production than in synthetic fuel production. Both methanol production and use lead to CO_2 emissions. Most of the additional methanol is produced with coal.

The latter subsidy scheme (ALL2) produces emission reductions in other sectors too all through the studied timescale, although the power sector seems to be the most important source for reductions also with this subsidy scheme. No carbon leak is observed and practically all of the individual sectors reduce their emissions. This subsidy scheme can therefore be considered more efficient than ELEC2.

The cost of the subsidy schemes per unit of avoided CO_2 are calculated based on two indicators: (1) changes in system costs and (2) subsidies paid. We use the following formulas for the indicators:

$$\text{Cost of avoided } CO_2 \text{ (I)} = \frac{\text{cumulative subsidies (2010-2050)}}{\Delta \text{ cumulative emissions (baseline vs. subsidy case)}}$$

$$\text{Cost of avoided } CO_2 \text{ (II)} = \frac{\Delta \text{ cumulative systems costs (baseline vs. subsidy case)}}{\Delta \text{ cumulative emissions (baseline vs. subsidy case)}}$$

Because of the above mentioned carbon leak, the costs are higher for the case where only renewable electricity production is subsidized (ELEC2). This cost is between 356 and 358 €/tC mitigated, the higher price corresponding to the difference in total system costs. The other scheme (ALL2) produces a more effective option and the costs go from 274 to 280 €/tC mitigated. These costs appear quite high, since the subsidies are applied to all renewable production, part of which would have been already economical in the baseline, while the CO_2 reductions comprise only the differences between the subsidy case and the baseline. In other words, the measured benefits (CO_2 mitigation) are restricted to those that are additional to the baseline while the costs (paid subsidies) are paid for the total renewable production.

5.1.2 Sensitivity analysis

The effect of subsidy level on the share of renewable energy

To further study the dynamics of the indicators, we study the two subsidy cases with initial subsidy levels from 1 to 6 €ct/kWh (ELEC1 to ELEC6 and ALL1 to ALL6). Figure 5.8 and Figure 5.9 show the share of renewables in electricity production as a function of the subsidy level and the studied year.

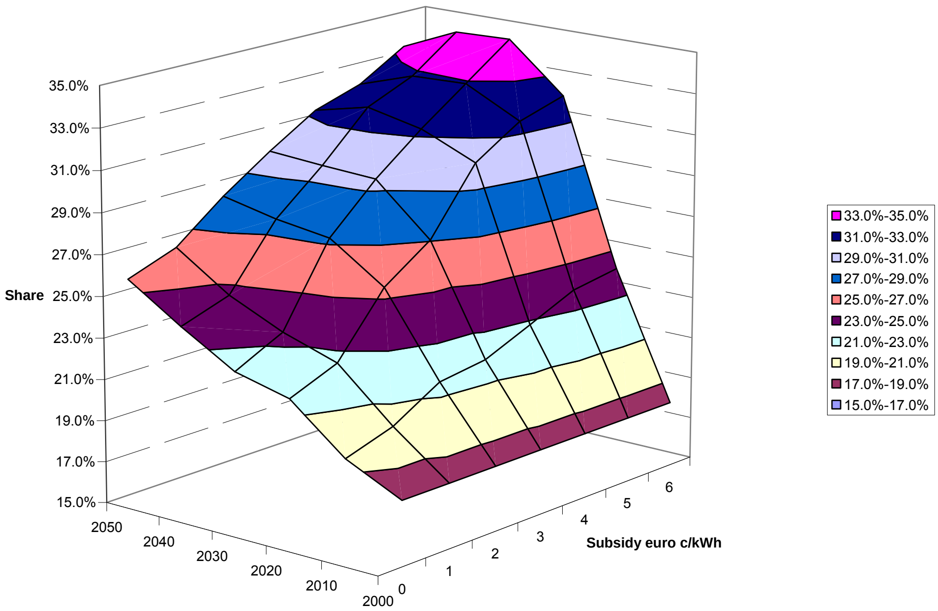


Figure 5.8 *Global share of renewables in electricity production, only electricity subsidized (ELEC1 - ELEC6)*

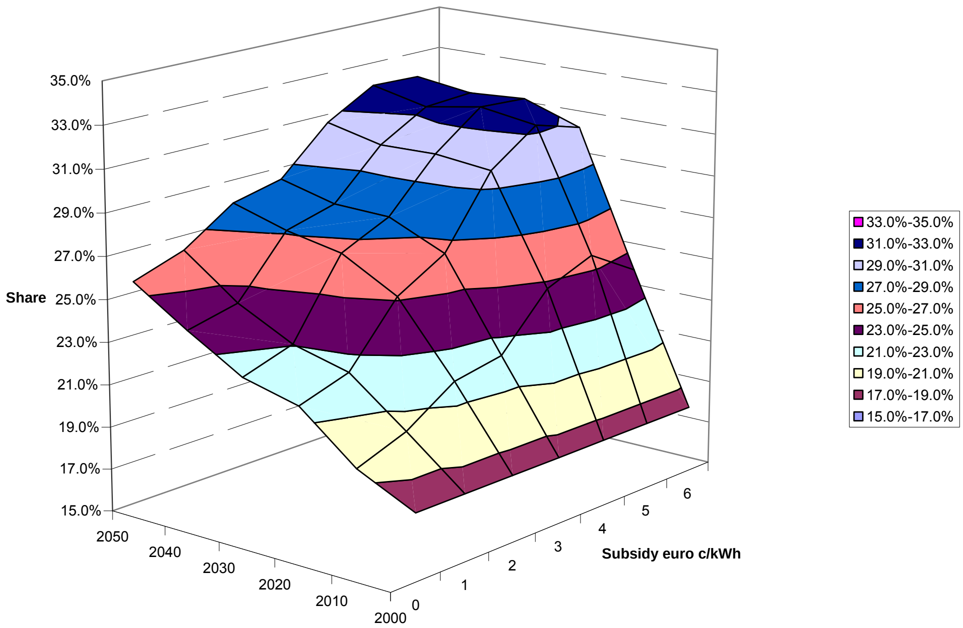


Figure 5.9 *Global share of renewables in electricity production, all energy carriers subsidized, (ALL1 - ALL6)*

Figure 5.8 and Figure 5.9 confirm the trends already observed for the central cases that when the subsidy is concentrated only on electricity, higher shares of renewable electricity production are reached. However, this does not imply that total energy-related CO_2 emissions are reduced more effectively (mainly due to fuel substitution and recarbonization of non-electric sectors - see e.g., the effect of recarbonization in the central ELEC2 case described above). Because of this recarbonization effect in the ELEC cases, the respective impacts on the renewable shares in primary energy are also less pronounced under these schemes (as compared to the ALL cases). The effect of this trend in terms of CO_2 emissions can be seen from Figure 5.11 and Figure 5.12.

Figure 5.10 shows how effective the subsidies are in monetary terms. These indicators are calculated from the cumulative differences in costs and renewable energy use between the subsidy cases and the baseline. Note that non-discounted costs are used for both, direct subsidy costs and difference in total system costs. We use different indicators to measure the effectiveness of the ELE and the ALL cases:

$$\text{Cost per unit ren. electricity added (ELECa)} = \frac{\text{cum. subsidies (2010-2005)}}{\Delta\text{ cum. ren. elec. power (baseline vs. subsidy case)}}$$

$$\text{Cost per unit ren. electricity added (ELECb)} = \frac{\Delta\text{ cum. systems costs (baseline vs. subsidy case)}}{\Delta\text{ cum. ren. elec. power (baseline vs. subsidy case)}}$$

$$\text{Cost per unit ren. PE added (ALLa)} = \frac{\text{cum. subsidies (2010-2050)}}{\Delta\text{ cum. ren. primary energy (baseline vs. subsidy case)}}$$

$$\text{Cost per unit ren. PE added (ALLb)} = \frac{\Delta\text{ cum. systems costs (baseline vs. subsidy case)}}{\Delta\text{ cum. ren. primary energy (baseline vs. subsidy case)}}$$

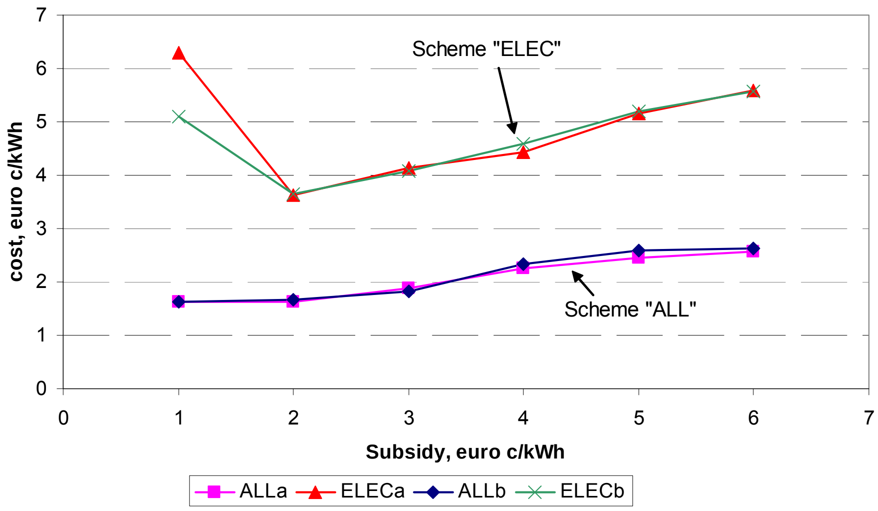


Figure 5.10 *Unit costs for renewable energy added to the baseline*

The series with higher costs shows the costs for renewable electricity added. This graph is drawn for the case where no other energy carriers are subsidized (ELEC). The high cost per kWh for the lowest subsidy is explained by the fact that also renewable production already in the baseline is subsidized. When little additional renewable production is achieved because of the low subsidy, most of the subsidies are paid to the production that was already cost-effective in the baseline. This is also the reason why the cost given by this indicator is for many cases above the initial subsidy level. Judging from this information, it would seem that the subsidy of 2 €ct/kWh is the most efficient, that is, it manages to add renewable electricity production to the baseline with the lowest unit cost. This is, however, not surprising, since by definition the higher categories assume that more subsidies are paid per unit of electricity, which at the one hand leads to a higher overall production, but at the same time also to higher per-unit costs.

The lower lines combine the subsidy cases for all energy carriers (ALL) with the changes in renewable primary energy. The subsidy of 2 €ct/kWh is slightly less effective than 1 €ct/kWh, but the difference is negligible. Here the price stays well below the initial subsidy level most of the time, because the subsidy is connected to the output (production) and the indicator to the input (primary energy).

The effectiveness of subsidies in reducing CO_2 emissions

To give a more concrete understanding on the effect of the level of the subsidy on the CO_2 emissions, the cumulative emission reductions are calculated for both subsidy cases with subsidy levels from 1 to 6 €ct/kWh (Figure 5.11 and Figure 5.12).

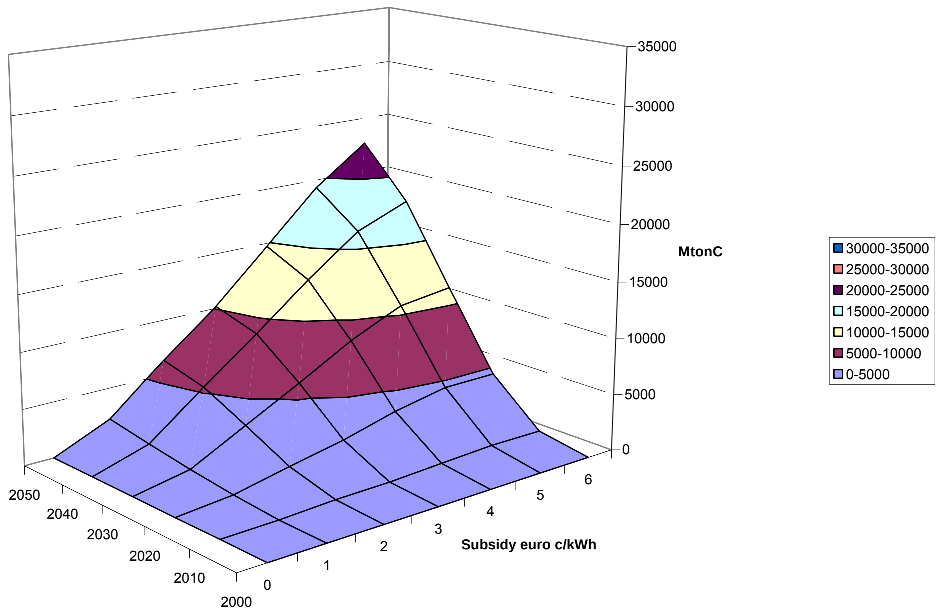


Figure 5.11 *CumulativeCO_2 reductions, only electricity production subsidized (ELEC)*

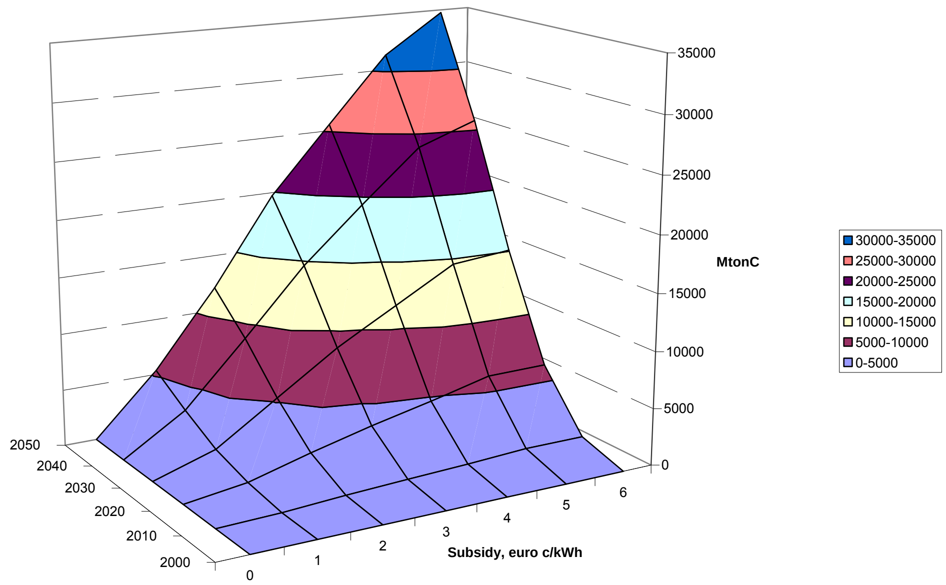


Figure 5.12 *Cumulative CO_2 reductions, all energy carriers subsidized (ALL)*

As these figures show, the effect on CO_2 emissions is higher the more ambitious the subsidy scheme is (and this is the case for both alternative schemes, ELEC & ALL). Another important finding is that subsidizing all energy carriers provides much more potential for emission reductions. For example, to reach reductions of 10 GtC by the year 2050, an initial subsidy level of three cents per kWh is needed if only electricity is subsidized. An initial subsidy level of approximately 1.8 €ct/kWh would be enough with the other subsidy scheme (ALL).

Note also that although with the same initial subsidy level the absolute costs of the ALL schemes would be higher, the price per tC, which measures the effectiveness of the policy in terms of emissions reductions, would still be lower (see Figure 5.13). Given our assumptions on the baseline and on the aspiration levels for the subsidies, a reduction of about 35 GtC in cumulative emissions may be reached by the year 2050.

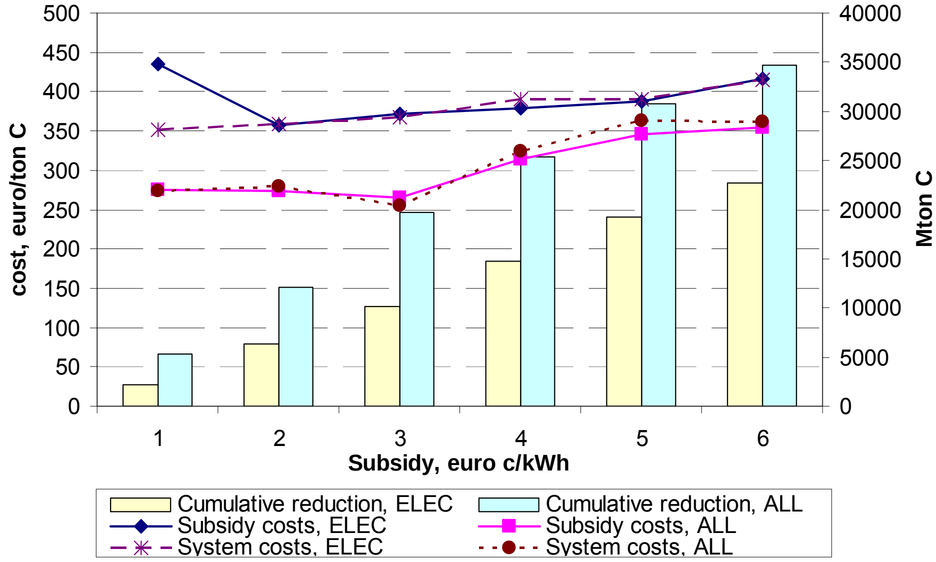


Figure 5.13 *Cumulative emission reductions and their costs*

Figure 5.13 presents cumulative reductions by the year 2050 (bars). The lines show the cost of avoided CO_2, calculated in two alternative ways: 1) based on the relative increase in cumulative energy systems costs; and 2) based on the subsidy payments during the time frame (see also formulas from Section 2). The subsidy scheme where all energy carriers are subsidized constantly performs better, both in absolute quantities mitigated as well as unit costs, no matter what the actual level of the subsidy is.

Sensitivity to the modeling of technological change

In the aforementioned scenarios technological change is represented exogenously, i.e., investment costs improve over time following a predefined path. In this representation, we mimic the relationship between cumulative installed capacities and specific costs of technologies (as given by endogenous learning) with dynamic penetration constraints. By doing so, the technology penetration is characterized along S-shaped diffusion curves. This permits the representation of upfront investments during the initial niche market phase, where the pace of deployment is relatively slow.

To test the sensitivity to the way the development of investment costs is modeled, we calculate two cases by adopting endogenous learning. The case studied is 'ALL6' and a new baseline with endogenous learning is created for comparison. 'ALL6' is chosen because it is assumed it will lead to largest differences in primary energy consumption between the baseline and the subsidy case by 2050.

The costs of 13 technologies are modeled with learning by doing. These technologies include most of the subsidized technologies; only geothermal power plants and small hydro plants are modeled exogenously as before. Hydrogen and ethanol produced with renewable energy sources are also modeled with learning by doing. In addition to these, some non-renewable technologies are also included among the learning technologies. These technologies are advanced coal power plant, advanced nuclear plant and combined cycle gas power plant.

Technological change of other technologies is still represented exogenously, i.e. their investment costs develop along a predetermined path.

It has to be noted that the baseline is now also altered due to the implementation of endogenous learning; hence the results are not directly comparable to the earlier results. In the sequel we primarily focus on quantifying the impact of the renewable subsidy under endogenous learning and draw qualitative conclusions as to how the results differ compared to the exogenous cases.

Figure 5.14 presents the differences in primary energy between the new baseline and the new 'ALL6' case with learning.

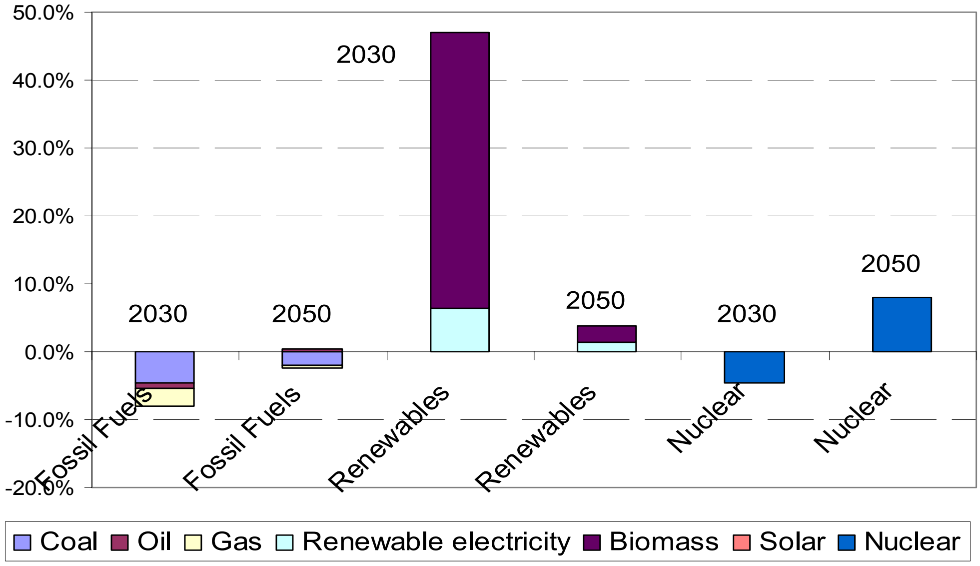


Figure 5.14 *Difference in primary energy consumption between the modified subsidy case 'ALL6' and the new baseline (endogenous learning implemented for both)*

If Figure 5.14 is compared to Figure 5.3, it is quite clear that the general trends of 'convergence' observed before have not changed. There are, however, some changes among the individual technologies; for example, the subsidy does not help the penetration of solar technologies into the markets by 2050. Nuclear is also higher in 2050 than it is in the learning case baseline. Some of these differences can be attributed to the higher subsidy level than what was applied for the case presented in Figure 5.3, but some of them also seem to follow from the different modeling of technological change. The share of renewables is about 7%-points above the baseline for the subsidy case in 2030, but this difference is cut to less than 1%-points by 2050.

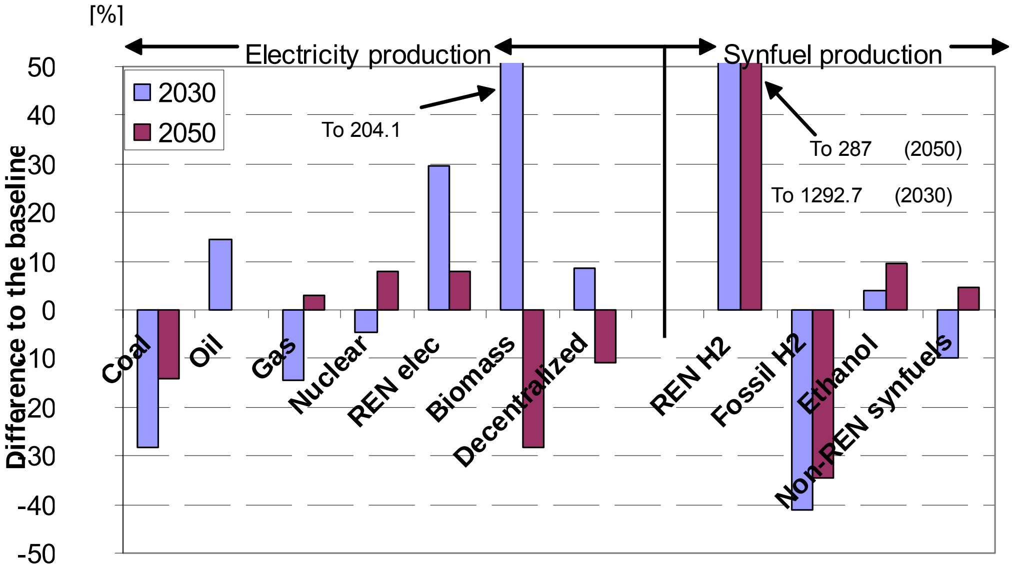


Figure 5.15 *Difference in electricity and synfuel production between the baseline and the subsidy case, endogenous learning implemented*

Figure 5.15 presents the effects of the subsidy on electricity and synfuel production.

The converging trend is again quite clear in the electricity sector: both biomass and decentralized solar based electricity production are below the levels of the baseline by the year 2050. Nuclear and gas are used more than in the baseline by 2050. The share of renewables in electricity production in 2030 is clearly higher with the subsidy case (21.9% vs. 34.8%), but by 2050 the situation has changed drastically and the share of renewables has dropped to 26.3% with the subsidy, while in the baseline this share is 27.4%. This means that not only is there more renewables in electricity production without subsidies in 2050, but the share of renewables has gone down quite a bit from the share in 2030.

The synfuel production, however, shows a different pattern. Fossil based hydrogen production is reduced significantly and replaced with hydrogen produced with renewable sources, mostly with biomass. The difference to the baseline is still large by 2050, when the subsidy has been already phased out. The reduced biomass-based electricity production is also partly explained by this increase in the use of biomass for the synfuel production. Ethanol production is also some 10% higher than in the baseline in 2050.

When compared to the learning baseline, annual total CO_2 emissions are reduced as presented in Figure 5.16. This figure also shows the cumulative reductions reached by a given year.

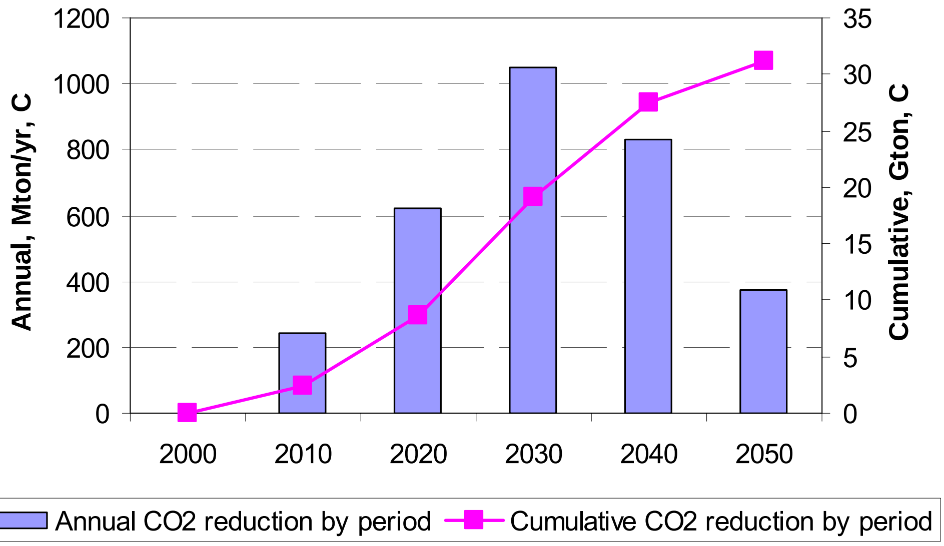


Figure 5.16 *Annual and cumulative mitigation of CO_2, difference between the subsidy case 'ALL6' and the baseline (both with endogenous learning)*

The total cumulative reductions shown in Figure 5.16 are comparable to the reductions achieved with the same subsidy level and exogenous learning (see Figure 5.12).

Although the penetration of some individual technologies differs significantly in the cases with endogenous learning, the main qualitative conclusions are still valid. This concerns particularly the convergence of renewable shares between the subsidy case and the corresponding baseline as a result of decreasing subsidy levels over time. This is mainly due to the fact that in all cases a certain fraction of the renewable portfolio is benefiting from relatively high subsidies and turns out to be not economic after the point when the subsidies are released again. Note nevertheless that the cumulative effect of technological learning becomes more pronounced after the year 2050, which is beyond the scope of this study. For example in the case of endogenous learning, the penetration of renewables in the baseline is slightly accelerated in the second half of the century, resulting in a decarbonization of about 17 percent by the year 2100 (as compared to the case without end. learning).[25]

Note also that these results depend strongly on the assumed learning rates, which are subject to considerable uncertainties. Further sensitivity analysis with respect to the learning assumptions would be needed for a better understanding of the range of possible technology adoption potentials for renewables, particularly in the very long-term post 2050.

5.1.3 Conclusions and recommendations

The two subsidy schemes studied have shown that it is important to target the subsidies correctly. If only one sector is subsidized, the renewable share in this sector will be high, but there is a carbon leak to other sectors and the share in primary energy is only mildly affected. If the subsidy is divided to several sectors, no such leak takes place and the use of fossil fuels is reduced instead of redirected.

[25] Note that the baseline with endogenous learning was calibrated to reflect main trends of the exogenous baseline up to the year 2050, the timeframe relevant for this study.

The renewable energy source playing the biggest role in these scenarios is biomass. Biomass is also playing a central role in the carbon leak story, since the leak can be mostly attributed to a switch from ethanol to methanol in the transport sector. This switch is eliminated in the other subsidy scenario when also biomass based ethanol production is subsidized.

The subsidy scheme directed for all energy carriers (ALL) is more effective in reducing CO_2 emissions and increasing the share of renewables in primary energy. A cumulative reduction of about 35 GtC can be achieved by the year 2050, if the highest studied subsidy (6 €ct/kWh) is used. The emissions reductions achieved with this scheme come with a lower cost per ton of carbon mitigated and the absolute amounts are also higher. A subsidy of three cents per kWh results in the lowest cost for ton of carbon mitigated. If only electricity production is subsidized, the level of this subsidy is 2 €ct/kWh. However, if particular emission targets are assigned, higher subsidies might be necessary.

5.2 GMM

5.2.1 Introduction

To provide long-term global insights from implementation of policies in favor of renewable electricity sources, a subsidy scheme for renewable power generation has been developed. Three levels of subsidies have been considered and attendant impacts are reported herein.

The subsidy levels of 2, 4, and 6 €ct/kWh for the renewable electricity generation are adopted for the industrialized countries (NAME, OOECD, EEFSU), starting from 2010. Subsidy diminishes linearly reaching zero in the year 2050. Developing regions (ASIA, LAFM) join the subsidy scheme in 2020 and apply the same subsidy levels as the industrialized regions between the years 2020 and 2050.

The subsidy scheme implies a trade of 'green certificates' across regions. The 'green certificates' serve as a commodity that represents electricity generated from renewable-energy sources. The trading regime starts in 2010 among industrialized regions and is extended on the global level in 2020. The subsidy level as a function of time is shown in Figure 5.1.

The hydropower is modeled in an aggregated way in GMM, i.e., large and small hydro plants are merged in one generic technology. Since the subsidy scheme has been originally designed to support only small hydropower, the subsidy for hydropower in GMM has been limited to maximum one third of total hydropower generation, i.e. only 33.33% of total generated hydroelectricity can be subsidized. Similarly, only 1/3 of total hydropower generation is allowed for trade of 'green certificates'.

Table 5.1 *Subsidy levels for renewable electricity generation applied in GMM*

Subsidy level		2010	2020	2030	2040	2050
[€ct/kWh]						
I	(2 €ct)	2	1.5	1	0.5	0
II	(4 €ct)	4	3	2	1	0
III	(6 €ct)	6	4.5	3	1.5	0
[€/GJ]						
I	(2 €ct)	5.6	4.2	2.8	1.4	0.0
II	(4 €ct)	11.1	8.3	5.6	2.8	0.0
III	(6 €ct)	16.7	12.5	8.3	4.2	0.0

There are six technologies based on renewable energy sources defined in each region of the GMM model. Table 5.2 summarizes cost and performance specifications for each renewable technology in the model. It has to be mentioned that rather conservative value for the capital investment cost for hydropower is used, since the difference in cost for small and large plants are not considered.

Two technologies, wind turbines and solar photovoltaic (SPV) systems, are implemented as 'learning' technologies, with the investment cost being endogenously determined by the model as a function of cumulative installed capacity. The endogenous technological learning (ETL) algorithm used in GMM incorporates knowledge spillovers across world regions, i.e., the learning performance of a technology in one-region influences the speed of learning in all other regions. Learning rates (expressed in the form of progress ratio) for wind turbines and SPV are given in Table 5.2.

An additional sensitivity model-run has been performed for the 2 €ct subsidy level assuming endogenous learning rates for biomass and geothermal systems of 5% (presented herein as 2 €ct-ETL scenario).

Table 5.2 *Specification of renewable electricity technologies in GMM*

Technology	Start year	Life time	Load factor (max.)		Efficiency		Investment cost	Fixed O&M cost	Variable O&M cost	Progress ratio
			start	2050	start	2050	$/kW	$/kW/yr	$/GJ	
Hydro-electric plant	2000	50	0.42	0.46	0.385	0.471	2150	49.5	0.12	
Solar photovoltaics (SPV)	2000	20	0.2	0.25	0.400	0.400	5000	9	1.25	0.81
Solar thermal electric	2000	20	0.2	0.2	0.400	0.400	2900	9	1.25	
Wind turbine	2000	20	0.3	0.3	0.330	0.330	1150	13.5	0.83	0.9
Biomass power plant	2000	20	0.75	0.75	0.333	0.333	2650	47.8	0.92	
Geothermal electric	2000	20	0.75	0.75	0.381	0.381	2900	28	0.9	

Penetration of renewable power generation is controlled in GMM by the imposition of exogenous bounds both on capacity and activity levels, and by annual growth/declination-rates for each technology. Regional bounds on renewable electricity generation, which correspond to assumed technical potential of a respective technology, are summarised in Table 5.3. Additionally, the large market penetration of intermittent electricity sources, which might interfere the power-network stability, is addressed by a constraint restricting the maximum amount of generation from wind and SPVs below 25% of total electricity production.

Table 5.3 *Potentials for renewable electricity generation in GMM. Bounds on activity (ACT) given in [PJ/yr]; bounds on installed capacity (CAP) given in [GW_{el}].*

			2000	2010	2020	2030	2040	2050
NAME	hydro	ACT	2184.0	2228.1	2440.2	2561.4	2666.4	2756.3
		CAP	166.0					
	solar	ACT	0.1	636.2	1162.2	1922.0	2796.0	3572.9
		CAP	0.2					
	wind	ACT	21.1					4437.0
		CAP	2.5					
	biomass	ACT	274.3	491.2	1467.3	2627.7	4705.9	8427.5
		CAP	12.0					
	geothermal	ACT	52.8					973.3
		CAP	3.0					
OOECD	hydro	ACT	2386.4	2509.3	3112.8	3241.1	3337.1	3411.4
		CAP	168.0					
	solar	ACT	0.4	430.7	774.2	1094.8	1563.8	2246.5
		CAP	0.6					
	wind	ACT	82.0					9668.0
		CAP	13.0					
	biomass	ACT	241.5	318.9	571.2	1022.9	1831.8	3280.5
		CAP	14.0					
	geothermal	ACT	44.3					815.6
		CAP	1.8					
EEFSU	hydro	ACT	1035.1	1135.0				5841.0
		CAP	89.0					
	solar	ACT						1580.0
		CAP						
	wind	ACT	0.1					2640.0
		CAP	0.1					
	biomass	ACT	14.5	70.0				10811.9
		CAP	2.0					
	geothermal	ACT	0.3	25.0	50.0			1989.0
		CAP	0.0					
ASIA	hydro	ACT	1455.4	2283.3	4393.5	5447.0	6503.5	7557.0
		CAP	127.5					
	solar	ACT	0.2	1375.1	2062.7	6248.1	10430.3	14618.8
		CAP	0.1					
	wind	ACT	5.4					5880.0
		CAP	1.4					
	biomass	ACT	14.0					53523.0
		CAP	1.9					
	geothermal	ACT	51.4					4978.0
		CAP	2.1					
LAFM	hydro	ACT	2407.2	3450.2	4761.6	6121.3	7412.5	8513.9
		CAP	146.0					
	solar	ACT	0.3	441.9	979.3	1855.2	3331.3	5244.2
		CAP	0.1					
	wind	ACT	1.2					3399.0
		CAP	0.2					
	biomass	ACT	48.3					112384.0
		CAP	3.3					
	geothermal	ACT	29.7	98.0	204.0			2003.0
		CAP	2.1					

5.2.2 Results

Electricity generation

The subsidy-and-trade scheme implemented in this study results in increased contribution of renewable electricity to the total power generation mix as compared to the Baseline (BAU). The increase in renewables-based generation, summarised in Figure 5.17, is most pronounced between 2020-2040, however, the growth is reduced in 2050, as the subsidy level reaches zero. On the global level, the generation from renewables, including hydropower, is increased in the 2 €ct case over the Baseline by 8% in 2020, and by 5% in 2050. In the 6 €ct case, the relative increase by 23% in 2020 and by 14% in 2050 is reported. For the OOECD region, the increases over BAU in 2020 and 2050 are 6.5% and 4% in the 2 €ct subsidy level, and 11% and 4.2% in the 6 €ct case.

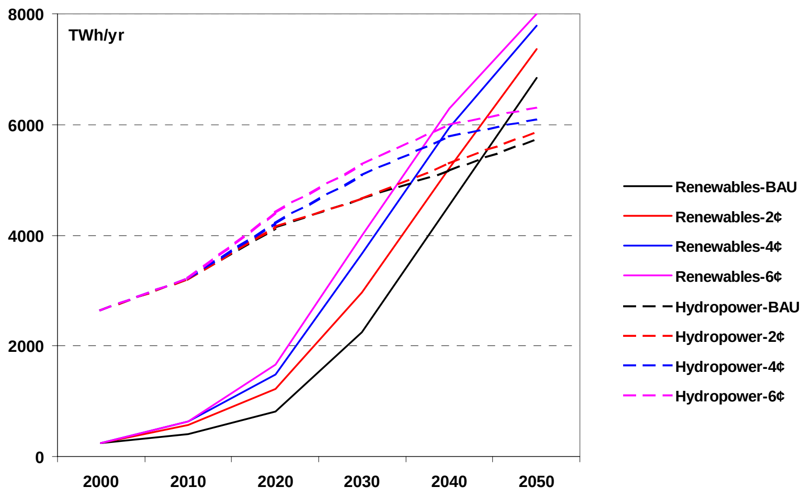


Figure 5.17 *Power generation from renewable sources and hydropower in the Baseline and under subsidy schemes*

Figure 5.25 shows that the global share of electricity generation from renewables in the 2 €ct case reaches 19% in 2020, and is increased to 20% in 2050. With the subsidy level of 6 €ct, shares of 21% in 2020 and 2050 are achieved. Share of renewables in the OOECD region, presented in Figure 5.18 for 2 €ct and 6 €ct cases in 2020 and 2050, is 22.4% and 36.3% in the former case, and 23.4% and 36.4% in the later case.

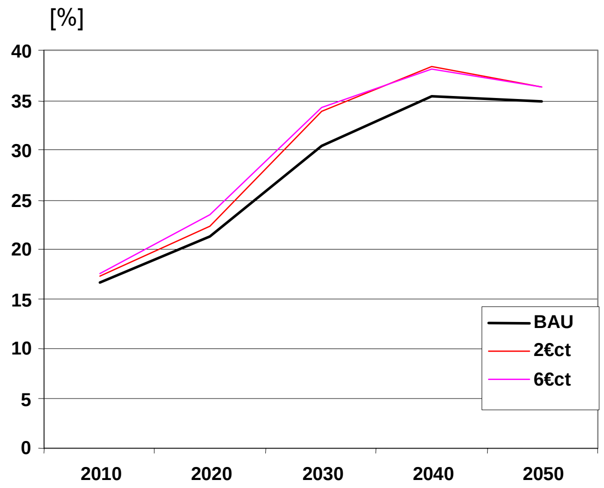


Figure 5.18 *Share of renewable electricity, including hydropower, in the total power production for the OOECD region*

In the sensitivity scenario that applies endogenous learning also to the geothermal and biomass power plants (2 €ct-ETL), the growth in contribution from renewable systems continues beyond the period 2040, as opposite to the scenario with ETL applied only to the wind and SPV systems. Renewable electricity production increases over the Baseline by 18% and 40% on the global level in 2020 and 2050. The relative share of renewable electricity in the total power production increases to 26% in 2050, as compared to 20% share achieved in the case without ETL.

Increased generation from renewables induced by the subsidy schemes is balanced by reduced contribution of power production based on natural gas and coal. Figure 5.19 indicates that lower investments in fossil-fired systems might stimulate a market penetration of nuclear power plants in the end of time horizon.

The relative increase over the Baseline in production from renewables is most significant between 2010-2030 with subsequent decline in later periods; increase in hydropower peaks in 2040.

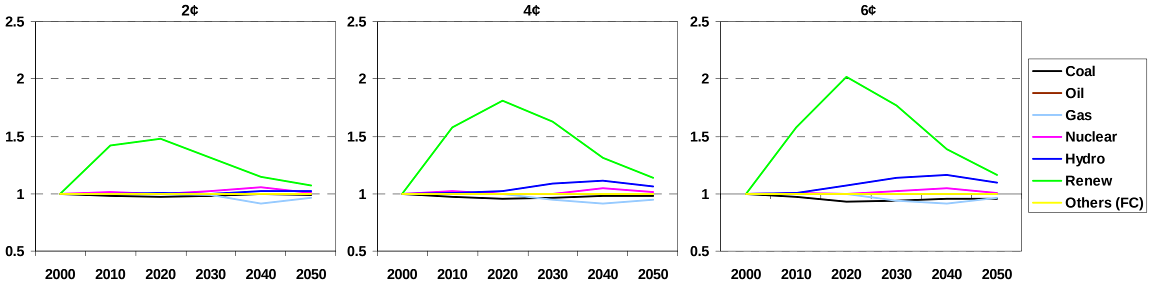


Figure 5.19 *Change in power generation by fuel relative to the Baseline under different level of subsidy*

Role of renewable technologies in the electricity production

The main objective of implementation of the subsidy scheme for renewable electricity technologies is to increase the competitiveness of these systems as compared to conventional and well-established electricity sources primarily based on fossil fuels combustion. As discussed above, penetration of renewables on the electricity market is determined by the cost characteristics, and assumed potentials and market-penetration rates. In the case of wind power, the subsidy policy induces only limited impact on the technology penetration, since the wind turbines increase the contribution to the power generation mix substantially already in the Baseline, and further increase is limited by the upper bounds imposed on this technology. On the other hand, biomass and geothermal sources experience significant increase over BAU scenario. As shown in

Figure 5.20, an increase in generation from biomass peaks around 2030 in 4 €ct and 6 €ct cases, while the geothermal plants contribute the most in the period 2040 in all cases considered. Power generation from biomass and geothermal plants is lowered significantly in 2050, where the subsidy is not provided. A similar trend is reported for hydropower, which is reported separately in Figure 5.17. There is no impact observed for the penetration of SPVs in 2 €ct and 4 €ct cases. Only the 6 €ct subsidy-level results in a given market expansion, which is further enforced by the ETL performance of SPVs.

If the ‘learning-by-doing’ option is applied for biomass and geothermal plants in the 2 €ct-ETL case, significant increase in power production from both systems takes place over the whole time horizon as compared to the 2 €ct case. Decrease in investment cost due to installed capacity doublings together with subsidy supply into these technologies result in a substantial production increase especially in regions of EEFSU, ASIA and LAFM. This result suggests that early learning investments in systems like biomass in regions with large biomass-fuel potentials can accelerate introduction of renewable electricity technologies into the market.

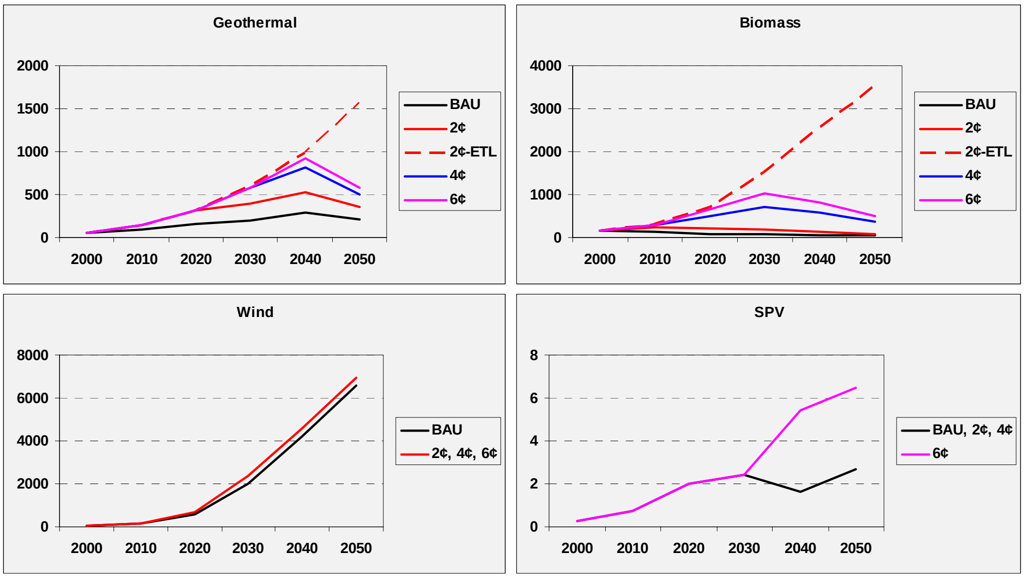


Figure 5.20 *Power generation from renewable electricity systems in TWh/yr*

Figure 5.21 shows the regional distribution of the additional renewable electricity generation for the central case with 2 €ct subsidy level and for the sensitivity scenario (2 €ct-ETL) with endogenous learning applied to all renewable electricity sources except hydro-power. In the former case, the largest increment in renewable power production is observed for regions NAME and OOECD between 2010-2030, with biomass, wind turbines and geothermal plants being the largest growing systems. The OOECD region holds the largest fraction in the additional generation in 2030 due to increase in contribution from wind power and partly from geothermal plants. Increases in hydro and wind power make the LAFM region the main contributor to the incremental renewable-production by the end of horizon. In the 2 €ct-ETL case the additional renewable generation is distributed almost equally across the regions in 2030. The contribution from EEFSU, ASIA and LAFM regions, however, prevails in 2050 due to significant penetration of biomass-based systems.

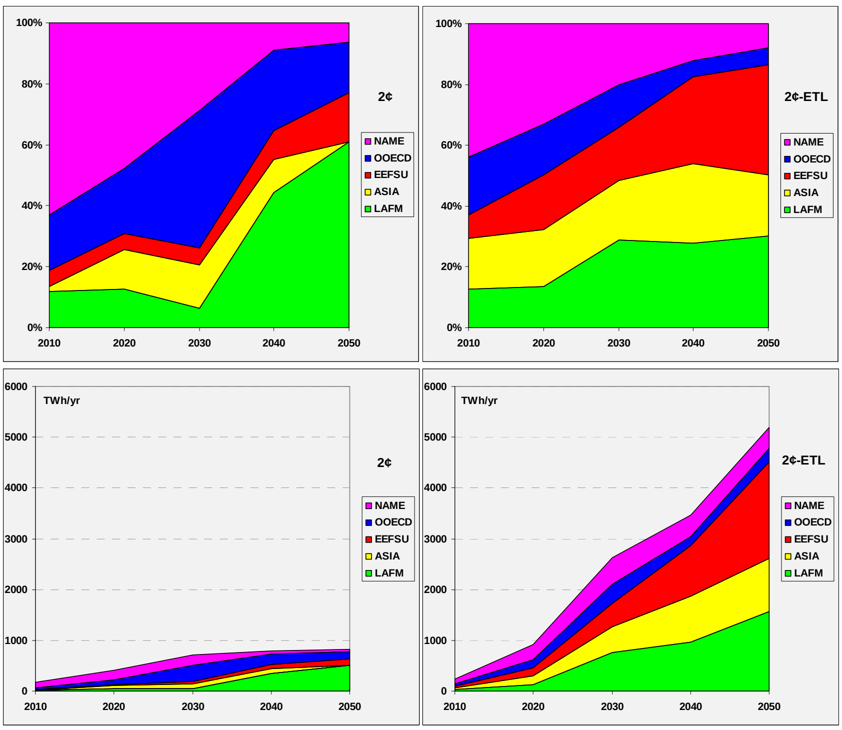


Figure 5.21 *Regional distribution of the additional renewable electricity generation*

The profile of electricity generation for the global energy system in 2050 is given in Figure 5.22 for the Baseline and the different subsidy levels. Electricity supply from hydropower, biomass and geothermal systems increases with higher subsidy level. Larger contribution from wind power is bounded by its potential-limits and by the growth rate assumed. Changes in generation from fossil systems are determined by the development in previous periods, total generation from fossil fuels, however, is reduced in the end of horizon.

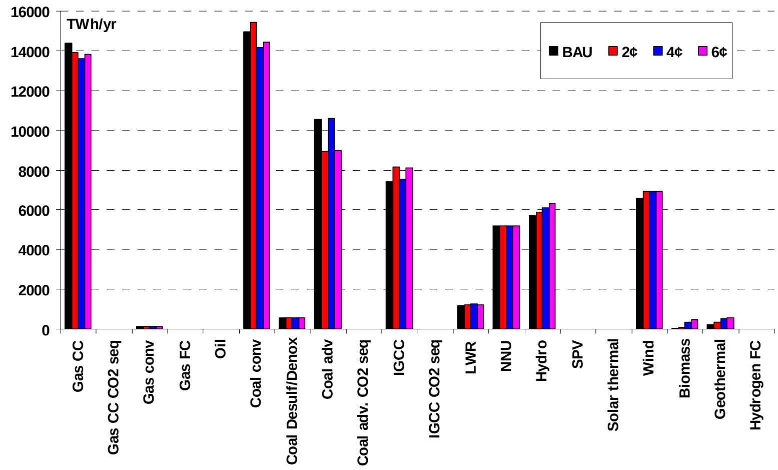


Figure 5.22 *Power generation profile in 2050*

Primary energy consumption

Change in primary energy demand as compared to the Baseline follows basically the development in the electricity sector. Figure 5.23 compares the impact of subsidy level on fuels consumption. While the demand for renewable sources and hydropower increases with increasing subsidy level by 2040, consumption of coal, natural gas and oil is reduced relative to the reference development. Around 2040, nuclear power contributes by a slightly higher level to the total primary demand relative to the Baseline.

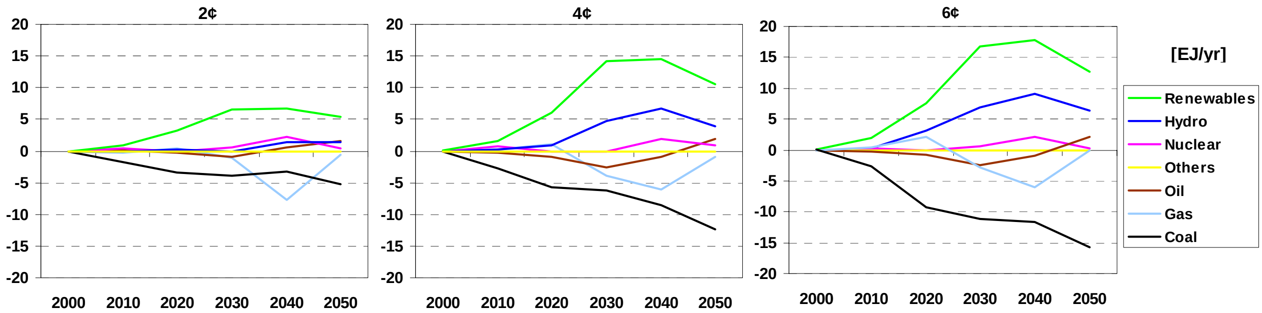


Figure 5.23 *Change in the primary energy consumption over the Baseline for different subsidy level*

Final energy demand and electricity consumption

By 2030, significant rise in electricity consumption is observed under the subsidy schemes on the global level, as shown in Figure 5.24. The growth in electricity demand is reduced with diminishing subsidy payments in 2040 and 2050. Most affected fossil fuels on the demand side of the energy systems are oil and natural gas with relative demand reduction around 2% in 2030. Contribution of biomass and other fuels is slightly reduced as well. The highest increase in electricity consumption is reported in the 6 €ct case for the industry sector, which benefits the most from subsidies applied on the renewable power generation and shows the greatest ability to replace fossil fuels with electricity.

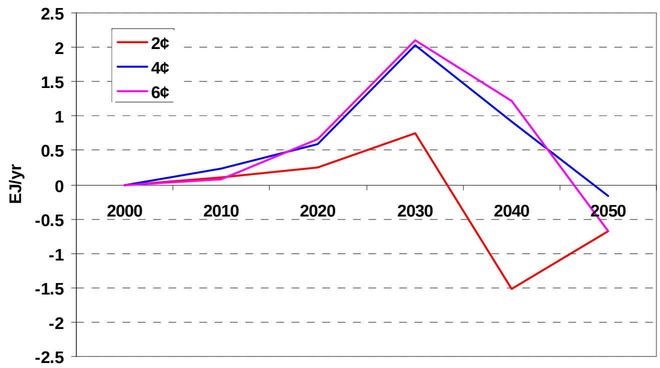


Figure 5.24 *Change in global electricity consumption over the Baseline for different subsidy level*

5.2.3 Consequences of implementation of subsidy scheme for renewable power generation

Cost impacts

Since the subsidy scheme implemented in this study applies to all world regions with a cross-regional trading of 'green certificates', the level of subsidy equals the marginal cost of renewable electricity traded between 2020 and 2050. To evaluate the effectiveness of subsidy policies in terms of cost and achievable renewable electricity shares, an additional 'cap-and-trade' scenario that forces renewable electricity generation to reach a fraction of 35% in 2050, has been analyzed. Resulting marginal cost of this renewable-electricity constraint is compared with the subsidy schemes proposed in our analysis. As summarized in Figure 5.25, different shares of renewable power generation can be achieved at different cost levels, depending on the policy set-up. While in the subsidy scheme the subsidy is provided equally to each renewable source (with an exception for hydropower), under the renewable constraint the model finds the least cost solution that defines the supply curve of renewables. Optimization under 'cap-and-trade' scenario provides us with marginal cost of achieving a given fractional target. Results of our study indicate, that the subsidy scheme that assumes the elimination of subsidies in the long run might not be able to assure the continuous growth in the renewables-share.

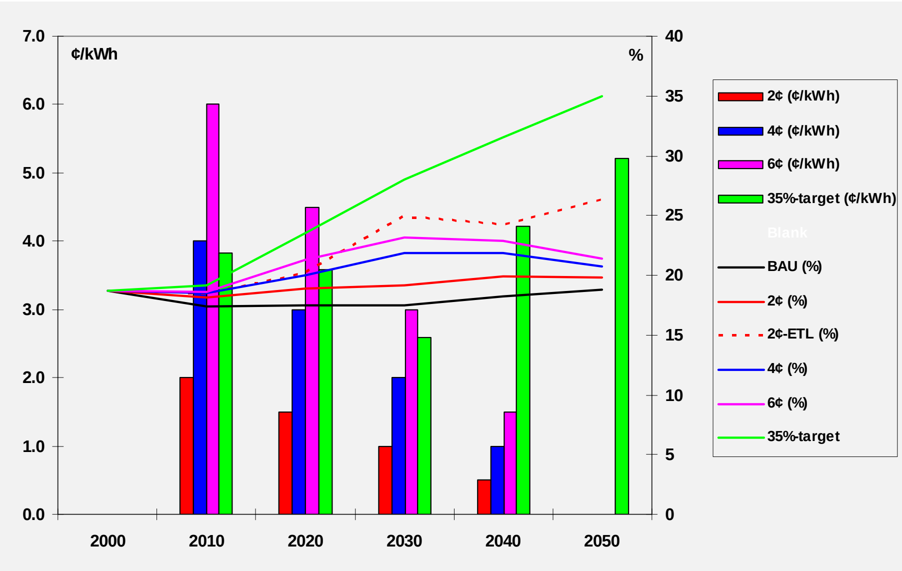


Figure 5.25 *Marginal cost of 'green certificates' and the relative share of renewables in the total power generation*

An example of penetration of SPVs is provided here to document the level of support needed for new technologies that cannot compete under present market conditions against well-established generation systems. As shown in Figure 5.20, the market penetration of SPV under the 6 €ct case increases over the Baseline or the 2 €ct case. Electricity generation from SPV counts for 6.5 TWh/yr in 2050 and corresponds to 0.01% of the annual electricity production. The cumulative investment for this level of penetration is of 18 10^9 €. However, the generating cost for SPV remains at levels much higher than the cost for conventional power plants, which varies between 3.3 to 6 €ct/kWh.

Under the 35%-renewable target, SPV systems penetrate the electricity market between 2040-2050 at cumulative production levels of 15’000 TWh. This significant increase in generation from SPVs and the associated increase in cumulative installed capacity imply the reduction in specific investment cost from initial value of 5000$/kW to 1000$/kW in the year 2040. As shown in Figure 5.26, the generating cost for SPV undergoes a strong reduction due to the ‘learning-by-doing’ effect and around 2040 reaches a level of 5 €ct/kWh, which can be considered as a break-even point for SPV technology. The cumulative undiscounted investment cost, or ‘learning investments’ necessary for reach the breakeven point of SPV systems, by 2040, is around 260 10^9 €. Gaining this immense amount of learning investment will remain a challenging task, although proper application of other promising policy options, e.g., feed-in laws or a stimulation of niche markets, may contribute to overall cost reduction.

It has to be mentioned that this is an illustrative example that tries to identify the order of magnitude of future investments needed for SPVs to progress down the learning curve. However, Figure 5.26 also indicates that application of flat subsidies may result in a situation, where mature technologies, e.g. wind power, receive subsidies while technologies like SPV remain under-subsidized.

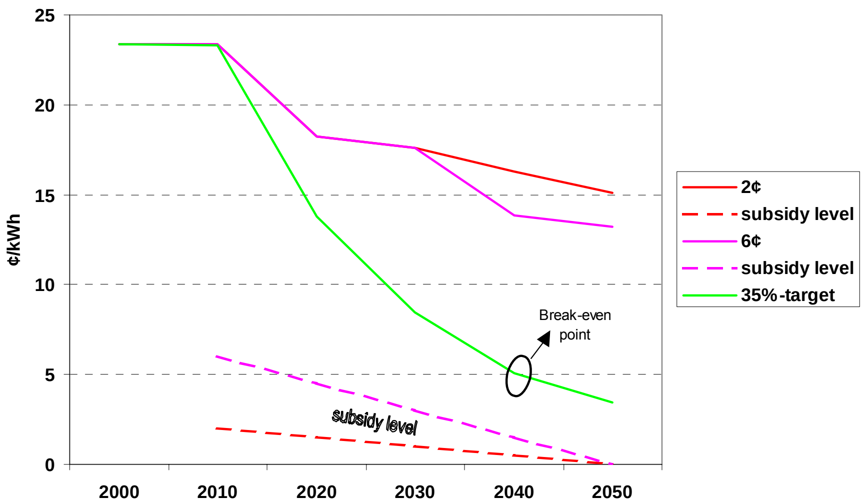


Figure 5.26 *Generating cost for SPV and the subsidy level for 2 €ct and 6 €ct cases. Assumed learning rate for SPV is 19% meaning that each doubling of cumulative capacity reduces the specific investment cost by 19%*

The modeling results suggest rather insignificant changes in the total discounted system costs for the subsidy schemes considered relative to the Baseline. The change in total system cost over BAU, as illustrated in Figure 5.27, represents only the cost associated with technology switching and fuel substitution. In all scenarios the total cost increase is below 0.5%.[26]

[26] Although the energy system cost differences are low the amount of subsidies required are quite high in the case we want to have a significant penetration of e.g., solar PV systems. One possibility to accumulate resources and finance such systems could be a carbon tax. This also reduces the demand for fossil fuels.

Furthermore, the modeling results for policy scenarios assuming the trade of 'green certificates' suggest that the total cost are reduced by 25% as compared to the cases where the trading is not envisaged.

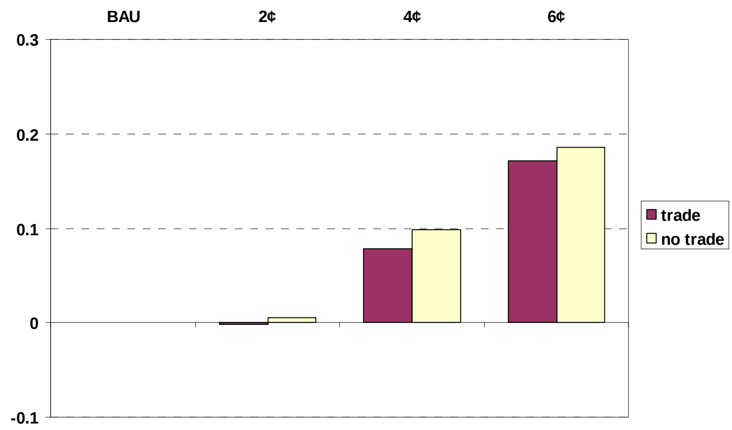


Figure 5.27 *Change in the total discounted system cost relative to the Baseline (excluding the amount of subsidies provided for renewable electricity production)*

Trading of 'green certificates' across world regions helps to identify the most efficient locations to install renewable electricity systems and at the same time moderates the induced cost impacts. Figure 5.28 illustrates the development of certificates trading for the OOECD region in the 2 €ct case between periods 2010-2040, where the subsidies are provided. The region oscillates between a buyer and a seller position over the given time frame. Main suppliers of certificates are the regions of LAFM and ASIA, while the NAME and EEFSU regions remain certificate buyers until the end of horizon. Additional cost arising from e.g. verification, monitoring and registration of 'green certificates' has not been considered in our study, although this cost can influence the success of the trading regime proposed.

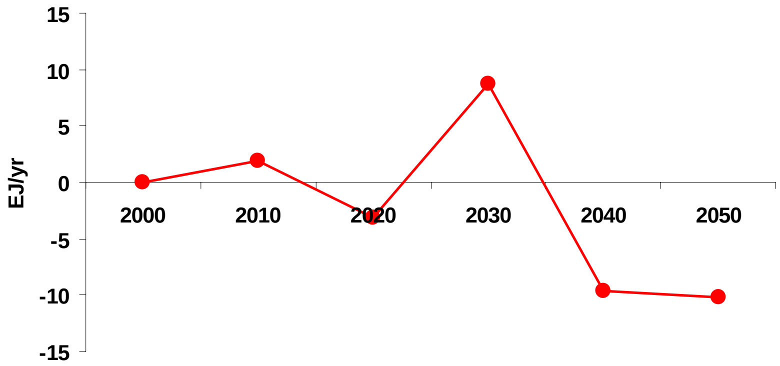


Figure 5.28 *Trade of 'green certificates' for the OOECD region in the 2 €ct subsidy case*

CO_2 emissions

The increased role of renewable electricity sources in the primary energy mix induced by the subsidy scheme is reflected in carbon emission reduction as compared to the BAU development. Figure 5.29 indicates that the highest reduction in CO_2 emissions emerges in 2030 and continues at a lower pace towards the end of horizon. Cumulative carbon emission reduction for the 2 €ct case between 2010-2050 over the Baseline represent nearly 20 GtC, while this reduction is almost three times higher in the 6 €ct case.

The CO_2-reduction trajectory in the 2 €ct-ETL case shows a declining trend over the modelled time horizon, despite the subsidy removal in 2050. Continuous emission reduction is a consequence of substantially larger introduction of biomass and geothermal electricity induced by cost-reducing effects of ETL in the 2 €ct-ETL case as compared to the scenario where endogenous learning for biomass and geothermal plants is not considered.

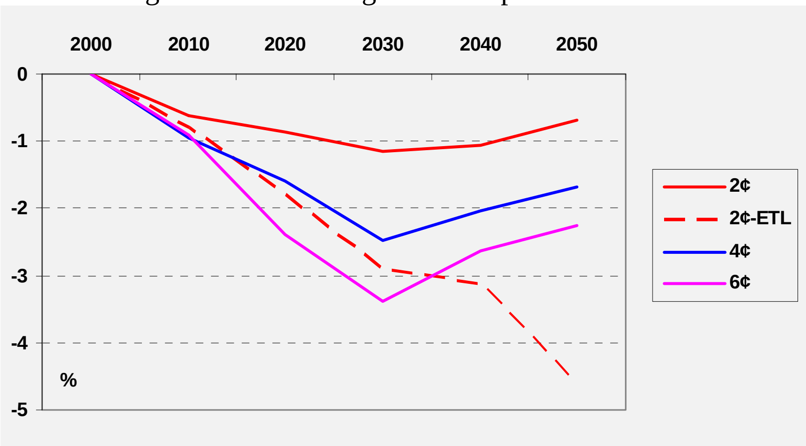


Figure 5.29 *Change in CO_2 emissions relative to the Baseline*

5.2.4 Conclusions and recommendations

- Estimation of potentials and market growth rates for renewable electricity systems are particularly important as they determine the results for BAU and policy scenarios.
- The level of penetration of renewables within the electricity market increases with increased level of subsidy provided.
- The highest relative increase in penetration of renewable sources over the Baseline is 34% and is reported for the 6 €ct case in the year 2030.
- Introduction of the 'learning-by-doing' option for biomass and geothermal plants results in a significant increase in power production from renewables over the whole time horizon. However, implicit to this development are early investments in systems based on e.g., biomass, in regions with large biomass-fuel potentials.
- For the long-term growth of shares of renewable power generation, the elimination of the subsidies by 2050 is probably not appropriate and may lead to a situation, where promising new technologies, e.g., SPV, remain locked-out.
- The wind power is highly competitive already in BAU and the subsidies do not influence substantially its market penetration.
- Application of a subsidy scheme has to take into consideration actual competitiveness of a given technology to avoid potential over- and under-subsidizing.
- The subsidy schemes, as designed for this analysis, result in a reduction of energy-related CO_2 emissions by up to 3.5% in 2030 as compared to the Baseline. This reduction is increased to 4.6% by 2050 in the scenario that considers endogenous learning for all renewable sources except hydro power.
- Tradable instruments may reduce the total cost related to technology and fuel switching. However, potential expenses associated with implementation of the 'subsidy & trade' scheme (i.e., the transaction cost) have to be considered and quantitatively assessed.

5.3 DNE21+

5.3.1 Introduction

The following subsidy scheme was set up for RES case:

- For Annex I countries, the subsidy shown in Table 5.4 is applied.
- Non-Annex I countries have the same subsidy as the Annex I countries do between the years 2020 and 2050.
- Distinction between large scale and small scale hydro plants is not explicitly made in DNE21+. In the model, the potential of hydropower is derived from the WEC data and it is divided into 5 cost grades for each region. Here, we assume that small scale hydropower falls in higher cost grades, and the subsidy in Table 5.4 is applied to high cost grades beginning from the highest cost grade down to the next highest and so on until one third of the total hydropower potential is reached.

Table 5.4 *Subsidy in the representative time points of DNE21+*

	2010	2015	2020	2025	2030	2040	2050
Subsidy [M$/TWh]	20	17.5	15	12.5	10	5	0

As to technology progress, DNE21+ adopts exogenous cost reduction for renewables. In this case study, the final energy demand is assumed unchanged under the above subsidy scheme.

5.3.2 Results

Primary energy consumption

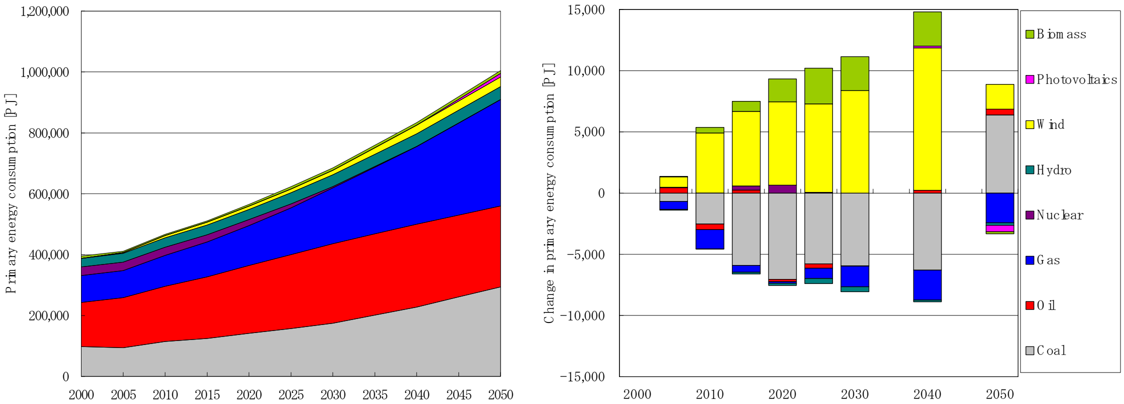
The world primary energy consumption for RES case and the difference between RES case and Base case are shown in Figure 5.30. Renewables are expressed in primary equivalent by using conversion factor of 0.33. The representative time points of the model are 2000, 2005, 2010, 2015, 2020, 2025, 2030, 2040 and 2050. The largest increase of renewables is achieved in 2040, and the amount is 14EJ. In 2050 when the subsidy scheme is terminated, the increase of renewables is 1EJ. The increase in 2050 is much lower than that in other time points. This result may depend on the above-mentioned assumption of exogenous cost reduction of technology. The achieved total increase over the period between the years 2000 and 2050 is about 387EJ. The major renewable energy resources that are increased by the subsidy scheme are wind and biomass. On the other hand, the increase in renewables reduces coal and gas consumption.

The achieved shares of renewables in the total primary energy consumption are 9.4% in 2040, 9.5% in 2050 and 9.2% in average over the 50 years. Whereas these shares for Base case are 7.7% in 2040, 9.4% in 2050 and 8.0% in average over the 50 years, respectively. By the subsidy scheme, the share of renewables for the 50 years is increased by 1.2 percentage point. The increase ratios of renewables relative to Base case are 21.1% in 2040, 1.2% in 2050 and 14.9% in average over the 50 years.

Figure 5.31 and Figure 5.32 show in the same way the primary energy consumption for EU15 and EU30, respectively. Compared with Figure 5.30, the increase of biomass is relatively large. In 2020 which is the target time point for the European models, the increases of renewables for EU15 and EU30 relative to that for Base case are 0.5EJ and 0.7EJ. On the other hand, the renewables rather decrease in 2050 as compared to Base case, although the amounts of reduction are small.

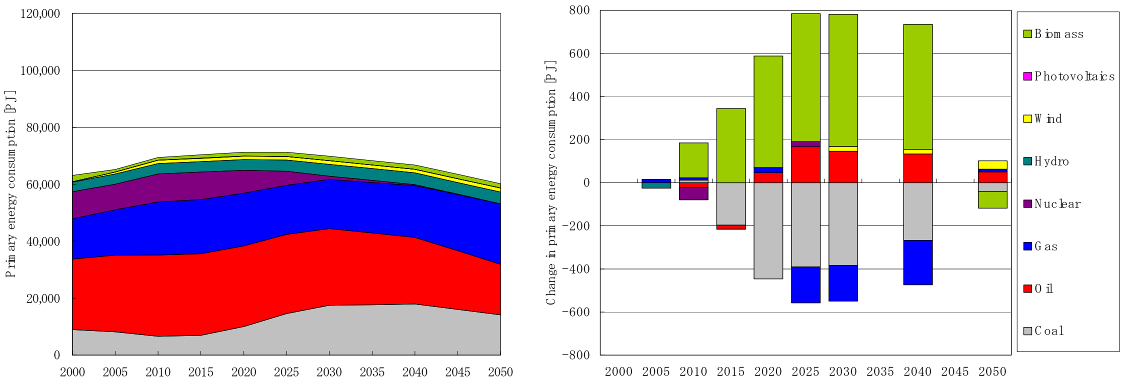
The achieved shares of renewables are 9.0% and 10.8% for EU15 and EU30 in 2020. In 2050, they are 11.8% and 12.1%, respectively.

The relative increase ratios of renewables to Base case are 8.8% for EU15 and 7.1% for EU30 in 2020. These shares are considered low relative to EU target, and more accelerative measures are needed for the achievement of the EU target.



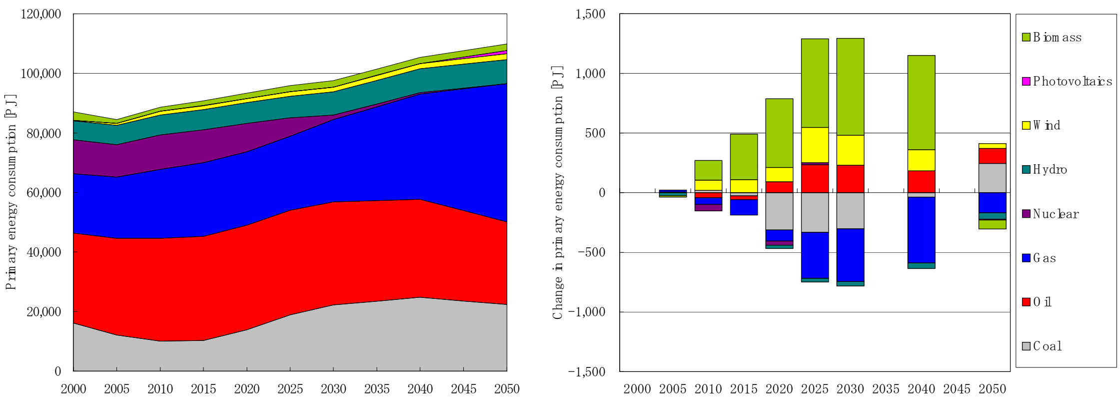
(a) RES case (b) Difference (RES case - Base case)

Figure 5.30 *Primary energy consumption (World total)*



(a) RES case (b) Difference (RES case - Base case)

Figure 5.31 *Primary energy consumption (EU15)*



(a) RES case (b) Difference (RES case - Base case)

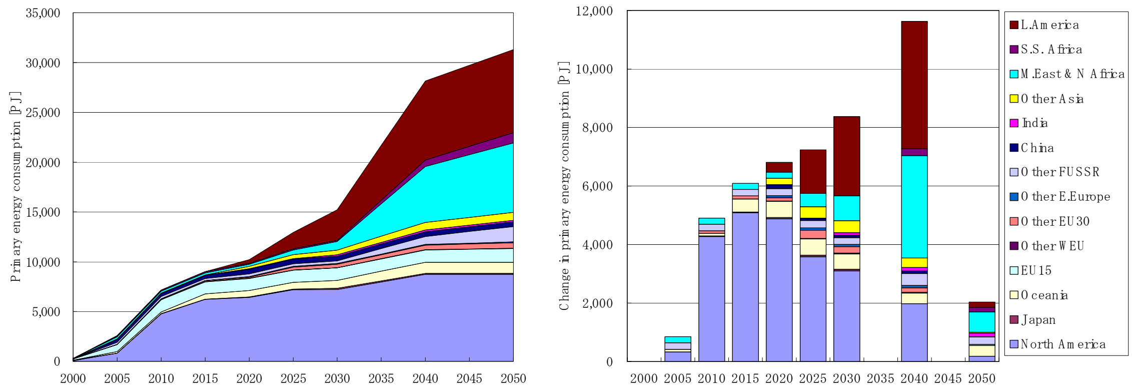
Figure 5.32 *Primary energy consumption (EU30)*

Key renewable energy sources and countries

The increase of wind and biomass by the subsidy scheme is relatively large as shown in Figure 5.30. These two sources are considered important between the years 2000 and 2050.

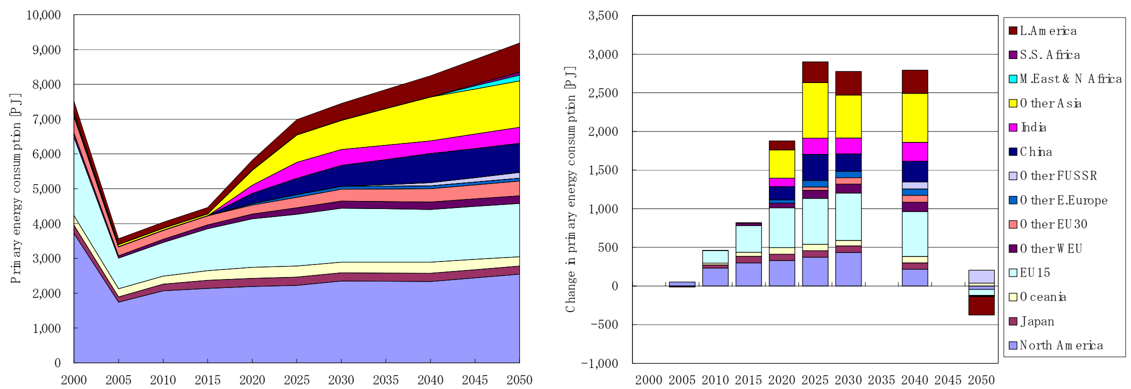
Figure 5.33 and Figure 5.34 shows the wind and biomass by region, respectively. For wind power, North America has the largest share in the world total over the 50 years. After 2030, developing countries such as Middle East & North Africa and Latin America achieve a large share. As shown in Figure 5.33 (b), there is a relatively large difference between RES case and Base case for wind in 2040. Compared with Base case, the increase of wind power in Middle East & North Africa and Latin America is 8EJ. The wind in these regions accounts for 48% of that in world total, and the increase ratio of wind relative to Base case in these regions is 138%.

For biomass, North America and EU have a large share in the world. Among the developing countries, Asian countries (China, India and Other Asia) have a large share. The large increase in these regions from Base case is shown. In these regions, the shares of the biomass in world total are 24.4 – tot 30.0% between the years 2025 and 2040, and the increase of the biomass relative to Base case is 1.0 to 1.3EJ for that period.



(a) RES case (b) Difference (RES case - Base case)

Figure 5.33 *Primary energy consumption (Wind)*



(a) RES case (b) Difference (RES case - Base case)

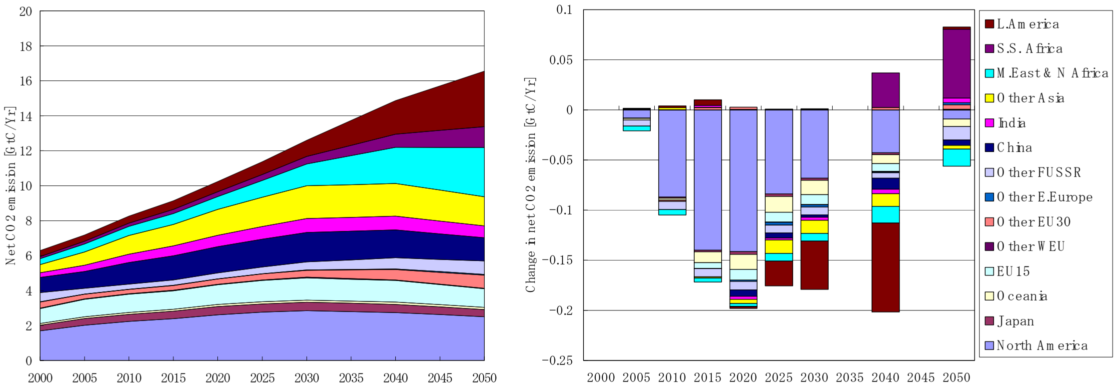
Figure 5.34 *Primary energy consumption (Biomass)*

5.3.3 Consequences of the subsidy scheme for renewables

CO_2 emissions

Figure 5.35 shows the world CO_2 emissions and sequestrations of RES case and difference between RES case and Base case. The maximum net CO_2 reduction (0.20 GtC/Year) is shown in 2020 and the reduction ratio relative to that for Base case is 1.9%. Evaluating for 50 years, net CO_2 reduction is 6.1 GtC and the reduction ratio is 1%. On the regional level, relatively large reduction is shown in North America and Latin America, the maximum net CO_2 reductions are 0.14 GtC (North America, in 2020) and 0.09 GtC (Latin America, in 2040), respectively.

The total reductions for 50 years are 3.3 GtC (North America) and 1.3 GtC (Latin America). These reduction ratios to Base case are 2.5 and 2.3%, respectively.



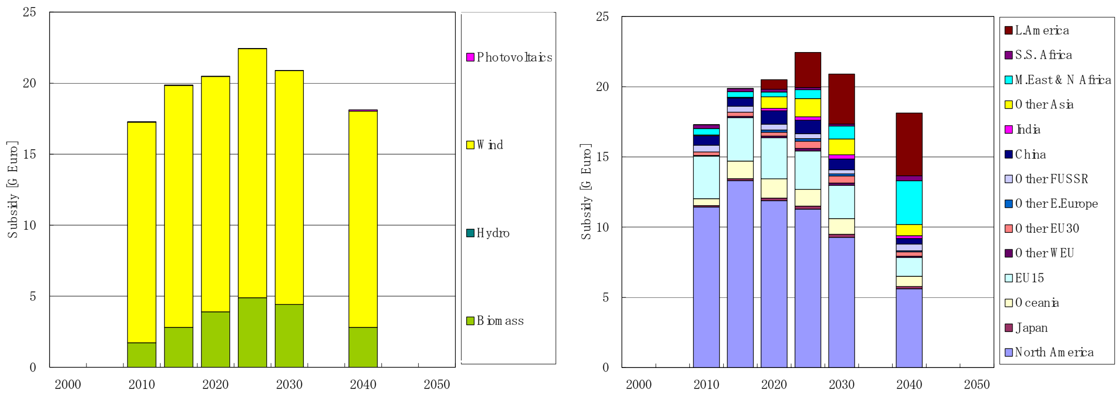
(a) RES case (b) Difference (RES case - Base case)

Figure 5.35 *Net CO_2 emission*

Cost

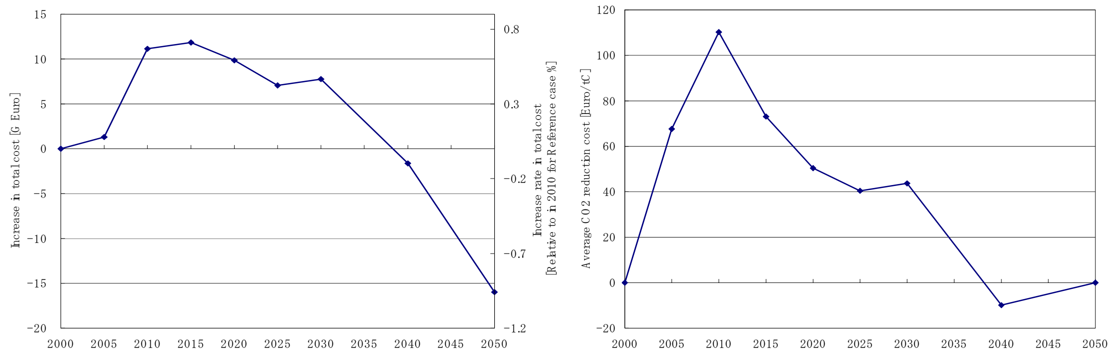
Figure 5.36 shows the sum of subsidy by energy source and by region. It is expected from the result of Figure 5.30, subsidy is mainly used for wind power and biomass. Subsidy for North America is the largest throughout the period that subsidy is applied and the share in world total is 31.0 - 67.0%. Subsidy for EU15 and Latin America is relatively large among the regions except North America.

The increase in world total discounted cost (energy system cost + subsidy) between the years 2000 and 2050 is € 97.6 mld and 0.28% (relative to the total cost in Base case). Here, a discount rate of 5%/year is used. Figure 5.37 shows the time series data of increase in total cost and average CO_2 reduction cost (total cost increase/CO_2 reduction). The peak of cost increase is € 11.8 mld in 2015. Average CO_2 reduction cost rises sharply in 2010 that is start year of subsidy and the cost is 110.3€/tC. On the other hand, the cost in 2040 is negative values. In DNE21+, the world total discounted cost for 50 years is minimized. Therefore, the cost may happen to be smaller at some representative time points than that in Base case depending on the circumstances, even if CO_2 emission is reduced from that in Base case.



(a) By energy source (b) By region

Figure 5.36 *Sum of subsidy (RES case)*



(a) Increase in total cost (b) Average CO_2 reduction cost

Figure 5.37 *Cost increase and average CO_2 reduction cost (RES case, Relative to cost for Base case)*

5.3.4 Alternative emission reduction measures in terms of cost effectiveness

The cost effectiveness of the subsidy scheme is discussed in this section. We consider an emission constraint that every region keeps the CO_2 reduction in RES case throughout the time period and obtains the optimal solution by the model-run. The achieved result is the cost optimal for achieving the same amount of CO_2 reduction as RES case. Thus we call the case 'OPT case'.

Figure 5.38 shows the change in primary energy consumption relative to Base case. Compared with Figure 5.30 (b), the feature of OPT case is switching among fossil fuels, from Coal to Gas and Oil.

The increase ratio of world total discounted cost of OPT case to Base case is 0.08% whereas the increase ratio of RES case is 0.28% as shown in Figure 5.39. The cost increase for OPT case is below about one forth of that for RES case. Figure 5.40 shows the increase in total cost in the representative time points and average CO_2 reduction cost. Compared with the increased cost for RES case, that for OPT case is lower during the early evaluation period between 2000 and 2025.

The above discussion indicates that there exist more cost-effective measures to achieve the same amount of emission reduction as to RES case. However, it may be relatively complicated and need to overcome practical difficulties to implement those cost-effective measures.

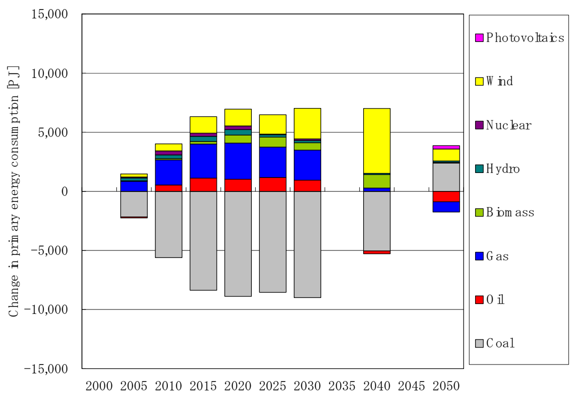


Figure 5.38 *Change in primary energy consumption relative to Base case (OPT case)*

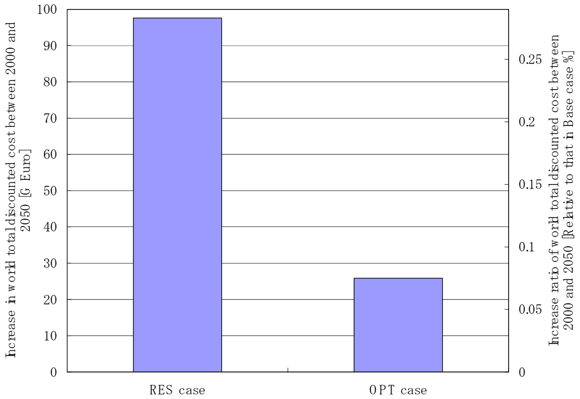
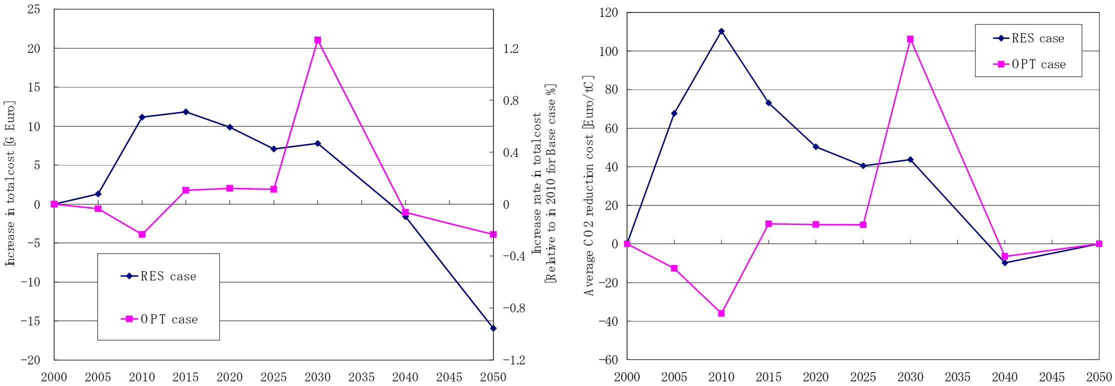


Figure 5.39 *Increase in world total discounted cost between 2000 and 2050 (RES case and OPT case, Relative to cost for Base case)*



(a) Increase in total cost (b) Average CO_2 reduction cost

Figure 5.40 *Cost increase and average CO_2 reduction cost (RES case and OPT case, Relative to cost for Base case)*

5.3.5 Sensitivity analysis concerning the technology learning effect

The above discussion is based on the assumption of the exogenous cost reduction for renewables. However, for evaluating the effectiveness of subsidy, it is important to consider the technology learning effect.

Wind power and photovoltaic technologies are regarded as technologies of mass production and it is reasonable to assume their cost reduction proceeds according to the typical learning curve of a constant learning rate. Thus, the endogenous treatment was tried as a sensitivity study for the technology learning of the wind power and PV. They have mature technology components whose cost portions are regarded to be fixed and only the remaining portions undergo the cost reduction according to learning rates as assumed in Table 5.6. The model-solving was conducted through iterative model-runs.

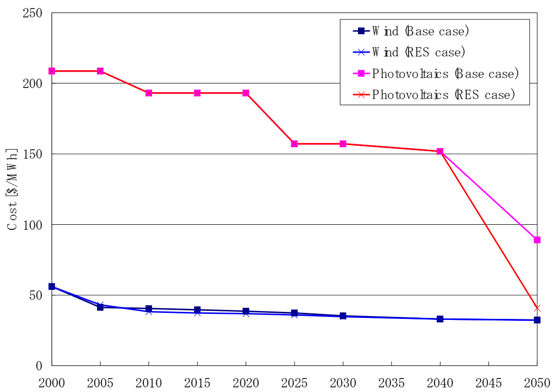
Table 5.5 *Assumed cost reduction for wind power and PV*

	Cost in 2000[1] [$/MWh]	Fixed cost ratio in 2000 [%]	Ratio of cost for learning in 2000 [%]	Learning rate[4] [% for doubling]
Wind power	56 - 118	36[2]	64	15
Photovoltaics	209 - 720	13[3]	87	25

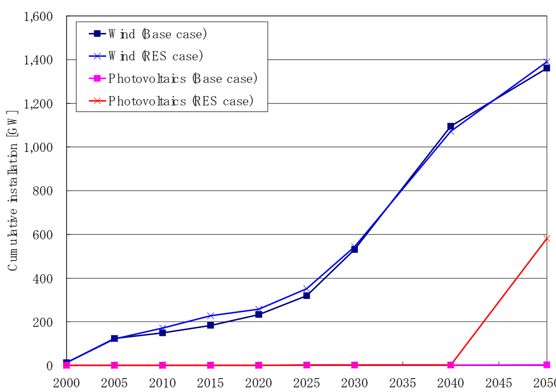
[1] Cost is divided into 5 grades.
[2] Construction, electric facilities, road for access, etc.
[3] Power conditioner Source) K.Yamada & H.Komiyama, 'Photovoltaic Engineering', 2002.
[4] Source) A.Grubler et al., 'Technological Change and the Environment', 2002.

The cost and cumulative installation of wind power and PV through iterative model run is shown in Figure 5.41. For wind power, the difference between Base case and RES case for cumulative installation is small. It can be said that the assumed subsidy scheme is not enough to accelerate diffusion. Significant penetration of photovoltaics is not observed, because the cost for photovoltaics is substantially higher than that of other technologies. However, the differences in the cost and cumulative installation between Base case and RES case are relatively larger than that of wind power and they are observed after 2040.

Figure 5.42 shows the comparison of cumulative installation between exogenous learning and endogenous learning. There is relatively large difference in cumulative installaed of wind power between the years 2030 and 2050 in Base case. Although about 900 GW installation of PV is shown with the exogenous treatment of the technology learning over the 50 years, such a installation is not achieved on the assumption in Table 5.6.

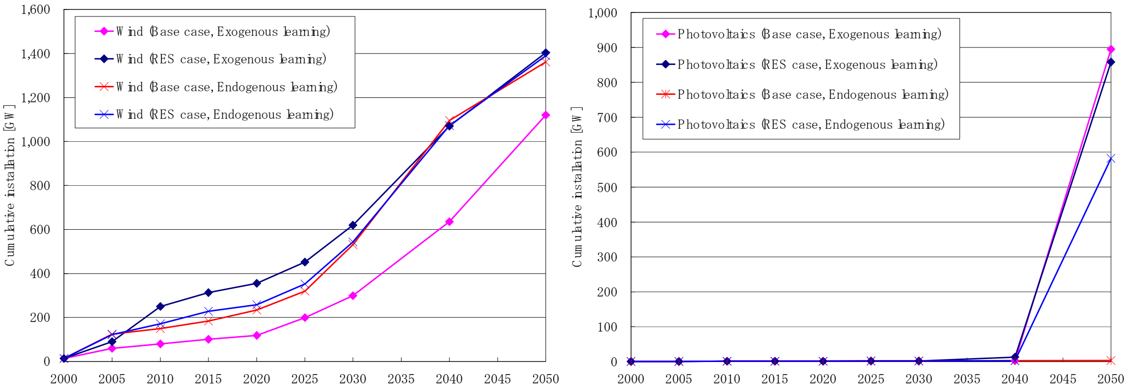


(a) Cost (lowest priced grade)



(b) Cumulative installation (World total)

Figure 5.41 *Cost and cumulative installation through iteration model calculation*



(a) Wind power (b) Photovoltaics

Figure 5.42 *Comparison of cumulative installation between exogenous learning and endogenous learning*

5.3.6 Conclusions and policy implications

The effectiveness of subsidy for renewable energy sources was analyzed by using DNE21+ model. The results are summarized as follows:

1) The achieved renewables increase is about 387EJ in the world by subsidy scheme between the years 2000 and 2050, and its ratio to the total primary energy consumption for 50 years is 9.2%.
2) For the achievement of the EU target of renewables share, more accelerative measures are needed.
3) Although North America has the largest potential of renewables, a large growth of renewables is shown also in developing countries such as Latin America, Middle East, North Africa for wind power and Asian countries for biomass. It can be said that policy instruments such as CDM have potential for effective CO_2 reduction.
4) The world net CO_2 emission is reduced by 6.1GtC between 2000 and 2050 by introducing the subsidy scheme, and its reduction ratio is about 1%.
5) The increase ratio of world total discounted cost between 2000 and 2050 is 0.28% for RES case, and that of OPT case is 0.08%. It is important to discuss carefully about tradeoff between cost effectiveness and practical difficulty in actually introducing the instruments.
6) Even when the learning effect is taken into account, the assumed subsidy scheme is not enough for accelerating the penetration of renewables significantly.

6. Synthesis: Effects of policy for renewables on long term global development

In Chapter 4, the focus has been on the efforts to stimulate the use of renewable energy sources (RES) on the short to intermediate term, in particular with a focus on the targets the European Union has set for itself. When extending the focus to the longer term, say until 2050, a restriction of the efforts to the European Union only is unlikely to provide a realistic view on future prospects of renewable energy systems. When considering such time horizons, the world as a whole should make an effort towards a considerable contribution from renewable energy systems, as issues related to competitiveness of the European Union will become relevant with an ever-increasing contribution.

Beyond direct questions related to the competitiveness of the EU in case of substantial stimulation of RES, there are more indirect reasons why a global focus is inevitable. For one, biomass is likely to play a substantial role in case of simulation of RES, and in the long term competition for resources may play a crucial role for its further development in the EU. Another major issue for the EU to address on the longer term is the most cost-effective way in which subsidies may be spent - possibly, development of RES in other regions in the world may prove to be a more cost-effective way of reaching long-term emission reduction.

It is clear that a long-term perspective of RES can only be drawn from a global viewpoint. Thus, in the present study three global models (DNE21+, GMM, and MESSAGE) have been used to study the effects of subsidies on renewable energy systems.

6.1 Technological deployment

6.1.1 Subsidies - a never-ending story?

The assumption on the subsidies for RES is that they gradually decrease, so that in the end the systems are no longer subsidized. This subsidy scheme reflects a situation where the policy maker is willing to provide a subsidy for market uptake, but is decreasingly willing to support systems that are not entering the market by itself. The zero support in 2050 reflects the fact that over a period of 50 years, the technologies supported should have reduced their costs sufficiently to make it on the market of their own - or fail.

Thus, the set-up of the long-term policy analysis is such that it is assumed that RES in the long term will gain competitiveness due to initial subsidizing. When considering the outcomes of the individual models, though, this appears to be a futile hope. The various analyses show a decreasing penetration of RES with decreasing subsidy level. By 2050, the effect in all three bottom-up models by and large show a ‘convergence’ of the outcome of the policy case to the baseline results - and hence the subsidy seems to have no lasting impact whatsoever.

The reason for lack of lasting effect of subsidies may be two-fold. First, in a world where the level of deployment of a technology does not influence its price, a non-lasting effect is understandable. Introducing the subsidy will only benefit the cost level of a technology in a direct manner, and as soon as the subsidy is decreased, the effect for the deployment of the technology decreases proportionally.

Although this may seem a trivial conclusion, it is not, as it clearly indicates that support schemes will only be of lasting impact for those technologies that have a potential for cost reduction under further deployment, i.e. for technology that can exhibit *Learning by Doing (LBD)*[27].

It may not suffice for a technology to exhibit LBD, though. This is most strikingly illustrated by the GMM model, which includes both wind power and solar PV as LBD-technologies. In spite of their learning potential, the policy case shows the convergence towards the baseline. As it happens, these two systems illustrate two possible frustrations for learning. The wind power technology is already quite successful in the in the baseline, and consequently physical limitations thwart further application of the technology. At the same time, the costs for solar PV systems is too high to benefit from the support scheme, although the highest subsidy level studied with the model indicates that at some point this may no longer be the case.

6.1.2 Learning can increase effects of subsidies

Based on the seemingly robust, but unwanted conclusion that non-lasting subsidies will have non-lasting effects, all three models have extended their study to include (extended) learning effects in some way. Two out of three models show lasting effects for some technologies, with generally are modest due to physical constraints in combination with the modest subsidy level. The third model, analyzing the competition between various sectors for biomass, shows that increases in one sector may be achieved at the expense of another sector. In all, the conclusion is supported that subsidizing endogenous learning renewable energy systems will likely lead to increased deployment of such technologies, even beyond the period where the technology is subsidized.

6.1.3 Subsidies as internalization of benefits

In the previous sections, it was argued that the potential to realize cost reductions through learning-by-doing is essential for the success of a subsidy scheme for renewable energy systems. There is an alternative view possible, based on the observation that the modest and decreasing subsidy levels in the case study give rise to an enhanced contribution from RES in the intermediate periods. This is illustrated in the next figure, where the increased use of RES is shown for the case study, for the three models.

[27] Endogenous Technological Learning, or learning-by-doing, is the effect that costs for a technology generally depend on the cumulative installed capacity, i.e. the more a technology is deployed, the lower the costs of the technology will be.

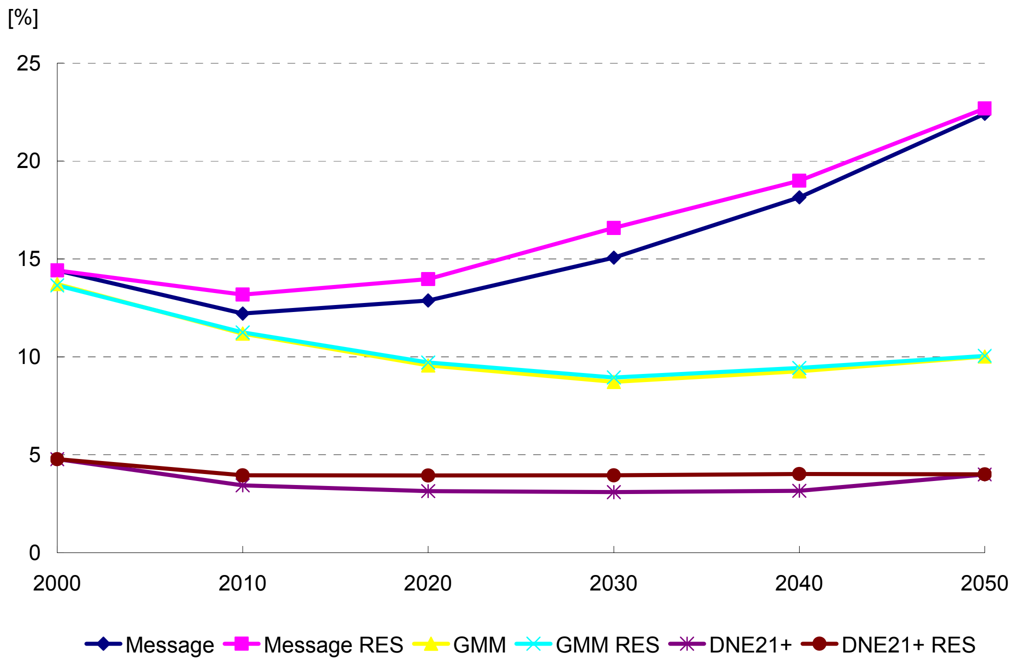


Figure 6.1 *Share of renewable energy in primary energy consumption (Eurostat convention)*

The figure shows that in all models the additional use of RES as percentage of primary energy source peaks around 2030 to 2040, at a value of 1.3 ± 0.4% in the latter period. At the same time, the subsidy is definitely not peaking in this period. Thus, it seems likely that in the long run a relatively low subsidy suffices to stimulate the contribution from renewable energy systems. It is important to realize that such a small stimulus is already included in the baseline, where a moderate CO_2 tax is included. Based on the observations done here, it could be interesting to see whether the combination of an initial subsidy scheme with a stronger CO_2 tax from 2050 onwards would lead to similar result. Such a scheme could be justifiable from the point of view of internalizing costs for non-renewable energy resources, or alternatively internalizing the benefits from renewable resources.

6.1.4 Technology mix

There are only few robust conclusions to be drawn from the analysis on the level of technologies in the three models. First, a major stimulus is provided by the subsidy scheme to the application of wind energy in all three models, as is illustrated in upper left panel in Figure 6.2. In GMM, the increase is relatively modest due to the high contribution of wind energy in the baseline, there due to learning effects. Note furthermore that the increase in use of wind is still significant by 2050 in all models, although in percentages it is small due to the rising contributions from wind in the baseline.

Contrary to the case of wind energy, the initial increase in application of biomass is annulled by the year 2050 in all three models, as is also illustrated in Figure 6.2, in the upper right panel. This indicates that the low and decreasing subsidy level is insufficient to induce a lasting effect on the additional deployment of biomass. In one of the three models (GMM), the use of biomass is hardly increasing at all, when the potential for endogenous technological learning for the associated technologies is disregarded. In the other two models biomass plays a significant role in the enhancement of renewables in any case. Using the MESSAGE model, it was shown that biomass can play a role in various sectors, and that a stimulus in a particular sector may cause ‘carbon leakage’ to other sectors, due to a shift in application of biomass, leaving the total use of biomass relatively unchanged.

The use of both solar and hydro energy is relatively insensitive to the subsidy scheme described here, albeit for different reasons. Again, this is illustrated in Figure 6.2, in the lower left and right panels, respectively. Solar remains roughly at its baseline level because the subsidy is too small to compensate for the higher costs. Note however that there is a large uncertainty in the development of solar energy. The use of hydro is limited by the availability of resources, and furthermore by the exclusion of large-scale facilities from the subsidy.

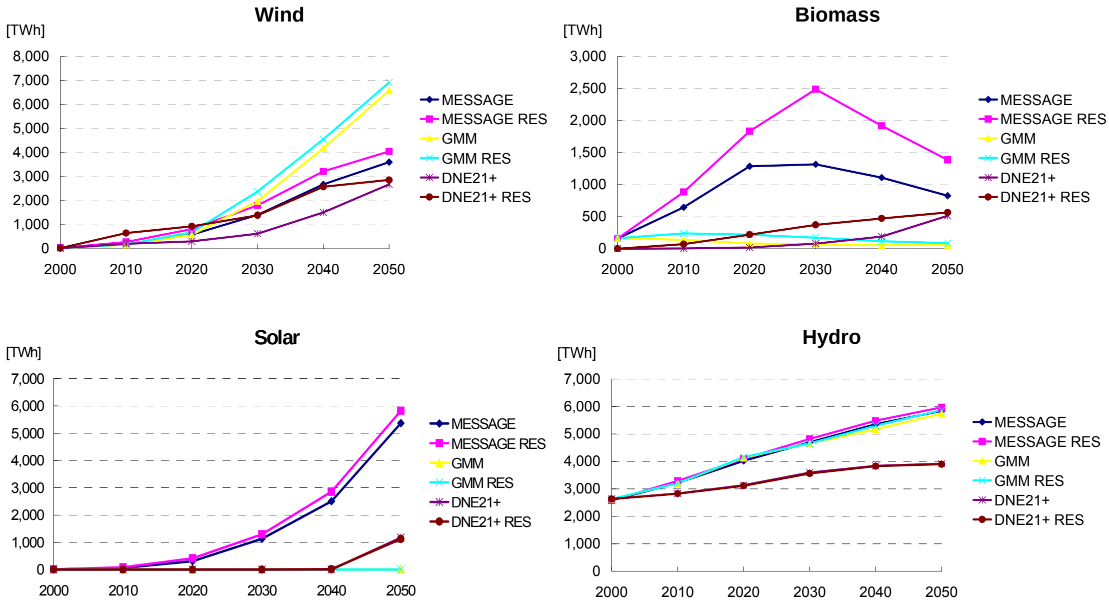


Figure 6.2 *Electricity generation from renewable energy sources in the three world models, in the baseline scenario and in the RES policy scenario. Note the difference in scales*

A fifth renewable resource, geo-thermal energy, is not depicted in Figure 6.2. This resource is generally strongly limited by physical constraints, making extensions beyond the baseline utilizations particularly difficult. Only in the GMM model roughly a doubling of the contribution from this resource is observed. In the other two models, the subsidy either does not influence the deployment (MESSAGE), or the technology is not considered at all (DNE21+). This latter approach seems justified by the other two models, as the contribution in absolute terms remains small, even in the GMM analysis.

One striking feature from the figures above is that the uncertainty in the development of utilization of resources over the various models seems to be much higher than the effects of the subsidy investigated here. Thus, it would seem that it is more beneficial to first resolve this uncertainty, before trying to draw definitive conclusions on the application of subsidies to enhance the contribution from renewable energy sources.

6.2 Global costs and benefits

The subsidy scheme induces stimuli for renewable energy systems, as was illustrated above. The mere fact that there are effects generally is insufficient for the scheme to be implemented, though. The costs linked to the scheme are of decisive importance, as these determine the cost-effectiveness in comparison to competing schemes.

6.2.1 Costs

In all models, the costs for enhanced penetration are considerable. However, there is considerable uncertainty in the overall costs. The total discounted costs are given by one of the models (DNE21+) as being of the order of 100 G€. This corresponds to some 0.3% of the total system costs, and is mostly in paid subsidies. In terms of the costs per reduced ton of CO_2 emission, this is equivalent to 4.34 €/tCO_2. One of the other models (MESSAGE) gives the average cost as close to 100 €/tCO_2, while the third model (GMM) indicates a change of at most 0.2% in overall system costs (not including spending for subsidies) as compared to the baseline.

The costs depend strongly on the subsidy scheme - in general, it is assumed that the subsidy applies to all renewable energy systems. Thus, subsidies are also paid for systems that would have been installed anyway. A more dedicated scheme, with tailor-made subsidy levels, would lead to lower overall costs.

6.2.2 CO_2 emission reduction

A major aim of subsidizing of renewable energy systems is to reduce the emission of the greenhouse gas CO_2. In all models, the cumulative emission of CO_2 from energy use is reduced by 22 ± 2 GtCO_2 until 2050. The emission reduction exhibits a peaking behaviour, as is illustrated in Figure 6.3. To a large extent this is caused by the peak in the enhanced application of RES, which in turn is caused by the gradual decrease in subsidy levels as discussed before. However, some of the reduced effects towards 2050 is caused by other features, such as a shift from low-carbon fossils towards high-carbon fossils, particularly coal.

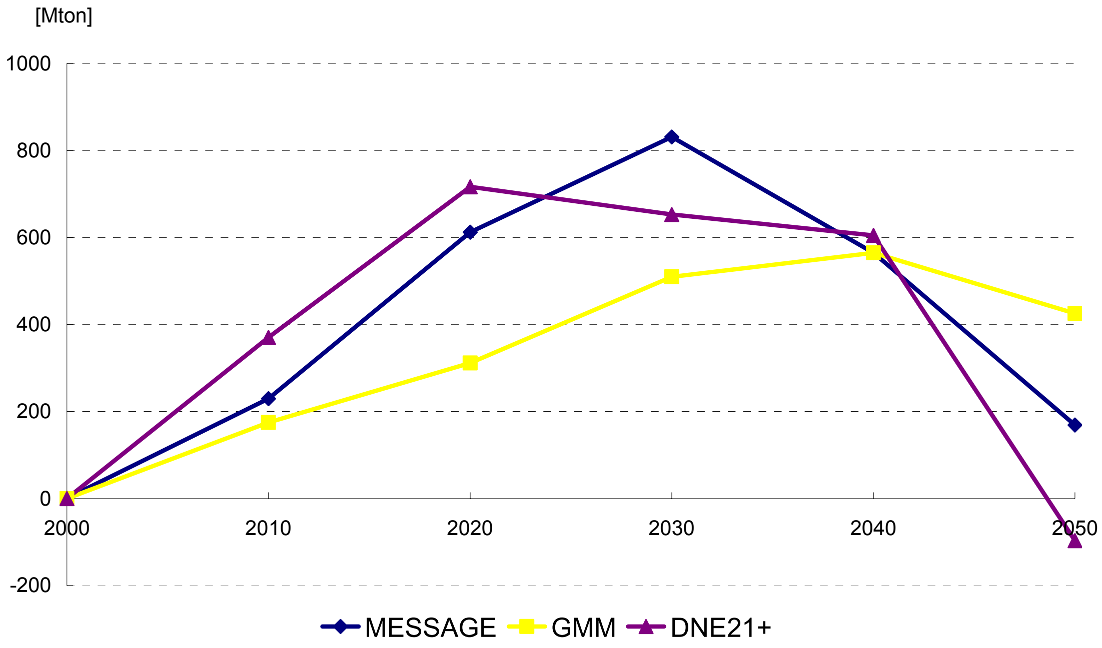


Figure 6.3 *CO_2 emission reductions relative to the baseline in the three world models*

The reduction in itself is quite substantial, but this is less so when it is compared to the overall global energy related emissions. Expressed as percentage of these total emissions in the baseline, the reduction ranges from 0.8% to 1.1%, with an average over the three models of 0.93%.

6.2.3 Security of Supply

The stimulation of the use of renewable energy systems is limited, as is illustrated in the preceding paragraphs. Therefore, it should come as no surprise that the impact on the Security of Supply (SoS) is limited. While for CO_2 emissions cumulative reductions can give a representative view of the overall effect of the subsidy, even when the change in emissions is limited, such a measure is not available in the SoS. The models show hardly any effect on the import dependency.

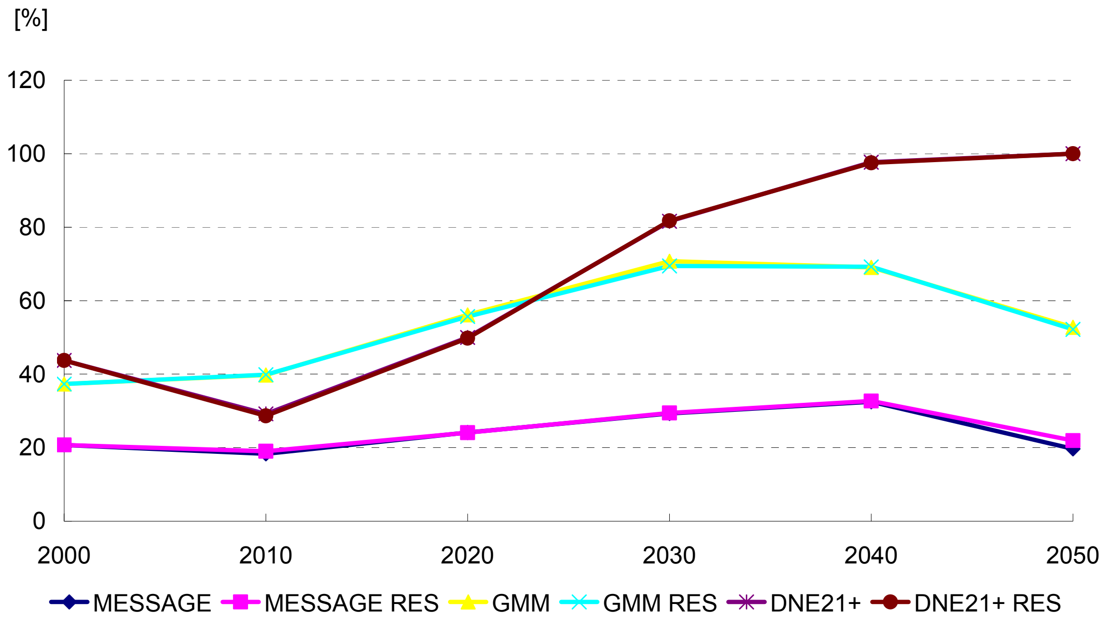


Figure 6.4 *Import dependency for gas in the three global models, for the region encompassing the EU15*

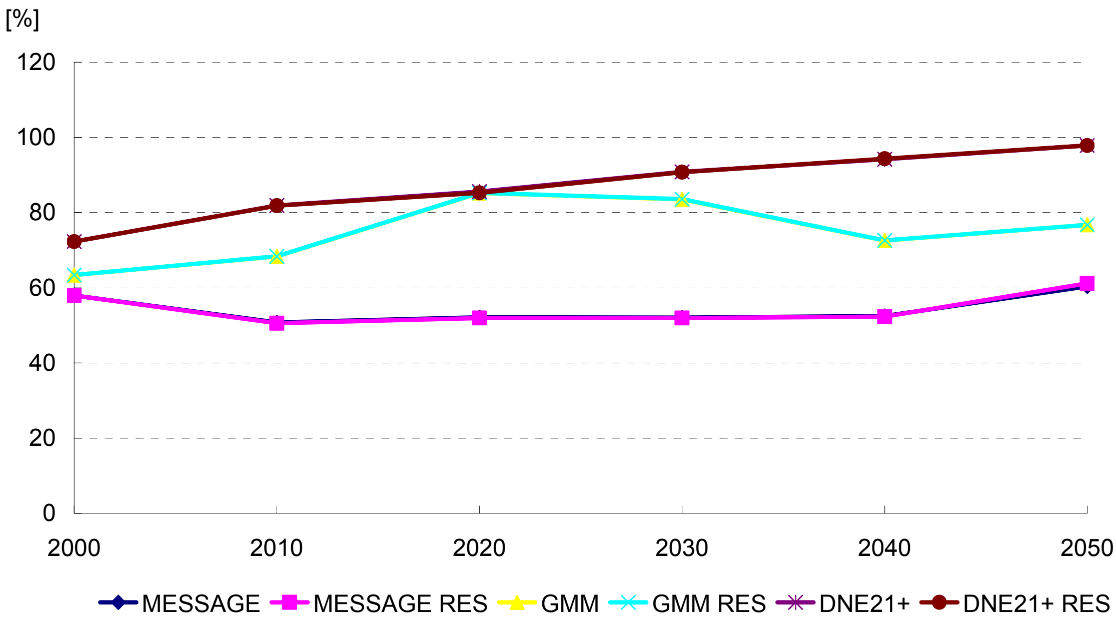


Figure 6.5 *Import dependency for oil in the three global models, for the region encompassing the EU15*

6.2.4 Complexity of scheme pays off

Each of the models involved have looked at particular alternatives to the subsidy on renewable energy systems. In one study, the CO_2 emission levels per region from the subsidy case were set as targets, to be achieved in the most cost-optimal way. In that case, the reduction is achieved through a fuel switch from coal to gas and oil, rather than through application of RES. As this increases the dependency on relative scarce fossil fuels, the back-draw of the cost-optimal solution might be increased concerns for security of supply. Furthermore, like in the RES subsidy case, the cost-optimal solution shows a peak in CO_2reduction costs, albeit somewhat lower, with the most remarkable feature that is shifted towards later years. This seems to indicate that even if one allows for enhanced use of relatively clean fossil fuels, in the long run the use of more expensive options is unavoidable.

As was noted in the section on costs, applying the same subsidy level to all renewable energy systems is likely to be ineffective, as compared to a system-dependent subsidy scheme. This has been illustrated in one of the models by comparing the subsidy case to a 'cap-and-trade' scenario. There, a target has been set for the overall contribution from RES (35% in 2050). It is shown that such a target is feasible, and that the costs associated to such a scheme are initially lower than those of the subsidy scheme. From 2040 onwards the costs increase beyond the subsidy level, but this is due to the decreasing level of the subsidies. However, one should realize that the subsidy scheme was shown to be hardly able to yield lasting effects in the contribution from RES, so that one should be careful in comparing costs in the later years of the period. Indeed, while the 'cap-and-trade' scheme ensures a 35% contribution by 2050, the level in the subsidy case remains close to 20%.

The subsidy was assumed to apply only to renewable energy systems in the power sector, at first, as this is the sector most extensively covered in the models. However, stimulation of the use of RES in the power sector will lead to enhanced competition for scarce resources, particularly biomass. Indeed, as one of the models shows, the subsidy in the power sector enforces a decreased application of biomass in the transport sector, and thus effectively a 'leaking' of CO_2 from the power sector to the transport sector. In an alternative approach, it is shown that a subsidy scheme in which also production of alternative fuels from renewable resources leads to a more effective reduction of CO_2 and a higher share of renewable energy sources in primary energy use. Thus, this illustrates that one should carefully consider all applications of renewable resources when devising subsidy schemes.

6.3 Conclusions

It was shown that the central case study with a rather low and decreasing subsidy has little lasting effect on the application of renewable energy sources. The effects are even outweighed by the large uncertainty in the possible technological progress, as comparisons of the case study with the baseline results show. Such uncertainties for a large part can be attributed to the impact learning may have on the application of certain technologies.

When looking at the results of the various models, and the additional scenarios studied with those models, it is clear that a more complex scheme than simply providing a flat subsidy rate to all RES pays off. Furthermore, extending the subsidy beyond the power sector reduces CO_2-'leakage' and leads to a more efficient scheme.

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