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The contribution of renewable energy to a sustainable energy system

Policy brief in the CASCADE MINTS project

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The following partners are involved in Part 2 of the Cascade Mints project:

- Energy research Centre of the Netherlands (ECN) (The Netherlands); coordination / MARKAL model.
- ICSS/NTUA - E3MLAB (Greece); PRIMES and PROMETHEUS models; coordination Part 1 of the CASCADE MINTS project.
- 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.
- ERASME-Équipe de Recherche en Analyse des Systèmes et Modélisation Économiques, University of Paris (France); NEMESIS model.
- International Energy Agency (France); ETP model.
- U.S. DOE/EIA Energy Information Administration of the U.S. Department of Energy (USA); NEMS model.
- Research Institute of Innovative Technology for the Earth (Japan); DNE21+ model.
- National Institute for Environmental Studies (Japan); AIM model.
- Natural Resources Canada (Canada); MAPLE model.

Overview of the models participating in the CASCADE MINTS project (models marked with * were not involved in the analysis of the renewables scenarios):

<table>
<tr><th rowspan="2"></th><th colspan="2">Top down</th><th colspan="2">Bottom up</th></tr>
<tr><th>Macro-economic</th><th>Computable General Equilibrium</th><th>Energy System Optimisation</th><th>Integrated Energy System simulation</th></tr>
<tr><td rowspan="2">Global,
US, Canada</td><td rowspan="2"></td><td rowspan="2">AIM*
NEWAGE
PACE</td><td>DNE21+
ETP*
GMM
MESSAGE</td><td>POLES
NEMS
MAPLE*</td></tr>
<tr><td colspan="2">PROMETHEUS</td></tr>
<tr><td>Europe</td><td>NEMESIS</td><td></td><td>MARKAL Europe
TIMES-EE</td><td>PRIMES</td></tr>
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Contents

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.

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[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.

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

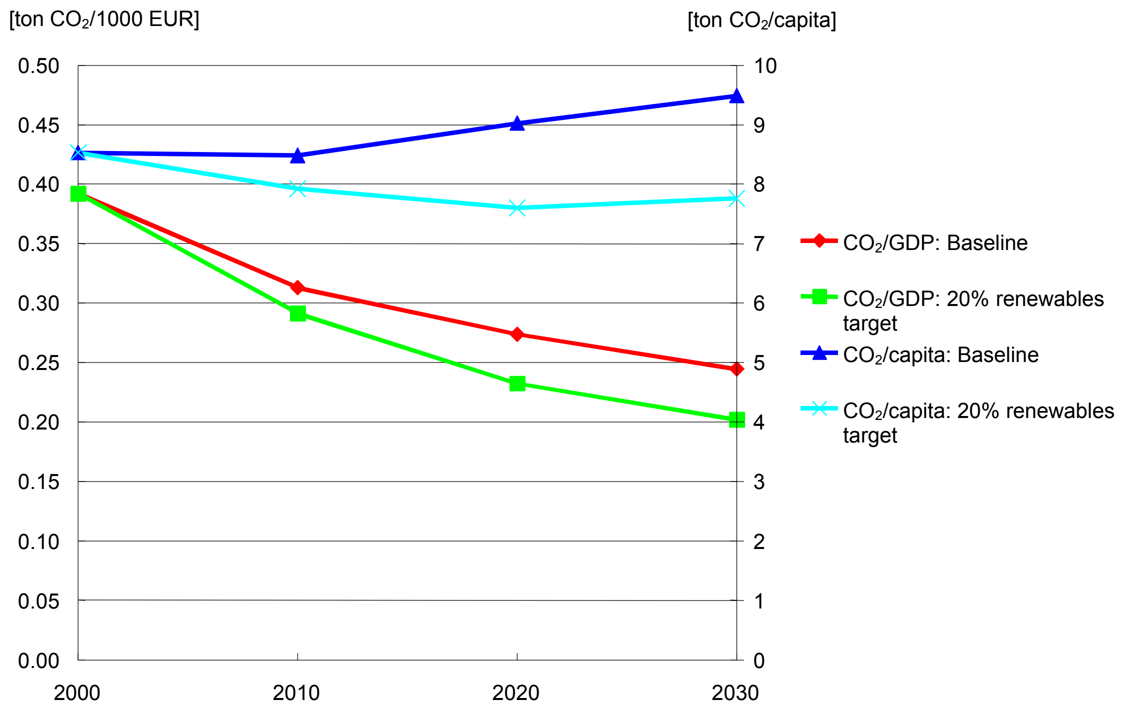

Figure P.1 *Energy-related CO_2 emissions per capita and per GDP in Europe; averaged over results of POLES (EU-30), PRIMES (EU-25) and MARKAL (Western Europe)*

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 because it may substitute imported energy. The economic models do not agree on how the re-

[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.

newables 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, e.g. FORRES 2020 (Ragwitz et al, 2004), and "European energy and transport – scenarios on key drivers"[4] 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 so-

[4] http://europa.eu.int/comm/dgs/energy_transport/figures/scenarios/index_en.htm

lar 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.

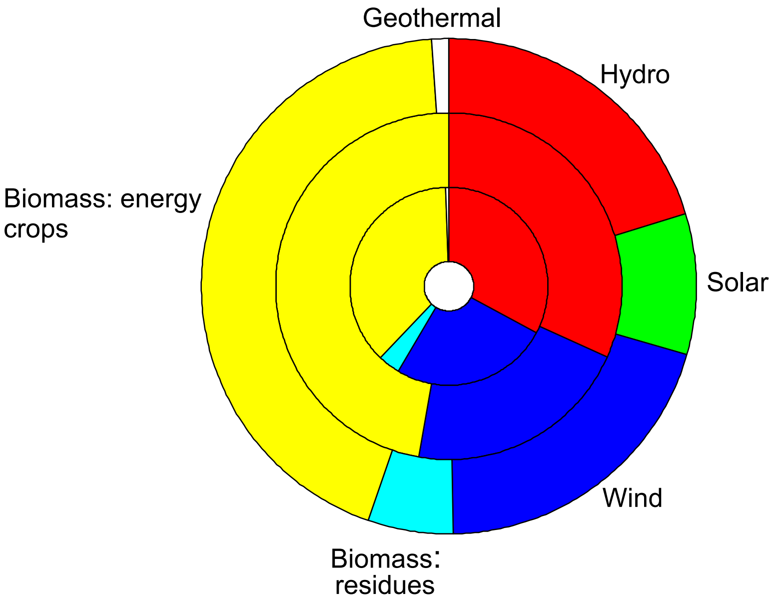

Figure P.2 *Shares of renewable technologies and resources in Europe's primary energy consumption in 2020; from outer to inner circle: PRIMES, POLES and MARKAL*

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).

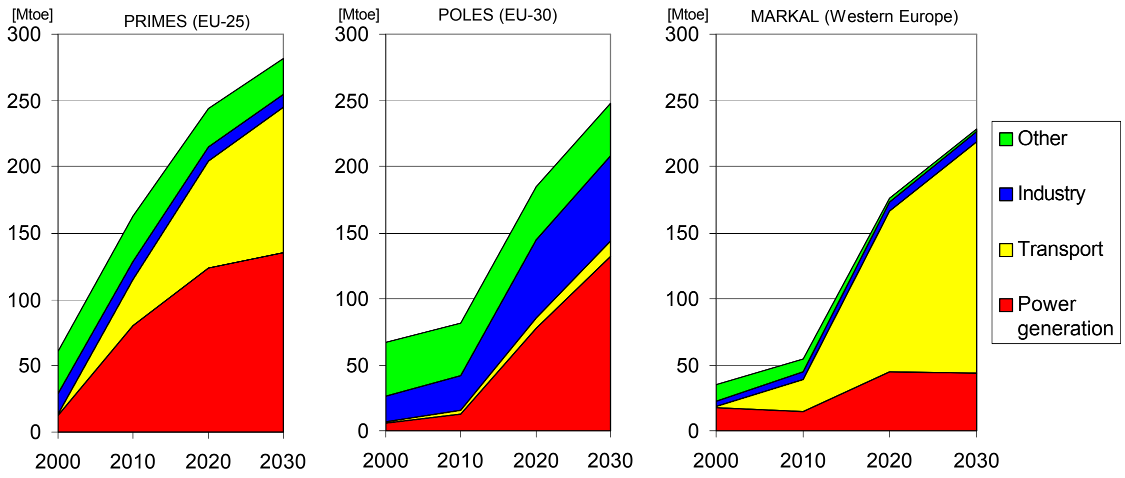

Figure P.3 *Deployment of biomass and waste by sector according to different models*
Note: the sector definitions in POLES are not completely comparable to those in the other models and part of power generation falls in the category 'Other'; EU-30 here excludes Turkey).

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.

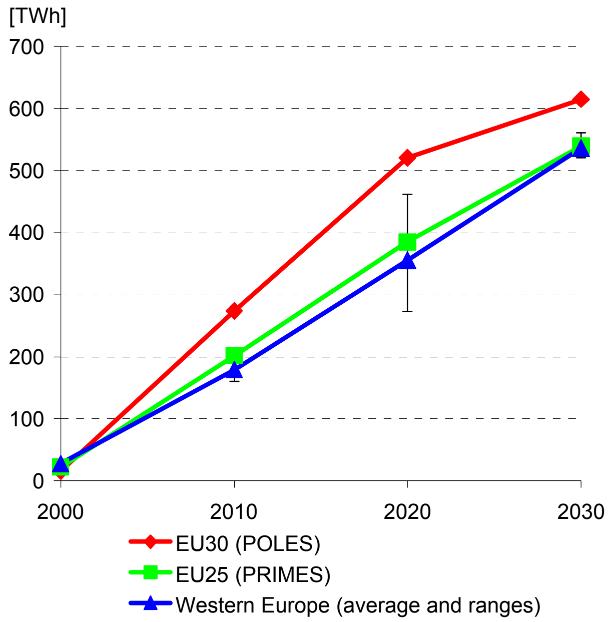

Figure P.4 *Production from wind energy*

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.

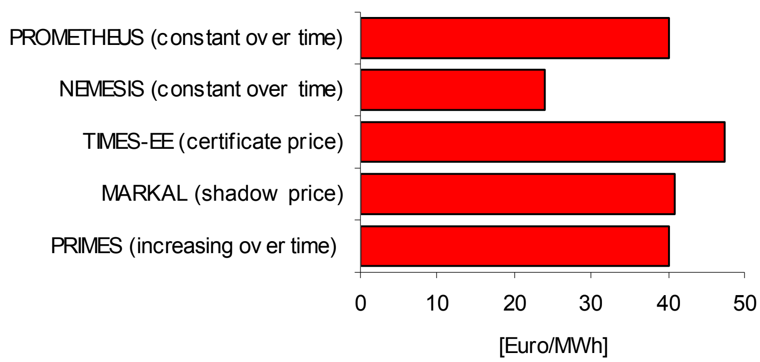

Figure P.5 *Subsidies required for achieving 33% renewable electricity consumption in 2020*

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.

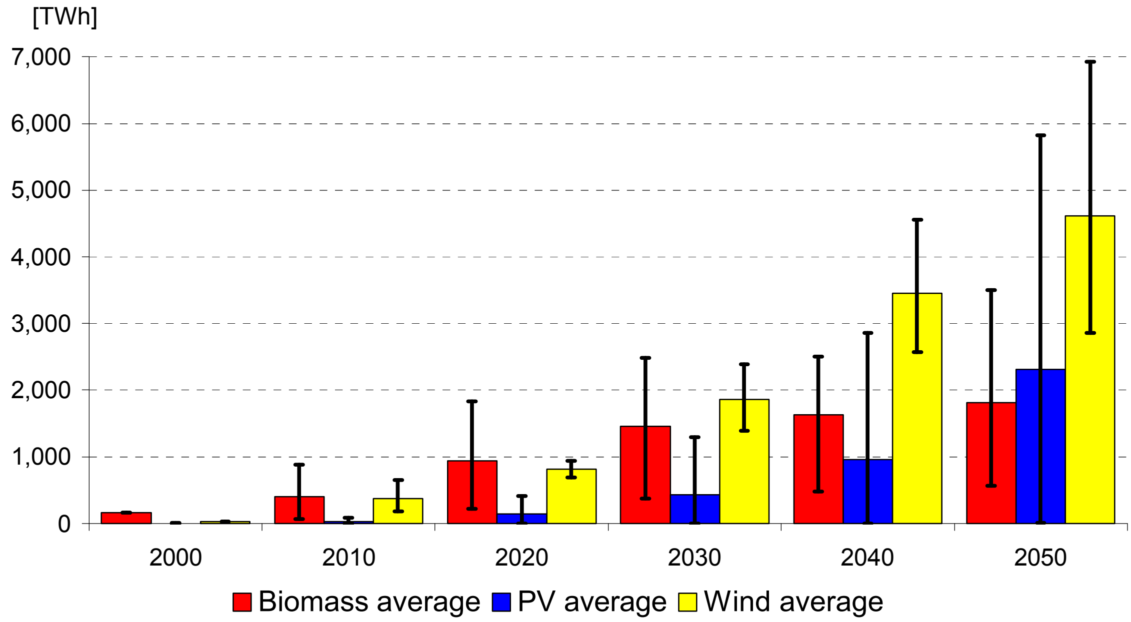

Figure P.6 *Global electricity production from biomass, PV and wind under a subsidy scheme of 20 €/MWh, decreasing to zero in 2050; averages over three models and ranges*
Source: MESSAGE, GMM and DNE21+.

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[5]. 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.

5 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.

Global 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).

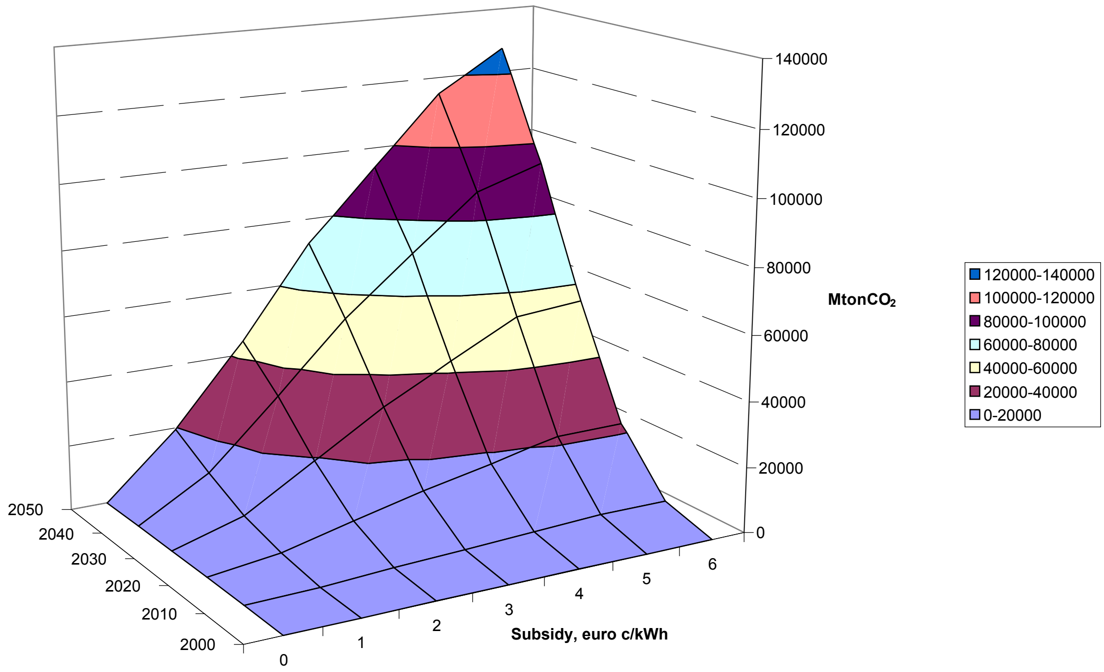

Figure P.7 *Cumulative CO_2 reductions as a function of the subsidy level, renewable energy in all sectors subsidized*
Source: MESSAGE.

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.