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Renewable Energy Road Map
Renewable energies in the 21st century: building a more sustainable future

IMPACT ASSESSMENT

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Renewable energy roadmap – impact assessment

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1. PROCEDURAL ISSUES AND CONSULTATION OF INTERESTED PARTIES

On 8 March, 2006, the European Commission adopted an Energy Green Paper, entitled *A European Strategy for Sustainable, Competitive and Secure Energy.*[1] The Green Paper responded to the calls from Heads of State and Government in October (Hampton Court) and December 2005 for the Commission to present new proposals on a common energy policy.

The European Council debated the Green Paper at its meeting in March 2006. In the Presidency Conclusions from the meeting,[2] the Commission was asked to put forward a Renewable Energy Roadmap and to look into the option of a 15% target for renewable energy in 2015. The European Parliament, for its part, has called for a mandatory target for renewable energy of 25% of overall energy consumption in 2020 (together with mandatory sectoral targets).[3]

In its 2004 communication "The share of renewable energy in the EU"[4], the Commission noted that EU policy had been guided since 1997 by the objective of a 12% share for renewable energy in 2010. It acknowledged the importance of providing a longer-term perspective. Before deciding on adopting targets beyond 2010 and taking a position on the 20% target for 2020 proposed by the Parliament, the Commission declared its intention of carrying out an impact assessment to examine the feasibility and the economic, social and environmental implications of renewable energy.

In the light of these strong political messages, this impact assessment aims to shed light on the question of whether the EU should adopt quantified targets for the share of renewable energy in 2020, and if so, for what amounts and in what form. It is based on a variety of inputs and analyses including studies carried out by external experts – notably exercises using the PRIMES and Green-X models.

The various scenarios using the PRIMES and Green-X models have been carried out for EU25. However, to take account of the enlargement of the European Union on 1 January 2007 to include Bulgaria and Romania, a model run on the EU27 using the PRIMES model[5] was also carried out.

An interdepartmental Commission group was set up to coordinate this work. It met seven times between April 2005 and November 2006.[6]

The main issues addressed in the roadmap were debated in the public consultation on the Energy Green Paper and the Strategic European Energy Review between March and September 2006. This process included consultations with Member States, the European Council, the European Parliament, citizens, stakeholder groups, civil society organisations,

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[1] COM(2006)105 final.

[2] Presidency Conclusions 7775/06 of 24/03/06.

[3] European Parliament resolution of 14 December 2006.

[4] COM (2004) 366.

[5] The PRIMES High renewables and efficiency scenario.

[6] DG TREN chaired the meetings. Representatives of the following Directorates-General attended: AGRI, COMP, DEV, ECFIN, EMPL, ENTR, ENV, JRC, REGIO, RELEX, RTD, SG, TAXUD, TRADE.

NGOs and consumer organisations, discussions on various forums, a web page created on the Europa website including a questionnaire and a mailbox for unresolved questions[7].

The questions raised in the public consultation on the Green Paper included whether renewable energy can contribute to ensuring access to energy at reasonable prices in Europe; whether it can contribute to diversification of the energy mix and sustainable development in the EU; and whether defined long-term targets and an action plan to promote renewable energy are important for the further development of clean and renewable energy sources in the EU.

The main messages that emerged from this consultation are as follows:

- The renewable energy targets proposed in the Presidency conclusions of March 2006 are welcomed. Clear and quantified targets beyond 2010 are useful, taking regional circumstances into account. There was wide support for a longer-term target for renewable energy, with suggestions ranging from 20% in 2020 to 50% and more by 2040/2050. The use of obligatory targets was widely supported, as was the internalisation of external costs.

- Three quarters of respondents to the questionnaire saw an increase in the share of renewable energy as the most important step to take to diversify the energy mix.

- Two thirds of respondents considered that the best way to fight climate change is through renewable energy sources and energy efficiency.

- The wider use of renewable energy was also favoured as a means to protect the environment, support technology development and jobs and pave the way to a post-oil era.

- Energy technology development should be innovative and should be backed by a Strategic EU Energy Technology Action Plan. The majority of respondents emphasised further development of renewable energy technologies (solar, wind, biomass).

- Two thirds of respondents considered renewable energies the best option to ensure that all Europeans enjoy access to energy at reasonable prices.

- More than two thirds of respondents believed that the EU should incorporate renewable energy in its external energy policy.

- Discussion of Europe-wide optimisation and possible harmonisation of framework conditions is needed.

- A regional approach, taking into account local circumstances, should be a key element in devising a renewable energy policy.

Complementary consultation exercises were conducted, including consultation of the European Energy and Transport Forum. This is a consultative body set up by the Commission

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[7] 1680 responses were received (1516 via the questionnaire and 164 additional written comments), of which 1287 came from individual members of the public. 18 Member States and Romania responded, as did the European Parliament, the European Economic and Social Committee and the Committee of the Regions. The full text of the analysis is available on http://ec.europa.eu/energy/green-paper-energy/index_en.htm.

in 2001[8] with 34 full members directly appointed by the Commission to represent operators (energy producers, carriers, and manufacturing industry), managers of networks and infrastructure, users and consumers, unions, environmental protection and safety organisations, and academics. A large majority of the Forum concluded that the European Commission should propose mandatory targets for 2020. The level of the 2020 targets should be based on ambitious and realistic assessments of national renewable potentials.

At the same time, the Commission consulted stakeholders on the review of the biofuels directive and on renewable energy in heating and cooling.

2. PROBLEM DEFINITION

The European Union faces major challenges concerning climate change, security of energy supply, and the need to increase market competitiveness. Energy demand is steadily increasing and dependence on fossil fuels from outside the European Union is growing, at a time of fiercer competition on the global energy markets, inevitably pushing up energy prices. The main factor driving the underlying growth in energy demand is economic growth.

Current policy analyses show that greenhouse gas (GHG) emissions are rising. The risks and costs related to climate change are many: increasing natural disasters worldwide, flooding, and countries being submerged. The costs of catastrophes are high and the costs of adaptation are potentially large. Combating climate change will require substantial reductions in GHG emissions, which means switching to low-carbon energy and reducing energy consumption.

The challenge of climate change is coupled with the challenge of increased dependence on imports of fossil fuels. The current rate of import dependency is expected to rise from about 50% to 70% over the next 30 years. Import dependency,[9] combined with the increasingly volatile world energy market, increases uncertainty of energy supply and the risks of supply disruption. These developments are inflationary and economically destabilising and have an adverse impact on economic growth and investment. The instability of the world energy market has geopolitical consequences and imposes costs on energy importing countries.

Despite numerous ongoing energy efficiency efforts[10], energy consumption growth is still a cause of concern.

Renewable energy sources have the potential to tackle these environmental and economic problems. However, renewable energy is not developing as fast as hoped. Since 1997, the EU has been working towards a target of a 12% share of renewable energy in gross inland energy consumption by 2010. In 1997, the share of renewable energy was 5.4% and in 2004 it had reached 6.5%. It is likely that only a 9-10% share will be reached by 2010.[11]

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[8] OJ L 195, 19.07.2001, p. 58.

[9] Import dependency is one of several indicators of security of supply. Other main indicators are fuel diversity and diversity of import regions, and political stability of energy source regions.

[10] Communication from the Commission to the European Parliament and the Council on an Energy Efficiency Action Plan (COM (2006) 545).

[11] There are several important reasons for this development. Firstly, the development of renewable energy has mainly been achieved in the electricity sector. Renewable electricity is likely to account for 19% of gross electricity consumption in the EU in 2010. This is not far from the target of 21%. However, less progress has been made in the transport and heating sectors.

3. OBJECTIVES

The overall objective of European energy policy is to contribute to sustainability, competitiveness and security of supply. Given the immediate threat of climate change and the increasing dependence on fossil fuels, the point of departure for a common energy policy as stated in the Strategic Energy Review[12] is *"the dual objective of limiting the EU's dependence on imported hydrocarbons and combating climate change through a progressive transformation towards a highly energy efficient and low CO2 European Economy"*. A key strategic energy objective for the EU is to reduce CO2 from energy use in the EU by 2020 by at least 20% compared to 1990 levels in a manner compatible with its competitiveness objectives.

The development of renewable energy sources has been and will continue to be a central aim of European Union energy policy. Renewable energy sources are indigenous, they do not contribute to the build-up of greenhouse gases and they are predominantly decentralised. A strong policy for renewable energy deployment and energy efficiency will not only contribute to the dual objective of limiting EU's dependence on imported hydrocarbons and combating climate change, it can also contribute to competitiveness and Lisbon goals, in particular through the creation of high-quality jobs in Europe and in maintaining Europe's technological leadership in a rapidly growing global sector. Furthermore, developing renewable energy sources will lead to a number of new producers entering the market, which will have a positive impact on the competitiveness of the energy markets.

In the context of, and following on from, the problem analysis in section 2, this impact assessment looks into two questions:

Firstly, should the promotion of renewable energy play an important part in the Community's future energy policy?

Secondly, if renewable energy is to be promoted, what is the best way to do this?

4. POLICY OPTIONS

This chapter defines two sets of policy options. The first set is designed to crystallize the choice between a business-as-usual approach and an ambitious policy of renewable energy promotion; the second consists of options for tools to implement such an ambitious policy.

Secondly, although the contribution of renewable energy has increased by 55% in absolute terms, from 74 Mtoe in 1995 to 115 Mtoe in 2005, energy consumption has been following a business as usual path, and thereby "swallowing" renewable energy development. Strong growth in energy consumption will reduce the increase in the percentage accounted for by renewables, despite the efforts being made to develop renewable energy.

Thirdly, it is important to take into consideration the accounting method used. The target of a 12% share for renewable energy was based on the expectation that 68% of the increase in renewable electricity would come from biomass and 24% from wind power. With the successful development of wind power, this technology will instead account for at least 50% of the increase in renewables. In the accounting used, 1 TWh of electricity produced by biomass counts for 2.4 times that of 1 TWh of wind. If wind had been counted in the same way as biomass in producing TWh, an extra 7.6 Mtoe would have been generated, giving a renewable share of gross inland energy consumption of 7% instead of 6.5%.

[12] Communication from the Commission to the European Parliament and the Council on "An Energy Policy for Europe" (COM (2007) 1)

4.1. Future energy policy: business-as-usual or strong renewable energy policy?

The single most important choice facing the Community is whether to adopt a "business-as-usual" attitude to the development of renewable energy, or to adopt a coherent policy stance in its favour.

It should be underlined that opting for a **business-as-usual approach** does not mean opting to rely on conventional energy alone. The models used here[13] suggest that even under business-as-usual conditions, the share of renewable energy will grow to between 10.4 and 12.6% in 2020, compared with 6.5 % today. The Community needs to decide whether this is enough, or whether a more ambitious approach is needed.

There is a convergence of views between the Parliament, Commission and Council on defining a policy option to embody this more ambitious approach. In 2004, the European Parliament called for a target of a 20% share of renewable energy in 2020.[14] Also in 2004, the Commission agreed to "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 a 20% target for the share of renewable energy in 2020."[15] And in 2006, the spring European Council asked the Commission to look into a 15% target for renewable energy in 2015. The scenarios the Commission has devised to illustrate the impact of a significantly higher share of renewable energy in 2020 all imply the achievement of a higher share in the region of 15% in 2015. In the light of this, the **ambitious policy approach** chosen for comparison with the business-as-usual approach is one that would deliver a significantly higher renewable energy share in 2020.

To compare the business-as-usual approach with the ambitious approach, the following impacts are examined in section 5.1:

- feasibility and achievability risks (*5.1.1*);
- costs (*5.1.2*);
- benefits (*5.1.3*):
  - greenhouse gas (GHG) emissions
  - security of supply
  - employment, GDP and export opportunities
  - biodiversity impacts
  - regional development and rural economy.

The section also includes a sensitivity analysis examining the consequences of aiming for a 16%, 18% or 22% share instead of the 20% share that reflects the positions taken by the Parliament and Council.

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[13] The PRIMES and Green-X models – for details, see section 5.1. It is important to note that the "business-as-usual" scenario is not the same as a baseline scenario, since it includes around 13% more energy savings than can be expected under the baseline scenario, and therefore reflects the measures set out in the Energy Efficiency Action Plan (COM (2006) 545).

[14] European Parliament resolution on the share of renewable energy in the EU and proposals for concrete actions (2004/2153 (INI).

[15] Communication on the share of renewable energy in the EU (COM (2004) 366).

4.2. Options for instruments for a strong renewable energy policy

Although the cost of renewable energy sources is falling, most types of renewable energy still cost more than their conventional counterparts. Renewable energy is also disadvantaged by the existence of market failures (external costs, imperfect information, capital market failure) and strong barriers to further development. The wider costs of energy, in particular the external cost of using conventional and nuclear energy, are not fully reflected in today's energy prices. This has an adverse effect on investment decisions in renewable energy and leads to sub-optimal levels of renewable energy production. In addition, numerous administrative barriers exist to further deployment of renewables. For these reasons, renewable energy will only develop if efforts are made to promote it.

A wide range of tools is available to promote renewable energy. They can be divided into non-regulatory, price-related and quantity-related measures, as discussed in the following sections.

4.2.1. Feasibility of relying entirely on non-regulatory measures

This section looks into three types of non-regulatory measures: voluntary agreements; consumer information; and research and technological development (RTD). Non-regulatory measures have always played a part in EU and national work to promote renewable energy. They will continue to do so. The policy question here is not whether this should be the case, but whether this should be the only type of measure used. This section therefore examines whether the option of relying entirely on non-regulatory measures will be enough to achieve a significantly higher share in 2020.

Voluntary agreements

In various policy areas (most recently the "ACEA agreement" on CO_2 emissions from cars), market failures can be addressed by industry or other stakeholders publicly entering into voluntary commitments to achieve a certain goal. Such an approach is useful where a regulatory approach is likely to be especially burdensome and where the stakeholders involved convincingly demonstrate their commitment.

For example, stakeholders could conclude a voluntary agreement to increase their use of renewable energy sources with existing energy suppliers (e.g. electricity generators promoting solar power or biomass electricity generation).

Voluntary agreements may be appropriate as a "soft", non-regulatory approach to addressing any given problem. They are useful if they are credible: that is if they do, in the end, provide an effective means of attaining a certain objective. In the context of renewable energy, it is not obvious that voluntary agreements are a feasible policy option. This is because the market players (energy producers, suppliers, distributors) are often direct competitors with producers of renewable energy sources. As a result, cooperation to boost renewable energy growth is unlikely to occur. In the car sector (where the ACEA agreement is the main example of voluntary agreements as a policy tool), agreement was possible because vehicle manufacturers agreed to work to the same goal and were each undertaking technological efforts in this area. In the energy sector, market incumbents are generally conventional energy producers who compete directly with renewable energy producers. The structure is thus unlikely to lend itself to a successful voluntary agreement.

Consumer information

One reason why renewable energy is not growing faster is the poor and asymmetric flow of information between actors, not least between equipment suppliers and consumers. One policy option is clearly to take measures to provide information to the market, boosting consumer awareness of the costs and benefits of using renewable energy. Such measures may include information campaigns, labelling and product certification.

A great deal of effort is already made to increase consumer awareness (through labelling campaigns, certification and standard setting, and R&D into consumer-related aspects of renewable energy policy). Such measures normally imply a regulatory approach and, hence, additional costs. Through Community legislation, consumers now have the right to know what proportion of the electricity they consume is generated from various sources.[16] The evidence[17] from Member States that have made such information available for some time, along with a right to switch to a renewable energy supplier, is that these measures do indeed encourage a shift towards renewable energy. However, the scale of this shift is too small to suggest that such measures could play a central part in achieving an ambitious Community target share for renewable energy in 2020.

Research and Technology Development (RTD)

When there are technological barriers that have to be overcome or when there are other unknown aspects regarding the development and deployment of a certain product or technology, it is appropriate to promote research and development in the area, either directly or indirectly.

The European Union finances considerable research and development and technology deployment in the field of renewable energy through the 6th Framework programme on Research and Technology Development, addressing technological, economic, social, environmental, distributional and fiscal barriers to market development. There are other Community instruments addressing economical and social barriers, such as the Intelligent Energy for Europe (IEE) Programme.

Renewable energy RTD at Community and national levels already represents a huge effort. Further demands on the limited Community budget, coupled with the limited effectiveness of RTD's ability to address market failures, mean that, whilst it is an appropriate tool for supporting medium- to long-term technology development and deployment, it is not a tool with the power to solve the full range of market failure problems that will have to be tackled if the Community is to reach an ambitious renewable energy objective.

Conclusion

While non-regulatory measures such as voluntary agreements, consumer information and RTD can play a helpful role, it is clear that they cannot be expected, on their own, to lead to the achievement of a renewable energy share compatible with the ambitions expressed. To do this, a regulatory approach is needed. The option of a purely non-regulatory approach is therefore not considered further in this impact assessment.

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[16] Article 3(6) of Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC.

[17] The E-Track project financed under the European Commission's Intelligent Energy for Europe programme looks at how the requirement of electricity disclosure (Directive 2003/54/EC) is implemented in various Member States. Further details can be found on the following web-site: http://www.e-track-project.org.

4.2.2. Feasibility of ensuring that prices in the European energy sector internalise external costs and benefits

Current energy prices do not fully take into account the external costs of conventional and nuclear energy and the benefits of renewable energy. A system of pricing that correctly reflected these externalities could be expected to lead to a significant increase in the share of renewable energy.

Traditional fossil fuels (coal, oil and natural gas) exhibit the highest external costs for electricity-generating technologies. Non-internalisation of external costs is a clear market failure. It provides an implicit subsidy to conventional energy. Explicit subsidies are also provided to many segments of the energy sector (for example, through low tax rates or state aid)[18]. Figure 1 shows the distribution of energy subsidies in the EU15, which were estimated at around €29 billion in 2001, most of which is directed towards fossil fuels. Such subsidies distort prices and thus impede the efficient allocation of resources.

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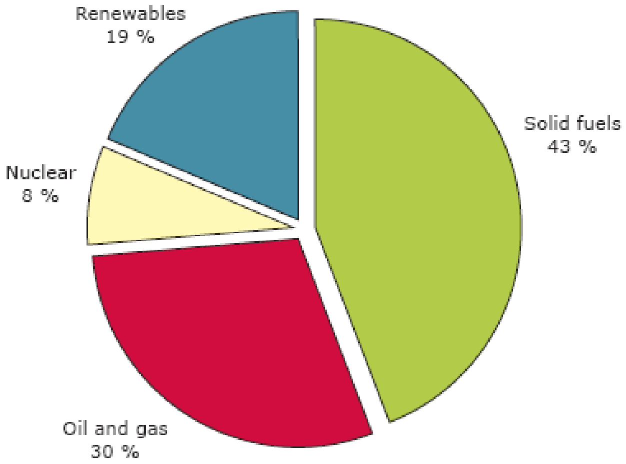
[18] Solid fuels received the largest quantity of subsidies. Renewables received higher support on a per-energy unit basis than other fuels.

Figure 1 Indicative estimate of the distribution of energy subsidies in the EU-15, 2001



Source: European Environmental Agency (EEA), 2004

The corresponding "corrective" policy option is to "get the prices right". In the context of renewable energy, a range of such instruments have been tried or are in place.

Europe has taken some steps towards internalising external costs of fossil energy. Member States levy taxes under the Energy Taxation Directive[19] (CO2 taxes, energy taxes or excise duties) and are also allowed to exempt renewable energy sources from taxation (should they in certain cases become taxable under the Directive). In a similar way the European Emissions Trading Scheme (EU ETS) establishes a price for carbon. Such efforts are ongoing, but progress is slow, and insufficient to achieve the Community's renewable energy objectives. Further progress could nevertheless be achieved by reviewing the European Emissions Trading Scheme.

In the absence of correct prices and a well functioning market, subsidies or other support measures are commonly used to level the playing field. Such measures, generally applied at Member State or regional level, tend to be sector-specific.

4.2.3. Options for renewable energy targets

Setting targets for meeting objectives is a common means of establishing a policy framework. Targets serve as a public commitment on the part of the government or other authorities to maintain a certain policy stance, which will form the basis of and justification for a range of implementing measures. These commitments, when credible, can provide stability to the sector and give the industry more confidence to invest in and develop a market.

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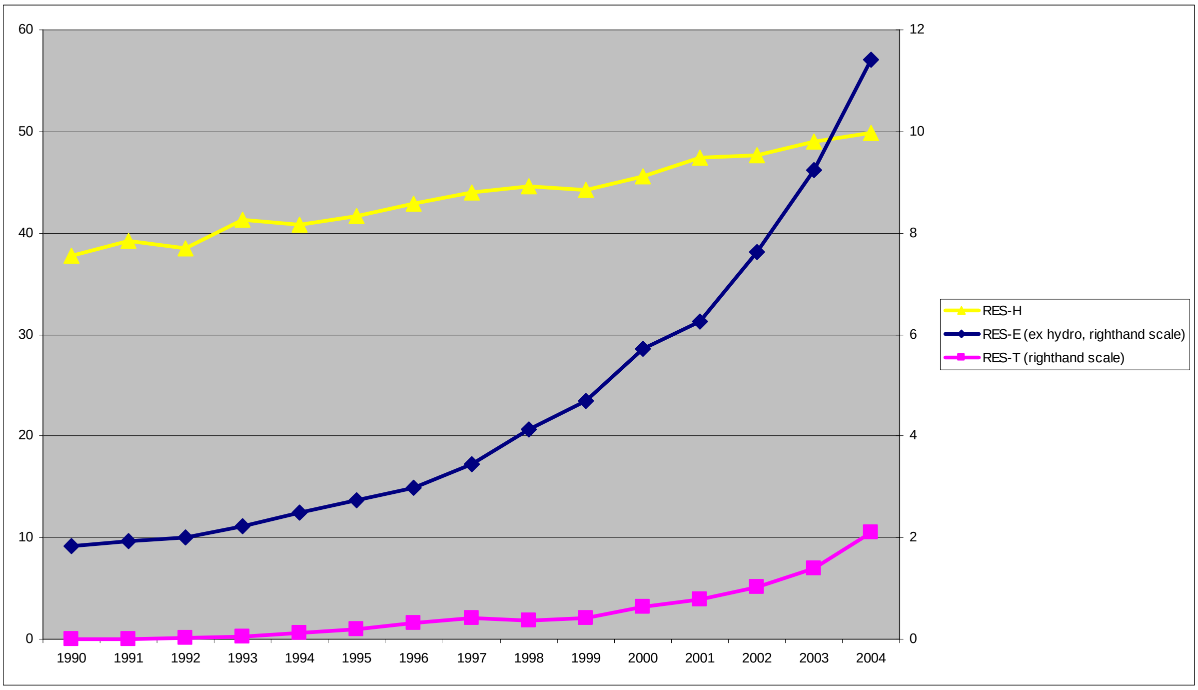
[19] Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity (OJ L 283, 31.10.2003, p. 51).

Targets have been used since 1997, when the Community began working towards an overall, "political" target of 12% renewable energy in 2010. This was implemented by a sectoral target laid down in law to achieve a renewable energy share in electricity consumption of 21% by 2010[20] and a biofuel share in petrol and diesel consumption of 5.75% by 2010.[21]

The chart below gives a picture of the rates of development in the different renewable sectors. It shows how the use of renewable energy has progressed rapidly in electricity, where the EU introduced a system of national indicative targets and a requirement to take appropriate steps to achieve them. Progress has clearly begun in renewable energy in transport, following the introduction of a European system of national indicative targets (but without a requirement to take appropriate steps to achieve them). By contrast in heating and cooling, which is not covered by European legislation, little progress has been made.

Figure 2 Growth of renewable energy in the electricity, heat and transport sectors (Mtoe), 1990-2004



Source: Eurostat

The developments outlined above, notably the variations in progress between sectors, suggest that targets have had a positive effect where they have been used. It is therefore appropriate for this impact assessment to examine whether the EU should retain a system of sectoral targets for 2020, or set a single target for all types of renewable energy. This question is addressed in section 5.2.2.

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[20] Directive 2001/77/EC of 27 September 2001 of the European Parliament and the Council on the promotion of electricity produced from renewable energy sources in the internal electricity market (OJ L 283, 27.10.2001, p.33).

[21] Directive 2003/30/EC of 8 May 2003 of the European Parliament and the Council on the promotion of the use of biofuels or other renewable fuels for transport (OJ L 123, 17.5.2003, p.42).

5. ANALYSIS OF IMPACTS

5.1. Impact of different levels of renewable energy use: business-as-usual vs. ambitious share in 2020

The starting point for this part of the impact assessment is scenarios developed using two models: PRIMES (designed to analyse developments across the whole energy sector) and Green-X (giving more detail on renewable energy). Annexes 1 and 2 describe the methods they use.

A business-as-usual scenario was developed using each model. In addition, three scenarios were developed, each with an overall share of 20% in 2020, but with a different breakdown of renewable energy between sectors. The three different "20% renewable share" scenarios are:

(1) A PRIMES "**high renewables and efficiency**" scenario[22], under which a 20% share is achieved by reinforcing renewable energy above all in the sectors that are already subject to Community legislation (electricity and transport). In this scenario, renewable energy is developed more slowly in heating and cooling.

(2) A Green-X "**least cost**" scenario, which focuses on cost variations between renewable energy technologies and the countries in which they are deployed. It is assumed that cost optimisation is done across all sectors (heat, electricity and transport), all technologies and all countries.. This results in a higher share of renewable energy in heating and cooling than the PRIMES high renewables and efficiency scenario; a lower share of renewable energy in transport; and a similar share in electricity generation[23].

(3) A Green-X "**balanced**" scenario, designed to illustrate a case in which the potential of renewable energy is fulfilled through similar efforts across each sector and across technologies. This results in a share of renewable energy in heating and cooling that is higher than in the least cost scenario; a share in transport that is similar to the PRIMES high renewables and efficiency scenario; and a smaller share in electricity generation than in either of the others. A variant of the balanced scenario is used to illustrate the effect of excluding the most expensive electricity generation technologies from the mix.

Although the three 20% renewable share scenarios provide for exploring the impacts of differing the mix of renewable energy, in this part of the impact assessment, the main focus is on understanding the range of impacts that can be expected if business is left to proceed as usual, as compared with setting a target of a 20% renewable energy share. Annex 3 contains a summary of the main costs and benefits under the three specific scenarios developed for the impact assessment.

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[22] A "high renewables and efficiency" scenario was carried on for EU25 and EU27 (including Bulgaria and Romania). For the EU25 and EU27 model runs the share of renewable energy in 2020 was 19.9% and 20% respectively.

[23] It should be noted that this method does not take into account economic relationships as they result from the interaction of EU and world agricultural and biomass markets, and therefore the already existing production of biofuels at EU level.

5.1.1. Feasibility

Renewable energy offers an increasingly credible alternative to conventional energy sources in all energy-using sectors. Nevertheless, it would be unwise for the EU to commit itself to the 20% objective, tripling the contribution of renewable energy over less than 15 years, without reviewing whether this is really an achievable result. It is frequently suggested, for example, that the limited availability of biomass, the limited ability of the electricity system to absorb variable power, or the slow turnover in equipment and long lives of power stations are constraints on ambitious renewable energy scenarios.

The question of feasibility has two main elements:

(1) Will enough biomass be available?

(2) Can the electricity system cope with the necessary volume of variable power?

Biomass

Among the "20%" scenarios, the highest biomass contribution anticipated is 230 Mtoe. This includes a maximum of 63 Mtoe that would have to come from agricultural crops (if all biofuel's contribution had to come from first-generation biofuels).

On the conservative assumption that 15% of the biomass used is imported,[24] the contribution that would have to come from the EU would be a maximum of 195 Mtoe. The Green-X and PRIMES models are both built on a thorough assessment of biomass availability. To check this a comparison was made with the European Environmental Agency's estimate, which show that the EU-25 will be capable in 2020 of supplying 235 Mtoe of bioenergy, including 96 Mtoe from agricultural crops, without environmental damage.[25] Since this EU-25-based assessment does not take into account Romania and Bulgaria, which both have low domestic energy consumption and a high potential for bioenergy production, it can be concluded with some confidence that biomass requirements are not a feasibility constraint on any of the scenarios.

Electricity from variable sources

It is sometimes suggested that the limited ability of the electricity system to absorb wind power and other forms of variable power is a constraint on ambitious renewable energy scenarios.

Under the PRIMES high renewables and efficiency scenario and the Green-X balanced scenario, variable power is expected to contribute around 15% of the total electricity supply.

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[24] The models used here do not forecast what the share of imports will be (it is imposed exogenously). However, most regions of the world have a higher ratio between biomass production potential and expected energy demand than Europe does, and thus the capacity to produce biomass for export. If transported by ship in forms such as wood chips or liquids, such exports do not carry a significant cost or environmental penalty. In practice, biomass imports are likely to make an important contribution to EU renewable energy consumption in 2020. It should be noted that the assumptions on import shares used here for expository purposes do not prejudge future policy choices on this question.

[25] European Environmental Agency (2006), How much bioenergy can Europe produce without harming the environment?, EEA Report No 7/2006.

Under the least cost scenario, this figure rises to 18%.[26] There are a number of comprehensive national studies, some ongoing, related to the feasibility and cost of wind integration into the European power market[27]. These studies show that it is technically possible to integrate these levels of variable power use into the power market.

Although technically feasible, the limits of integrating large amounts of variable capacity in power systems will depend on socially and economically acceptable costs. Keeping in mind the stochastic nature of demand and supply in the grid systems, the power market has been designed to cope with varying and uncertain demand plus unexpected outages. The power market can be further developed to cater for greater use of variable energy with its characteristic fluctuations. Greater use of variable energy is therefore a question of economics and regulatory rules rather than of technical constraints. As stated in COM (2005) 627 *The support of electricity from renewable energy sources*, the following issues are especially important to increasing the penetration of wind energy into the grid system: forecasting wind production, the timing of gate closure of the spot electricity market and the charging of balancing costs. Intelligent design of the market system and regulatory rules would help wind energy to be included appropriately as well as reduce the costs of integrating larger shares of variable energy into the power market.

Investment cycles and the speed of uptake of renewables

The PRIMES and Green-X models simulate the growth of different technologies in all three energy sectors. They start with the existing energy capital base and simulate its evolution based on the costs of the different technologies and the rate at which the technologies can be replaced[28]. Thus, for both the business as usual and the 20% scenarios, the lifetimes and investment cycles of the sector are reflected in the analysis.

5.1.2. Costs

In the absence of a full internalisation of external costs and benefits, most forms of renewable energy cost more than the conventional alternatives. The difference is expected to narrow but not disappear by 2020. It follows that the cost of the "20%" scenarios will be higher than that of the business-as-usual scenarios. The models have investigated investment needs and *additional* production costs[29] for renewable energy under the different scenarios.

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[26] Variable sources are defined here as wind, solar, wave and tidal power. Hydropower is not included because most comes from water stored in reservoirs, allowing power to be generated when needed. Tidal power ought also to be excluded because the timing of its availability is predictable, but it is included in the figures on variable power sources because separate data for tidal power are not available.

[27] GWPC 2006 Conference Paper: "Design and operation of Power Systems with Large Amounts of Wind Power, first results of IEA collaboration". See website of IEA Implementing Agreement on Wind: http://www.ieawind.org/AnnexXXV/Task25_Publications.html.

[28] For example, in the electricity sector, the PRIMES modelling assumes the following plant lifetimes: 40 years for nuclear plants (unless it is clear that a power station will be closed earlier for technical or political reasons (e.g. nuclear phase out), 35 years for most coal plants and 20 years for most gas plants. Anticipated plant retirement in the period 2006-2020, under the PRIMES high renewables and efficiency scenario, is in total 254 GW of electricity generation capacity (renewable energy 13 GW, nuclear – 37 GW, solid fuels – 114 GW, gas – 43 GW and oil – 47 GW). Green-X follows the PRIMES assumptions.

[29] *Additional* is here used within the respective scenarios as the additional or extra cost that occurs as a result of renewable energy being used instead of conventional energy. The additional production costs are therefore calculated as the total cost of production per unit of renewable energy output minus the

Under Green-X, the cumulative investment needed to increase the share of renewable energy consumption from 6.5% in 2005 to 12.6% in 2020 is projected to be €317bn (business-as-usual case). The cumulative investment needed to increase the share from 6.5% in 2005 to 20% in 2020 is in the range of €600–670bn (€2005).

Under PRIMES, which works in detail with the electricity sector, investment needs in this sector are calculated to be about €160bn in the business-as-usual case (renewable share across all sectors: 10.4%) and some €280bn to reach 20% by 2020 in the PRIMES high renewables and efficiency scenario. In comparison, the Green-X model projects, for the power generation sector, an investment cost of €232bn for renewable energy in the business-as-usual scenario and a range of €285–414bn in the 20% scenarios. In the Green-X scenarios, the cumulative additional production costs for new renewable energy plants in the period 2005-2020 are around €123bn under business-as-usual conditions, compared with a range of €210–290bn (with energy price assumption of $48/bbl) in the "20%" scenarios.

Both models provide the additional production cost in the year 2020 of achieving a 20% share for renewable energy. They give additional production costs in a range of €24–31bn[30] in the year 2020. The PRIMES model estimates the lowest cost (€24bn) and the Green-X model the highest costs (€26bn for the least cost scenario, which is based on a cost minimisation approach and brings into the market the cheapest renewable technologies, and €31bn for the balanced scenario, which reflects the need to develop a portfolio of longer-term technologies). The difference between the cost of the balanced scenario and that of the least cost scenario is due in large part to the different assumed shares of more innovative (and expensive) renewable energy technologies. Under a variant of the balanced scenario with a lower share of innovative technologies in the electricity generation sector, the additional production cost in 2020 would fall to €26bn, the same as for the least cost scenario. When looking at the cumulative additional production costs for the whole period, these will still be lowest in the least cost scenario (€210bn). However, the variant of the balanced scenario shows that lowering the share of innovative technologies will lead to a reduction of the cumulative additional productions costs from €290bn, which has been projected under the balanced scenario, to €250bn.

The additional production costs are highest in the year 2020 due to the costs rising over time as more renewables are developed. The average yearly additional production costs are projected to be €8bn in the business-as-usual case, compared to the range of €13–18bn in the policy case in the period 2005–2020.

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reference cost of energy production per unit of energy output. The reference cost of energy production in the Green-X model is calculated for various generation technologies. Further details on the calculation of generation costs can be found in Annex 2.

[30] The Green-X figure includes additional production costs from new plants in the period 2005-2020, whereas the PRIMES figure represents the difference in total energy system costs between the high renewables and efficiency scenario and the high efficiency scenario, therefore capturing all the changes in investment, operation and fuel costs for increasing the share of renewables to 20% in 2020.

Table 1 Comparison of cost ranges of achieving a business-as-usual share of 13% versus achieving a 20% share of renewable energy in 2020[31]

€bn	**Renewable energy share of 13% in 2020**	**Renewable energy share of 20% in 2020**
Cumulative investment needs for renewable energy in the period 2005–2020	317	600–670
Cumulative additional production costs in the period 2005–2020	123	210–290
Sensitivity case: high energy price (oil price of \$78/barrel instead of \$48)	-	125[32]–170
Average additional production costs per year	8	13–18
Additional production cost in the year 2020	13	24–31[35]
Sensitivity cases:		
1) high energy price	-	0-11
2) high CO_2 price[33] *(emissions allowances at €50/t instead of €20/t)*	-	14–21[36]
3) combined high energy price and high CO2 price[34]		5

Source: Green-X, PRIMES

The costs are influenced by key parameter assumptions, such as energy and CO_2 price assumptions. A sensitivity analysis of changing these assumptions was undertaken in the least cost and balanced scenarios. The sensitivity analysis looked at how the cumulative additional production costs for the period 2005-2020 and the *additional* production costs in the year 2020 are affected by increasing the energy and CO_2 prices. The energy price assumptions in these two scenarios are based on an oil price of $48/boe in 2020). A sensitivity analysis shows that high energy prices with an oil price of $78/boe in 2020 reduces total additional production costs by 41%, to a range of €125–170bn and the additional production costs in the year 2020 to an annual amount of €0–11 billion.

The sensitivity analysis also shows that costs are highly sensitive to CO_2 allowance prices. In the Green-X balanced scenario, results show that increasing the allowance price from €20/t to €50/t will lead to a reduction of additional production costs by 31%. This implies additional production costs in the range of €14–21bn instead of €24–31bn in the year 2020.

These cost estimates take into account the fact that the unit costs of renewable energy, like other innovative technologies, tend to fall over time as practitioners gain experience. If the volume of use of a particular technology grows more rapidly, experience will be gained more

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[31] Note: except for the cell "Additional production cost in the year 2020: main case/policy share of 20%", these data are drawn from the Green-X model runs only.

[32] This range is based on the sensitivity analysis in the Green-X balanced scenario, which showed a 41% reduction in costs where the high energy price assumption is used rather than the low energy price assumption.

[33] Refers to CO_2 price that affects only the electricity sector. Green-X balanced scenario.

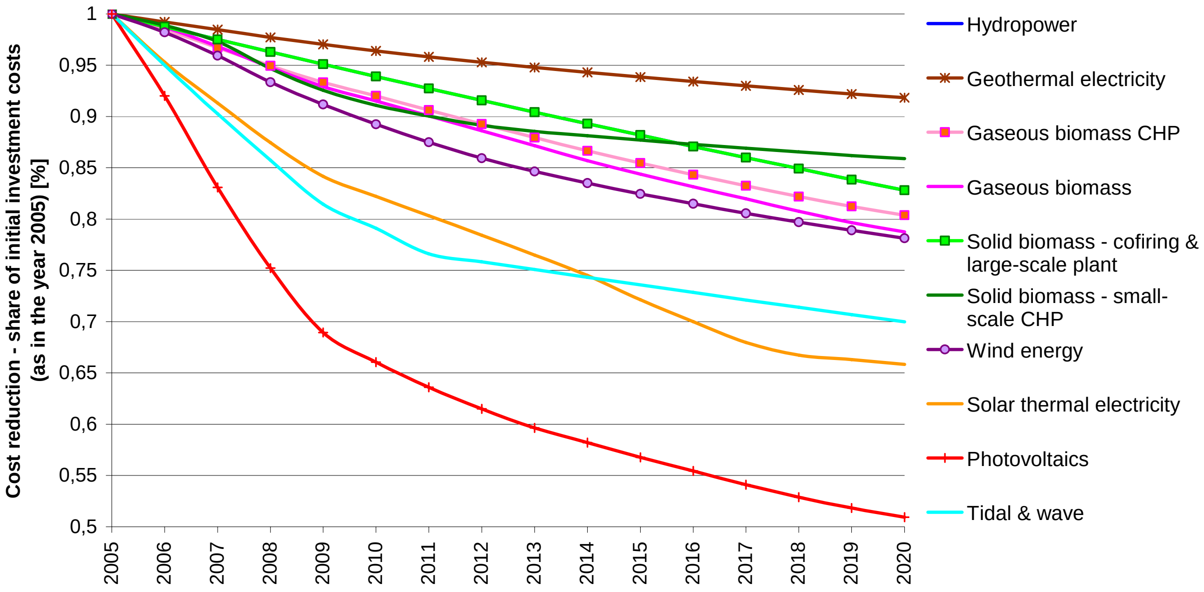
[34] Refers to CO_2 price affecting all sectors. Green-X balanced scenario.

[35] Cost figure from PRIMES high renewables and efficiency scenario.

[36] This range is based on the sensitivity analysis in Green-X least cost scenario, which showed a 41% reduction in costs where the high CO_2 price assumption is used rather than the low CO_2 price assumption.

rapidly and costs will fall more rapidly. The chart illustrates the estimated rate of unit cost reduction forecast in the balanced scenario in the electricity sector.

Figure 3: Estimated rate of unit cost reduction for renewable electricity generation technologies.



Source: Green X balanced scenario

5.1.3. Benefits

<u>GHG emissions</u>

The PRIMES and Green-X models allow changes in the level of CO_2 emissions to be calculated.[37]

According to the Green-X model, increasing the share of renewable energy from 6.5% in 2005 to 12.6% in 2020 (business-as-usual scenario) would lead to CO_2 emission savings of 430 Mt in 2020,[38] whereas an increase from 6.5% in 2005 to 20% in 2020 would lead to an annual saving in the range of 700–900 Mt of CO_2 emissions in 2020. Under PRIMES, the equivalent saving can be estimated at just over 600 Mt CO_2 emissions.[39]

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[37] The emissions calculations in these models include CO_2 but not other greenhouse gas emissions covered by the Kyoto Protocol, including methane (CH4) and nitrous oxide (N2O). This means that the GHG benefits of biomass are overstated, since production process (included in life-cycle analysis) leads to both CH4 and N2O emissions. These emissions calculations only include direct emissions, not lifecycle emissions. These methodological issues are particularly important in the case of biofuels, and are fully taken into account in the impact assessment for the review of the biofuels Directive.

[38] The equivalent figure could not be calculated in PRIMES.

[39] This figure is the sum of two effects; firstly, 450 Mt CO_2, which is the difference in CO_2 emission in 2020 between the PRIMES high renewables and efficiency scenario, which achieves a 20% share of renewable energy, and the PRIMES high efficiency scenario, which achieves a 10.5% share of renewable energy, and secondly, 150 Mt CO_2, which are the savings calculated as a result of increasing the share from 6.5% in 2005 to 10.5% in 2020. This second effect is calculated on the assumption that CO_2 savings per percentage point increase of renewable energy's share is constant. The EU27 "high

The range of emission savings, from 600–900 Mt CO_2, in the two models, can be explained by the variation of technologies used and the different shares of electricity, heat and biofuels considered under the different scenarios. Higher CO_2 savings in the least cost scenario compared to the balanced scenario can be explained by the fact that the latter scenario uses more renewable energy in the heating sector and less in the electricity sector. The average emissions factor is higher for the electricity sector than it is for the heat sector.

Air quality

The relevant air pollutants include the following: sulphur dioxide (SO_2); nitrogen oxides (NOx); non-methane volatile organic compounds (NMVOC); and particulate matter (PM).[40] Replacing fossil-fired electricity generation with renewable energy has generally favourable air quality effects, especially where the fuel replaced is coal. Replacing conventional transport fuels with biofuels has minimal air quality effects, because of the strong controls on pollution from road transport. Replacing conventional heating with biomass heating can have an adverse air quality effect if poor quality equipment is used.

Security of supply

In addition to concerns about environmental sustainability, securing energy supply is one of the major reasons for promoting the development of renewable energy sources. Increasing the share of renewable energy by 2020 will have an impact on fossil fuel demand and fossil fuel imports. This can be expected to have beneficial effects on security of supply. It is difficult to put a value on these benefits.

Oil is the fuel posing the most serious security of supply problems, especially in transport. A scenario with higher biofuel shares would do most to address the EU's most serious security of supply problem. Security of supply is also an important issue in the heating sector, given its high reliance on oil and gas, and as is the case with the biofuels sector, albeit to a lesser extent, a scenario with a higher share of heating and cooling based on renewable energy improves security of supply.

The Green-X and PRIMES policy scenarios show that increasing the share of renewable energy consumed would enable the EU to avoid consuming fossil fuels in the range from around 234–300 Mtoe/year[41] from 2020, including approximately 200 Mtoe per year of imported fuels. Oil imports from the Middle East and CIS can be expected to be at least 50 Mtoe lower[42].

In monetary terms, calculated in the Green-X model, increased capacity for renewable energy production in the period 2005–2020 would account for around €50–57bn per annum in fossil

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renewables and efficiency" model run gives slightly higher CO_2 savings compared to the EU25 model run.

[40] Of these emissions, SO2, NOx, and NMVOC are reported to the UNFCCC Secretariat because they influence climate change indirectly: NOx and NMVOC (together with CO) are precursor substances for ground-level ozone which itself is a greenhouse gas. Sulphur emissions produce microscopic particles (aerosols) that can reflect sunlight back out into space and also affect cloud formation.

[41] The figures from the EU25 "high renewables and efficiency" scenario in the PRIMES model is 234 Mtoe, whereas the Green-X scenarios give a range of 250–300 Mtoe. The EU27 "high renewables and efficiency" model run gives a slightly higher avoided fossil fuels consumption compared to the EU25 model run.

[42] Estimated on the basis that these are marginal producers of these sources.

fuels avoided.[43] High energy prices (an oil price of $78/boe in 2020) would increase the value of fossil fuel avoided over the period by 40-57%.

Employment, GDP and export opportunities

PRIMES and Green-X are partial equilibrium models focusing on the energy sector. This means that they fail to provide sufficient analysis of the wider economic effects of increasing the share of renewable energy. Additional studies which focus on the GDP and employment implications of increasing the share of renewable energy were commissioned. These studies have been performed by feeding energy portfolio results from PRIMES, GREEN-X, POLES or the ESIM agricultural model into models of the whole economy. They take into account, inter alia, the price changes that can be expected to result from the promotion of renewable energy.

The ASTRA model was used to assess the employment and GDP impact of the achievement of a 20% renewable energy share[44]. It aggregated the effects in all three energy sectors. Details are given in annex 4. It found that GDP would be a little more than 0.5% higher than under business-as-usual conditions[45] and that employment would grow by around 0.3%, which amounts to about 650 000 additional jobs.[46]

In order to assess the wider economic effects of increasing the share of renewable energy in the electricity sector, model runs combining the energy system model POLES and the extended version of the general equilibrium model PACE were carried out[47]. Details are given in annex 6. [48] The model was used to assess the welfare[49] impact of achieving a 35% share of

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[43] Based on calculations made in the Green-X model.

[44] The ASTRA model presents developments in a 20% scenario in comparison with a reference scenario by indicating the % change of GDP and absolute increase in employment. Renewables are supported through different support mechanisms in different sectors; tariffs for renewable electricity, tariffs and subsidies for renewable heating and cooling and zero tax for biofuels.

[45] The comparison was with the Green-X business-as-usual scenario.

[46] The model suggests that additional investment in renewables and avoided imports of fossil fuels leads to a growth in GDP. This is offset by a reduction in GDP due to reduced investments in conventional energy technology. The model also shows a positive effect on GDP of the funding mechanism for renewable energy. Although the rising overall cost of energy (as renewable energy costs more and support is needed) would reduce consumption in other sectors and therefore have a negative effect on GDP, this is counterbalanced by the positive effects resulting from the change in consumption patterns arising from the price increase and subsequent investment growth in other sectors (multiplier effect).

[47] Due to modelling limitations it was only possible to carry out an analysis of the impacts of increasing the renewable share in the electricity sector and not for the biofuels and the heating and cooling sectors.

[48] This modelling is an innovative attempt to link partial and general equilibrium modelling. This is an important area for future methodological development. In this first attempt, however, the model was not able to generate and work with as rich and satisfying an analysis of the practical working of the renewable energy sector as were other modelling exercises drawn on in this impact assessment. Inter alia, it should be noted that there are a number of differences between the PACE-POLES model and the PRIMES and Green-X models. POLES mimics the evolution of international energy markets for the main traded energy commodities by modelling the supply reaction to international demand based on endogenous extraction capacity, refining and transportation. The PACE model is specified as a full bilateral trade model with two regions: EU-25 and the rest of the world. The POLES-PACE modelling is based on more restrictive assumptions on the biomass availability from dedicated crops and set-aside land compared to the PRIMES and Green-X models. The POLES-PACE model is also based on estimates of the cost of renewable energy that appear to be substantially greater than those used in other, more sectorally specific models such as PRIMES and Green-X. The assumptions on the biomass cost, of 89 €/MWh, seems to exclude the often competitive option of co-firing with costs varying from

renewable energy in the electricity sector in 2020 through the introduction of a subsidy for renewable energy.[50] The estimated impact was a welfare loss of 0.05%.

For biofuels, the Commission's Institute for Prospective Technology Studies (IPTS) constructed an input-output (I/O) model, using inputs from the Commission's ESIM agricultural market model, to estimate the GDP and employment effects. Details are given in Annex 5. Achieving a 14% share of biofuel by 2020, if primarily through domestic production, was estimated to lead to employment in the EU being up to 144 000 higher than it would otherwise have been – assuming that oil behaves like other commodities, so that changes in demand affect its price. (If changes in demand for oil are assumed to have no effect on its price, the figure would be -32 000). On the same assumption, EU GDP would be an estimated 0.23% higher than it would otherwise have been.

These figures are in line with current realities. The European Union is already the global leader in renewable technologies, which account for a turnover of €20 billion and employ 300,000 people[51]. Further opportunities to create employment will arise from the export of renewable energy technology.

An active renewable energy policy creates substantial potential for European manufacturers to export this technology, which would grow with domestic production. Annex 7 considers this question.

Biodiversity

Climate change is the major threat to biodiversity in the world today. After energy efficiency and energy savings, renewable energy is one of the most effective tools available to tackle climate change. While no comprehensive indices of biodiversity exist, it is certain that the effect of the "20%" scenarios on biodiversity is substantially positive, relative to business-as-usual conditions.

Nevertheless, it is important to take into account the fact that energy production facilities – both conventional and renewable – can have substantial local biodiversity impacts, independent of the positive global impact of renewable energy.

35€/MWh to 75 €/MWh. The POLES model is constrained in depicting high shares of renewable energy; these cost assumptions appear to be an important reason for this.

[49] In this analysis, welfare implications of the different scenarios are measured in Hicksian equivalent variation in income (HEV). Since the utility function in the CGE model PACE is linearly homogeneous, percentage changes in the utility level U are equivalent to percentage Hicksian equivalent variations in income and U can be used directly as a welfare measure. With this convenient cardinalization of utility, percentage Hicksian equivalent variations in income is equivalent to percentage change in real consumption with respect to business as usual. Thus, the welfare changes reported in the model can be treated as approximations of the GDP effect.

[50] It should be noted that contrary to the way in which renewable energy is funded in practice, the scenario examined depicted part of the subsidy paid as being transferred to consumers in the form of a reduction in electricity prices. It is likely that this transfer from tax payers to electricity consumers will have made the assessed welfare impact worse than it would otherwise have been. Scenarios were also developed based on financing renewable energy through (1) introduction of a tax on conventional energy and (2) introduction of a carbon tax. However, it was not possible at this innovative stage in the development of this modelling approach to specify these scenarios in a way that satisfyingly reflected how such measures could be expected to be implemented in practice.

[51] European Renewable Energy Council "New renewable energy target for 2020 – a Renewable Energy Roadmap for the EU".

Careful study of two prominent forms of renewable energy – wind power and biofuels – shows that in general, the biodiversity effects of their production processes, while present, are minor. In both cases it is possible to avoid production processes which have a negative biodiversity impact: for example, avoiding siting wind turbines in locations through which migrating birds are obliged to pass, or avoiding felling rain forest to permit the production of palm oil to make biodiesel.[52]

The biodiversity impact of a 20% renewable energy share is substantially positive, even if it is assumed that conventional energy production has no biodiversity impacts. In fact, conventional energy production has substantial biodiversity impacts (oil spills are just one high profile example) which have, unfortunately, not been studied using the systematic approach that has been applied in the case of renewable energy. The risk related to these impacts will fall because a high share of renewable energy will avoid the use of equivalent amounts of conventional energy – thus reinforcing the already positive biodiversity impact of such a policy.

International aspects

The European Union is the global leader in many renewable energy technologies. In wind power, for example, it has a 60% world market share. The global wind power market is growing strongly, with significant Asian market growth (especially from India) and a strong increase in the rate of North American installations. A strong renewables policy will enable the Union to keep up its position as world leader in this market. (See Annex 7).

European demand for biomass, and especially biofuels, can contribute to improving trade relations with the European Union's trading partners, in particular with developing countries, which have potential for producing and exporting biomass and biofuels at competitive prices. Renewable energy sources offer major opportunities for job creation and rural development in developing countries. A strong renewables policy in the EU can therefore be regarded as an important tool in our policy towards developing countries. It should also be mentioned that renewable energy, especially biofuels, could represent an important negotiating element for the successful conclusion of ongoing free trade area negotiations.

Finally, it will be difficult for the EU to maintain its leadership in combating climate change if it relaxes its efforts in renewable energy.

5.1.4. Sensitivity analysis

It is necessary to be certain that the chosen share of renewable energy reflects an acceptable balance between the costs and benefits of reaching the target. In order to study the effect on costs and benefits of varying the share of renewable energy, a sensitivity analysis was carried out looking at the impact of achieving 16%, 18% and 22% shares, using the 20% share as a benchmark. This analysis was carried out using the Green-X least cost scenario. These effects are summarised in Table 2 below.

As the table shows, the cost of increasing the share of renewable energy grows more sharply after reaching a share of 20% renewable energy. While this is most obvious in the case of

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[52] It should be underlined that while rainforest encroachment for the EU biodiesel market is a worrying possibility for the future, it is not something that has yet happened. It is estimated that only 1% of EU biodiesel production in 2005 came from palm oil.

investment costs, the effect is also present in the case of additional production costs. By contrast, the benefits (CO_2 emissions avoided and fossil fuels avoided) tend to grow at a constant rate, or even grow less rapidly after 20% (in the case of emissions avoided).

These data tend to reinforce the wisdom of not aiming at a share above 20%.

Table 2 Changes in costs (cumulative investment needs in the period 2005-2020) and benefits (cumulative avoided CO2 emissions and avoided fossil fuels) under changing renewable energy targets

%Δ from 20% renewable share	**16%**	**18%**	**22%**
Avoided CO2 emissions	*- 19%*	*-9%*	*+7%*
Avoided fossil fuels	*-24%*	*-12%*	*+12%*
Investment costs	*-23%*	*-12%*	*+26%*

Source: Green-X (least cost scenario)

A sensitivity analysis was also carried out on the effect of changing central model parameters, such as energy prices, CO_2 prices, energy efficiency and rates of technological learning.

Figure 4Additional RES generation costs under changing parameters (average for 2016-2020)

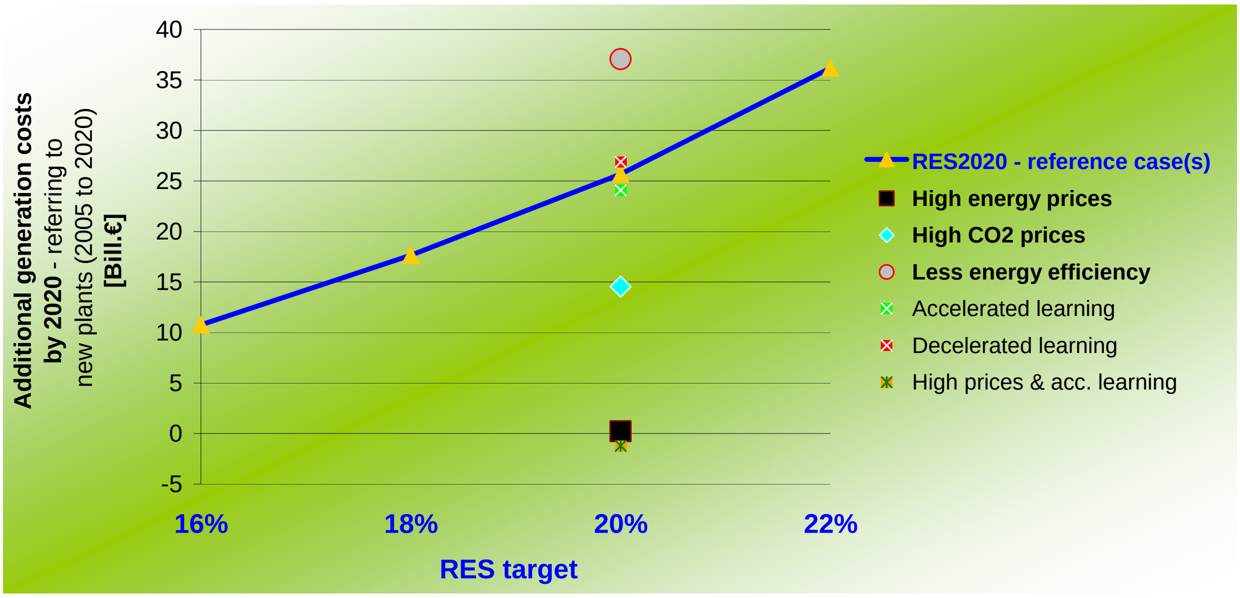

Figure 4 shows that the dominant factor influencing the cost of promoting renewable energy is the conventional energy price. When the oil price increases from $48/bbl to $78/bbl the additional production cost falls 99% from from €26 bn to €0 bn in the year 2020. Note that this does not necessarily mean that the 20% share of RES would be achieved at nearly no additional cost[53] nor that RES technologies would penetrate the market without any further policy support. In the case of higher CO_2-prices in the electricity sector (€50 per ton), additional production costs are reduced by 43%. CO_2-prices are clearly an important factor concerning the cost-effectiveness of renewable energy technologies vis-à-vis their fossil fuel alternatives.

5.2. Impact of different options for renewable energy targets

There are several choices as to the type and scope of targets. These include whether targets should be voluntary or mandatory (legally binding), sectoral or global, technology- or emissions-based. In broad terms, as described in section 4.2.3, targets form a public commitment to a certain policy stance which, when backed by implementing measures, helps create a more stable investment climate. Thus their effectiveness depends on how credible a policy environment they create.

5.2.1. Mandatory or indicative targets

The legal strength of a target largely determines its credibility, as stronger targets mean that efforts will be made by governments to ensure that targets are met. This in turn means that the market has greater certainty for planning and investment. Current examples include the mandatory national Stability and Growth Pact and Kyoto targets (where Member States are

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[53] This large cost reduction in the case of *Higher energy prices* includes also a compensation of positive additional cost within one sector by negative additional cost, which appears if renewable options are below the reference prices. However, taking only positive additional cost into account, the resulting costs would still be 65% lower compared to the reference case. Furthermore it should be noted that these figures depict the additional costs on average – among sectors, countries and technologies differences still appear by 2020.

bound by Community legislation) and the voluntary targets of the ACEA agreement on CO_2 reductions from cars. In all cases, the targets are set on the basis of best available analysis and negotiations with the parties involved.

The existing European framework for renewable energy is based on indicative targets rather than mandatory targets. In the electricity Directive (2001/77/EC) and the biofuels Directive (2003/30/EC), Member States are required to set indicative national targets based on the reference values in the annexe to the Directives. The electricity Directive requires, in addition, that Member States take steps to attain their objectives. The biofuels Directive simply states that Member States should ensure that a minimum level of biofuels is placed on the market in line with their national indicative targets. Most recently, the energy services Directive (2006/32/EC) requires Member States to adopt and aim to achieve an overall national indicative energy savings target.

The ACEA agreement on CO_2, the two renewables Directives and the Community Kyoto commitment (Council Decision 2002/358/EC) illustrate the spectrum of target "strength" and at the same time illustrate the effectiveness of such targets: Member States (the EU-15) have taken a range of actions to ensure that the mandatory national Kyoto targets are met, and together with Community-wide measures (such as the ETS) every effort is being made to meet the targets. The electricity Directive, which requires action commensurate with the targets, has induced rapid growth in renewable electricity, but as this effort has been uneven across Member States, the target is unlikely be completely reached. In the biofuels Directive, neither target nor actions are mandatory, and whilst there has been some rapid growth in biofuels in a limited number of Member States, all but two have failed to take sufficient measures to achieve their targets. Finally, the voluntary agreement with industry did lead to improvements in CO_2 emissions from cars, but again, the target will not be reached.

These examples suggest that an effective policy and the attainment of policy goals require mandatory targets.

5.2.2. Sectoral targets vs. a single renewable energy target

Another key policy choice is whether to retain the current system of national sectoral targets for renewables, or to change to a system with a single renewables target for each Member State.

Establishing a single target has an intuitive appeal. Once one target is established and support measures put in place, the market is allowed to choose technologies and other cost effective means of achieving the goal. This should result in the cheapest solution, reducing the overall cost of the policy and reducing the administrative burden associated with managing multiple targets.

However, the practice in Member States, and the consensus amongst the renewable energy industry, suggests that a single broad target is too unfocused and would fail to provide sufficient guidance and certainty to businesses operating in a specific sector of the market. In addition, a single target promotes *current* cost effective technologies, which could result in uneven development of the technologies in different sectors (e.g. most growth in onshore wind power). This could maximise short-term reductions in CO_2 and minimise short-term costs, but could slow down technology development and innovation. Such a result could mean that abatement costs rise and the growth of new technologies, industry and jobs is delayed.

Alternatively, consideration could be given to measures designed to deliver a balanced result across sectors and technologies. Such measures could be developed with the specific conditions in the electricity, heating and cooling and transport sector in mind.

For biofuels in particular, it is clear that the market alone will do little to develop the sector. Left to choose between all renewable energies, efforts will first be directed towards electricity and heating. This is due to the high current costs and the high development costs associated with second generation technologies. And yet, progress must be made in the transport sector: it is the sector where fuel choice is negligible (oil constitutes 98% of transport fuels), where greenhouse gas emissions are growing most strongly and where fuel supply and price is least stable. In order to address these serious problems in the transport sector, stronger efforts could be made to promote biofuels, specifically. .

The staff working paper[54] accompanying the biofuels progress report[55] looks into the consequences of biofuel shares of 7% or 14% for 2020. It shows that these shares are achievable in agricultural terms. It also shows that they have positive environmental effects (in terms of greenhouse gas savings) and neutral or positive economic effects (in terms of employment, GDP and security of supply), and that the positive effects of the 14% scenario are greater than those of the 7% scenario.

The three overall renewable energy scenarios examined here (Green-X least cost, Green-X balanced and PRIMES) judge the optimum renewable energy share at 12, 14 and 15% respectively within an overall renewable energy share of 20%.

There is therefore good reason to believe that – on present knowledge – the optimum share of biofuels in 2020, within an overall renewable energy target of 20%, will be in the region of 14%.

However, in fixing a minimum target, and one which should be binding, a more cautious approach should be adopted.

In particular, it should be taken into account that a 14% share will only turn out to be the optimum share if two conditions are fulfilled.

First, achieving the 14% share will require several million tons of imports of vegetable oil for the production of biodiesel. As in the European Union, imported vegetable oil can be produced in compliance with environmental standards; but it is also possible to produce it in ways that have negative environmental effects, especially if land harbouring diverse natural ecosystems is converted to crops for biofuel production. As stated in the renewable energy roadmap, the Commission intends to bring forward a proposal for the differentiation of biofuel support. One effect of this proposal should be to minimise the risk of such environmental damage happening. But no such system is yet in place. In the light of this, it makes sense to aim in the minimum target at a level of first-generation biodiesel consumption that would not require the use of significant amounts of imported palm oil. This is consistent with first-generation biodiesel consumption of 9.7 Mtoe.

Second, achieving the 14% share will require new measures to ensure that biofuels can enter the fuel market. This can be done in three ways:

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[54] SEC (2006) 1721.

[55] COM (2006) 845.

a) Increase the amount of low-blend biofuel that may be blended in ordinary fuels

Current rules limit biofuel content to 5% ethanol in petrol and 5% biodiesel in diesel (both by volume). The European Standardisation Committee (CEN) is already working on a Commission mandate for a 10% share of biodiesel – sufficient to accommodate the volume of biodiesel referred to above. In ethanol, the highest blend currently available on a mass market is the 25% blend used in Brazil. It would make sense to limit the minimum target to the quantity consistent with a lower (20%) blend. This implies ethanol consumption of 18.8 Mtoe.

b) Increase take-up of special vehicles capable of using high-blend or pure biofuel, and of the special pumps needed to serve them

This could potentially be a powerful strategy. However it is more difficult to put into practice than a strategy based on low blends. It should not form part of the minimum target.

c) Bring Fischer-Tropsch diesel (BTL) to market

Efforts to develop second-generation biofuels focus on BTL and cellulosic ethanol. Cellulosic ethanol is chemically identical to first-generation ethanol and does not open up new ways for biofuel to enter the fuel market. By contrast, BTL is superior both to biodiesel and to existing diesel, and is not caught by rules limiting biofuel content in diesel. This is one of the reasons why BTL is supported through Community research programmes, and why efforts need to be intensified to bring it to market.

However, BTL is not as close to market as cellulosic ethanol. Numerous technical problems remain to be solved. While substantial progress can be expected by 2020, it would not make sense to base the minimum target on more than a small contribution from BTL. The suggested amount is 2.5 Mtoe.

It should be taken into account that, as shown in the staff working paper on biofuels[56], a 14% share would lead to higher prices for agricultural commodities in the EU unless accompanied by charges to the rules for governing agricultural markets in the EU and internationally.

This analysis suggests that the minimum target for biofuels in 2020 should be approximately 31 Mtoe, equivalent to a 10% share of the petrol and diesel market.

Based on interpolation from the effects of a 7% and 14% share, the approximate impact of this target could be annual extra average costs of €5.3bn, reduced oil imports from Middle East and CIS rising to 31 Mtoe in 2020, extra employment in the EU rising to 120 000 and greenhouse gas emission reductions rising to 68 $MtCO_2eq$. Finally, GDP benefits would be expected to reach 0.17%.

5.2.3. Renewable energy targets or CO_2 targets?

Energy policy has been developed so far with overall CO_2 targets under the Kyoto Agreement, together with targets for energy efficiency improvements and sectoral renewable energy targets, to speed up the development of technologies that address our security of supply concerns as well as climate change. This separate and distinct effort in one part of the energy sector has also been driven by the need to kick-start technology development from a very low base.

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[56] SEC (2006) 1721

If climate change and CO_2 emissions were the sole goal of energy policy and the renewable energy sector were a mature and well-functioning market, then a single CO_2-based target (reached through ETS for example) would be an appropriate policy approach. But this situation is still a long way off. Until the renewable energy sector becomes a mainstream component of the energy sector, is able to compete fairly in the internal energy market and is of a scale large enough to develop and deploy new technologies, it requires targets and specific policies of its own.

6. COMPARING THE OPTIONS

6.1. Comparison of options for levels of renewable energy use

The impacts described in section 5.1 can be summarised as follows:

The EU's total energy bill is expected to be about €350bn in 2020. The annual cost of achieving a 20% share of renewable energy is likely to reach €24-31bn per year in 2020 (€2005). This cost will vary with the mix of renewable energy technologies used and, to a greater extent, with the conventional energy price. For example, under the balanced scenario with a barrel of oil at $78 (rather than $48), the extra cost of renewable energy would fall to €11bn.

In exchange for this cost, the EU would obtain major benefits.

Annual greenhouse gas emissions would be 600-900 Mt lower. From the point of view of security of supply, fossil fuel consumption would be 235-300 Mtoe per year lower in 2020, including 50-55 Mtoe less oil imports from the Middle East and CIS, and 85-90 Mtoe less gas imports from those regions. This energy would mostly be replaced by domestically produced renewable energy. There would be substantial biodiversity benefits.

Some studies estimate that this strategy would lead to a GDP increase, others to an even smaller decrease. In all studies, the effect would be small (0.5% or less). Estimations show that there would be a small net increase in employment. The EU would be well placed to maintain its leading role in renewable energy research, and would continue to benefit from opportunities for renewable energy technology exports.

6.2. Comparison of options for renewable energy targets

The question of the type and scope of targets in section 5.2 can be summarised as follows: The legal strength of a target largely determines its credibility, as stronger targets mean that efforts will be made by governments to ensure that targets are met. This in turn means that the market has greater certainty for planning and undertaking investments. This clearly favours mandatory over indicative targets.

Whilst setting a single target has an intuitive appeal and gives the market flexibility to choose a cost-effective way of deploying technologies, sectoral measures are likely to be needed to create the forward-looking confidence needed to induce investment in a broad range of renewable energy sources. This is particularly important for biofuels if Europe is to achieve any reduction in fossil fuel consumption, emissions and import dependency in the transport sector.

Based on this analysis, and depending on the political weight placed on these various factors, the recommendation is to combine the EU's future renewable energy target with a sectoral target of 10% for biofuels.

7. MONITORING AND EVALUATION

The core indicator of progress towards meeting the objectives is data on the quantity and share of renewable energy consumed.

This will be obtained by way of national reports and data collected by Eurostat. As national reporting requirements by Member States and data collection by Eurostat are already in place, the additional administrative costs this will generate are not considered to be of any important size. Progress towards the overall objective of promoting renewable energy will be evaluated every two years as part of the regular series of Strategic European Energy Reviews.

Annex 1: PRIMES methodology and modelling approach

Overview of the PRIMES model

The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply matches the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships.

The model is behavioural, but it also represents in an explicit and detailed way the available energy demand and supply technologies and pollution abatement technologies. The system reflects considerations about market economics, industry structure, energy/environmental policies and regulation. These are conceived so as to influence the market behaviour of energy system demanders and suppliers (agents). The modular structure of PRIMES reflects a distribution of decision-making among agents who make individual decisions about their supply, demand, combined supply and demand, and prices. Then the market integrating module of PRIMES simulates market clearing.

The PRIMES model is a general-purpose energy system model. It is conceived for forecasting, scenario construction and policy impact analysis. It covers a medium to long-term horizon. It is modular, making it suitable either for unified model use or for partial use of modules to support specific energy studies.

Modelling of Renewables Penetration

Assumptions for baseline scenario

The PRIMES baseline energy scenario up to 2030 reflects trends under the current state of knowledge of policies in place and in the process of being implemented, restructuring in progress and improved energy technologies. Renewable energy technologies are assumed to improve over time under the baseline scenario. This improvement (reduced capital and fixed costs, higher efficiency rates and lower biomass fuel costs) reflects both "autonomous" technical progress (as a result for example of long-term research effort) and "endogenous" progress, the latter driven by what is expected to be an increasing volume of new installations in response to high energy prices and a growing concern for the environment (under baseline trends).

Regarding the numerical assumptions about technological progress of renewables under the baseline scenario, the PRIMES model relies on a technology dataset prepared under a series of research projects[57] which collected detailed techno-economic data per technology and linked these data with historical explanatory drivers, such as research effort, deployment in scale, and past investment. It is known that for energy technologies, the correlation between technology progress and the changing pattern of explanatory drivers is at a global market level and not on a local or even a regional level. For this purpose, the research projects have mostly used world energy market models (such as Poles[58], Prometheus[59] and Message[60]) to

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[57] The collaborative research projects are TEEM, SAPIENT, SAPIENTIA and CASCADE-MINTS; all co-funded by DG Research since 1998.

[58] Prepared at IEPE, France

[59] Prepared at E3mlab/NTUA, Greece

prepare baseline and alternative scenarios under which technology progress has been made partly endogenous, linked with research spending and cumulative investments.

Consequently, in preparing the baseline scenario, the PRIMES team used the techno-economic dataset on future technology progress that corresponds to an “average” world baseline scenario, as conventionally used in the above research projects. As it happens, this dataset coordinated well with the results of the Prometheus energy model, which is linked to Poles model projections and fully incorporates endogenous energy technology progress, in addition to autonomous progress.

The dataset used for the PRIMES baseline scenario involves substantial technology progress for renewable energy, as summarised in the table below:

Table 1: Capital Cost of Energy Technologies assumed for the PRIMES baseline

in Euro of 2005	**€/kW**								**Annual rate of progress since year 2000**				
	Base year Investment cost	**2005**	**2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**up to 2010**	**up to 2020**	**up to 2030**	**up to 2040**	**up to 2050**
Average conventional solid fuel	1,540	1,489	1,451	1,422	1,400	1,370	1,353	1,343	-0.60%	-0.48%	-0.39%	-0.32%	-0.27%
Average new solid fuel	1,747	1,595	1,490	1,417	1,367	1,308	1,280	1,266	-1.59%	-1.22%	-0.96%	-0.78%	-0.64%
Turbine oil-gas plants	477	464	454	446	440	432	427	424	-0.51%	-0.41%	-0.34%	-0.28%	-0.24%
Combined cycle natural gas	576	563	554	546	540	532	526	523	-0.39%	-0.32%	-0.26%	-0.22%	-0.19%
Nuclear	2,389	2,270	2,183	2,119	2,072	2,013	1,981	1,964	-0.90%	-0.71%	-0.57%	-0.47%	-0.39%
Fuel cell	11,755	5,756	2,964	1,665	1,060	648	559	540	-13.78%	-12.03%	-9.66%	-7.61%	-6.16%
Average biomass combustion	2,255	1,898	1,669	1,521	1,425	1,324	1,282	1,265	-3.03%	-2.31%	-1.79%	-1.42%	-1.16%
Average biomass gasification	2,195	1,879	1,672	1,537	1,449	1,354	1,314	1,297	-2.72%	-2.07%	-1.61%	-1.28%	-1.05%
Average on shore wind	1,078	976	907	859	826	788	770	762	-1.73%	-1.33%	-1.04%	-0.84%	-0.69%
Average off shore wind	1,755	1,557	1,424	1,334	1,274	1,206	1,175	1,161	-2.09%	-1.60%	-1.25%	-1.00%	-0.83%
Average solar photovoltaic	4,611	3,105	2,253	1,772	1,501	1,260	1,184	1,159	-7.16%	-5.61%	-4.32%	-3.40%	-2.76%
New run of river	1,681	1,490	1,362	1,276	1,218	1,153	1,123	1,110	-2.10%	-1.61%	-1.26%	-1.01%	-0.83%
Tidal	2,404	2,127	1,942	1,817	1,733	1,639	1,597	1,578	-2.14%	-1.64%	-1.28%	-1.02%	-0.84%
Geothermal high enthalpy	2,163	2,082	2,021	1,976	1,941	1,896	1,871	1,857	-0.68%	-0.54%	-0.44%	-0.36%	-0.31%

Of course, the competitiveness of a particular technology for power generation depends not only on capital cost but also on the price and availability of the resource used as input (e.g. biomass cost, availability of wind and solar energy) as well as on heat efficiency, in the case of combustion. When considering those factors, technical progress in terms of capital cost places wind power in the top ranks of competitiveness, a trend which is in line with expectations of the massive deployment of wind power under the baseline scenario. In other cases, like solar photovoltaic, the impressive improvement in terms of capital cost is not enough to generate massive deployment until 2030 under baseline trends. The same holds true for fuel cells and partly for new biomass, because their deployment crucially depends on the conditions and infrastructure of supply of input fuels (crops and hydrogen respectively); regarding infrastructure, the baseline scenario involves provides for little development until 2030.

High renewable energy scenarios

Basic Methodology

A High Renewable Energy Scenario for the EU aims at quantifying the energy system implications of imposing a certain mandatory numerical target for the penetration of renewable energy in the EU energy system at a future time.

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[60] Prepared at IIASA, Austria

Supposing that the quantum and the time dimension of the target are set for the EU as a whole, the PRIMES model is used to work out the target per EU country and sector of activity (electricity-steam generation, transport sector, other final demand sectors). According to economic theory, optimality is obtained by specifying different target levels per country and sector in such a way that every country and every sector faces the same level of marginal cost associated with its individual target, and at the same time the target levels are such that globally the EU achieves the overall target for renewables penetration.

To do this calculation with the PRIMES model we need to do iterative model runs. Instead of imposing directly an overall target for renewables, it is assumed that a certain positive monetary value is associated with any unit of energy produced by a renewable energy source. A monetary value does not involve direct payment transfers (as taxes would do), but its presence alters the economic optimality calculations of the agents (either demanders or producers of energy). This monetary value could be interpreted as a "virtual" subsidy and appears in calculations as a negative unit cost (or a positive unit gain). In mathematical terms the monetary value is the dual variable associated to the global quantity constraint, signifying the marginal value in terms of global system costs of relaxing the quantity constraint by one unit. Let us call this monetary value a "renewables value"[61]. Being a virtual subsidy, the renewables value does not make energy cheaper, but merely influences the optimum fuel mix as considered by each economic agent. Compared with the baseline scenario, energy would generally become more expensive, since the presence of the renewables value alters the optimality of decisions in just the same way as if the global renewables quantity constraint was added.

Model iterations proceed as follows: start with a certain level of renewables value, insert this value into the economic objectives of each agent and each country as in the model, and run the model for all EU countries; calculate the level of overall penetration of renewable energy in the EU and compare with the target for the EU; if total renewables quantity is below target, then increase renewables value, otherwise decrease; repeat this cycle and compare against target until convergence is achieved. At convergence, the resulting scenario is identical to the baseline except for the renewable value. By comparing with baseline, it is possible to assess the energy systems implications of the overall EU renewables target. The marginal cost of the renewables target is exactly equal to the renewables value; if plotted against different levels of targets, a marginal renewables penetration cost curve is obtained. Total energy system cost under the high renewables scenario is expected to be higher than at baseline, as explained above.

As usual, the comparison of renewables scenario to baseline will provide details about how incremental renewables penetration is realised and which of other energy forms and technologies are displaced; details are given by country, sector and technology.

<u>ENDOGENOUS TECHNOLOGY PROGRESS in the Renewable Scenario</u>

If, in the high renewable scenario, techno-economic and fuel supply assumptions were the same as for the baseline scenario, there would be no additional technology progress. This means that despite the higher deployment of renewables, unit costs of renewable technologies remain to the same as the values in baseline.

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[61] A similar methodology has been used to simulate global carbon emission constraints with models such as PRIMES; in these cases the dual variable is called "carbon value".

One argument against this assumption is that the higher deployment of renewable technologies may facilitate greater technology progress (lower capital costs and higher efficiency) as compared with baseline trends. This would make it possible to achieve the renewables target at lower overall costs, hence yielding a lower renewables value.

This is usually called technology learning-by-doing. If these effects are linked to certain model variables, such as levels of deployment of a technology, the learning is called endogenous. Because of modelling and measurement difficulties, this effect usually includes increasing returns to scale, which might be attributed to the scale of industrial deployment rather than to learning. Within the research projects mentioned above, a series of learning-by-doing curves[62] for individual and clustered energy technologies have been estimated econometrically on a historical time series.

Available learning curves relate capital cost reduction and heat efficiency improvement to total installations of an energy technology on a global geographical scale. Therefore, expectations concerning higher penetration of an energy technology, for example in a scenario like the high renewables one, drive technological progress, which further facilitates technology penetration and reduces the marginal costs of policy targets.

To do this on a European scale, we have to bear in mind that the EU market accounts for quite a small fraction of the world market for an energy technology. Therefore to see significant effects of learning-by-doing, we have to combine the EU scenario with assumptions about the penetration of energy technologies at world level. For the baseline scenario this has been done, as explained before, by considering technology improvement trends on a global scale, through linking the PRIMES model with Poles and Prometheus baseline scenarios.

For the EU high renewables scenario, two options are possible: a) assume that on a global scale too, a high renewables scenario will take place and so consider total world installations as a driver of learning-by-doing on top of the baseline scenario; b) assume that high renewables policies are put into effect unilaterally at the EU level, so additional learning-by-doing effects would be somewhat limited in magnitude. In the PRIMES modelling in this exercise, the second option has been chosen so as to avoid overestimating the learning-by-doing effects. Although renewables action is assumed in this analysis to take place only in the EU, the rest of the world benefits from economic spillovers driven by lowering energy technology costs, leading other countries (albeit less so than in the EU) to invest more in renewable technologies. The Prometheus model was used to estimate the additional reduction of capital cost driven by a high renewables scenario for the EU. The results were used for the PRIMES modelling of the high RES scenario.

Endogenous change of biomass supply infrastructure in the high renewables scenario

A fuel supply curve relates the price or unit cost of a fuel to total actual or expected demand. To obtain market equilibrium, either directly through matching supply against demand or indirectly through optimisation, the fuel supply curve must have an upward slope at least beyond a certain level of demand. This feature can be justified by exhaustion of a resource, or simply related to the economic mechanisms of supplying demand by using cheaper supplies before more expensive ones.

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[62] In addition, learning-by-research curves have been estimated; they can be used to incorporate technology progress effects driven by additional R&D spending.

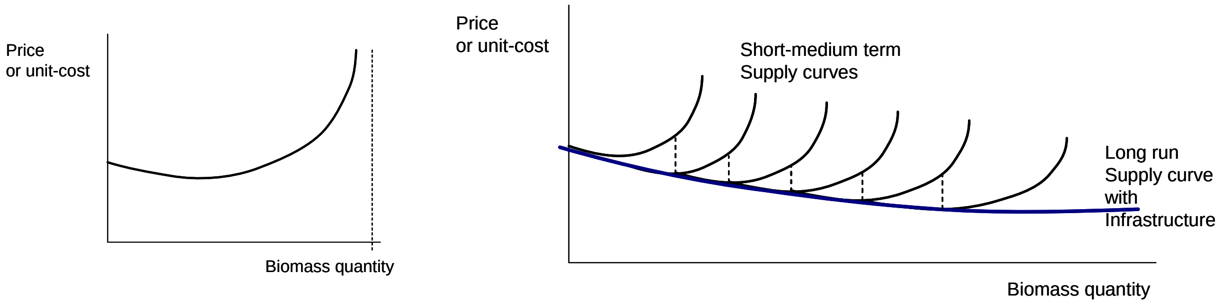
Such a mechanism is already incorporated into the PRIMES model not only for energy resources but also for all action of a cumulative nature, like investment to make up for exhausted sites or non-linear risk factors.

For various biomass fuel types, the current PRIMES model and dataset use fuel supply curves per country that are calibrated to the data provided by ECN and are derived from a detailed bottom-up model which calculates the potential of renewables per country under various economic and technical assumptions.

On this basis, PRIMES includes biomass supply curves and similar curves for other renewables. Beyond a certain quantity of biomass these curves are upward sloping; this means that under a high renewables scenario, prices and costs of biomass will be higher than under baseline. However, there are also arguments that under a high renewables scenario the prices of biomass might be lower than in baseline. These arguments refer to the development of large-scale infrastructure needed to collect and prepare/condition biomass, in particular where the biomass market is a big one. Within a high renewables scenario, ambitious expectations about the size of future markets for biomass might drive significant investment in large-scale infrastructure for collecting and conditioning biomass products, generating a considerable reduction in biomass unit costs, given that the costs of collection and product conditioning are significant elements in the final price of biomass. The unit cost of land use for biomass will be upward sloping with higher biomass quantities, as more productive land is expected to be used first before less productive land is deployed. Moreover, the price of biomass might include higher rents or opportunity costs when suppliers serve increasing demand. However, under a high renewables scenario it is possible that the cost-lowering effect due to massive new infrastructure will dominate over other factors, causing price and costs to increase with the higher demand for biomass.

This mechanism is illustrated in the following diagram, which is also relevant for other resources, like oil/gas exploration and production, or new technologies like hydrogen. The diagram shows that although the short/medium-term supply curves (with generally constant basic infrastructure) are upward sloping, the long-term supply curve, which incorporates the effect of massive new infrastructure, might be downward sloping, at least up to a large demand quantity.

Figure 1: Fuel supply curves (first graph as in PRIMES, second graph including the effect of new infrastructure)



By taking into account the above long-run supply curve for biomass, in other words by considering exogenously the building of large-scale biomass infrastructure in the high renewables scenario, we obtain a fuel cost reduction effect similar to the learning-by-doing effects explained above. This is equivalent to assuming that in the high renewables scenario, renewables policy is backed by appropriate agricultural policies (land use, subsidies and financing of infrastructure development) that help biomass supply to attain industrial maturity. Clearly, this assumption will further facilitate the penetration of biomass into the high renewables scenario and induce a lower renewables value (i.e. the marginal cost of achieving the renewable target). This approach has been followed by allowing for a shift to the right of the biomass supply curves, yielding a somewhat conservative estimate of the cost-lowering effects of more substantial biomass penetration.

Annex 2: Green-X methodology and modelling approach

The Green-X model facilitates a comparative, quantitative analysis of interactions between RES, conventional energy and combined heat and power (CHP) generation, demand-side management (DSM) activities and CO_2-reduction, both within the EU as a whole and for individual Member States. The model forecasts the deployment of RES under various scenarios in terms of supporting policy instruments, the availability of resources and generation technologies, and energy, technology and resource price developments.

The ***Green-X*** model matches demand and supply of energy sources. Demand is based on the EU energy outlook[63]. Supply is described by means of a cost-resource curve build up in two parts:

- A static cost-resource curve that describes the relationship between available technical potentials and the corresponding costs of utilising this potential.
- A dynamic cost-resource curve, which is based on the static cost-resource curve but incorporates such dynamic parameters as technological change (using the concept of experience curves or expert judgment) and the dynamic barriers to implementation, determining the yearly available RES potential. The dynamic curve is endogenous to the model and is determined annually.

The figure provides an overview of the ***Green-X*** model.

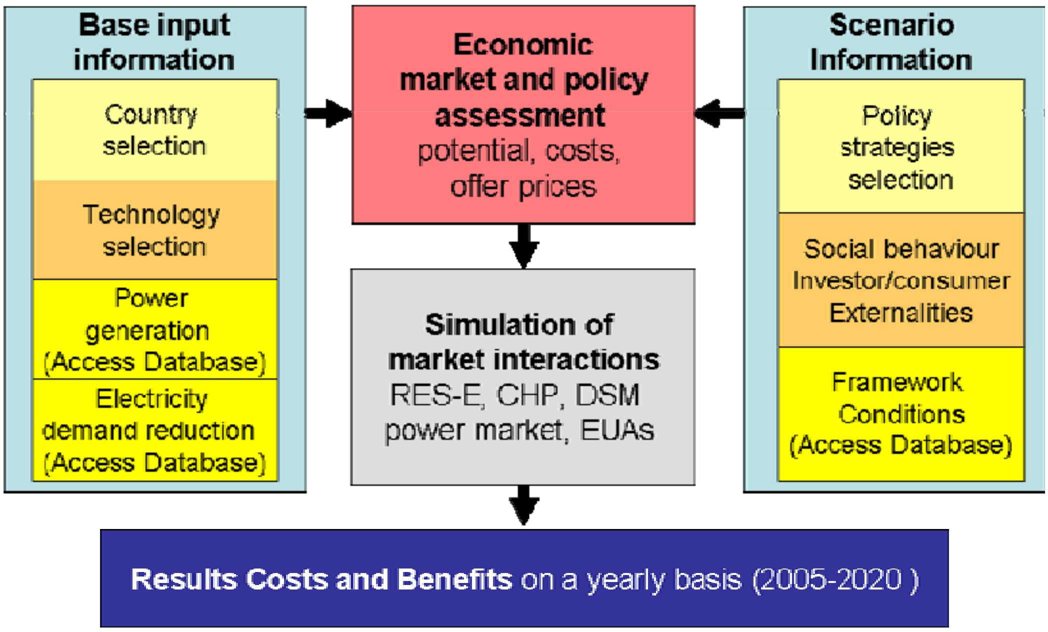


Figure 2 Overview of the computer model ***Green-X*** (electricity sector)

The ***Green-X*** model calculations are complemented by simulations from the **Green*Net*** model that determines the additional costs for system operation and grid extension resulting from variable RES-E.

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[63] European Energy and Transport Trends by 2030 / 2005 / Baseline and European Energy and Transport Trends by 2030 / 2006 / Efficiency Case (13.5% demand reduction)

Modelling approach

Least-cost scenario

The key approach in the modelling calculations is that the European energy market optimises the additional generation costs for RES against the background of a 20% RES target in 2020 as shown in Figure 3. This overall optimisation is modelled by comparing the difference between RES generation costs and conventional reference prices across all sectors (heat, electricity and biofuels), all technologies and all countries. Results are presented in terms of additional costs, that is, the total costs of generation per energy output minus the reference cost of energy production per unit of energy output. The optimisation exercise is conducted across all three sectors (RES-E, RES-H and RES-T). As biomass may play a role in all sectors, the allocation of biomass resources is a key issue. Consequently the overall optimisation across sectors includes an integrated optimisation of the distribution of biomass among the sectors. Of course, this may result in overestimating the flexibility in the use of biomass from energy crop plantations as the use of land is not entirely flexible and cannot be changed overnight. However, land use restrictions in terms of total availability of land per type of use are included in the derivation of primary energy potentials for energy crops.

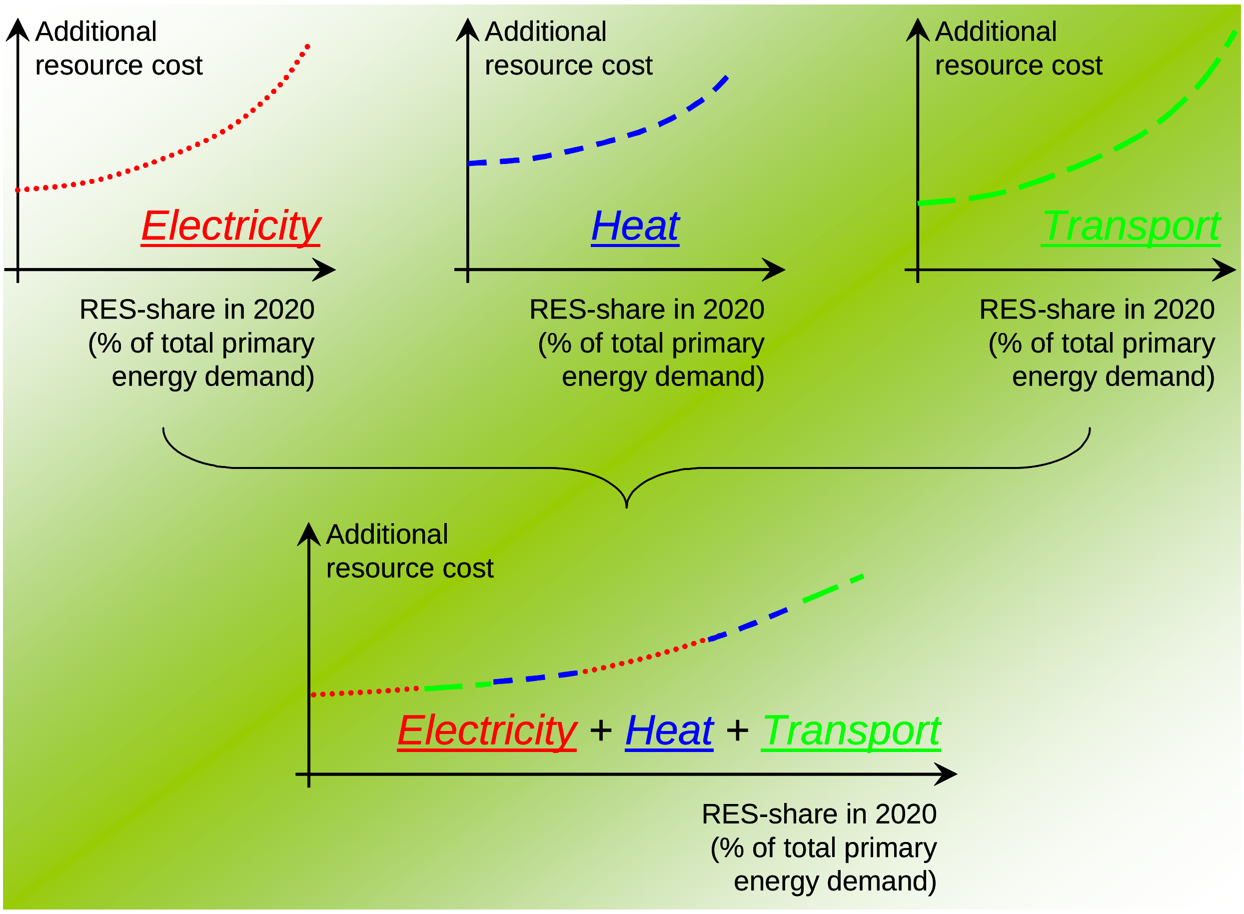

Figure 3 Definition of least-cost scenario

In the political discussions RES targets are based on the EUROSTAT method, while the cost optimisation in the ***Green-X*** model is based on an extended substitution principle. The main difference between the two methods is in their treatment of RES-E. Under the substitution method, RES-E counts for about 2½ times as much primary energy as under the EUROSTAT method, because the conventional fuels substituted are taken into account. The main difference between the classical substitution method and the applied extended substitution method is the treatment of biomass: the classical substitution method takes account of primary biomass energy, while the extended substitution method uses substituted fossil fuel. This means under the classical substitution method a biomass plant with low efficiency would contribute more to an RES primary energy target than a highly efficient one. As regards comparability of the different methods, the 20% target in the *Least-cost scenario* based on EUROSTAT convention corresponds to 24.8% based on the classical substitution method, and to 22.3% based on the extended substitution principle. By using the extended substitution principle in the model, the amount of conventional energy saved for a given target is maximised: this is a very good proxy for the key energy policy objectives of the EU concerning security of supply and climate change.

Balanced scenario

In this scenario it is assumed that technology-specific support provides opportunities for the deployment of the most efficient technology options within each renewable energy source category. The key criterion in this scenario is to request a **comparatively similar effort from all three sectors** (heating and cooling, electricity and transport). This means that for the electricity sector, effective and efficient policies are implemented, leading to compliance with the RES-E Directive (2001/77/EC) in 2010 at EU level, and a continuation of efforts up to 2020. Similarly for the biofuels sector, effective and efficient policies are assumed that lead to compliance with the Biofuels Directive (2003/30/EC), with a continuation of efforts up to 2020. For the heating and cooling sector, it is assumed that renewable policies are implemented in all Member States, which is presently not the case. Such renewable heating policies provide sufficient incentives for the deployment of all relevant RES-H technologies across the EU. In this way the level of effort for the heating sector assumed for the balanced scenario is similar to the electricity and biofuels sectors.

Conventional supply portfolio

The conventional supply portfolio, i.e. the share of the different conversion technologies in each sector, has been based on the PRIMES country-specific forecasts. These projections of the portfolio of conventional technologies impact particularly on the calculations made in this study on the avoidance of fossil fuels and CO_2-emissions. The following assumptions are made concerning the displacement of conventional energy by renewable energy: Keeping in mind that fossil energy represents the marginal generation option that determines the prices on energy markets, it was decided to stick, at the country level, to the sector-specific conventional supply portfolio projections as provided by PRIMES. Sector- and country-specific conversion efficiencies, derived on a yearly base, are used to calculate the amount of primary energy avoided. Assuming a constant fuel mix, avoidance can be expressed in units of coal or gas replaced. A similar approach is applied to the avoidance of CO_2-emissions, where yearly changing average country- and sector-specific CO_2-intensities of the fossil-based conventional supply portfolio from the basis for calculations.

Figure 4 shows the dynamic development of average conversion efficiencies as projected by PRIMES for conventional electricity generation and for grid-connected heat production. Conversion efficiencies are shown for both the PRIMES baseline and PRIMES efficiency case. Error bars indicate the range in country-specific average efficiencies between EU Member States. For the transport sector, where efficiencies are not explicitly expressed in PRIMES results, the average efficiency of the refinery process to derive fossil diesel and gasoline was assumed to be 95%.

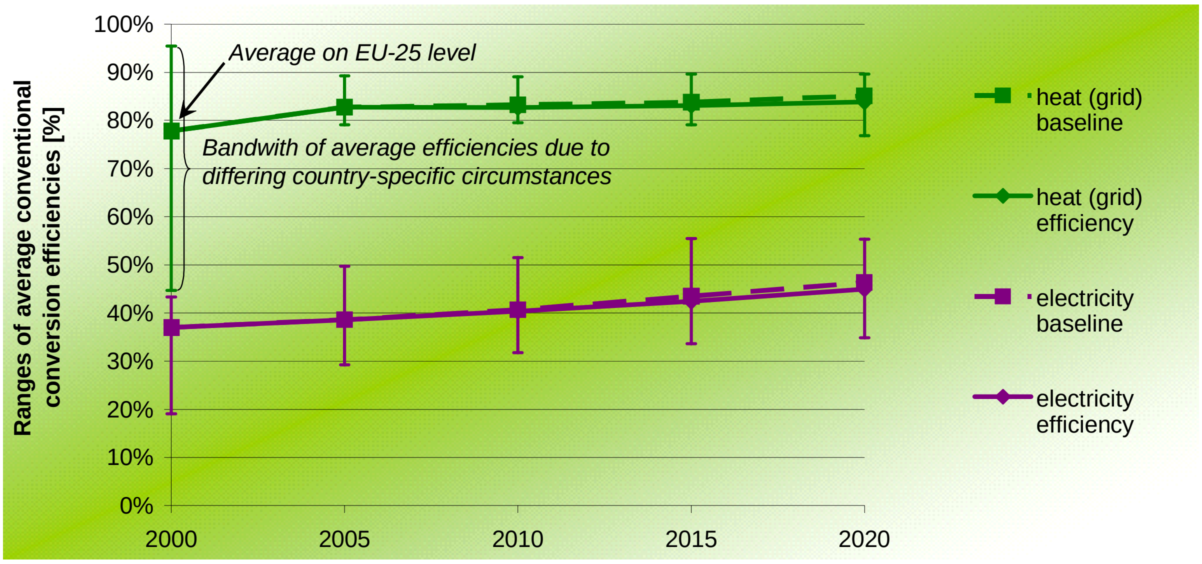

Figure 4 Country-specific average conversion efficiencies of conventional (fossil-based) electricity and grid-connected heat production in EU-25 (source: PRIMES scenarios)

The corresponding data on country- and sector-specific CO_2 intensities of the conventional energy conversion system are shown in figure 5. The bars again illustrate the variation between countries.

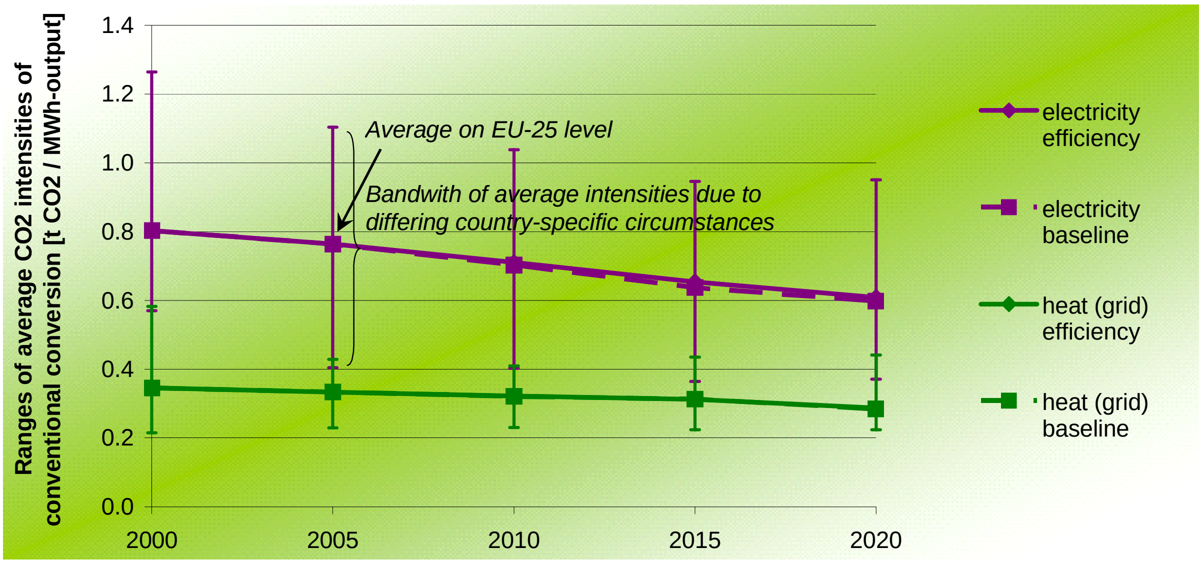

Figure 5 Country-specific average sectoral CO_2 intensities of the conventional (fossil-based) energy system in EU-25 (source: PRIMES scenarios)

Note: The differences between the PRIMES efficiency and baseline case for non-grid heat and transport are very small and therefore not shown.

Fossil fuel and reference energy prices

National reference energy prices used in this analysis are based on the primary energy price assumptions as used in the EU energy outlook. Compared to current energy prices the price assumptions in the PRIMES energy efficiency and baseline scenario are low for the later years up to 2020. The reference oil price for instance goes up to $48 per barrel while actual world market prices in the last year have fluctuated between $55 and 78 per barrel. A sensitivity analysis is therefore conducted for *Higher energy price* assumptions, taken from the PRIMES high energy price scenario. Table 2 and figure 6 set out the development of energy prices assumed in both cases.

Table 2 Primary energy price assumptions in $2005/boe (source: PRIMES scenarios)

Baseline	**2005**	**2010**	**2015**	**2020**
Oil	54	44.59	44.95	48.08
Gas	30.31	33.86	34.22	36.99
Coal	13.32	12.53	13.38	14.1

High price	**2005**	**2010**	**2015**	**2020**
Oil	54	61.86	67.58	77.61
Gas	30.31	36.84	44.71	53.03
Coal	13.32	13.63	14.19	16.29

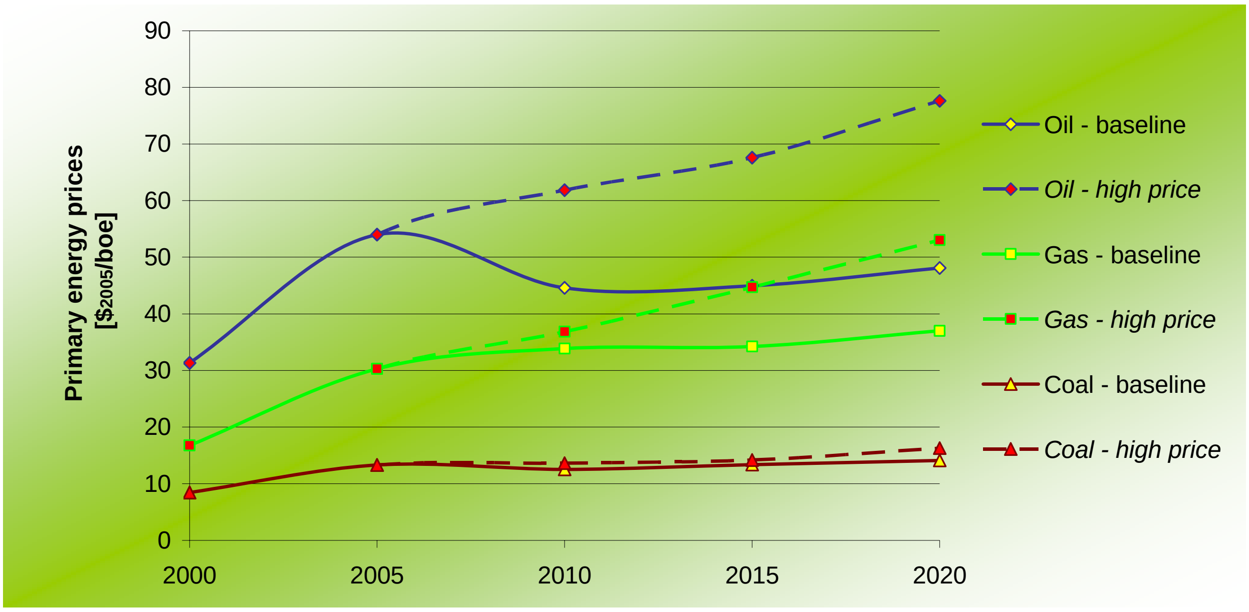

Figure 6 Primary energy price assumptions (source: PRIMES scenarios)

Reference prices for the electricity sector are taken from the ***Green-X*** model. Based on the primary energy prices, the CO_2-price and the country-specific power sector, the ***Green-X*** model determines country-specific reference electricity prices for each year in the period 2005-2020. Reference prices for the heat and transport sector are based on primary energy prices and the typical country-specific conventional conversion portfolio. Reference prices for grid-connected heat supply from district heating and CHP plants do not include the costs of distribution – they represent the price directly at the plant. All reference prices are set out in Table 3.

Table 3 Reference prices for electricity, heat and transport fuels

in €/MWh output	**2005**	**2010**	**2015**	**2020**

Electricity price	52.1	54.9	49.6	48.6
Heat price (grid)	28.3	29.3	30.3	30.6
Heat price (non-grid)	50.5	51.2	51.6	53
Transport fuel price	42	40.1	37.8	41

CO_2 prices

The CO_2-price in the *Least-cost scenario* is exogenously set at 20 €/t, again similar to existing EU scenarios. Actual market prices (for 2006 EU Allowances) fluctuated between 7 and 30 €/t in the period January-July 2006, with averages fluctuating roughly between 15 and 20 €/t. Prices are however expected to rise in the coming years if stricter caps are put in place, which depends largely on the post-2012 framework. A sensitivity case is defined with a *Higher CO_2-price* of 50 €/t. In the model, it is assumed that CO_2-prices are passed through to electricity prices. This is done fuel-specific based on the PRIMES CO_2-emission factors.

Increased RES deployment can have a CO_2-price-reducing effect as it slows the demand for CO_2-reductions. As RES deployment should be anticipated in the EU Emission Trading System and the CO_2-price in the *Least-cost scenario* is set exogenously, this effect is not included, which is a somewhat conservative approach.

RES potential

A broad range of renewable energy technologies exists today. Obviously, to get a full picture of the future development of RES it is of crucial importance to take a detailed look at the country-specific situation – e.g. the potential of RES in general as well as their regional distribution and the corresponding generation cost. Major efforts have recently been made within the FORRES 2020 study to make a comprehensive assessment of Europe's RES resource base. Consequently, this project builds directly on these consolidated outcomes as presented in the Commission's Communication 'The share of renewable energy'.[64]

Within the model ***Green-X***, supply potentials for all main technologies for RES-E, RES-H and RES-T are described in detail.

- RES-E technologies include biogas, biomass, biowaste, onshore wind, offshore wind, small-scale hydropower, large-scale hydropower, solar thermal electricity, photovoltaics, tidal & wave energy, and geothermal electricity.

- RES-H technologies include heat from biomass – subdivided into log wood, wood chips, pellets, and district heating –, geothermal heat and solar heat.

- RES-T options include traditional biofuels such as biodiesel and bioethanol, advanced biofuels, and the impact of biofuel imports

The potential supply of energy from each technology is described for each country analysed by means of *dynamic cost-resource curves*. Dynamic cost curves are characterised by the fact that the costs and the potential for electricity generation / demand reduction can change each

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[64] COM (2004) 366.

year. The magnitude of these changes is given endogenously in the model, i.e. the difference in the values compared to the previous year depends on the outcome of this year and the (policy) framework conditions set for the simulation year.

Realisable mid-term potentials form the basis for the overall approach. This potential describes the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. This ensures that general parameters such as market growth rates and planning constraints are taken into account. It is important to mention that this potential must be seen in a dynamic context – i.e. the realisable potential has to refer to a certain year: for the purpose of this study 2020 has been chosen.

The following figures illustrate – taking the electricity sector as an example – the potential contribution of RES in the electricity sector within EU-25 up to 2020 by considering specific resource conditions in each country. Thereby, in accordance with the general modelling approach, a clear distinction is made between existing RES plants (installed up to the end of 2004 – i.e. the *achieved potential* in 2004) and future RES options – the *additional mid-term potential*. More precisely, Fig 7 depicts the achieved and additional mid-term potential for RES-E in EU-15 by country (left) and by RES-E category (right). A similar picture is shown for the new Member States (EU-10) in Fig 8. Note that in both figures no future potential is indicated for biomass, as the allocation of the total biomass potential to the different sectors (electricity/ heat/ transport) is part of the optimisation process in the applied modelling approach.

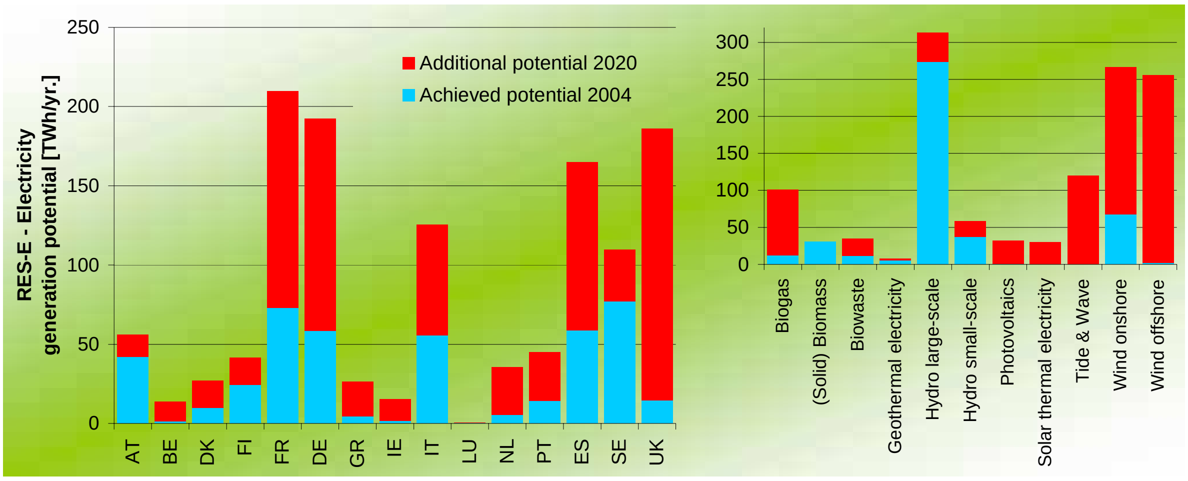

Figure 7[65] Achieved (2004) and additional mid-term potential 2020 for electricity from RES in EU-15 – by country (left) and by RES-E category (right)

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[65] This figure refers to the Green-X least cost scenario.

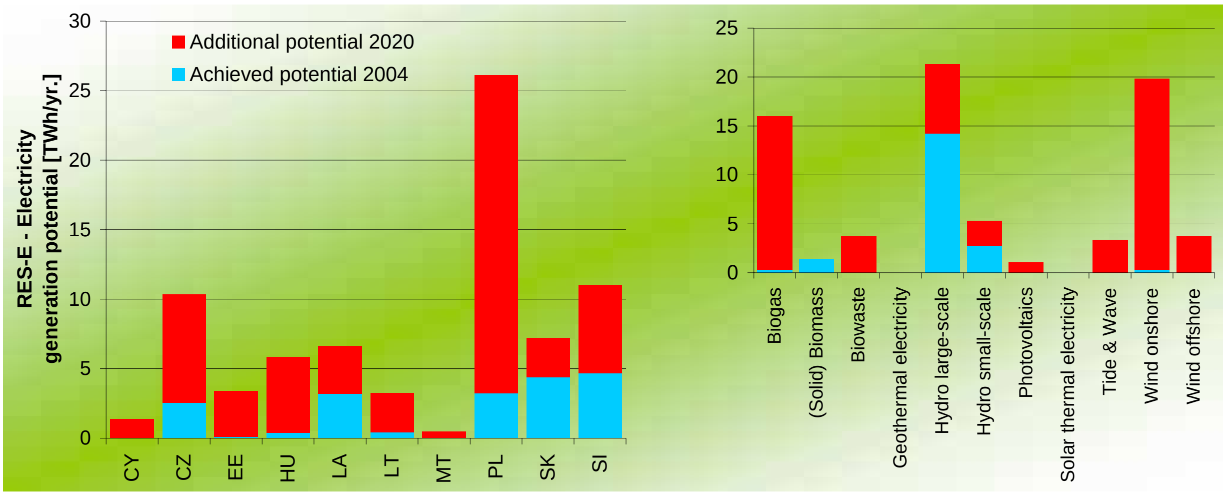


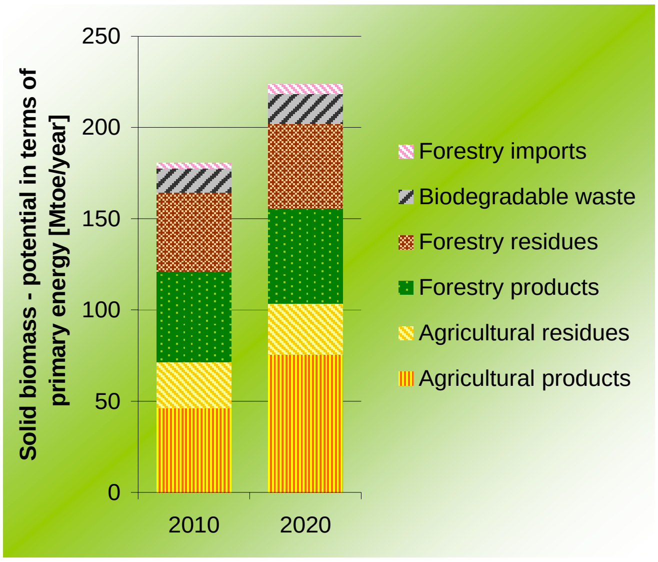
Figure 8[66] Achieved (2004) and additional mid-term potential 2020 for electricity from RES in EU-10 countries – by country (left) and by RES-E category (right)

Given the overall optimisation across sectors, the availability of biomass and the allocation of biomass resources across sectors are crucial. The total domestic availability of solid biomass was set at 219 Mtoe/yr. Biomass data have been cross-checked with the European Commission, EEA and the GEMIS database.[67] In the *Least-cost scenario* it has been assumed that biomass can be imported to the European market. Specifically:

- Solid biomass in the form of wood products and wood residues can be imported to a maximum of 15% of the total additional primary input of forestry biomass.

- Liquid biofuel in the form of ethanol and biodiesel products can be imported to a maximum of 30% (average to be achieved over the whole 15-year period), corresponding to a default case based on solely domestic biofuel supply.

Figure 9 Solid biomass potential in primary energy terms (Mtoe/year)



A sensitivity case analyses the effect on the deployment of RES of allowing no biomass imports to the EU (sensitivity case *No import of biomass to the EU*).

In this context, the figures indicate the dynamic development of identified biomass primary potentials at the EU-25 level.

RES targets

The *Least-cost scenario* assumes achieving a target of 20% RES in 2020.

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[66] This figure refers to the Green-X least cost scenario.

[67] For example the recent EEA report "How much bio-energy can Europe produce without harming the environment?" gives 235 Mtoe in 2020 for total biomass under the assumption of significant ecological constraints on biomass use.

Sensitivity cases are conducted to analyse the effect of a lower or higher RES target (16%, 18% or 22% instead of 20%) on additional RES generation costs and the deployment of various RES technologies (sensitivity case *Variation in RES target*). Note that the least-cost optimisation approach is defined as achieving an overall RES target; no sector-specific targets (separately for RES-E, RES-H and RES-T) are defined. The analysis assumes a linear path from current RES deployment up to the 20% target.

RES cost

Parameters on long-term cost developments of RES in the *Least-cost scenario* and the *balanced scenario* are based on the FORRES 2020 project.[68] Costs are adapted endogenously on the basis of technology-specific learning rates. Exceptions to this rule are the cost developments specified for solar thermal, tidal and wave energy, for which expert cost forecasts are used. In order to obtain a better understanding of the relation between long-term cost developments and the resultant overall costs of meeting future RES targets, the rate of technology learning is varied in sensitivity cases. Model results are obtained for *Accelerated and Decelerated technological learning*, assuming a 15% higher and lower learning rate respectively for each technology (compared to default learning rates).

Note that the analysis uses a quite detailed level of specifying costs and potentials. The analysis is not based on average costs per technology. For each technology a detailed cost-curve is specified for each year, based on "cost-bands". These cost-bands summarise a range of production sites that can be described by similar cost factors. For each technology a minimum of 6 to 10 cost bands is specified. For biomass at least 50 cost bands are specified for each year in each country. Economic conditions in respect of the various RES technologies are based on both economic and technical specifications, varying across the EU countries.[69] Fig 10 depicts the typical current band with of *long-run marginal generation costs*[70] per technology for the electricity sector. For the purposes of calculating the capital recovery factor, a default setting is applied with respect to payback time (15 years) and weighted average cost of capital (6.5%). The broad range of costs for several RES technologies reflects variations in resource (e.g. for photovoltaics or wind energy) or demand-specific conditions (e.g. full-load hours in the case of heating systems) within and between countries as well as variations in technological options such as plant size and/or conversion technologies.

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[68] Analysis of the EU renewable energy sources' evolution up to 2020 (FORRES 2020), financed by the European Commission, DG Energy and Transport, under tender n° TREN/D2/10-2002

[69] Note that in the model ***Green-X*** the calculation of generation costs for the various generation options is done by a somewhat complex mechanism, internalised within the overall set of modelling procedures. Thereby, band-specific data (e.g. investment costs, efficiencies, full load-hours, etc.) are linked to such general model parameters as interest rate and depreciation time.

[70] Long-run marginal costs are relevant for the economic decision as to whether or not to build a new plant.

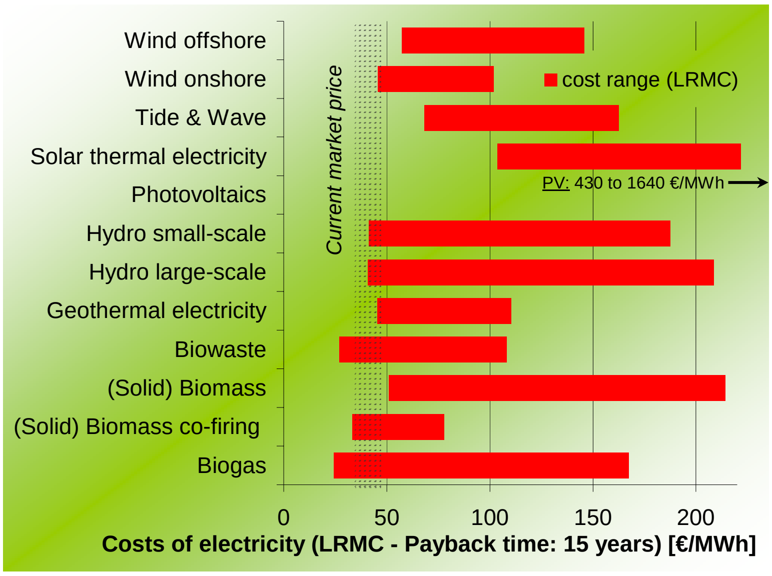

Figure 10 Long-run marginal generation costs (for 2005) for various RES-E options in EU Member States.

For hydropower (large- and small-scale) and wind onshore, non-harmonised cost settings are applied, i.e. country-specific data on investment costs and, where suitable, O&M-costs are also used. For all other RES-E options harmonised cost settings are applied across the EU. The ranges expressed for economic and technical parameters in these instances refer to differences in plant sizes (small- to large-scale) and/or conversion technologies applied. All data on investment costs, O&M-costs and efficiencies refer to the default start year of the simulations, i.e. 2005, and are expressed in $€_{2005}$.

Prices for imported biomass are set exogenously:

- The price of imported wood is set country-specific, indicating trade constraints and transport premiums. The current European average is 16 €/MWh.

- The price of imported biofuels is put at a European average of 62 €/MWh.

Scenario parameters and sensitivity cases

Key parameters with a likely major effect on the modelling results were selected and corresponding sensitivity cases defined:

- *Less energy efficiency policies*: Sensitivity analysis serves to quantify the synergies between ambitious energy efficiency policies and the achievement of renewable energy targets set in relative terms – i.e. defined as a percentage of corresponding demands.

- *Higher energy prices*: World-market energy fuel prices have been very volatile over recent years. Obviously the additional generation costs of renewable energy are largely affected by the variations in world-market fuel prices. Accordingly, the applied sensitivity analysis aims to quantify this sensitivity to variations in primary energy price assumptions.

- *Higher CO_2 prices*: The carbon-constraints affecting the European energy markets, especially the implementation of the EU emissions trading scheme, have put an explicit price on carbon emissions of fossil-fuelled energy production. As a result, a part of the externalities of energy production has been included in production prices, resulting in an improved level of competitiveness for renewables vis-à-vis fossil-fuelled production. Given the uncertainty of prices, with special reference to the global post 2012 climate change policy framework, a sensitivity case has been defined on the market price of CO_2.

- *Variation in target setting*: The sensitivity cases show the impact of variations in target setting between 16 and 22%.

- *Accelerated or decelerated technological learning of RES technologies*: An important factor in the further penetration of renewables is the extent to which larger penetrations of renewable production technologies can result in a further decrease in the costs of these technologies per unit of output. A sensitivity analysis is defined on this so-called technological learning of RES technologies.

Overview of parameters and sensitivity cases

In order to ensure maximum consistency with existing EU scenarios and projections, key *least-cost* and *balanced scenarios* parameters are derived from the PRIMES modelling and from the FORRES 2020 study. Table 4 shows which parameters are based on PRIMES and which have been defined for the two scenarios. More precisely, the PRIMES scenarios used are:

(1) European Energy and Transport Trends by 2030 / 2005 / Baseline

(2) European Energy and Transport Trends by 2030 / 2006 / Efficiency Case (13.5% demand reduction)

Table 4 Main input sources for scenario parameters

Based on PRIMES	Defined for this study
Sectoral energy demand	**20% target**
Primary energy prices	**Reference electricity prices**
Conventional supply portfolio and conversion efficiencies	**RES cost (FORRES, incl. biomass)**
CO_2 intensity of sectors	**RES potential (FORRES)**
	Biomass import restrictions
	Technology diffusion
	Learning rates

Annex 3: Details of PRIMES and Green-X scenarios used in the impact assessment

Background on the models

The scenarios in the PRIMES and Green-X models are slightly different. The PRIMES model is a partial equilibrium and a general purpose model which simulates market equilibrium for the energy sector as a whole in the EU. Green-X, also a partial equilibrium model, allows for a comparative, quantitative analysis of interactions between renewable energy, conventional energy and combined heat and power (CHP) generation, demand-side management and CO2 reductions, both within the EU as a whole and for individual Member States. The Green-X model is not a general purpose model, as its focus is on forecasting the deployment of renewable energy under various scenarios. The conventional supply portfolios used in the Green-X model are provided by the PRIMES model.

Under a "business as usual" or a "do nothing more" approach, the option of maintaining existing policies and supports is examined, with no new measures. A “business-as-usual” scenario has been developed and modelled using the PRIMES and Green-X models.

PRIMES business-as-usual scenario

The PRIMES “BAU” scenario is based on a continuation of existing policies, taking account of measures implemented at EU and Member State level up to the end of 2004. This scenario does not assume that indicative targets set out in Community directives are necessarily met.

The scenario simulates how the main energy source – solid fuels, oil, gas, nuclear and renewables – will develop in the future. No additional measures are implemented after the end of 2004 to promote renewable energy sources and energy efficiency. In this scenario, gross energy consumption will increase by 230 Mtoe between 2000 and 2020. As can be seen from the table below, the structure of energy demand in the PRIMES BAU scenario changes towards increasing shares of natural gas and renewables, and decreasing shares of solid fuels, oil and nuclear. Oil still remains the most important fuel source in the EU in 2020, followed by gas. The increase in energy consumption is covered by renewables and natural gas. The renewables share rises throughout the projection period from less than 6% in 2000 to 8% in 2010 and further to 10% in 2020. Under the BAU scenario, the EU target on renewables for 2010 will not be achieved.

Table 5 Share of energy sources in total energy consumption in PRIMES BAU scenario (%)

	2000	2010	2020
Solid fuels	18.5	15.8	13.8
Oil	38.4	36.9	35.5
Gas	22.8	25.5	28.1
Nuclear	14.4	13.7	12.1
Renewable	5.8	7.9	10.4

Source: PRIMES

Green-X business-as-usual scenario

As with PRIMES, the Green-X "BAU" scenario is also based on a continuation of existing policies to promote renewable energy and energy efficiency.

The share of renewable energy in the Green-X BAU scenario is 8.6% in 2010 and 12.4% in 2020. The Green-X data for total energy consumption are taken from the PRIMES BAU. However, the models have different starting points in their BAU scenarios because the total energy consumption figure is endogenously corrected within Green-X due to a different penetration of renewable energy sources.

PRIMES "high renewables and efficiency" scenario

The PRIMES "high renewables and efficiency" scenario was modelled assuming full implementation of all energy efficiency policies and additional incentives towards renewable energy sources, so that a 20% contribution of renewable energy sources to primary energy consumption is achieved by 2020. As regards energy efficiency, it is expected that full implementation policies and ongoing energy efficiency programmes at EU and Member States level will contribute to better energy efficiency and energy savings. See Annex 1 for further details on methodology and model assumptions.

Green-X "least cost" scenario

Under the Green-X “least cost” scenario, an overall renewable target of 20% in 2020 was exogenously imposed, and a renewable portfolio was derived on the basis of a least-cost approach, defined in terms of the additional production costs. Cost optimisation is achieved by minimising the difference between renewable energy production costs and conventional reference prices across all sectors (electricity, transport, and heating and cooling). This scenario is very similar to the PRIMES "high renewables and efficiency" scenario. Although the renewables share is the same, the gross primary consumption is somewhat higher in this scenario, resulting in a somewhat higher amount of gross primary consumption of renewable energy, which is 340 Mtoe compared to 325 Mtoe in the PRIMES "high renewables and efficiency" scenario. Both scenarios direct a majority of the renewable sources towards the electricity sector.

The costs and benefits of achieving a given share of renewable energy are largely affected by variations in key parameters such as the level of the target, energy and CO2 prices, technological learning of renewable technologies, and the availability of biomass. The Green-X “least cost” scenario also studies impacts in terms of changing these parameters.

Balanced scenario (and variant)

Taking a cost minimisation approach, the PRIMES high renewables and efficiency scenario and the Green-X “least cost” scenarios focus on bringing into the market the cheapest renewable technologies at each point in time up to 2020. There are, however, some important aspects not taken into consideration in these two scenarios. Firstly, they do not consider that a legislative framework will be put in place to boost the use of renewable energy for heating and cooling purposes. Secondly, they do not focus on the cost effectiveness of choosing a basket of technologies in the longer term (post 2020).

These aspects are, however, taken into account in the Green-X “balanced” scenario. This scenario has an overall exogenously imposed target of 20% and aims at a more realistic distribution between technologies (e.g. not letting the development of biofuels decrease to zero-deployment until 2010 or allowing an exaggerated increase in the development of renewables produced from renewable energy sources as in the Green-X "least cost" scenario), reflecting new policies in the heating and cooling sector and the need to focus on post-2020 renewable technologies. This scenario provides a more balanced share of renewables between the sectors, with more renewables being used in the heat and transport sector and less in the electricity sector compared to the Green-X “least cost” scenario and the PRIMES high renewables and efficiency scenario.

To illustrate the impacts on costs when changing the basket of technologies, a variant of the balanced scenario has been analysed. This scenario has the same sectoral breakdown of renewable energy as the "Balanced" scenario but does not include the longer term technologies.

The "balanced" scenario introduces a shift in the use of RES between the three sectors, assuming strengthened policies in the transport and heating and cooling sectors. The primary consumption of RES is marginally higher in the “balanced” scenario compared to the “least cost” scenario. The shares of RES in the electricity, transport and heating and cooling sectors under the “balanced” scenario are 34.2%, 11.9% and 20.7%, as against 42.8%, 10.6% and 16.3% respectively under the “least cost” scenario.

Costs and benefits of different mixes of renewable energy

The breakdown of renewable energy between sectors, and the quantified costs and benefits of the three 20% scenarios are summarised in the following table:

Table 6 Breakdown of renewable energy between sectors, quantified costs and benefits of the three 20% scenarios (Source: PRIMES and Green-X)

	PRIMES High renewables and efficiency scenario	***Green-X Least cost scenario***	***Green-X Balanced scenario***
Breakdown of final RES consumption between sectors			
Electricity (Mtoe):	*115*	*125*	*99*
Heating and cooling (Mtoe):	*91*[71]	*95*	*121*
Transport (Mtoe):	*47*	*38*	*43*
Costs			
Cumulative additional production costs for the period 2005-2020 (*€ bn)*	*(not available)*	*210*	*290*
Additional production cost in 2020 (*€ bn)*	*24**	*26*	*31*
Benefits			
Avoided CO2 emissions (Mt CO_2)Avoided fossil fuels (Mtoe)	*600** *234*	*891* *301*	*707* *252*

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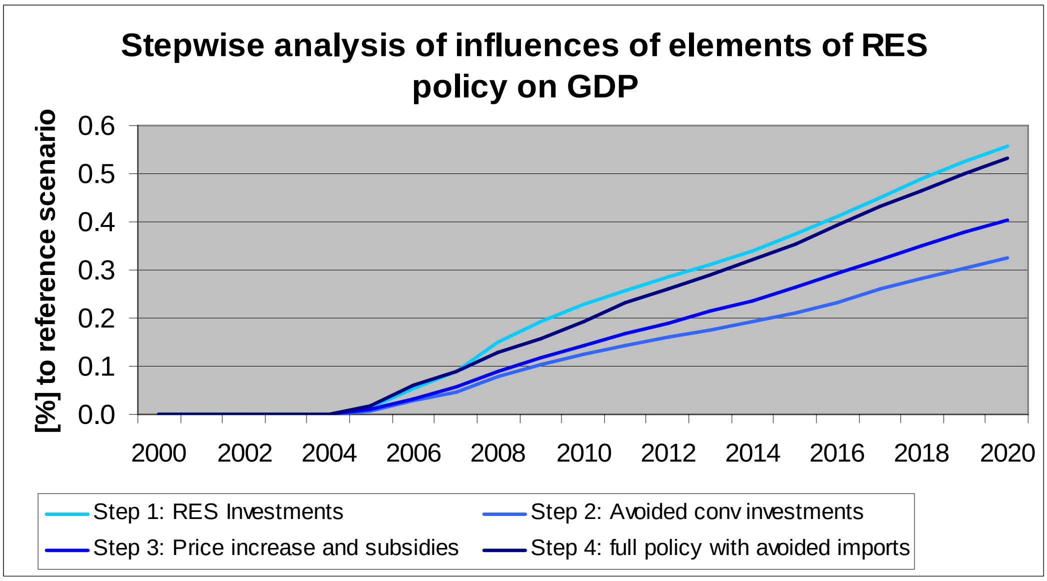
[71] It should be noted that the PRIMES model treats heat pumps as a very efficient means of using electricity and does not allocate the useful energy derived as renewable energy (as is also the case with Eurostat statistics for geothermal heat produced with heat pumps in the final demand sectors, given that this heat does not appear in market transactions). This may explain the somewhat lower consumption of renewable energy for heating and cooling purposes compared to the Green-X least-cost scenario.

Annex 4: The ASTRA employment and GDP model

The ASTRA model looks in particular at the influence on GDP and employment, quantifying the direct and indirect impacts of a given policy[72]. A stepwise analysis has been undertaken, which includes looking at the effects of 1) an increase in investments in renewable energy sources, 2) reduced investments in conventional energy technology, 3) implementation of funding mechanisms for renewable energy sources, and 4) avoided imports of fossil fuels, as a result of increasing the share of renewable energy sources.

Another assumption of the ASTRA model is that all RES installations within the EU are of European origin, whilst at the same time any export of RES technology or services is entirely disregarded. This approach is commonly applied in modelling because future export opportunities and competition on domestic markets are not easy to predict. However, potentially important additional welfare effects of technology and service exports are neglected in this approach (see subsequent section on export opportunities).

Figure 11: Development of GDP in the four steps of a Green-X "Balanced I" scenario implementation



Source: ASTRA model

Figure 11 sets out the forecast GDP development by indicating the percentage change in GDP over the BAU scenario. For steps 1, 2 and 4 the results show intuitively a plausible reaction, with a growth in GDP due to additional RES investments in step 1, a lower growth in GDP due to the reduced investments in conventional energy technology in step 2, and increased growth in GDP due to avoided imports of fossil fuels in step 4. In step 3, implementing the

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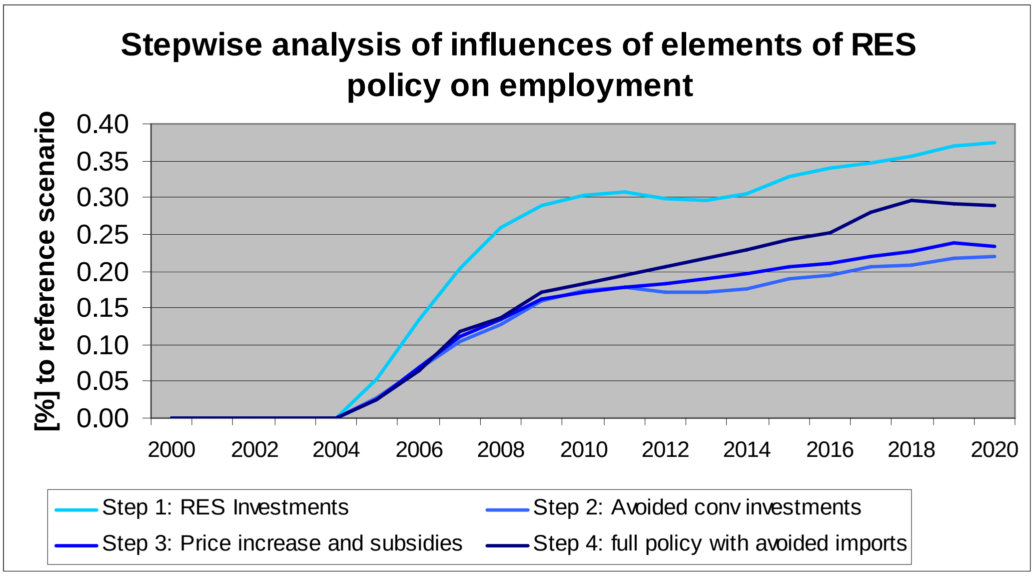
[72] The **direct impacts** will be that final demand for sectors producing RES technologies (RES sectors) would increase and thus also revenues and employment of those sectors. However, also two **indirect impacts** are obvious: first, the supplier industries of RES sectors would increase their production and employment, because of additional demand for intermediate goods from the RES sectors, and second, income generated by both the supplier sectors and the RES sectors will increase such that consumption expenditure is growing and is distributed onto those economic sectors producing consumption goods and services.

funding mechanisms for renewable energy investments, one would have expected lower growth in GDP compared to step 2, while it is actually a higher growth.

Figure 12: Development of employment in the four steps of a Green-X "Balanced I" scenario scenario



Source: ASTRA model

Figure 12 shows the development of employment in the four steps. In general, the four curves can be divided into two periods: during the first period from 2005 until 2009 we have the strongest and fastest employment growth. This is driven by the additional RES investments, causing total investments to grow strongest in this period. In the second period 2010 until 2020, employment is growing more slowly, and the driver is the continued GDP growth, i.e. the indirect impact of the renewable energy policy.

Annex 5: Input-output modelling of employment and GDP effects of biofuels policy

This model was developed primarily in order to estimate the impact of biofuels policies alone, decoupled from other renewables policies, on employment in the EU.

The model core used was a EU25 input-output-table (IOT) based on the GTAP6 database, for year 2001. No updating of the IOT based on forecasted sectoral growth rates was attempted for time reasons. Policy and development interventions were represented by the relevant demand shocks applied to base year technical coefficients. The IOT was fed with outputs from the Commission’s agriculture- and trade-specific model ESIM (DG AGRI). Long-term projections of input-output models (e.g. beyond 2010) are to be handled with particular care, and the adopted approach should be understood as a compromise; accordingly, the final results should be understood as only indicative of the impact pathways and magnitude, not as exact figures.

In the 57 sectors of the GTAP database, the level of detail as regards agricultural commodities is detailed enough to feed in the agricultural impact results as obtained from the ESIM model, but not as regards energy products. It was therefore necessary to introduce two new sectors for conventional fuels (diesel and petrol) and four new sectors for biofuels (first and second generation bioethanol and biodiesel). Fuel use data was derived from IEA data; the technological specifications for the production of biofuels were, in each scenario, consistent with the techno-economic data assumed in this impact assessment report.

The input-output table was been complemented with labour input data adapted from the OECD's STAN database. Additional data for labour inputs to the detailed agricultural sectors featured in GTAP have been adapted based on the information provided by the Farm Account Data Network of DG AGRI and on the total AWU (Annual Work Units) figures published by Eurostat (Farm Structure Survey). For comparability with other sectors, employment data in the agricultural sector are finally converted in full-time job equivalents assuming an average of 1800 yearly hours per full-time job.

Different modules were introduced in the input-output model in order to capture as far as possible the essential aspects of the biofuels scenarios.

An Input-output price model calculated price changes of all commodities induced by the exogenous price variation of agricultural and food products and crude oil, which was also assumed to have an effect on the price of all imports.

Commodity price variations, together with the direct policy costs, were the input of an Almost Ideal Demand System (AIDS) model, which calculated the final household consumption vector subject to the constraints of fixed total budget and prices. Elasticities of the AIDS model are adapted from the GTAP model elasticities.

The resulting consumption vector was then introduced in a mixed endogenous-exogenous variables IO model, which allowed for fixing the supply of agricultural commodities to the values known from ESIM results.

Annex 6: The POLES/PACE Hybrid approach

The approach combines two models, the energy system model POLES and the extended version of the computable general equilibrium (CGE) model PACE, in order to assess in an integrated way the economic and environmental effects of different targets for renewable energy within the European Union in the year 2020[73]. POLES is a partial equilibrium model of the world energy market that is being developed and exploited since 1991 under several European Commission (EC) RTD programmes. PACE is a computable general equilibrium (CGE) model that has been previously applied, e.g., for the analysis of discrete technology policies such as nuclear phase out or renewable quotas. The *hybrid approach* allows to better integrate the technologies in the general equilibrium model. At this stage, the analysis is confined to renewable energy in total electricity production given the novelty of the chosen hybrid approach. There are very few examples of large-scale analyses of energy policies using hybrid CGE models (e.g. Böhringer and Löschel, 2006).

The hybrid approach

The large-scale computable general equilibrium model PACE combines the technological explicitness of bottom-up (engineering) energy system models for the electricity sector with the economic comprehensiveness of the top-down CGE framework. The hybrid framework strengthens the robustness of CGE analysis because key technological options for the promotion of renewable energy within the power sector are now represented explicitly. The CGE model has been aligned as close as possible to the energy system model POLES up to 2020: (i) the different electricity generation technologies in the hybrid model are specified through the specific cost structure, capacity constraints and the output shares in the POLES business as usual scenario, (ii) the hybrid model is calibrated to the POLES benchmark equilibrium (i.e. the baseline or business-as-usual evolution until 2020) conducted for the World Energy Technology Outlook WETO H2 (GDP, fossil fuel prices, etc.), and (iii) substitution elasticities in the electricity sector are chosen to replicate POLES simulation results.

General description of POLES

The POLES model is a partial equilibrium simulation model of the world energy market. In its current version, POLES splits the world into 47 individual countries/zones, for which a detailed representation of the domestic energy markets has been developed, in terms of energy demand, energy transformation, domestic supply, deployment of non-conventional energy vectors including renewables, imports and domestic prices. POLES mimics the evolution of international energy markets for the main traded energy commodities by modelling the supply reaction to international demand based on endogenous extraction capacity, refining and transportation. Supply exhibits a short term price elasticity primarily linked to de extraction capability in swing producers, and a long term elasticity mainly driven by the evolution of the reserve-to-production ratio.

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[73] Böhringer, C. and A. Löschel (2006), Promoting Renewable Energy in Europe – A Hybrid CGE Approach, *The Energy Journal*, „Hybrid Modelling: New Answers to Old Challenges”, 123 – 138.

The power generation sector is treated within POLES with a great technological detail. The following technologies are considered within the central power generation system for each country/zone:

(1) Conventional, large scale hydroelectricity (HY)

(2) Conventional light water nuclear reactor (NU)

(3) New nuclear design (NND)

(4) Lignite-fuelled conventional thermal (LCT)

(5) Coal-fuelled conventional thermal (CCT)

(6) Pressurized coal supercritical (PFC)

(7) Pressurized coal supercritical with CO2 sequestration (PSS)

(8) Integrated coal gasification with combined cycle (IGC)

(9) Integrated coal gasification with combined cycle with CO2 sequestration (CGS)

(10) Oil-fuelled conventional thermal (OCT)

(11) Oil-fuelled turbine in combined cycle (OGC)

(12) Gas-fuelled conventional thermal boiler (GCT)

(13) Gas-fuelled gas turbine (GGT)

(14) Gas-fuelled turbine in combined cycle (GGC)

(15) Gas-fuelled turbine in combined cycle with CO2 sequestration (GGS)

In addition to this, the following emerging new and renewable power generation technologies are present in the model:

(16) Small hydro power plants (<10 MW) (SHY)

(17) Wind power plants on-shore (three different wind characteristic speeds) (WND)

(18) Wind off-shore (WNO)

(19) High temperature solar thermal power plants (SSP)

(20) Decentralised building-integrated photovoltaic (PV) with network connection (DPV)

(21) Decentralised PV for rural electrification (RPV)

(22) Biomass waste combustion for power generation (BF2)

(23) Biomass gasification & combined cycle (BGT)

(24) Industrial Combined Heat&Power (CHP)

For each of the technologies, a detailed techno-economic characterization sheet summarizes the present and expected performance, based on expert judgement and the foreseeable evolution of the corresponding leaning curves.

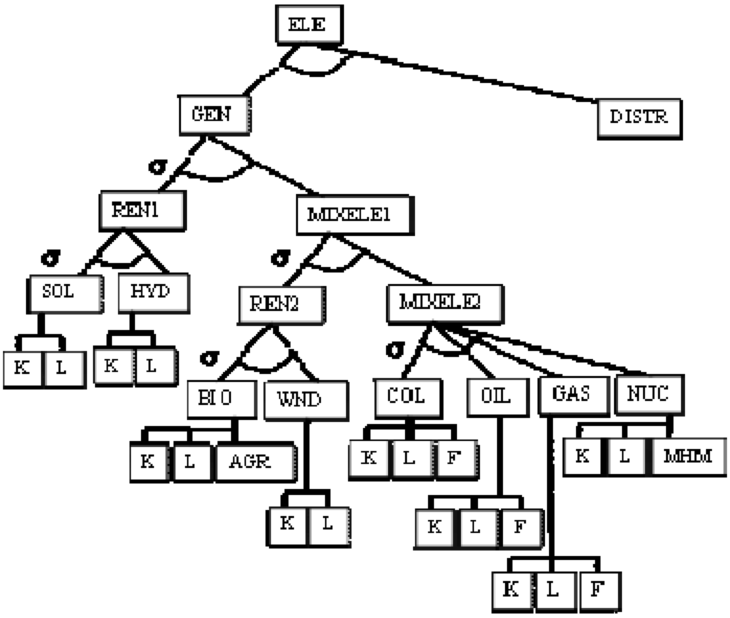
General description of PACE

The computable general equilibrium (CGE) model is an extended version of the PACE model for Europe (EU25) with a bottom-up description of power generation technologies for the electricity sector. Parameterization of the hybrid model requires the reconciliation of top-down data and bottom-up data which stem from different data sources. While the bottom-up data is technology data taken from POLES, the top-down data for the hybrid CGE model comes in the form of an aggregated social accounting matrix (SAM). The SAM summarizes the benchmark data to which the model is calibrated. Comprehensive base year statistics on global trade and energy use are provided by the GTAP5 database that features consistent accounts of regional production and consumption, bilateral trade, and energy flows for up to 66 countries/regions and 57 commodities in the year 1997 (Dimaranan and McDougall 2002). The sectoral aggregation in the model has been chosen to distinguish energy-intensive sectors from the rest of the economy as far as possible given data availability. It captures key dimensions in the analysis of energy policies, such as differences in energy intensities and the degree of substitutability across (primary and secondary) energy goods in intermediate and final demand. The energy goods identified in the model are hard coal, soft coal (lignite), natural gas, crude oil, refined oil products and electricity. There are eight non-energy sectors. The primary factors in the model are labour, physical capital and fossil-fuel resources. Primary factor endowments are exogenous. Factor markets are assumed to be perfectly competitive. Labour and capital are treated as perfectly mobile across sectors. Fossil-fuel resources are sector-specific. Factors are immobile between regions. The model is specified as a full bilateral trade model with two regions: EU-25 and the rest of the world. All agents are price takers, i.e. there are no market imperfections. Important elasticities, e.g. Armington elasticities for the terms of trade adjustments, have been taken from WorldScan.

Analysis of the adjustment of physical capital stocks or production structures to policy constraints over time requires a dynamic framework. A dynamic-recursive approach is adopted where dynamics are driven by the savings behaviour of households under myopic expectations. 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. The model is calibrated to the POLES baseline (business-as-usual assumptions on non-uniform growth rates for GDP as well as projections on fossil fuel production and use). To align the POLES projections on the baseline activity levels of the various power generation technologies up to 2020, technology-specific endogenous taxes and subsidies are introduced within the business as usual (BAU) model calibration of the CGE model. The taxes and subsidies work as a tangible proxy for a variety of regulatory measures in EU Member States in place under business as usual.

The model captures the production of commodities by aggregate, hierarchical (or nested) constant elasticity of substitution (CES) production functions that characterize the technology through substitution possibilities between capital, labour, energy and material (non-energy) intermediate inputs (KLEM). Each intermediate input represents a composite of domestic and imported varieties. Carbon emissions are associated with fossil fuel consumption in production, investment, and final demand. Power producers in the electricity sector have discrete choices with respect to alternative technologies and combine these based on capacity constraints in order to meet electricity demand in a cost-minimising way. As to the concrete model implementation, a few key technologies (clusters) as provided by the POLES model might be already sufficient to give an appropriate representation on the range of available technological options. The production structure in the electricity sector is characterized by nested CES production function of the disaggregated electricity supply technologies. Electricity from each technology is produced with (Leontief) fixed proportions of capital, labor, energy and material inputs. Figure 1 shows the nesting structure of the disaggregated-by-technology power sector. The elasticities in the technology nesting ($\sigma_1 - \sigma_5$) are calibrated to the POLES simulations.

Figure 13: Electricity production in the hybrid CGE model PACE



The proposed nesting structure has been designed to capture a fundamental difference in the market penetration dynamics of two broad groups of renewable electricity technologies. On the one hand, solar and hydro are expected to exhibit a relatively limited growth rate (both in terms of absolute production volume as well as in terms of its share over the total production). This limited growth rate is due in the case of hydro to the relative exhaustion of the potential expansion capacity, very close to the saturation level (a very mature technology), and, in the case of solar, due to the restrictions imposed by the still high capital costs and the limited equipment production capacity (a too immature technology). On the other hand, wind and biomass electricity are expected to be the main drivers of an increasingly important share of renewables in the European power mix, at a speed that will be primarily depend on the regulatory instruments put in place in the electricity market as well as the alternative policy measures adopted with respect to climate change.

Annex 7: The potential for exports of renewable energy technologies

There are good reasons to believe that if an effective RES export policy was applied substantial additional opportunities for adding value to the European economy could be harvested from RES technology and service exports.

Given its size, the EU is one of the most outward-oriented economies in the world. EU trade in goods and services accounts for 15% of its GDP (that is 3 percentage points above the US or Japan), and the share of industrial exports in industrial added value is more than twice this figure. The EU is the leading exporter of goods and services and the leading investor abroad. Against this background, the external dimension of competitiveness seems unavoidable: the EU can ill afford to ignore the role of opening markets in its jobs and growth strategy.[74]

Over recent years the machinery sector (excluding electronics) has shown a considerable surplus in the trade balance. The development of EU exports of machinery to third countries is strongly linked to development in individual regions of the world. To take an example, the great need for modernisation in the economic and industrial framework of Eastern European countries in transition has resulted in new sales opportunities for EU machinery producers. Thanks to its advanced technology and high quality, the EU machinery industry is still internationally highly competitive.[75]

EU industry is particularly strong on exports in energy technology markets. In large heavy duty gas turbines (LHDGT), for instance, there are only four companies with proprietary LHDGT technology worldwide, of which two are European. Other companies manufacture LHDGT under licence. In industrial steam turbines, European manufacturers hold a global market share of 20-50%.

The business opportunities in the RES sector are supported by massive global growth: Investment in new RES capacity in 2005 amounted to $38 billion, up from $30 billion in 2004. Germany and China were the investment leaders, with about $7 billion each, followed by the United States, Spain, Japan and India. The RES industry has captured investors' attention, as the number of RES companies or divisions with market valuations greater than $40 million has increased from 60 to 85. The estimated total valuation of companies in this category was $50 billion, double the 2004 estimate. The United States extended its tax credit up to and including 2007. A number of countries dramatically stepped up targets for biofuels and at least states/provinces and six countries added blending mandates. New feed-in laws were enacted in four states/provinces in India and Canada. Initiatives from grid-connected solar PV multiplied, including several programmes in the United States, Australia and China. Developing countries took new steps in record numbers to incorporate RES into their energy systems, including programmes and new policy developments in Brazil, Chile, Colombia, Egypt, India, Iran, Madagascar, Malaysia, Mexico, Morocco, Pakistan, the Philippines, South Africa, Thailand, Tunisia, Turkey and Uganda. [76]

Examples from the German case

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[74] http://ec.europa.eu/trade/issues/sectoral/competitiveness/index_en.htm

[75] http://ec.europa.eu/trade/issues/sectoral/industry/machinery/index_en.htm

[76] Renewable Energy Policy Network for the 21st Century: Renewables Global Status Report 2006 Update. http://www.ren21.net

Wind turbines are the most prominent example of today's RES export opportunities for EU industry. Europe leads the world in wind power generation: European manufacturers account for over 80% of global industry turnover (2004); but foreign competitors are aggressively fighting for market share.[77] Germany remains one of the world's largest wind power markets. In 2005, the worldwide market volume for wind power comprised more than €10 billion, with new installations amounting to around 10 000 MW. Around half of these were produced by the German wind power industry. With a turnover of €4.5 billion, German turbine manufacturers and suppliers produced more than 50% of the turbines and components manufactured worldwide in 2004. [78]

Recent corporate press releases prove that even outside the wind turbine sector Europe's RES industry is striving strongly for exports. Lurgi AG, a major machinery manufacturer in Germany, states in recent press releases: "As market and technology leader, Lurgi continues to benefit from the globally increasing demand for alternative fuels like biodiesel and bioethanol… Our focus on profitable proprietary technologies in fast growing markets is reflected in the increasingly impressive performance of our business… Lurgi will build ethanol production plants in Dallas, US, (€ 130 million project value), Yorni, US, (€95 million), and Kansas, US (€54 million)… Once the currently projected processing plants have been completed, between 60 and 70% of global output of biodiesel will be produced using Lurgi technology. In Germany, this proportion will be between 70 and 80%." Solarworld AG, a fast growing and vertically integrated PV system provider from Germany, recently announced that "SolarWorld AG has further strengthened its group business by concluding additional expert contracts for the delivery of solar silicon wafers made in Germany. On the whole the subsidiary company Deutsche Solar AG – one of the largest manufacturers of wafers for the solar cell industry worldwide – has firm supply contracts for twelve years (2007 through 2018) amounting to a total volume of more than €2.3 billion. Some 70 per cent of the orders come from abroad, demonstrating the broad international basis of the business. The most important export region is Asia, with a share of 36.5 per cent of the total volume. China and Taiwan alone account for some 26.5 per cent of the business. This is followed by Europe (excluding Germany), with a share of 22.5 per cent. Some 10 per cent of the volume is shipped to customers in the USA."

A recent expert study analysed the impacts of the increased use of RES on employment inside Germany with particular regard to external trade. The study was carried out by the German institute for economic research (DIW) in co-operation with scientific partners and on behalf of the German ministry for environmental affairs. Based on interviews with more than 1000 companies and extensive modelling, the experts concluded that even under conservative assumptions a doubling of direct employment in the German RES sector can be expected by 2020. Also on a net base, i.e. after accounting for all possible negative employment effects in other sectors, a clear and sustainable positive employment impact can be expected. An essential pre-requisite for this positive outcome, however, is that Germany continues to play an important role on global RES markets. The experts stress that this is not happening by itself although German industry is well prepared for this. In most RES sub-sectors German industry is the technology leader because of supportive national framework conditions in the past. The German government will continue its support for the RES sector, e.g. through

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[77] European Wind Energy Association: www.ewea.org

[78] German Energy Agency, dena: www.renewables-made-in-germay.com

research and development, an intensified export initiative for RES, and stronger use of RES inside Germany.[79]

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[79] Federal Environment Ministry of Germany (BMU): Renewable Energies - Employment effects. In German, 2006, http://www.erneuerbare-energien.de/inhalt/36860/