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Support Activities for RES modelling post 2020

Interim report

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This interim report presents the envisaged approach, progress and preliminary findings of the project Support Activities for RES modelling post 2020. The project is supported by the European Commission, DG Energy, under contract ENER/C1/428-2012.

Partners in the Support Activities for RES modelling post 2020 are Fraunhofer ISI (Germany), Ecofys (the Netherlands), Energy Economics Group (EEG) (Austria), Rütter + Partner Socioeconomic Research + Consulting (Switzerland), and Société Européenne d'Économie (SEURECO) (France).

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0 Organisation of work and technical progress report

Work in the project is organized in five work packages. A graphical presentation of the work packages is depicted in Figure 0-1. In this section, we present the technical progress in the separate work packages. A description of the methodological approach and preliminary results are presented in the following sections.

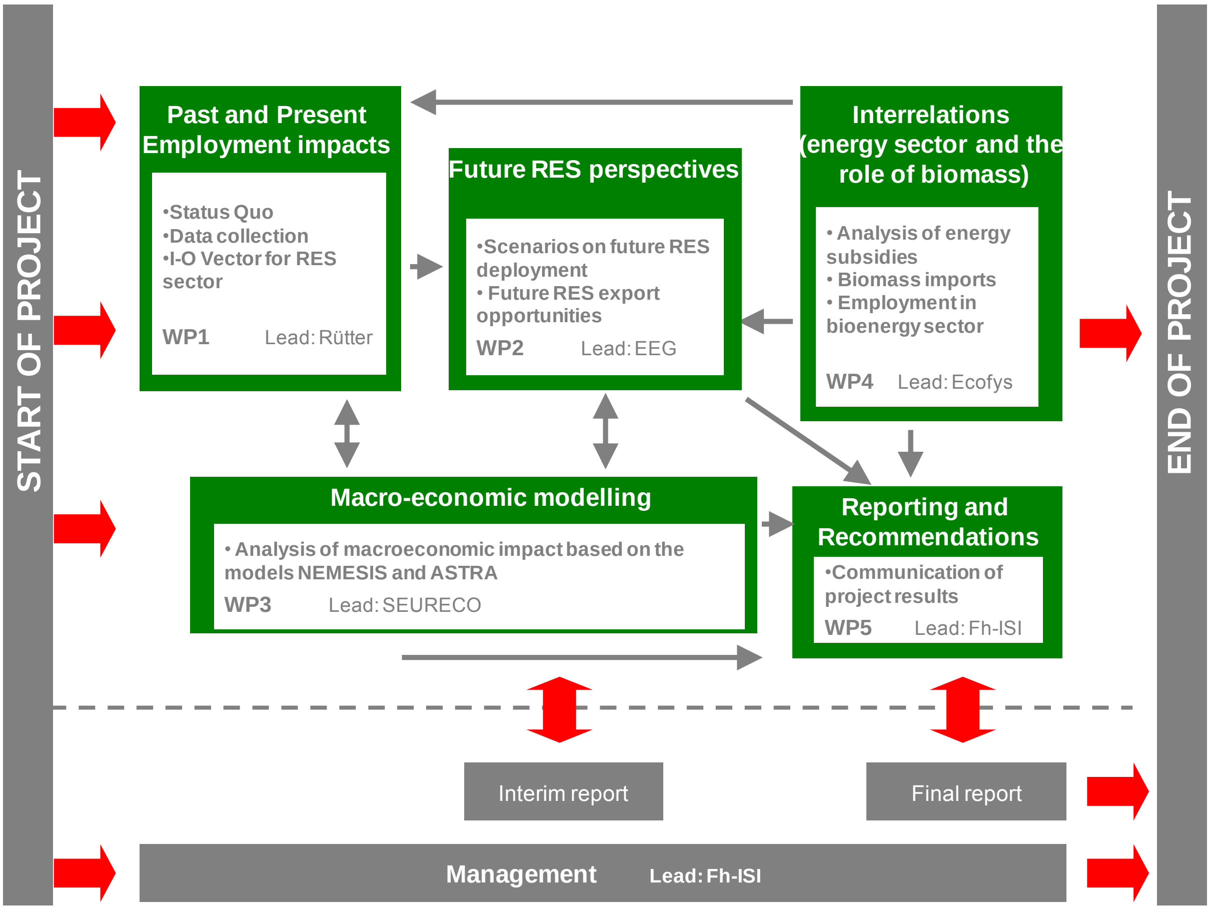

Figure 0-1 Project overview

Work package 1: Assessment of past and present economics and employment impacts of renewables

The core objective of this working task is the assessment of past and present gross economic and employment impacts of renewable energy deployment in the EU. For the assessment of these impacts the refinement and update of existing data on RES penetration and costs in an important step.

In more detail, the following progress was achieved during this first working period:

- Adaptation of the database on RES generation and capacities

  The existing database on RES capacities and generation was updated to the latest EUROSTAT figures accompanied by data of sector organizations and other data providers

- Adaptation of the database on RES cost

  The existing database on RES costs (investment and operation and maintenance) was updated to the year 2010.

- MULTIREG

  - The algorithm described in chapter 2.1 for processing the capacity and cost data to estimate the economic activity in the various countries and economic sectors has been implemented in MULTIREG.
  - The model MULTIREG is being adapted to the needs of this project. All EU 27 countries except Cyprus are represented with data from the WIOD database and national IO tables or IO tables supplied by Eurostat. Data for Cyprus are being estimated. Employment data for MULTIREG are being updated.
  - The necessary data on RES capacities and specific installation, O&M and fuel costs have been collected. Data on cost structures for all technologies are available. Cost structures from different sources are currently being harmonised.
  - Data on supplier market shares are being collected for wind energy, photovoltaics, solar thermal energy and hydro power until 2010. The quality of data regarding the historical development differs among technologies and currently is being improved through expert interviews.

Work package 2: Perspectives on future RES opportunities

The core objective of this work package is to provide a detailed depiction on future RES opportunities up to 2050 from a techno-economic viewpoint, considering deployment of RES technologies in the European Union as well as possibilities for export to abroad. Future perspectives of RES will be elaborated by means of scenarios, including a business-as-usual forecast as well as selected distinct alternative RES policy tracks. The model-based assessment of the energy sector focuses on RES technologies but also includes impacts on overall energy supply.

Work in this WP concentrates on a detailed determination of key scenario parameters, a model and database adaptation according to the specific requirements, the conducting of scenarios, accompanied by an in-depth analysis as well as the assessment of export opportunities. Two distinct tasks are defined:

- Task 2.1 (Scenarios on long-term RES deployment up to 2050 in Europe) has a geographical focus on Europe and comprises in-depth modelling activities.
- Task 2.2 complements the model-based assessment with the analysis of export opportunities to abroad.

At this interim stage the following progress was achieved with respect to task 2.1:

- Software adaptation and database preparation is close to completion: The geographical coverage of the Green-X model and its database was extended in order to include the new Member State Croatia in full detail (i.e. the previous version included only data for RES electricity, and with a limited time-scope (2020 instead of 2050)). At this point-of-time pending is to incorporate long-term perspectives related to biomass supply and in particular feasible biomass imports to the EU – this will be done once the corresponding outcomes of WP4 are applicable.
- Scenario formulation is completed: In close collaboration with the European Commission, DG ENER the conceptual definition of to be assessed scenarios of future RES deployment within the EU has been finalised. While the framework up to 2020 is well defined, exploring the RES development beyond 2020 means to enter a terrain characterized by a higher level of uncertainty – both with respect to the policy pathway as well as with regard to potentials and cost for applicable RES technology options. In order to reflect this uncertainty well, in total 6 key policy pathways will be analysed for the EU, ranging from no dedicated RES support beyond 2020, to a business-as-usual case (in line with PRIMES reference) up to four distinct RES policy cases where dedicated support either follows a similar approach as set by the energy and climate package for 2020 or where a harmonised scheme would be used for RES in the electricity sector. Moreover, policy cases vary with respect to the ambition level related to future RES deployment – i.e. either a RES share of 30% by 2030 or a higher deployment (35% RES by 2030) shall be achieved.
- Conceptual elaboration of advanced cost indicators for the electricity sector has progressed well. Thus, advanced indicators for assessing impacts of an enhanced RES deployment on overall energy-related costs & expenditures (from both the supplier and

the consumer perspective) have been defined, and a critical reflection first within the consortium, and later with the client will be undertaken. These indicators well reflect (lower) market values of variable RES, a further aim is to assess the merit-order effect in the wholesale electricity market in a concise manner – as far as feasible under the timely and budgetary constraints of this project.

- The scenario calculation is pending: Since important input parameter for the RES-related modelling work is pending (i.e. data on energy demand and prices will be provided by forthcoming PRIMES scenarios from the impact assessment of Europe's 2030 strategy) the Green-X scenario calculations on RES deployment within Europe according to selected RES policy pathways could not be launched as originally envisaged.

With respect to task 2.2, the assessment of opportunities for RES technology exports to global markets, the following progress has been achieved: Preparatory tasks were undertaken and key input sources (e.g. IEA's WEO2012) assessed. Within the forthcoming period the quantitative work will be based on European scenarios of future RES deployment as to be elaborated within task 2.1.

Work package 3: Macro-economic modeling

The objective of this work package "macro-economic modelling" is the assessment of employment and economic impacts of the future deployment of renewable energies in Europe, using two macro-economic models (ASTRA-EC and NEMESIS).

WP3 is a downstream task of the technology-based scenarios of Green-X. So, at this stage of the project, the process achieved remains modest, only preparatory tasks have been conducted.

- The ASTRA and NEMESIS teams have participated in the modelling workshop on the 30th of September, in Karlsruhe. During this workshop, important advances have been made in the preparation of the variable exchange between models and tools. Each macro-modelling team has provided a template of the input required to run the assessment.
- As macro-economic models need an economic scenario and especially a reference scenario to assess the different options of renewable energy deployment, it has been decided to replicate, as close as possible, the DG ECFIN Ageing report 2012 economic

projections up to 2050.

- Each macro-modelling team is also preparing its tool to provide the expected results.
  - ISI is developing a data transfer tool in order to allow for the seamless exchange between the energy system model Green-X and the two macro-economic models
  - SEURECO is working on the integration of Croatia into the NEMESIS model (ASTRA-EC does not include Croatia). At this stage, the Croatia modelling will be lighter than for other EU-27 countries, insomuch as available detailed data are very weak, especially at the sectoral level.
- A set of lead market indicators has been updated for the formulation of RES-export scenarios.

Work package 4: Work package 4: Interrelations (energy subsidies and the role of biomass)

The objective of this work package is to provide the project with analyses on interrelations of renewable energy growth post-2020. No final results have been delivered yet, but the following progress was achieved during the first working period:

- Financial and administrative support for non-renewable forms of energy in the EU
  Ecofys will deliver a meta-analysis on subsidies to fossil fuels in the EU using existing studies. The main goal of this analysis is to support the interpretation of the modelling results of Task 2 and 3. The overview of existing data on fossil fuel subsidies directly feeds into the discussion on energy-related costs and expenditures. Results will be available by mid-December.
- Imports of biomass to the EU
  Ecofys provides an overview of biofuel imports to the EU based on existing literature and studies. The 2010 data on biofuel imports to the EU are used as starting point for assessing imports until 2050. We ensure that the biomass import data delivered will be supplied in format that is ready to use in the Green-X model. Results are expected by mid of November 2013.

Work package 5: Reporting & recommendations

The objective of this work focuses on reporting and the formulation of recommendations. The following progress was achieved during the first working period:

- Reporting
  This report shows the progress of the work during the first working period. It contains a more technical section (section 0). A description of the methodology as well as preliminary results are provided in sections A – D.
- Stakeholder workshop
  No further steps on the stakeholder workshop have been taken so far.

Project meetings:

In total, four 1-day meetings with the Commission are envisaged in this project. In addition, internal meetings take place as required.

- Kick-off meeting
  The kick-off meeting took place at 6 August 2013 in Brussels. Minutes of this meeting were distributed among all participants.
- Internal modelling workshop
  An internal modelling workshop took place at 30 September 2013 in Karlsruhe. Main purpose of this meeting was to define the model linkages and develop a specification for a transfer tool between the energy system model and the macro-economic models. Furthermore, proposals for possible scenarios and sensitivity analyses were developed and forwarded to the Commission.
- Progress meeting 1
  The first progress meeting is scheduled for 17 December 2013 in Brussels.

A Background, motivation and objectives of the study

Background

The Commission Communication "Renewable Energy: a major player in the European energy market"[1] clearly states the points of departure for a European energy policy: combating climate change, limiting the EU's external vulnerability to imported hydrocarbons, and promoting growth and jobs: *"Renewable energy enables us to diversify our energy supply. This increases our security of supply and improves European competitiveness creating new industries, jobs, economic growth and export opportunities, whilst also reducing our greenhouse gas emissions."*

The Energy Roadmap 2050[2] reaffirms the strong role of renewable energy sources on the way to a low carbon European energy sector by 2050. "*Regardless of scenario choice, the biggest share of energy supply in 2050 will come from renewable energy. Strong growth in renewables is the so-called 'no regrets' option. However, despite the strong framework to 2020, the Roadmap suggests that growth of renewable energy will drop after 2020 without further intervention due to their higher costs and barriers compared to fossil fuels. Early policy clarity on the post 2020 regime will generate real benefits for investors in industry and infrastructure as well as for renewable energy investors directly.*"

As financial support will still be required for some time due to remaining externalities, it is important to gain further understanding and awareness of the economic and employment benefits from renewables. This is of particular importance in a time where decisions need to be taken on the future role of renewable energy targets in the EU target system.

In order to support an objective discussion on the growth and employment effects of enhanced RES deployment a sound scientific basis is needed on the gross effects (direct and indirect) as well as on the net effects (including negative effects like conventional replacement and budget effects).

Furthermore the future development of RES in Europe will take place against the background of a global market for RES technology. These global markets and the potential share of the European industries in these markets play a critical role in the potential to create growth and employment.

This study aims to provide a sound scientific analysis of these issues.

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1 Communication from the Commission to the European Council and the European Parliament - "Renewable Energy: a major player in the European energy market" COM(2012) 271 final

2 COM(2011) 885/2

Objectives and results

This study aims to present a complete analysis of the employment and economic growth impacts of renewable energies, covering past, present and future prospects. More specifically, the project's objectives are:

- To study employment and economic effects of renewable energy deployment per renewable energy sector, per economic sector and per country.
- To support the development of a common understanding of the various gross and net employment and growth impacts of (an accelerated diffusion of) renewables.
- To use a modelling system with a sound scientific basis and to ensure a high level of transparency in order to promote confidence in the quality of analysis.
- To facilitate an open and transparent review process with all the relevant stakeholders. This process allows all the stakeholders involved to share their views, incorporates these views in the analysis and thus facilitates a high level of acceptance of the results.
- To facilitate an improved and common understanding of the balance between the costs and benefits of (an accelerated growth of) renewables.

The expected results of this project include:

- An analysis of the direct and indirect gross economic and employment impacts resulting from past and present RES developments for each of the 28 EU member countries and each of the RES technologies.
- A business-as-usual scenario, a no-policy scenario and four different policy scenarios on the deployment of and support policies for RES technologies in the EU-28 up to 2050, and various sensitivity analyses of scenario assumptions and boundary conditions.
- An in-depth analysis of the future gross and net economic and employment impacts in the EU-28 up to 2050 resulting from the scenarios described above based on a validated and transparent macroeconomic modelling approach.
- A stakeholder workshop towards the end of the project to present and discuss draft results. The workshop has a strong dissemination character.

B Project concept, modelling tools and structure of the report

The project involves intensive data analysis and economic modelling. The overall framework - in particular the links between various models - is described in this section. The inputs and results for each individual modelling step are presented in chapters 1 to 7.

The key rationale for the modelling approach is that it has to be tailored to the task in hand. In the past, there have been many studies of the economic effects of economy-wide measures, especially CO_2 taxation. In contrast to these studies, the effects of RES technologies are much more technology-specific. To achieve such a technology-specific analysis, the modelling approach must be based on a sound technological analysis and therefore follows a bottom-up approach: The cost and structural demand effects must be accounted for on a disaggregated level. Further, the additional export potential due to the technological competitiveness of EU countries must be accounted for rather than the economy-wide price changes. These requirements have important implications for the model choice: Economic models such as general equilibrium models, which are good at analysing changing relative prices on a macroeconomic level, are not suitable here. Instead, macroeconomic models are preferred as these can be easily linked to technological bottom-up models, and are able to model the changes in costs and demand.

Overview of the modelling system

The main idea is to combine diverse models to reflect the impacts on technologies and the economy as a whole. Therefore, a static input-output model that calculates the current value added of RES activities as well as employment effects is combined with a sector model that provides future investments and expenditures for RES according to selected RES policies. In the next step, the data are adjusted with respect to first mover advantages and then form the input to the macro models which calculate the economic effects. This sequence of models is roughly depicted in Figure 0-1. The detailed approach, the interfaces between models and the modelling steps are explained in the following subchapter.

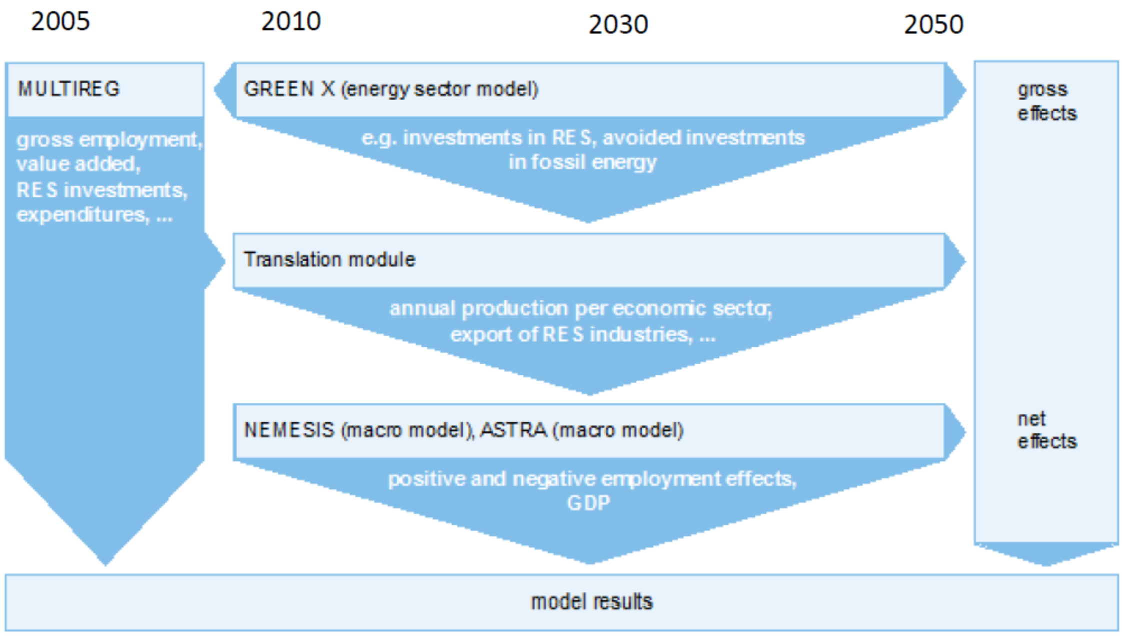

Figure 0-1 Modelling approach

The phases and interfaces in the project concept

To fully understand the method as well as the different models and their interdependence in this study, the project is illustrated in Figure 0-2 in detail. This should help guide readers through this report. The figure distinguishes between the models (green rectangles) and data sources (grey parallelogram) used for the project. It also shows inputs and outputs (turquoise rounded rectangles): These include outputs from different data sources which are used as inputs to the models, but also outputs from models used as input for another model.

The project is divided into four phases corresponding to the four dotted boxes in the figure below and the following chapters in this report. The four phases/chapters are titled according to the main results produced in each stage. The different steps in producing these results are briefly described below and the numbers in the corresponding dotted box help to follow these steps. Details of the four phases are given in the following paragraphs.

Phase 1: Past deployment and cost of RES

RES deployment (i.e. capacity and production) and cost data are extracted from the Green-X database that already comprehensively illustrates the historical deployment and the present situation of the individual RES technologies by country.

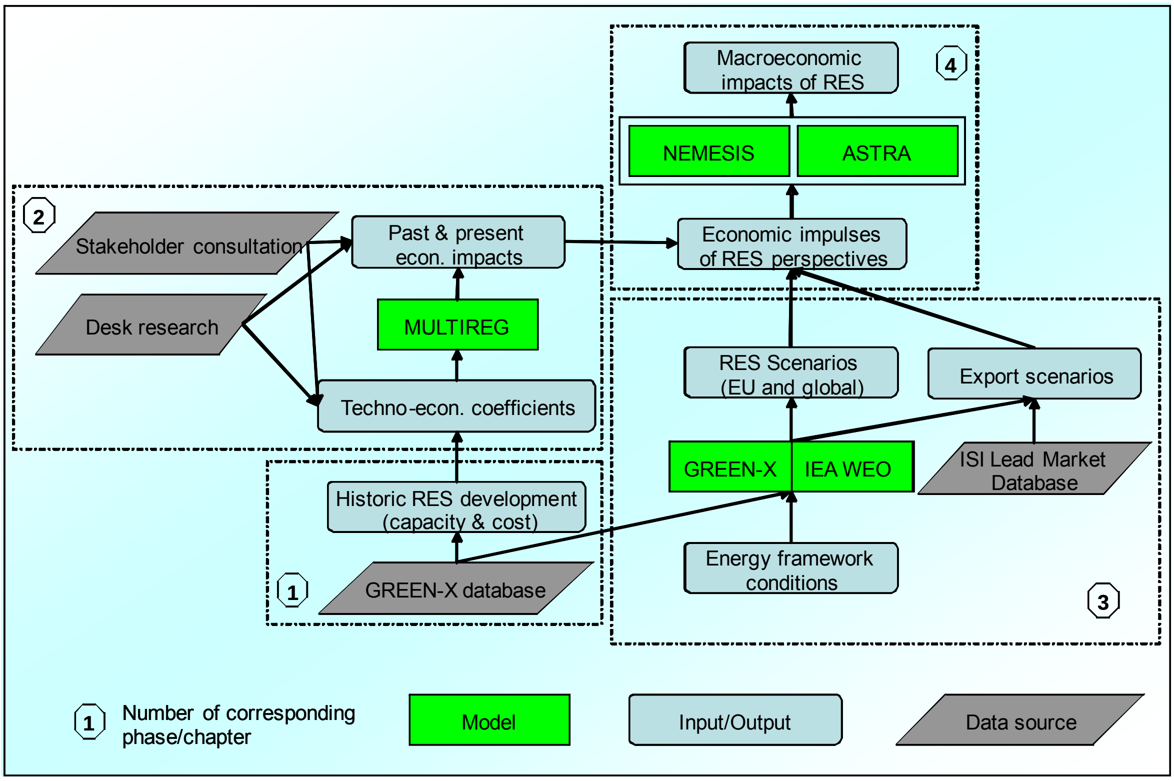

Figure 0-2 The overall modelling approach of the project

Phase 2: Past economic and employment impacts of RES deployment

In Phase 2, the gross economic and employment impacts of past and present RES deployment are calculated. They highlight the economic significance of the RES industry including the supplying industries. A modelling approach using the MULTIREG model is taken in this phase.

Techno-economic coefficients are needed as input for the MULTIREG model that transform the historical development of expenditures for a certain RES technology in a specific country into demand for products from different economic sectors. In order to be able to calculate these techno-economic coefficients, the past deployment and cost data from the Green-X database (Phase 1) are complemented by the following data obtained through desk research and expert interviews:

- cost structures of investment in the various RES technologies, their operation and maintenance and fuel supply,
- information on the regional supply patterns of cost components, especially the market shares of technology suppliers.

With the necessary adjustments, these data also serve to transform the impulses of RES deployment into data input for the macroeconomic models ASTRA and NEMESIS.

The MULTIREG model – a static multi-country, input-output model - is used to calculate the direct and indirect economic and employment impacts of historical RES deployment.

MULTIREG is harmonised with the macroeconomic models NEMESIS and ASTRA to ensure methodological comparability between the results of the historical and the future gross effects.

Phase 3: Future renewable energy deployment and export scenarios

Scenarios on future RES deployment are derived using the Green-X model, a simulation model for energy policy instruments that has been successfully applied in this context in projects such as FORRES 2020, OPTRES and PROGRESS. Important data input for Green-X are, besides the applied support schemes for RES, the general energy framework conditions such as future energy demand and energy prices. Assumptions on the general energy framework conditions are harmonised with Commission views of future energy development based on official DG ENER projections. Based on these general assumptions, six main scenarios will be calculated for the future development of renewable energy sources until 2050 in the EU-28. The results of this modelling step serve as a main input for phase 4 of this project.

To estimate the future export opportunities of European RES industries to the rest of the world, a reliable scenario for the global deployment of renewable energy sources has to be used. In this project, the alternative scenario of the World Energy Outlook of the IEA is used and comprehensively prepared for the purposes of this study. The share of this global market which will be actually supplied by European companies is estimated in a subsequent step: Various studies on the economic effects of new technologies and innovations have demonstrated the importance of accounting for the induced foreign demand for the technologies. In the economic literature, this effect is known as the first mover advantage or lead market effect, and is behind the rationale of the Lisbon goals and European efforts to increase technological competitiveness. In order to come up with sound and reliable assumptions about the magnitude of such a first mover advantage, the technological competitiveness of the EU countries with regard to RES policies, and the supporting role of regulation in setting incentives for future innovations are considered (Walz 2006)[3]. The project draws on the extensive database at Fraunhofer-ISI on "Indicators of

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3 R. Walz, Impacts of strategies to increase RES in Europe on employment and competitiveness, Energy and Environment, 17, 6 (2006).

Sustainability Innovations for Lead Markets" (ISI/LM), which covers indicators for 50 countries. It includes innovation indicators such as patent statistics or the revealed comparative advantage (RCA) for RES technologies. These data are combined with the evaluation of the innovation effects of RES support mechanisms in order to derive a methodologically sound estimation of future additional exports of RES technologies from the EU.

Phase 4: Future macroeconomic impacts of RES

The first part of phase 4 is critical for obtaining consistent input data for the macroeconomic models.

All the relevant economic mechanisms (as described in chapter C) must be accounted for in order to produce reliable results. This point is crucial, because many modelling approaches in the past only covered some of the economic mechanisms and therefore arrived at biased results. The following aspects are crucial for reliable results:

- The outputs of the Green-X model in terms of RES deployment and accompanying costs serve as input for the further macroeconomic analysis. These data are transformed to specify the additional cost and price effects for the economy, which have to be accounted for in the macroeconomic modelling.
- The output of the Green-X model with regard to energy input and output is used to specify the induced changes in demand associated with the operation of RES technologies. A crucial factor is that these demand changes are specified with regard to import shares. Thus, the results are demand vectors for nationally produced goods and imported goods.
- The output of the Green-X model in terms of RES investments and avoided investments in conventional energy supply serves as input for the specification of the demand impulse. The use of specific techno-economic coefficients (see phase 2) allows a sectoral disaggregation of these demand effects. Furthermore, the specific direct employment effects from phase 2 are used as the basis for a forecast of the specific direct employment effects of operating RES-technologies in the scenarios.

In the second part of phase 4, the full macroeconomic modelling of the future economic and employment impacts of RES is done using two well-established macroeconomic modelling tools NEMESIS and ASTRA. Both models are real-world models which account for a broad spectrum of economic impulses of energy policy measures. A crucial point is that both models are able to integrate the impulses from additional exports. Thus, they have enough similarities to be used in one modelling approach and both of them are based on the same data input from Green-X.

Using two models, NEMESIS and ASTRA, has the main advantage of providing more reliable results than can be obtained from one model alone. This is reflected in the model philosophy behind the two models: The econometric NEMESIS model attaches a higher weight to neo-Keynesian effects. The ASTRA model integrates neoclassical production functions with the effects of changing structural demand. It uses system dynamics and thus can also incorporate non-linear effects from evolutionary economics. Thus, the differences in results between the models can be used as a sensitivity analysis to show the effect of emphasizing different economic mechanisms.

In addition, the parallel use of two models also has technical advantages in modelling:

- Detailed cross-checking of results at different stages of the modelling exercise.
- Making use of a particular strength of representation of energy-related sectors: NEMESIS features a more detailed sectoral structure for the energy system, ASTRA a more detailed representation of the implications of RES-transportation technologies.
- Filling in gaps that exist in one model with results from the other model.
- Benefiting from past experience and the existing links between Green-X and ASTRA on the one hand and the link between NEMESIS and technological bottom-up data provided by ISI from previous EU projects on the other hand.

The structure of the report

This report is divided into four main parts, A, B, C and D. While the first three covers the introduction, the theoretical approach, the modelling steps and structure of the report, the fourth part, part D, discusses in detail the models and results of the project. It begins with chapter D 1 which describes past RE deployment and its costs. Then follows the past macroeconomic impacts presented by gross effects on employment and value added (D 2). Thereafter, the future potential (D 3) and future deployment (D 4) of renewable energy sources (RES) are discussed. Before the presentation of the future gross and net effects, the scenarios used in the macro-economic models (D 5) are explained in detail. Finally we depict the future gross and net impacts on employment and GDP in D 6 and D 7, respectively. The comparison between the results of the two models and our conclusion for the study follows in chapter D 8 and 9.

C Theoretical approach: The impact of the promotion of renewable energy on employment and economic growth – economic mechanisms and first mover advantage

In order to provide a theoretical basis for the study, this chapter seeks to discuss and answer two central but rather complex questions in a simple way:

- Through which economic mechanisms do RES support schemes trigger positive impacts on GDP and employment?
- What effects can be expected in countries which are the first movers or lead markets in RES?

The first question can draw on the discussion of the economic mechanisms triggered by climate policy measures (Walz/Schleich 2008), but has to account for some specifics of the RES technologies and support schemes. In general, RES support schemes set off diverse adjustment reactions among individual companies and private households which are then felt as structural effects on a sectoral and regional level. The sum of these adjustment reactions and their subsequent impacts then result in changed macroeconomic variables at the macroeconomic level. The various economic mechanisms describe which adjustment reactions and consequential effects are induced by climate policies. However, they are strongly influenced by the respective theoretical paradigm used. In line with the various schools of thought, we briefly describe these mechanisms in the following:

- Price and cost effects: impact of prices (energy costs) on industry and households.
- Structural demand effects: impact of demand on industry, household, trade.
- Multiplier and accelerator effects: impact of household and industry behaviour on other economic sectors.
- Innovation/productivity effects: impact of innovation or productivity on industry and households.

The second question refers to the discussion of lead markets: When do they emerge and what are the preconditions for their appearance? Lead markets are defined as regional markets with specific attributes that increase the probability that a locally preferred design becomes internationally successful, too (Beise and Cleff 2004). Export orientation, technological competitiveness, regulation and market context factors such as demand, prices, market structures etc. play an important role here. Hence, it is not price competition only, but quality competition that determines foreign trade successes. Especially trade with technology-intensive goods requires high innovation capability, learning effects and an early market presence. The factors that need to be taken into account when assessing the potential to become a lead market will be discussed in the last part of this chapter.

Figure 0-1illustrates the economic mechanisms and questions considered in this study in a simplified way. It shows the impact of RES supporting policies on households and firms as well as the first mover advantage caused by the direct or indirect promotion of RES technologies via policy measures. Households, firms and trade react to price, quality and quantity changes. When this reaction is amplified by multiplier, accelerator and innovation effects, this in turn leads to an overall effect on demand and prices in the economic sub-sectors investment, operation and maintenance and consumption across all economic sectors. The sum of all the positive economic effects is termed the gross effect. Adding up the negative and positive effects gives us the economic net effect. The various effects are discussed in detail in the subsequent paragraph.

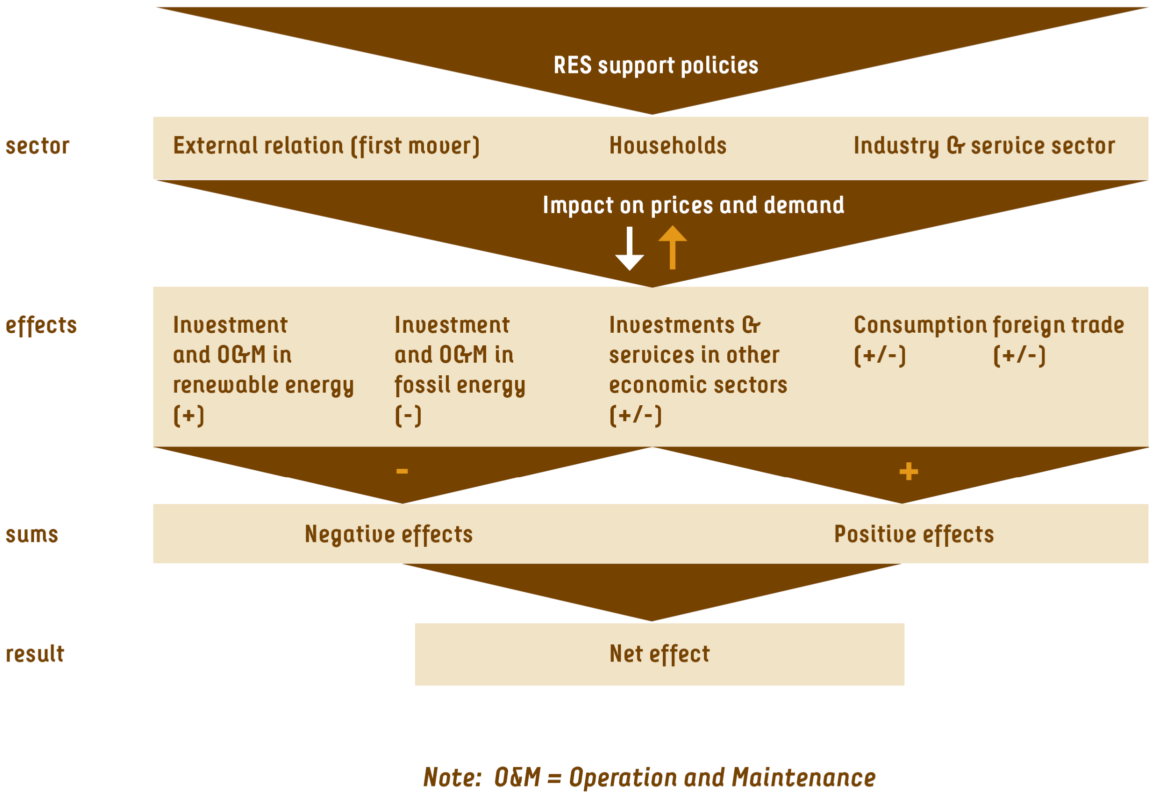

Figure 0-1 Simple illustration of the various economic mechanisms

Economic effects and adjustment mechanisms

The structural demand effect is depicted in Figure 0-2 as an example for the adjustment mechanisms and impulses. It shows the impulses deriving from the promotion of RES and illustrates where shifts in demand have various effects in the manufacturing and service sectors and at the household level (impulses via prices). Revenue and employment effects in this figure refer to a change in turnover or employment in the industry sector caused by structural demand effects in industrial and household sectors. Direct impulses occur in those industries which are directly involved in RES or fossil energy activities, while indirect impulses occur in industries which are only linked to RES and fossil energy activities through other industries. It is not really possible to illustrate the structural demand effect in isolation since the impulses sparked by prices, demand and innovation are interdependent and occur simultaneously.

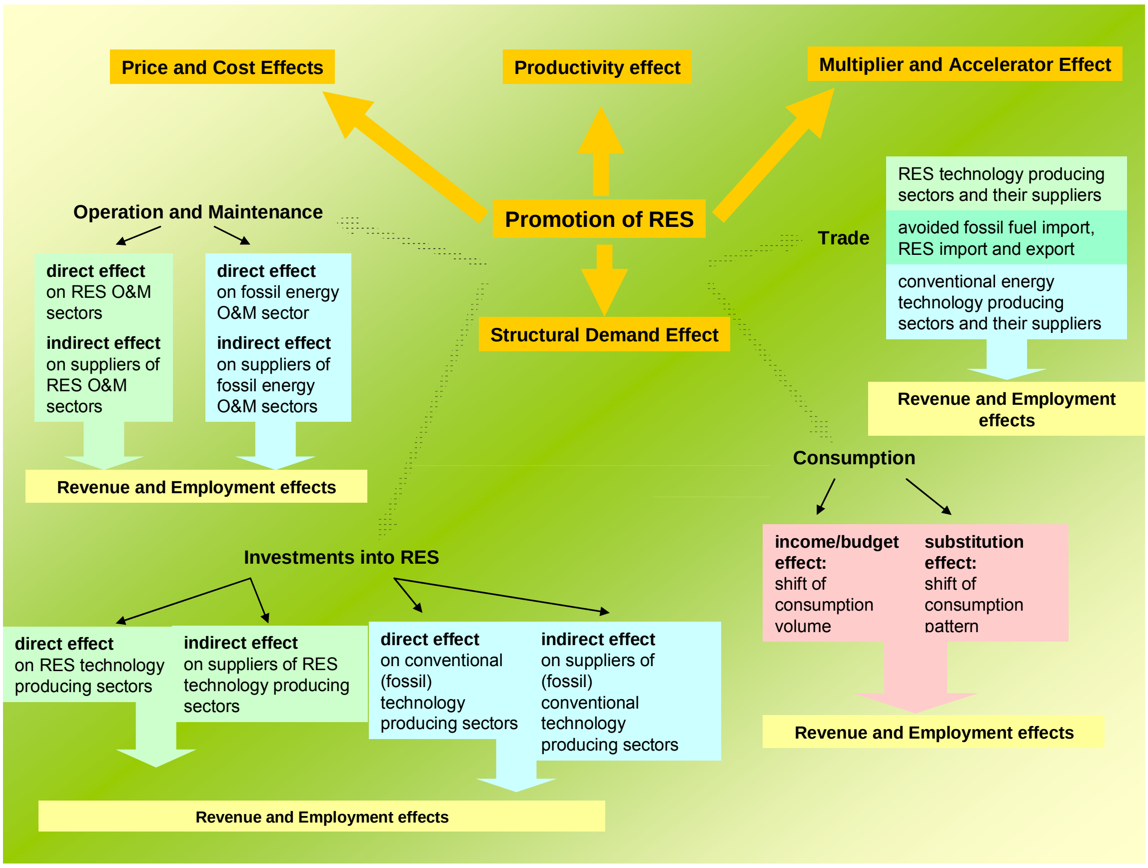

Figure 0-2 Economic effects and adjustment mechanisms

Table 0-1 Glossary

Direct effects	Effects which are directly related to RES generation and RES technologies and occur directly in the sector addressed by the policy promotion.
Indirect effects	Effects in up/downstream sectors that are not directly (but only indirectly) related to the promotion of RES and that might occur with a time delay.
Substitution effect	Money for consumption will be shifted from one good to another good, e.g. from travel to RES, due to the higher price of RES
Income/budget effect	With the same income (nominal) less/more goods can be consumed due to a (energy) price change
Revenue effect	Changes in demand for RES or other investment or consumption goods affect revenues in (all) economic sectors
Employment effect	Changes in demand for RES or other investment or consumption goods affect employment in (all) economic sectors
Gross employment	The sum of positive, direct and indirect employment effects derived from investments in RES without taking negative employment effects in other sectors into account.
Net employment	The sum of positive and negative direct and indirect employment effects, taking negative employment effects in other sectors into account.

Price and cost effects

Price and/or cost effects are often mentioned as an important mechanism in how RES policies influence the economy. The primary cost factors in the general economic discussion are the costs of labour (wages) and capital. With regard to RES, another cost factor is the higher cost of supplying RES compared to conventional forms of energy. This cost increase triggers various supply-side effects. It leads to a reduction of the output due to higher costs and furthermore, to substitutions in favour of other production factors. This in turn might result in a lower demand for the production factor labour. If the market mechanism on the labour market leads to lower real wages, a new equilibrium with full employment is reached. If this is not the case, unemployment will result. Furthermore, an increase in costs entails disadvantages in international competition, leading to further pressure to lower real wages.

It is also relevant who has to bear these macroeconomic effects. If the increased cost burden falls on energy-intensive industries that are subject to strong international competition, the effects might be greater because the negative effect is aggravated by the loss of international competitiveness. If, on the other hand, the cost burden cuts into the monopolistic profits of utilities (because they are either unsuccessfully regulated or not subject to competition), the detrimental effects will be weaker.

If the cost burden falls on private households, i.e. if they have to pay higher prices for energy, they will modify their consumption pattern if possible to reduce their consumption level and by substituting other goods for energy. Depending on the price sensitivity of households' demand for consumption goods (elasticity), this impact might be stronger or weaker.

If the cost burden is to be borne by the public budget, the government will have to reduce other expenditures (public budget effect), or alternatively, the government will raise tax revenues in other areas and thus reduce the available budget of consumers or producers (leading to private budget effects). This leads to a crowding out of other investments or consumer spending. To sum up, compensatory effects occur within the structural adjustment mechanism and in the case of higher costs (see section above), negative consumption effects have to be accounted for when analysing structural shifts of demand.

Thus, the macroeconomic effects depend on the support scheme and on the adjustment mechanisms in the economy which in turn depend on the relative supply and demand elasticities of the different economic agents.

In many studies of the economic effects of climate policies, the double dividend of CO_2 taxes has played a major role. However, this actually depends on the effects occurring because such a tax can replace other taxes which are associated with a higher excess burden. There has been an intensive debate about the double dividend effect centring on the magnitude of the so-called tax interaction and revenue recycling effect. However, RES support schemes in general are not associated with such a green tax reform. Thus, this specific effect does not play a role in this study.

Structural demand effects

In addition to changes in costs or prices, an increase in RES also leads to structural changes in the economy. Both positive and negative effects are to be found among the direct impulses of a RES policy. Implementing a RES policy requires additional investments to increase RES capacities and, in the case of biomass and biofuels, an increased demand for forest and agricultural products (direct positive impulses). At the same time, there is a drop in demand for both conventional energy carriers and conventional energy supply investments (direct negative impulses). In general, however, the costs for RES (which consist mainly of capital costs) are assumed to be higher than the capital and running costs for the conventional energy supply. Typically, a substantial share of the higher cost is transferred to the consumers. Thus, they have less income to spend on other consumption goods (private budget effect).

Since numerous inputs from other sectors are necessary to supply the respective demand, the direct positive and negative impulses are carried forward as positive and negative *indirect effects* according to the production linkages of the industries involved. Thus the different positive and negative impulses lead to a different structural composition of the overall economy.

The direct and indirect demand impulses are very much linked to technological changes and the RES support schemes. Therefore, they are described in more detail, distinguishing impulses in the area of investment, operation and maintenance, consumption of households, and trade.

In the study, the direct positive and negative impulses will be delivered by the analysis with the Green-X models. The macroeconomic models used will then be able to further account for the indirect effects of structural adjustments.

Structural investment impulses

Primarily, the promotion of RES affects all activities which are related to instalments of the RES generation facility. These include planning and financing, construction and manufacturing sectors. An increase in investments in RES power generation increases the demand in RES-related services and RES-technology producing sectors. Hence, an increased demand leads to an augmentation of the production in these sectors. We call these impulses on the RES-producing technology or service sectors direct positive investment impulses, since they are directly related to RES power generation and occur directly in the sector addressed by the policy. However, there are also policy impacts in sectors not directly, i.e. indirectly, related to RES power generation. The sectors that are indirectly affected by the policy are the suppliers of RES-technology producers or service providers like the steel producing sector, transportation sector, IT-service providers, etc. The increased production at suppliers of RES-technology producers induces higher revenues and employment in these indirectly affected sectors.

Besides the suppliers of the RES technology producing sector, we also have to take into account the effect of RES promotion on the fossil energy generation sector. Conventional investments in this sector will decrease since the generation of fossil energy will be replaced by RES. Hence, revenues and employment will decrease at conventional (fossil) energy technology producers and service providers as well as at the suppliers of technology producers. We consider this a direct negative investment impulse. Furthermore, this will also induce indirect negative investment impulses.

In addition, when modelling an energy system with a high share of RES power generation as assumed for the year 2050, it needs to be taken into account that the requirements for the power grid. Partly decentralized generation and large amounts of power from suitable regions such as off-shore wind energy from the coasts change the regional distribution of power generation, while the fluctuating nature of many RES technologies generates demand for storage capacities. These system integration costs are taken into consideration and put in relation to the investment costs for RES technologies. Investment impulses will only be accounted for in the modelling if they are found to be of reasonable scale.

In summary, we can state that sector revenues and employment and hence income will:

- increase among RES-technology producers and service providers (direct positive impulse)
- increase among suppliers of RES-technology producers and service providers (indirect positive impulse)
- decrease among fossil energy technology producers, service providers (direct negative impulse) and
- decrease among suppliers of fossil energy technology producers (indirect negative impulse) and
- System integration costs of RES technologies if found not to be negligible.

Structural operation and maintenance impulses

After the instalment of the generation plant, the investment activities are completed and the radiated effects from investment will fade. But a certain number of employees are necessary for operation and maintenance of the RES generation facility. This results in higher revenues in this realm and subsequently in higher incomes. Hence, RES-related maintenance and operation activities reflect a direct positive impulse. Furthermore, there are indirect effects as well. The RES maintenance and operation sector causes demand for products and services in forward- and backward-linked sectors which in turn increases production and employment in these sectors. These we call indirect positive RES maintenance and operation impulses. Analogous to investment effects, there are negative direct and indirect impulses because the maintenance and operation sector of energy generation from fossil sources as well as in its forward-linked sectors will gradually be reduced. Overall, it is clear that sector revenues and employment and hence income will:

- increase among providers of RES maintenance and operation (direct positive impulse)
- increase among forward/backward-linked sectors of RES maintenance and operation providers (indirect positive impulse)
- decrease among maintenance and operation providers of fossil energy generation facilities (direct negative impulse)
- decrease among forward/backward-linked sectors of fossil energy facility maintenance and operation providers (indirect negative impulse).

Structural consumption impulses at the household level

Further, we consider the sector which benefits from the additionally generated revenues in the various economic sectors and which has to bear the higher energy prices: the household sector. The use of RES causes additional costs which are passed onto the households through higher prices for energy. Higher prices for RES reduce the real income of households. So, for the same (nominal) income, fewer goods can be consumed, real income has declined. We call this effect of prices changes a budget impulse, since it affects the available household budget for consumption. Therefore, a relatively larger part of household income will be spent on RES and is not available for other goods. So households have fewer funds for the consumption of other goods and use relatively more for RES consumption. Thus, the budget impulse triggers a substitution effect where money for consumption will be allocated (shifted) from other goods to the consumption of renewable energy as its price increases. All in all, through the budget impulse, the demand for other goods will decrease. Recapitulating, higher prices for RE reduces the consumption of households, their available (real) income declines (budget effect) and consumption is shifted from other goods to RE. However, if the additional investment, maintenance and operation for RES induce more employment, the households will have more money available for consumption (total income of household increases). This might compensate the negative price effect and increase consumption.

The argument so far has demonstrated the importance of the positive and negative demand impulses. It has been shown that it is the effect on the supply chain which influences the demand effects. These include the effects due to interlinkages between the production sectors.

Structural trade impulses

Trade of energy from fossil sources will decrease as generation from RES increases. Since fossil energy is mainly imported, imports will be avoided. Besides that, imports or exports of technology products and related intermediate inputs may increase (see chapter C). For energy-importing countries or regions, it is significant that a considerable share of the negative demand effects - namely the reduction in demand for imported energy - takes effect not domestically, but in the energy-producing countries. If a higher share of the RES investments or RES-typical inputs is produced domestically, a net increase in domestic production results. If, in contrast, a considerable share of the energy substituted by RES is produced domestically, and a considerable share of the RES investments has to be imported, then the result is a reduction in aggregated domestic demand. A comparison of the labour intensities[4] and the import shares[5] of the value chains of RES products provides a first impression of the probable structural effects on growth and employment. Briefly summarized, there are similar effects as for investments and O&M:

- increase in trade of RES (direct impulse)
- increase in exports of RES technology (direct positive impulse, first mover advantage) or increase in imports of RES technology (direct negative impact)
- increase in trade of backward/forward-linked products (indirect impulse)
- decrease of trade in fossil energy, fossil energy technology, and backward/forward-linked products (direct and indirect impulses).

Figure 0-3 gives a first impression of the order of magnitude of import shares of the value chain for impulses from different sectors and three EU countries. The mineral oil product chain has by far the highest share, while the total accumulated import of the value chain of electricity production is rather low. This reflects, among others, the important role of very capital-intensive nuclear power in France and Germany and the importance of German coal in electricity production. The import shares of the average consumption value chain are also quite low. The value chains of the sectors most likely to benefit from RES strategies, e.g. investments in equipment or the agricultural and forestry sector, tend to have import shares which are in-between the value chains of the sectors they will substitute (electricity and fuels). Given these results, a substitution of conventional electricity production and oil products by renewable energy has no clear effect with regard to import substitution and depends on the specifics of the RES strategy which influences the composition of technologies. Furthermore, this effect has to be accounted for in all of the EU member states.

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4 shows how many persons are employed per Euro of total domestic production induced by the direct impulse

5 shows which percentage of total production induced by the direct impulse is imported.

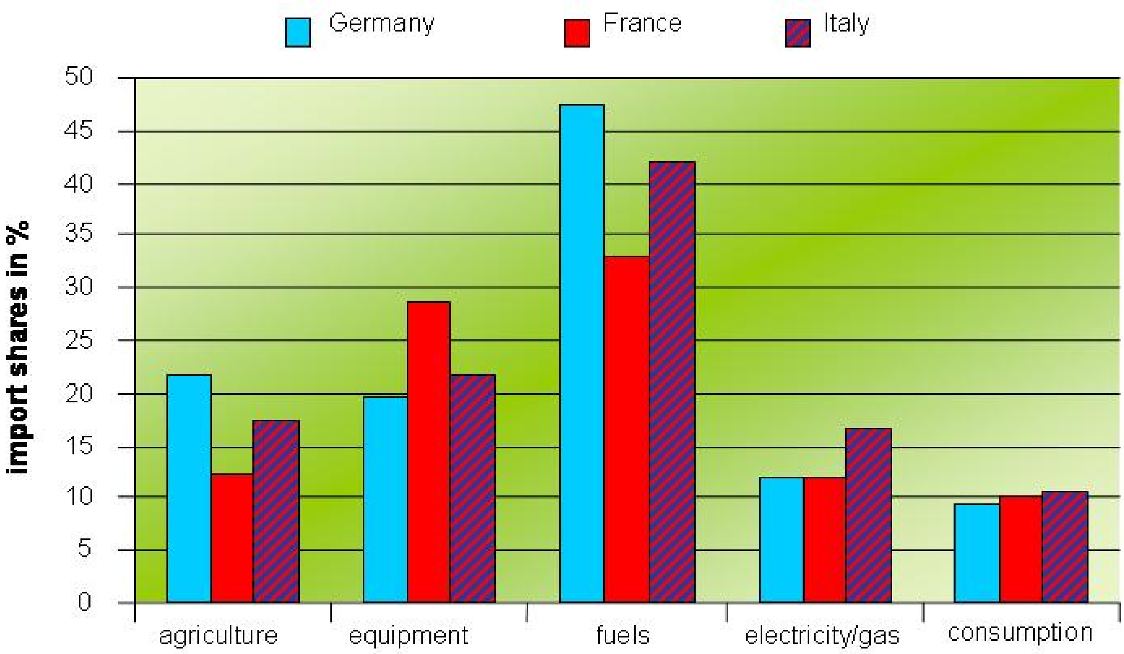

Figure 0-3 Import shares of the complete value chain of various goods

In addition to all the discussed structural demand effects, the labour intensity of the respective sectors plays a crucial role when assessing the potential impact on employment. An increase in employment occurs if the value chains of the sectors favoured by the RES policy have higher labour intensities than the value chains of the sectors favoured by the conventional energy supply. Typically, high labour intensities can be observed in the agricultural and forestry sectors (see Figure 0-4). These result in an above average labour intensity of the associated value chains. The value chain of fuels production has low labour intensity, followed by the value chain of conventional electricity production. The labour intensity of the investment sectors as well as of the agricultural sector is higher than the labour intensity of fuels and electricity production. Thus, it can be assumed that the substitution of the conventional energy supply by RES generally leads to an increase in labour intensity. However, if the additional cost of the renewable energy is very high, the value chain of consumption goods becomes increasingly important, because an ever larger share of consumption has to be sacrificed to cover the additional costs. The labour intensity of the value chain of consumption is greater than that for equipment. Thus, the higher the cost difference of renewable energies to conventional energy supply, the less prominent is the effect of structural change towards labour-intensive sectors because the reduction in consumption has a counterproductive impact on total employment.

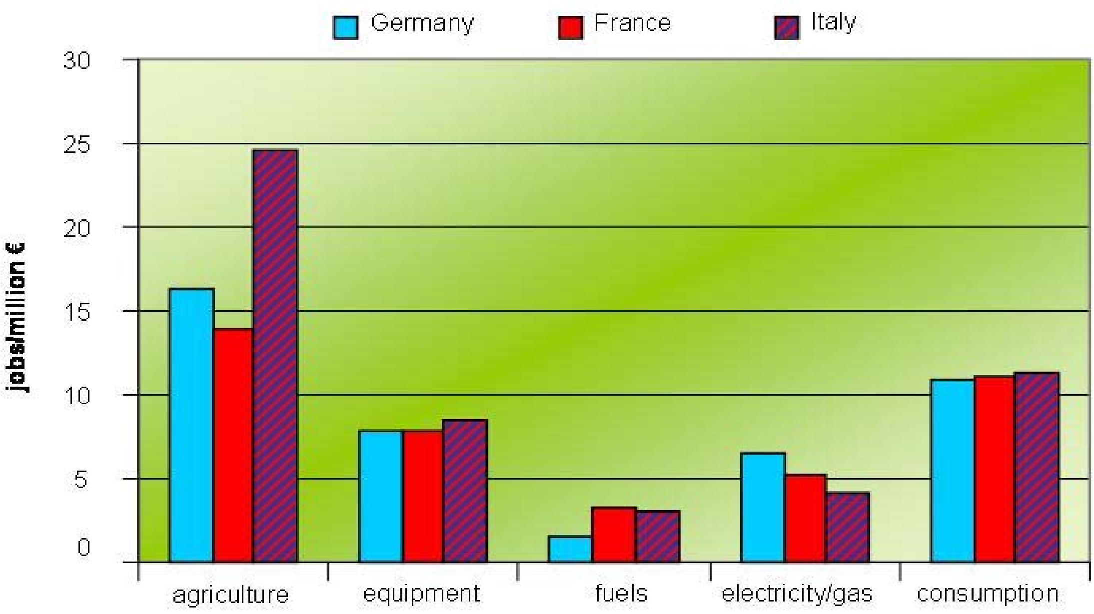

Figure 0-4 Labour intensity of the complete value chain of various goods

Income multipliers and accelerator effects

Demand-side effects are the cornerstone of the Keynesian model, which sees unemployment as caused by a deficit in aggregate demand. Assuming that the conditions for Keynesian unemployment are met, positive growth and employment effects are to be expected if RES policies result in an impulse which increases the effective demand for goods. Two effects have to be considered here:

- Income multiplier effects account for the spending of income generated by the production of the impulse.
- Accelerator effects account for the additional investments needed to provide the production capacity required for the additional goods.

The combination of these two effects can lead to a self-supporting increase in business activities triggered by such an impulse.

Especially the effects of shifts in income are interesting to look at. Households benefit from increased activities in RES but also suffer from decreased activities in fossil energy sources. An income reduction induces consumption cutbacks and, subsequently, the households' demand for all consumption goods declines, leading to a decrease in production in industry which in turn reduces revenues in the affected sectors. An increase in income has the opposite effect: Higher income induces a higher demand for consumption goods which translates into higher production and hence leads to higher revenues in the respective sectors resulting in high employment and hence income for households. This inducement of higher revenues in all sectors through increased investment activities in one sector is called a multiplier effect. An initial rise in spending can lead to an even greater increase in (national) income.

The accelerator effect refers to a similar mechanism but at the industry level. There, higher demand and hence rising revenues cause demand for investments in backward-linked industries. This increased demand in backward-linked industries in turn leads to higher production and revenues resulting in rising needs to invest, which leads to a growing demand of this industry for its own backward-linked industries and so on.

Income multiplier and accelerator effects depend on the economic conditions and the assumed reactions of the actors at the centre of the debate on Keynesian economics. An important assumption is that the demand from RES policies does not crowd out other segments of aggregate demand. Thus, some limitations have to be taken into account when considering this argument. The effect of Keynesian demand policy in the overlapping area of rational expectations and the internationalisation of goods and financial markets is substantially more complex than the mechanistic description above may suggest. Thus, the chances of success of a Keynesian demand policy have to be assessed within the context of empirically validated models.

In this study, empirically validated macroeconomic models are used which are capable of accounting for these effects based on the data input from the bottom-up analysis.

Productive effects of investments

Technical change in many cases is linked to previous investments. New systems incorporate technical change and bring about a modernisation of the capital stock. The production possibilities of a national economy increase over time due to the growth and renewal of the capital stock. It has to be asked which impacts the *diffusion of RES technologies* has on this process. Here it is decisive whether the RES technologies themselves show a productive effect in the sense of increasing the material goods output potential. Under the assumption of a constant total investment volume, the following two cases are conceivable:

- In the first case, it is assumed that RES technologies do not show any productive impact. Since the RES investments do not have any productive impacts themselves, under the assumption of a constant investment volume, the productive investments of companies are then crowded out. Thus, the increase in productivity is lower compared to the development in which all investments are used for productive technologies. To sum up, in case 1, the macroeconomic productivity increase would be diminished by such a "technological crowding out".

- In the second case, it is assumed that RES technologies also have a productive character. They thus simultaneously increase - in contrast to the first argument - the production possibilities of material goods. The crowding out of investments with productive effects derived under the ceteris paribus condition of a constant investment volume is then alleviated, or, in an extreme case, does not occur at all if climate protection investments result in the same increase in productivity as new productive investments.

The assumption of a constant investment volume can be abandoned if it is assumed that there is an increase in the investment volume, financed either by shifting demand from consumption to investments, or by an increased GDP. Under this assumption, this would be tantamount to a "technological crowding in" and an increased modernisation of the national economy would follow in its wake.

The effects of technical change induced by the RES support schemes depend very strongly on which of the two hypotheses with regard to the productive impact of climate protection technologies is given greater weight. The hypothesis of a non-productive effect of investments in environmental protection is probably valid for end-of-pipe solutions, which are added on to the production systems and tended to dominate environmental protection in the 1970s and 80s. On the other hand, it seems plausible that those investments which directly affect production, and which have become more important recently, have greater productivity-increasing effects than end-of-pipe systems. First empirical results indicate that climate protection investments do indeed have a productive effect as well (Walz 1999). However, it is also clear that the magnitude of this effect depends on the technology, and that, in general, a substantial increase in productivity is induced only by some of the climate protection investments.

First mover advantages

Besides price competitiveness, which is influenced by cost effects, foreign trade successes are also determined by quality competitiveness. Above all for technology-intensive goods, which include renewable energy technologies, high market shares depend on innovation ability and the achieved learning effects of a national economy and its early market presence. If there is a forced national strategy to increase the share of renewable energy, these countries tend to specialise early in the supply of the necessary technologies. If there is a subsequent expansion in the international demand for these technologies, these countries are then in a good position to dominate international competition due to their early specialisation in this field.

Being able to realise these kinds of first mover advantages requires other countries to follow suit. Given the growing demand for energy on the one hand, and the pressure to push for non-fossil fuels on the other, there is a high probability of this taking place. For first mover advantages to be realised, however, the domestic suppliers of climate protection goods have to be competitive internationally so that they and not foreign suppliers are able to meet the demand induced by the domestic pioneering role and so that they can actually profit from the demand in countries then following suit [29, 28]. Taking the globalisation of markets into account, this requires establishing competence clusters which are difficult to transfer to other countries with lower production costs. These competence clusters must consist of high technological capabilities linked to a demand which is open to new innovations and horizontally and vertically integrated production structures. The following factors have to be taken into account when assessing the potential of countries to become a lead market in a specific technology:

- Lead market capability: It is not possible for every good or technology to establish a lead market position. One prerequisite is that competition is driven not by cost differentials alone, but also by quality aspects. This is especially valid for knowledge-intensive goods. In general, the technology intensity of renewable technologies can be judged as being above average or even (e.g. photovoltaics) high tech. Other important factors are intensive user-producer relationships and a high level of implicit knowledge. These factors are not easily accessible, difficult to transfer to other countries and benefit from local clustering. Two other important characteristics are high innovation dynamics and high potential learning effects. They are the key to a country forging ahead technologically also being able to realize solutions which are cost competitive. Previous results demonstrate that, by and large, these two prerequisites are fulfilled for renewable energy technologies.
- Competitiveness of industry clusters: Learning effects are more easily realized if the flow of (tacit) knowledge is facilitated by proximity and a common knowledge of language and institutions. Empirical results found strong evidence that the international competitiveness of sectors and technologies is greatly influenced by the competitive-

ness of interlinked sectors. By and large, renewable technologies have very close links to electronics and machinery. Thus, it can be argued that countries with strong production clusters in these two fields have a particularly good starting point for developing a first mover advantage in renewable energy technologies.

- The importance of the demand side can be traced back in the literature to the 1960s. There are various market factors which influence the chances of a country developing a lead market position (Beise and Cleff 2004). In general, a demand which is oriented towards innovations and readily supports new technological solutions benefits a country in developing a lead market position. Another factor is a market structure which facilitates competition. The price advantage of countries is very important which benefits those countries able to increase their demand fastest and thus most able to realize economies of scale and learning. If one looks at the diffusion rate of the various forms of renewable energy in different countries, it can be seen that European countries have been forging ahead recently. Furthermore, the political goals of the EU will bolster this advantage in future. Nevertheless, there are also other countries which have recently increased their diffusion rates. If large markets, such as the U.S., China, India or Brazil, increase their use of renewables, this will cause a huge rise in absolute numbers which might strengthen their price advantage.
- In addition to technological and market conditions, a lead market situation must also be supported by innovation-friendly regulation. This is especially true for sustainability innovations in infrastructure fields such as energy, water or transportation. In these fields, the innovation friendliness of the general regulatory regime, e.g. with regard to IPR or the supply of venture capital, must be accompanied by innovation-friendly sectoral and environmental regulation resulting in a triple regulatory challenge. Accounting for this factor is not easy. One promising approach is a heterodox one which uses the sectoral systems of innovation approach as guiding heuristics and combines this with the outcome of regulatory and environmental economics and the policy analysis approach of political science (Walz et al. 2008). The first empirical case studies for renewable energies show that a feed-in-tariff system might serve the functions of an innovation system well, especially if it supports a variety of technological solutions. Other paradigms contribute to this approach, e.g. transaction and evolutionary economics, which emphasise that the decisions, e.g. with regard to financing renewable energy technologies, follow a different paradigm (e.g. other valuation of financial risks, bounded rationality with regard to alternative suppliers of electricity). Furthermore, the policy analysis approach of political scientists emphasises the long-term character of political goals for renewable energy within the EU, or the comparatively important role of green policies for voters, which are key supportive context factors favouring innovations.

Since the Leontief Paradox and subsequent theories such as the Technology Gap Theory or the Product Cycle Theory, it has become increasingly accepted that international trade performance depends on technological capabilities. This has also been supported by recent empirical research which underlines the importance of technological capabilities for trade patterns and success. Thus, the ability of a country to develop a first mover advantage also depends on its comparative technological capability. If one country has performed better in the past with regard to international trade than others, it has obtained key advantages on which it can build future success. Thus, trade indicators such as shares of world trade, the Relative Export Shares (RXA) or the Revealed Comparative Advantage (RCA) are widely used to compare the technological capability of countries. Furthermore, a country has an additional advantage in developing future technologies if it has a comparatively high knowledge base. Thus, patent indicators such as the share of patents or the Relative Patent Advantage (RPA) are among the most widely used indicators to measure technological advantages.

D Detailed approach and results

1 Past deployment and cost of RES

The core objective of this working task is to provide a detailed depiction of RES development in the period 1995 to 2011, considering generation, installed capacities and costs of RES technologies in the European Union.

1.1 Approach, assumptions and input

Data and facts expressing the progress achieved in the different Member States include the amount of energy produced (electricity production, heat production, transport fuels) by RES as well as the installed capacity in the different sectors. The data on RES penetration, which are used in this project, strongly build on databases developed in earlier projects such as Green-X, TRIAS, FORRES 2020, OPTRES and PROGRESS. Therefore, the additional effort concentrated on the update of existing data as well as the adaptation of data to the specific needs of this project. This comprises in particular the data on installed capacities and past investment and operation costs of RES plants. The data have been derived on the level of the EU-27 and the following categories:

- **RES-Electricity (E) capacity and production data**: hydropower (large (>10 MW) and small (<10 MW)), photovoltaics, solar thermal electricity, wind energy (onshore, offshore), biogas (including landfill gas, sewage gas and gas from animal slurries), solid biomass, biodegradable fraction of municipal waste, geothermal electricity, tidal and wave electricity
- **RES-Heat (H) capacity and production data**: grid and non-grid connected biomass (including wood, agricultural products and residues), renewable municipal solid waste, biogas, solar thermal (grid and non-grid), geothermal (grid and non-grid - incl. ground coupled heat pumps),
- **RES-Transport (T)**: biodiesel, bioethanol, advanced biofuels (e.g. BTL)

1.2 Result: Past deployment and cost of RES

This chapter provides an overview of the development of renewable energy sources in the EU since 1997 in the sectors electricity, heat and transport fuels. Aggregated data for RES-E, RES-H and Biofuels in the figures are provided up to 2011 as this is the most recent year for which data for all countries and technologies were available at time of writing of this document. Generally, the figures will be given in terms of generation. Additionally the development of generation capacity is shown exemplarily for the case of wind onshore. This section only serves to give the overall picture of the development of RES at European level. In the frame of this project all data are supplied on the Member State level for each of the technologies listed above.

Renewable electricity

Renewable energy sources play an increasingly important role in European energy supply. Electricity generation from renewable sources (RES-E) grew by ca. 30% from 371 TWh in 1997 to 664 TWh in 2011 in the EU-27. An overview of the historical development of electricity generation from renewable energy sources from 1990 to 2011 is presented in Figure 1-1. Hydropower is the dominant renewable energy source, representing about 90% of all RES-E generation in 1997, but its dominance has been slowly decreasing over the past years due in part to below average rainfall in some years, but also to continuous increases in deployment of other 'new' renewable energy sources such as wind and biomass. In 2011, hydropower represented only 46% of RES-E generation in the EU-27 also due to low precipitation.

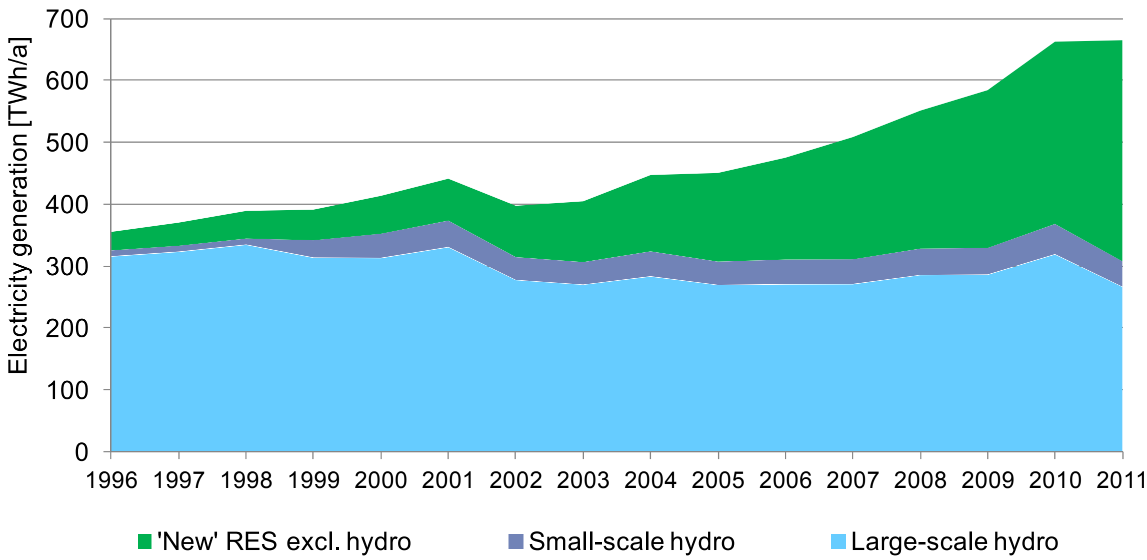

Figure 1-1 Historical development of electricity generation from RES-E in the European Union (EU-27) from 1996 to 2011

In order to avoid the influence of variable rain conditions on the picture, Figure 1-2 presents the development of electricity generation over the time period from all renewable sources except hydropower. A strong growth of several renewable energy sources over the last decade can be observed.

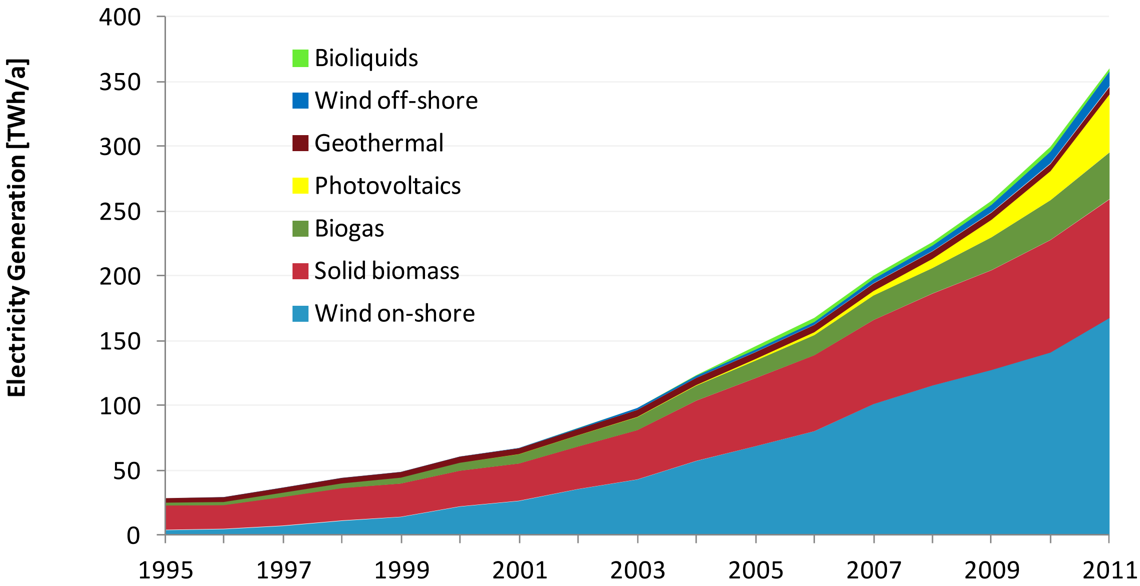

Figure 1-2 Historical development of electricity generation from RES-E without hydro power in the European Union (EU-27) from 1995 to 2011

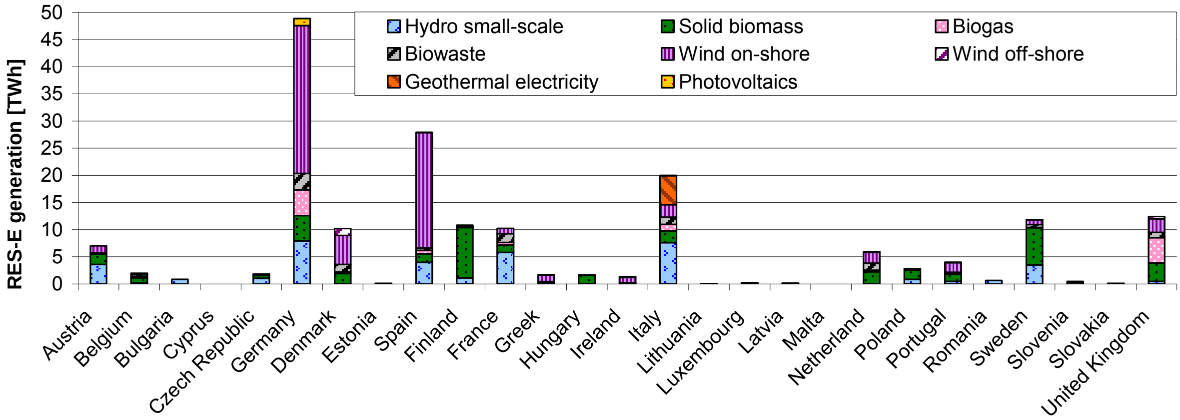

Figure 1-3 Breakdown of electricity generation from 'new' RES-E for 2006 by country

Electricity production from onshore wind equalled 168 TWh in 2011 compared to 7 TWh in 1997, which implies a spectacular average annual growth rate of more than 25% throughout this period. Offshore wind, though still relatively small in absolute terms, is starting to take off in several countries and is expected to grow rapidly in the coming years. In 2012, wind continued its impressive growth with additional new capacity of over 11,500 MW in the EU, resulting in an overall capacity of about 105,600 MW by the end of 2012. Also electricity generation from biogas has grown strongly, by 18% per year on average from 1997 to 2011. The highest average annual growth rate in this period has been realised by solar photovoltaics (PV), which grew on average by an impressive 65% over this nine year period, from 0.04 TWh in 1997 to 44 TWh in 2011.

The average annual growth rate of RES-E excluding hydropower in the period 1997 to 2011 is 17%.

Besides data on renewable energy generation, capacity data are of key relevance for studying the macroeconomic consequences of the renewable energy evolution. Therefore, the development of the installed capacity for two main new RES-E technologies is shown in the following. Onshore wind power has been the most successful RES technology in recent years. Figure 1-4 depicts the specific development of onshore wind power capacity in the EU-27 countries.

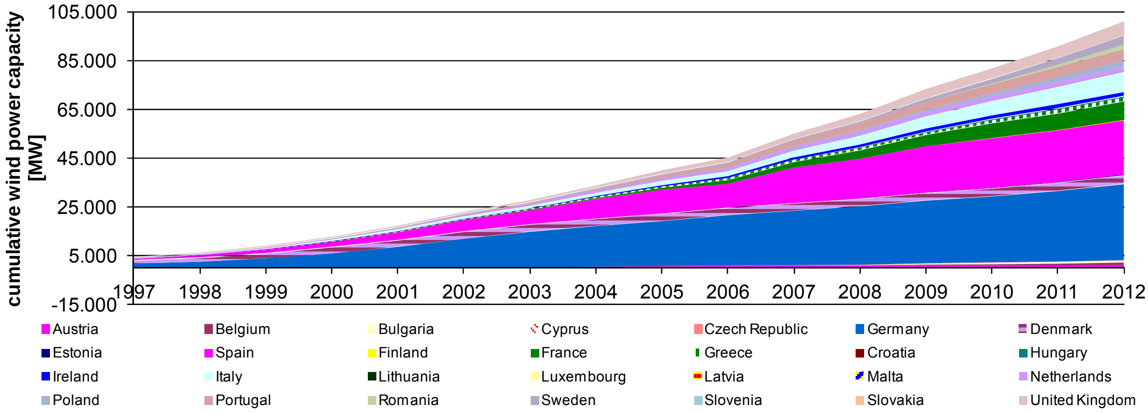

Figure 1-4 Historical development of cumulative installed wind capacity in EU-28 countries
Source: Eurostat

Biomass has the second largest percentage of renewable electricity generation in the EU-27. The biggest shares hold Finland, Germany and Sweden, whereby recently RES-E generation from biomass increased in Denmark, Italy, Poland and the United Kingdom, see Figure 1-5. Further increase of cumulative biomass generation is expected due to large potentials in the new EU Member States.

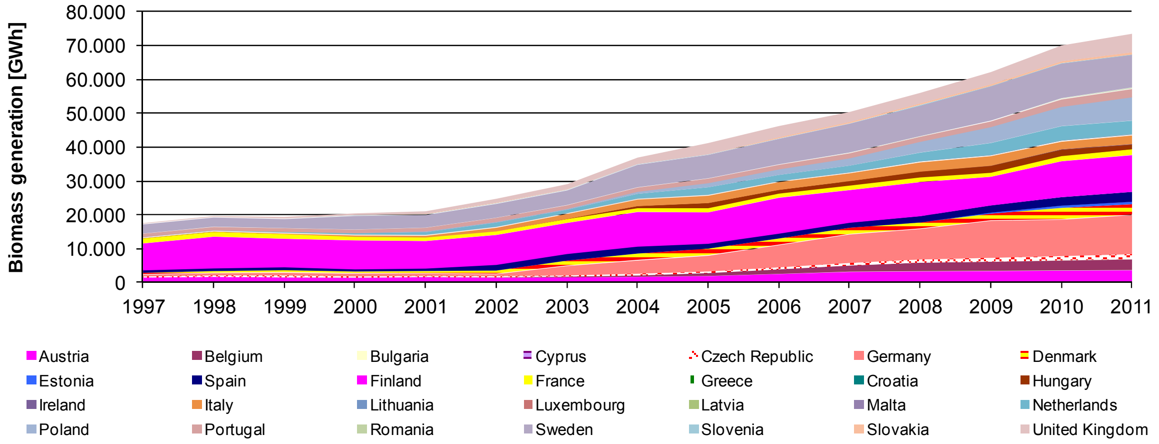

Figure 1-5 Historical development of electricity generation from biomass in EU-28 countries
Source: Eurostat

Renewable heat

Figure 1-6 shows the generation of heat from renewable energy sources (RES-H) in the EU-28 between 1995 and 2011.

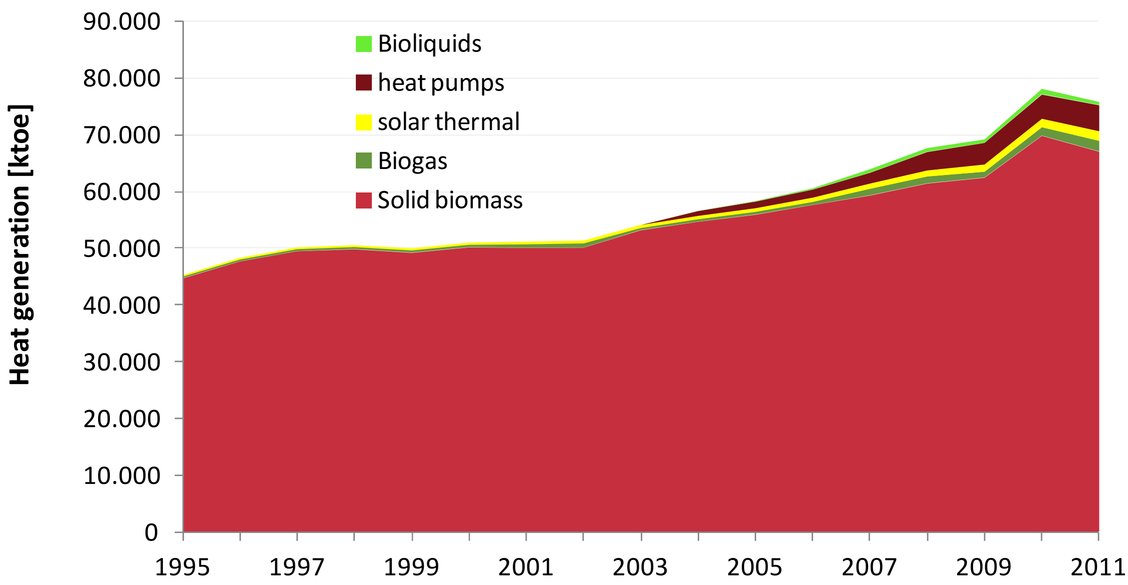

Figure 1-6 Historical development of heat generation from RES-H in the European Union (EU-27) between 1995 and 2011

Overall progress made in the EU in heat generation from biomass is moderate: since 1995 heat output from biomass has grown by 50% to 67 Mtoe in 2011, corresponding to an average annual growth rate in the period 1997-2005 of 2.6% for the EU-28.

Solar thermal heat generation increased by a factor of six from 0.28 Mtoe in 1995 to 1.69 Mtoe in 2011. In general, solar thermal heat has grown relatively steady, the overall EU growth rate in the period 1995-2011 being 12% per year. Geothermal heat generation from heat pumps was 4.5 Mtoe in 2011.

Overall one can conclude that developments in the heat sector have been moderate up to now and are clearly lagging behind growth rates realised in the electricity sector and – more recently – in the biofuels sector.

Biofuels

The Biofuels Directive of 2003 has meant an important stimulus to the creation of support frameworks for the production and consumption of biofuels in Member States, followed by the target and measures under the RES Directive for 2020. An overview of the production of liquid biofuels in the EU-27 in 1995 and 2011 is provided in Figure 1-7.

Biodiesel is dominating the European RES-T sector, with 70% of RES transport consup-tion in 2011 being biodiesel, only 19% bioethanol and 8% renewable electricity.

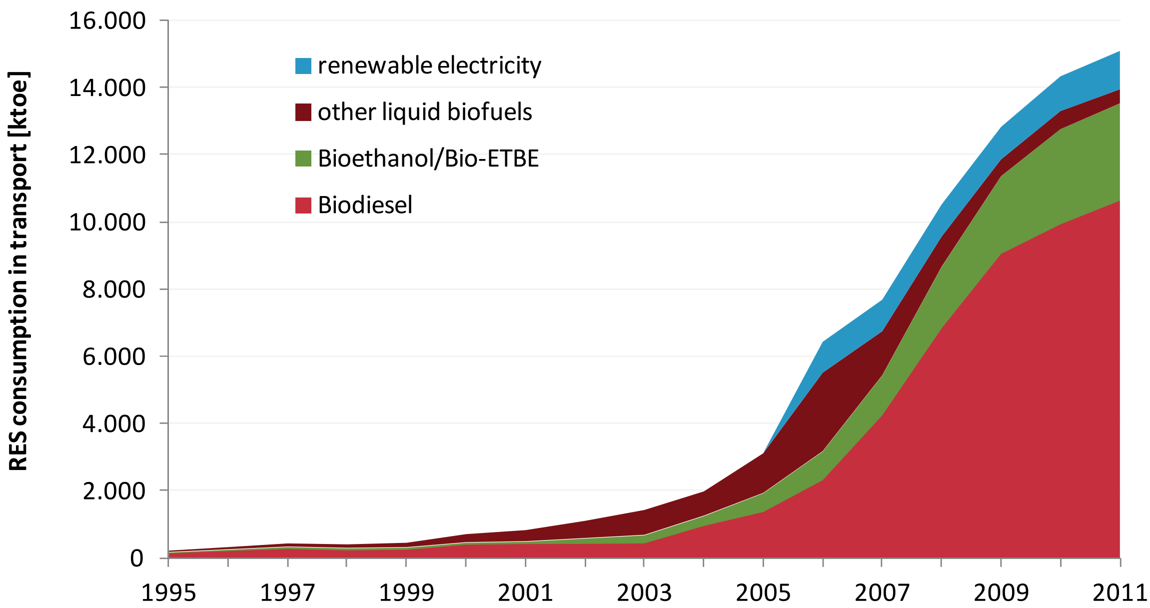

Figure 1-7 Historical development of RES consumption in transport in the European Union (EU-27) between 1995 and 2011

1.3 Assessment of economic parameters and costs for RES-E, RES-H and RES-T

The assessment of the economic parameters and accompanying technical specifications for the various RES technologies relies on a comprehensive literature survey and an expert consultation. All cost data represent a snapshot for the year 2010 and encompass RES within all energy sectors. The assessment provides important parameters for the Green-X model and is, hence, consistent to the model's framework and settings.

Economic conditions of the various RES technologies are based on both economic and technical specifications, varying across the EU countries.[6] In order to illustrate the economic figures for each technology Table 1-1 represents the economic parameters and accompanying technical specifications for RES technologies in the electricity sector, whilst Table 1-2 and Table 1-3 offer the corresponding depiction for RES technologies for heating and cooling and biofuel refineries as relevant for the transport sector. Note that all expressed data aim to reflect the current situation - more precisely, they refer to the year 2010 and are expressed in real terms (i.e. $€_{2010}$).

The Green-X database and the corresponding model use 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 so-called cost-bands. These cost-bands summarize a range of production sites that can be described by similar cost factors. For each technology a minimum of 6 to 10 cost bands are specified by country. For biomass, at least 50 cost bands are specified for each year in each country.

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

Assessment of potentials and cost for RES in Europe – Method of approach

The Green-X database on potentials and cost for RES technologies in Europe provides detailed information on current cost (i.e. investment -, operation & maintenance -, fuel and generation cost) and potentials for all RES technologies within each EU Member State. The assessment of the economic parameter and accompanying technical specifications for the various RES technologies builds on a long track record of European and global studies in this topical area. From a historical perspective the starting point for the assessment of realisable mid-term potentials was geographically the European Union as of 2001 (EU-15), where corresponding data was derived for all Member States initially in 2001 based on a detailed literature survey and an expert consultation. In the following, within the framework of the study "Analysis of the Renewable Energy Sources' evolution up to 2020 (FORRES 2020)" (see Ragwitz et al., 2005) comprehensive revisions and updates have been undertaken, taking into account recent market developments. Consolidated outcomes of this process were presented in the European Commission's Communication "The share of renewable energy" (European Commission, 2004). Later on throughout the course of the futures-e project (see Resch et al., 2009) an intensive feedback process at the national and regional level was established. A series of six regional workshops was hosted by the futures-e consortium around the EU within 2008. The active involvement of key stakeholders and their direct feedback on data and scenario outcomes helped to reshape, validate and complement the previously assessed information.

Within the Re-Shaping project (see e.g. Ragwitz et al., 2012) and parallel activities such as the RES-Financing study done on behalf of the EC, DG ENER (see De Jager et al., 2011) again a comprehensive update of cost parameter was undertaken, incorporating recent developments – i.e. the past cost increase mainly caused by high oil and raw material prices, and, later on, the significant cost decline as observed for various energy technologies throughout 2008 and 2009. The process included besides a survey of related studies (e.g. Krewitt et al. (2009), Wiser (2009) and Ernst & Young (2009)) also data gathering with respect to recent RES projects in different countries.

Box 1 About the Green-X potentials and costs for RES in Europe

In the following the current investment cost for RES technologies are described alongside the data provided in Table 1-1 and Table 1-3, whereby a focus may be put on the description of some key technology options. Since the original development of the Green-X database in the year 2004, several updates and adjustments have become necessary due to cost dynamics of RES technologies. In many cases, there was a trend for an increase of investment costs in the years up to 2008, followed by a stagnation or decrease in subsequent years.

Firstly, explanatory notes are provided on the technology-specific investment costs as depicted in Table 1-1:

- The current costs of biogas plants range from 1445 €/kW_{el} to 5085 €/kW_{el} with landfill gas plants offering the most cost efficient option (1445 €/kW_{el} – 2255 €/kW_{el}) and agricultural biogas plants (2890 €/kW_{el} – 5085 €/kW_{el}) being the highest cost option within this category;
- The costs of medium- to large-scale biomass plants only changed slightly and currently lie in the range of 2540 €/kW_{el} to 3550 €/kW_{el}. Biomass CHP plants typically show a broader range (2950 €/kW_{el} – 4885 €/kW_{el}) as plant sizes are typically lower compared to pure power generation. Among all bioelectricity options waste incineration plants have the highest investment costs ranging from 5150 €/kW_{el} to 7695 €/kW_{el} whereby CHP options show about 5% higher investment cost but offer additional revenues from selling (large amounts of) heat;
- The current investment costs of geothermal power plants are in the range of 2335 €/kW_{el} to 7350 €/kW_{el}., whereby the lower boundary refers to large-scale deep geothermal units as applicable e.g. in Italy, while the upper range comprises enhanced geothermal systems;
- Looking at the investment costs of hydropower as electricity generation option it has to be distinguished between large-scale and small-scale hydropower plants. Within these two categories, the costs depend besides the scale of the units also on site-specific conditions and additional requirements to meet e.g. national / local environmental standards etc. This leads to a comparatively broad cost range from 870 €/kW_{el} to 6265 €/kW_{el} for new large-scale hydropower plants. Corresponding figures for small-scale units vary from 980 €/kW_{el} to 6590 €/kW_{el};
- In 2010 typical PV system costs were in the range 2675 €/kW_{el} to 3480 €/kW_{el}. These cost levels were reached after strong cost declines in the years 2008 and 2009. This reduction in investment cost marks an important departure from the trend of the years 2005 to 2007, during which costs remained flat, as rapidly expanding global PV markets and a shortage of silicon feedstock put upward pressure on both module prices and non-module costs (see e.g. Wiser et al 2009). Before this period of stagnation PV systems had experienced a continuous decline in cost since the start of commercial manufacture in the mid 1970's following a typical learning curve. The new dynamic began to shift in 2008, as expansions on the

supply-side coupled with the financial crisis led to a relaxation of the PV markets and the cost reductions achieved on the learning curve in the meantime factored in again. Furthermore, the cost decrease has been stimulated by the increasing globalization of the PV market, especially the stronger market appearance of Asian manufacturers.

- The investment costs of wind onshore power plants are currently (2010) in the range of 1350 €/kW_{el} and 1685 €/kW_{el} and thereby slightly lower than in the previous year. Two major trends have been characteristic for the wind turbine development for a long time: While the rated capacity of new machines has increased steadily, the corresponding investment costs per kW dropped. Increases of capacity were mainly achieved by up-scaling both tower height and rotor size. The largest wind turbines currently available have a capacity of 5 to 6 MW and come with a rotor diameter of up to 126 meters. The impact of economies of scale associated with the turbine up-scaling on turbine cost is evident: The power delivered is proportional to the diameter squared, but the costs of labour and material for building a turbine larger are constant or even fall with increasing turbine size, so that turbine capacity increases disproportionally faster than costs increase. From around 2005 on the investment costs have started to increase again. This increase of investment cost was largely driven by the tremendous rise of energy and raw material prices as observed in recent years, but also a move by manufacturers to improve their profitability, shortages in certain turbine components and improved sophistication of turbine design factored in.

Table 1-1 Overview on economic-& technical-specifications for new RES-E plant (for the year 2010)

RES-E sub-category	*Plant specification*	*Investment costs* *[€/kW$_{el}$]*	*O&M costs* *[€/(kW$_{el}$* year)]*	*Efficiency (electricity)* *[1]*	*Efficiency (heat)* *[1]*	*Lifetime (average)* *[years]*	*Typical plant size* *[MW$_{el}$]*
Biogas	Agricultural biogas plant	2890 – 4860	137 - 175	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant - CHP	3120 – 5085	143 – 182	0.27 - 0.33	0.55 - 0.59	25	0.1 - 0.5
	Landfill gas plant	1445 - 2080	51 – 82	0.32 - 0.36	-	25	0.75 - 8
	Landfill gas plant - CHP	1615 - 2255	56 - 87	0.31 - 0.35	0.5 - 0.54	25	0.75 - 8
	Sewage gas plant	2600 - 3875	118 – 168	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant - CHP	2775 - 4045	127 – 179	0.26 - 0.3	0.54 - 0.58	25	0.1 - 0.6
Biomass	Biomass plant	2540 - 3550	97 – 175	0.26 - 0.3	-	30	1 – 25
	Cofiring	350 - 580	112 – 208	0.35 – 0.45	-	30	-
	Biomass plant - CHP	2600 - 4375	86 – 176	0.22 - 0.27	0.63 - 0.66	30	1 – 25
	Cofiring – CHP	370 - 600	115 – 242	0.20 – 0.35	0.5 - 0.65	30	-
Biowaste	Waste incineration plant	5150 – 6965	100 - 184	0.18 - 0.22	-	30	2 – 50
	Waste incineration plant - CHP	5770 - 7695	123 – 203	0.16 - 0.19	0.62 - 0.64	30	2 – 50
Geothermal electricity	Geothermal power plant	2335 - 7350	101 - 170	0.11 - 0.14	-	30	5 – 50
Hydro large-scale	Large-scale unit	1600 - 3460	33 – 36	-	-	50	250
	Medium-scale unit	2125 – 4900	34 – 37	-	-	50	75
	Small-scale unit	2995 – 6265	35 – 38	-	-	50	20
	Upgrading	870 – 3925	33 – 38	-	-	50	-
Hydro small-scale	Large-scale unit	1610 - 3540	36 – 39	-	-	50	9.5
	Medium-scale unit	1740 - 5475	37 – 40	-	-	50	2
	Small-scale unit	1890- 6590	38 – 41	-	-	50	0.25
	Upgrading	980 - 3700	36 – 41	-	-	50	-
Photovoltaics	PV plant	2675 - 3480	30 – 39	-	-	25	0.005 - 0.05
Solar thermal electricity	Concentrating solar power plant	6135 -7440	136 - 200	0.33 - 0.38	-	30	2 – 50
Tidal stream energy	Tidal (stream) power plant - shoreline	6085 – 7100	95 – 145	-	-	25	0.5
	Tidal (stream) power plant - nearshore	6490 – 7505	108 – 150	-	-	25	1
	Tidal (stream) power plant - offshore	6915 - 8000	122 – 160	-	-	25	2
Wave energy	Wave power plant - shoreline	5340 – 5750	83 – 140	-	-	25	0.5
	Wave power plant - nearshore	5785 – 6050	90 – 145	-	-	25	1
	Wave power plant - offshore	7120 – 7450	138 – 155	-	-	25	2
Wind onshore	Wind power plant	1350 – 1685	30 – 36	-	-	25	2
Wind offshore	Wind power plant - nearshore	2850 - 2950	64 – 70	-	-	25	5
	Wind power plant - offshore: 5…30km	3150 – 3250	70 – 80	-	-	25	5
	Wind power plant - offshore: 30…50km	3490 - 3590	75 – 85	-	-	25	5
	Wind power plant - offshore: 50km…	3840 - 3940	80 – 90	-	-	25	5

Table 1-2 Overview on economic-& technical-specifications for new RES-H plant (grid & non-grid) (for the year 2010)

RES-H sub-category	*Plant specification*	*Investment costs* [€/kW$_{heat}$][2]	*O&M costs* [€/(kW$_{heat}$*yr)][2]	*Efficiency (heat)*[1] [1]	*Lifetime (average)* [years]	*Typical plant size* [MW$_{heat}$][2]
Grid-connected heating systems						
Biomass - district heat	Large-scale unit	380 - 390	19 – 20	0.89	30	10
	Medium-scale unit	420 - 460	21 – 23	0.87	30	5
	Small-scale unit	500 – 580	24 – 27	0.85	30	0.5 - 1
Geothermal - district heat	Large-scale unit	820 – 840	50 – 52	0.9	30	10
	Medium-scale unit	1490 – 1520	55 – 56	0.88	30	5
	Small-scale unit	2145 – 2160	56 – 59	0.87	30	0.5 - 1
Non-grid heating systems						
Biomass - non-grid heat	log wood	390 – 430	12 – 15	0.75 - 0.85*	20	0.015 - 0.04
	wood chips	525 – 675	14 – 17	0.78 - 0.85*	20	0.02 - 0.3
	Pellets	510 – 685	11 – 15	0.85 - 0.9*	20	0.01 - 0.25
Heat pumps	ground coupled	735 – 1215	5.5 - 7.5	3 - 4[1]	20	0.015 - 0.03
	earth water	800 – 1195	10.5 - 18	3.5 - 4.5[1]	20	0.015 - 0.03
Solar thermal heating & hot water supply	Large-scale unit	660 – 680[2]	9 - 10[2]	-	20	100 - 200
	Medium-scale unit	760 – 780[2]	11 - 15[2]	-	20	50
	Small-scale unit	860 – 880[2]	15 - 17[2]	-	20	5 - 10

<u>Remarks:</u>

[1] In case of heat pumps we specify under the terminology "efficiency (heat)" the *seasonal performance factor* - i.e. the output in terms of produced heat per unit of electricity input

[2] In case of solar thermal heating & hot water supply we specify under the investment and O&M cost per unit of m^2 collector surface (instead of kW). Accordingly, expressed figures with regard to plant sizes are also expressed in m^2 (instead of MW).

Table 1-3 Overview on economic-& technical-specifications for new biofuel refineries (for the year 2010)

RES-T sub-category	*Fuel input*	*Investment costs* [€/kW$_{trans}$]	*O&M costs* [€/(kW$_{trans}$* year)]	*Efficiency (trans-port)* [1]	*Efficiency (electrici-ty)* [1]	*Lifetime (average)* [years]	*Typical plant size* [MW$_{trans}$]
Biodiesel plant (FAME)	rape and sunflower seed	205 – 835	10 – 41	0.66	-	20	5 - 25
Bio ethanol plant (EtOH)	energy crops (i.e. sorghum and corn from maize, triticale, wheat)	605 - 2150	30 - 142	0.57 - 0.65	-	20	5 - 25
Advanced bio ethanol plant (EtOH+)	energy crops (i.e. sorghum and whole plants of maize, triticale, wheat)	1245 - 1660[1]	57 -74[1]	0.58 - 0.65[1]	0.05 - 0.12[1]	20	5 - 25
BtL (from gasifier)	energy crops (i.e. SRC, miscan-thus, red canary grass, switch-grass, giant red), selected waste streams (e.g. straw) and forestry	825 - 6190[1]	38 - 281[1]	0.36 -0.43[1]	0.02 - 0.09[1]	20	50 - 750

<u>Remarks:</u>

[1] In case of Advanced bio ethanol and BtL cost and performance data refer to 2015 - the year of possible market entrance with regard to both novel technology options.

For RES-H plants as displayed inTable 1-2 the distinction between grid-connected and non-grid heating systems is important. Among the first category are biomass and geothermal district heating systems and among the latter one biomass non-grid heating systems, solar thermal heating systems and heat pumps. Depending on the scale investment costs for biomass district heating systems currently range between 380 €/kW$_{heat}$ and 580 €/kW$_{heat}$, and for geothermal district heating systems between 820 €/kW$_{heat}$ and 2160 €/kW$_{heat}$. In case of non-grid biomass heating systems the investment costs differ depending on fuel type between 390 €/kW$_{heat}$ and 685 €/kW$_{heat}$. Heat pumps currently cost from 735 €/kW$_{heat}$ up to 1195 €/kW$_{heat}$ and for solar thermal heating systems depending on scale the specific investment costs reach from 660 €/kW$_{heat}$ to 880 €/kW$_{heat}$.

Table 1-3 provides the current investment cost data for biofuel refineries. With regard to the fuel input / output different plant types are included in the database. Biodiesel plant (FAME) currently cost from 205 €/kW$_{trans}$ to 835 €/kW$_{trans}$, bio ethanol plants from 605 €/kW$_{trans}$ to 2150 €/kW$_{trans}$ and BTL plant from 825 €/kW$_{trans}$ to 6190 €/kW$_{trans}$. Please note that in the case of advanced bio ethanol and BtL the expressed cost and performance data represent expected values for the year 2015 - the year of possible market entrance with regard to both novel technology options.

While the investments costs of RES technologies as described above are suitable for an analysis at the technology level, for the comparison of technologies the generation costs are relevant. Consequently, the broad range of the resulting generation costs, due to several influences, for several RES technologies is addressed subsequently. Impacts as, variations in resource- (e.g. for photovoltaics or wind energy) or demand-specific conditions (e.g. full load hours in case of heating systems) within and between countries as well as variations in technological options such as plant sizes and/or conversion technologies are taken into account. In this context, for the calculation of the capital recovery factor a payback time of 15 years, which represents rather an investor's view than the full levelized costs over the lifetime of an installation, and weighted average cost of capital of 6.5% are used.

As can be observed from Figure 1-8, Figure 1-9 and Figure 1-10 the general cost level as well as the magnitude of the cost ranges vary strongly between the different technologies. It is thereby striking that RES-H options under favourable conditions are either competitive or close to competitiveness, while all RES-T options still are above the market price. Looking at RES-E options the situation is more diverse. The most conventional and cost efficient options like large hydropower and biogas can generate electricity below market prices. It is also noticeable that wind power (onshore) cannot deliver electricity at market prices even at the best sites. Of course, this proposition holds only for current market prices which have decreased substantially in the wholesale market in the near past. For most RES-E technologies the cost range at the EU level appears comparatively broad. In the case of PV or wind energy this can be to a lesser extent ascribed to (small) differences in investment costs between the Member States, but more crucial in this respect are the differences in resource conditions (i.e. the site-specific wind conditions in terms of wind speeds and roughness classes or solar irradiation and their formal interpretation as feasible full load hours) between the Member States. In the case of photovoltaics the broad cost range results also from differences in terms of application whereby the upper boundary refers to facade-integrated PV systems.

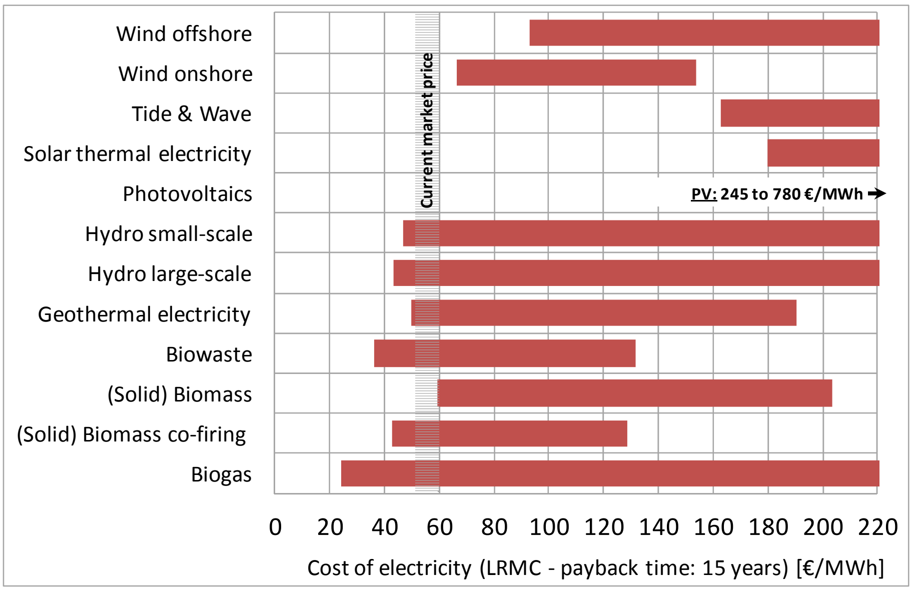

Figure 1-8 Long-run marginal generation costs (for the year 2010) for various RES-E options in EU countries

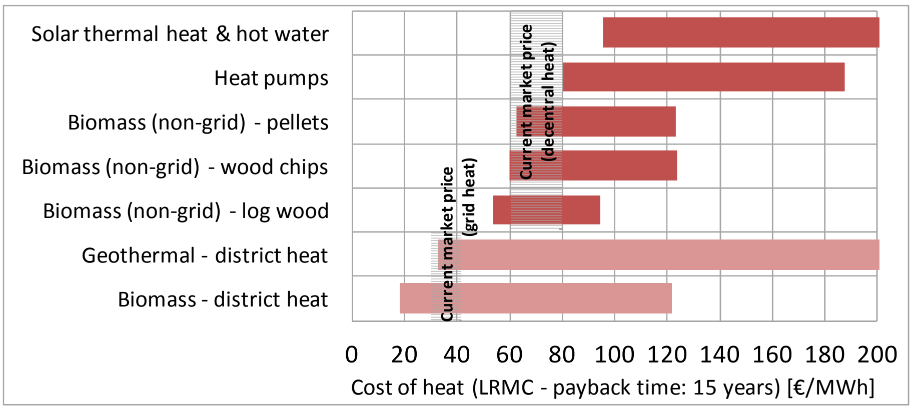

Figure 1-9: Long-run marginal generation costs (for the year 2010) for various RES-H options in EU countries

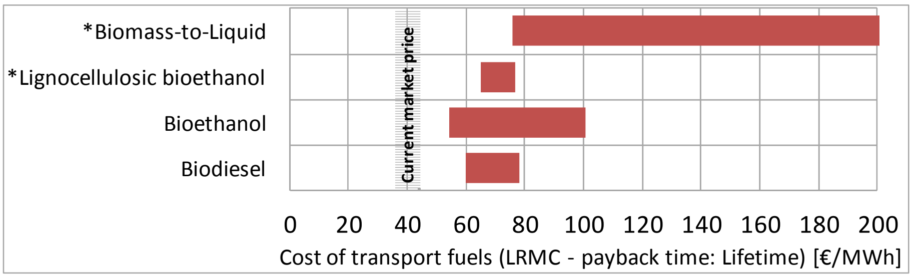

Figure 1-10: Long-run marginal generation costs (for the year 2010[7]) for various RES-T options in EU countries

7 In the case of advanced bio ethanol and BtL cost and performance data refer to 2015 - the year of possible market entrance with regard to both novel technology options.

2 Past economic and employment impacts of RES deployment

The dynamic evolution of RES deployment in Europe has led to the development of a cross-sectoral industry that centres around installation, operation and maintenance of RES facilities as well as the production of biomass fuels. The aim of this chapter is:

- to present the evolution of the RES industry in terms of its economic significance, or more concretely, to present its direct and indirect contribution to the gross domestic product and to employment in the EU Member States via the input-output model approach (MULTIREG) and
- to supplement the results from the input-output model by a direct data collection approach.
- Furthermore the transformation of technology specific data into (economic) sectoral data for use in macroeconomic models is presented.

Technically speaking the *gross* economic and employment impacts of the RES industry include the renewable energy industry itself and the industries indirectly depending on the activities of the renewable energy industry, either as suppliers of the intermediary inputs needed in the production process or as suppliers of capital goods. In this perspective the displacement of conventional energy generation and budget effects are not included. Conceptually, to estimate the economic significance of the renewable energy industry and its employment we distinguish here between two approaches: a supply side or direct data collection approach and a demand side or input-output (IO) model based approach.

In this study the IO model based approach is mainly used to analyse the past and present economic impacts of the renewable energy industry. The direct data collection approach is mainly used for validation purposes for the core part of the industry and might provide further development potential.

2.1 Using techno-economic data of RES technologies for macroeconomic analysis

In order to assess the economic impacts of RES deployment, it is necessary to translate the expenditures for installing and operating RES plants into economic activities or impulses, which can be fed into the economic models and are compatible with their sectoral classification. In this project these economic data are used as inputs in the model MULTIREG for the calculation of past and present economic impacts and - after the necessary adjustments - in the models NEMESIS and ASTRA for the assessment of future economic impacts. In this chapter this translation procedure is described in detail.

The costs for the deployment of RES technologies can be subdivided into four categories:

- costs for capacity increase,
- costs for replacement of existing capacity at the end of life,
- costs for operation and maintenance of RES facilities (without fuel use) and
- costs for fuel use, i.e. the use of biomass resources.

The costs for capacity increase and capacity replacement are summarized as investment costs.

Starting point are data from the Green-X model on specific costs per capacity or energy output unit for each year, country and RES technology.

For each technology the investment costs, O&M costs and fuel costs are divided into cost components that reflect the economic activities or goods and services needed for installation and operation of facilities (e.g. planning, manufacturing of the core technology, transportation and on-site installation) or that reflect different cost components of goods (e.g. the producer's share, the transport and trade share in the purchaser's price of wood pellets). The cost structures of the various RES technologies are derived from existing cost studies, other technical literature and expert judgement.

For the assessment of the economic and employment impacts it is important to consider the regional origin of the goods and services that are related to the cost components. Some of them are provided in the country, in which the RES facilities are installed (e.g. planning or construction). Other goods are imported from other countries and lead to economic impacts in the countries of origin. Wind turbines for instance are installed in several countries, whereas their production is more concentrated in a few European countries and countries outside Europe. In order to take the specific regional distributions of activities into account, each cost component of a technology can be classified as "local" or as "global" in our analysis. A cost component classified as "local" is mainly supplied by the country of installation, with the average inter-country trade being taken into account. For a cost component classified as "global" (e.g. wind turbines or solar cells) an adequate distribution of supplying countries can be determined.

For the globally manufactured cost components of a RES technology we add up the costs across all countries (including the rest of the world) to gain a global demand for the related products. We then break down the global demand to the countries supplying these products. In cases where technology-specific market shares of suppliers are not available, we use proxies of related economic sectors (e.g. the machinery sector) or adaptations based on expert opinion.

In a next step the production of each technology's cost components is allocated to the corresponding economic sectors according to the sector classification used in the macro-economic models.

Since also the cost components classified as „local" are related to products actually traded across borders (services to a smaller degree than commodities), these trade shares are accounted for in the economic models according to the average trade patterns of the respective economic sectors. A cost component of a RES technology can be treated as a global cost component, if its actual trade pattern deviates strongly from the average trade pattern of the respective economic sector and the necessary data for determining the actual trade pattern is available.

The result of this procedure is - for each RES technology - a vector of production by economic sector and by country, which serves as an input to the economic models. The exact manner, in which this input is used, differs between the three economic models and is specified in the respective chapters, in which the models are presented.

In the following, this approach is depicted in Figure 2-1 and described in more detail for the example of photovoltaic installations.

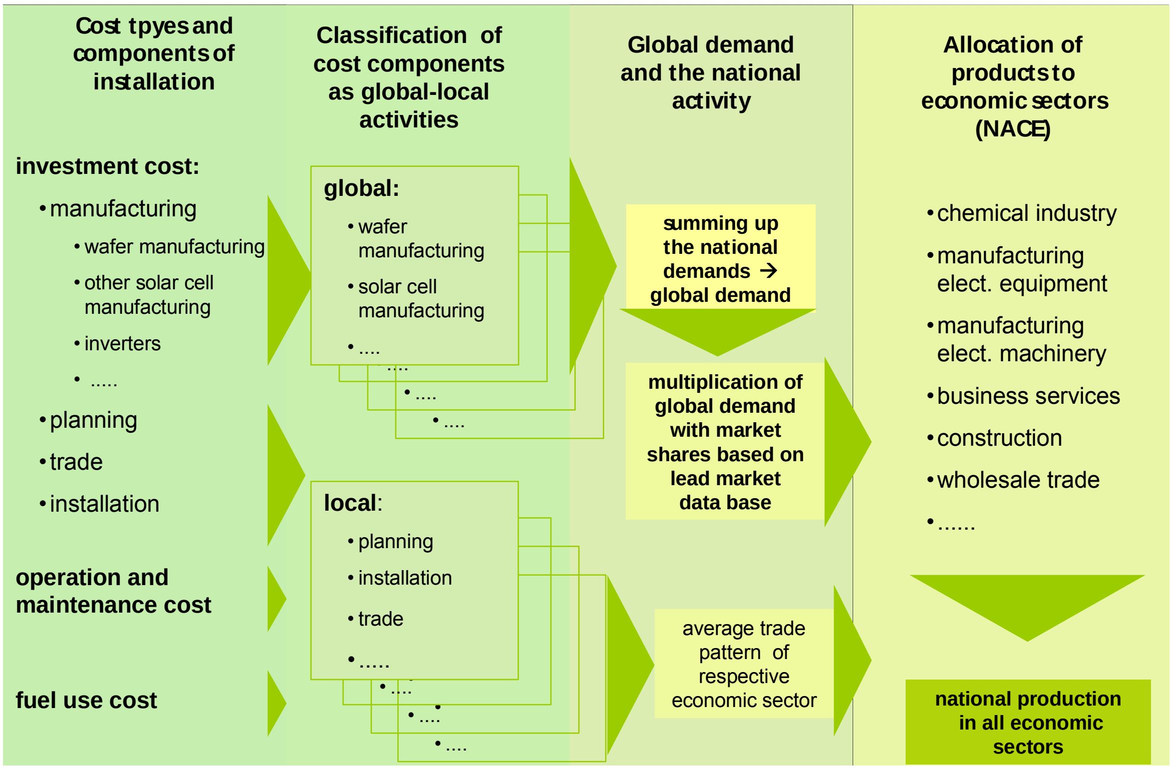

Figure 2-1 Overview and example of the classification and calculation of national investments of solar energy

Example: Photovoltaic installations

When analysing the cost structure of photovoltaic installations, one has to distinguish between two basic options, off-grid and grid connected installations. In the EU grid connected installations have a share of 95% of total installed capacity (Staiss, 2007). Among the grid connected installations decentralised rooftop installations clearly dominate the large-scale installations. Therefore the derivation of an average cost structure of PV installations focuses on grid-connected rooftop installations.

In terms of technology one has to distinguish between silicon-based PV systems and thin-film systems based on other materials, e.g. copper-indium-diselenide or cadmium-telluride. Since the latter are in a very early market phase, we concentrate on silicon-based PV systems.

Installation of photovoltaic modules for electricity generation includes the following components:

- planning
- PV modules,
- inverters,
- other installation components, summarised as the “balance of system” (BOS) and
- installation of the complete PV system.

The value chain for producing PV modules includes the following main steps:

- silicon production,
- wafer production based on silicon,
- production of solar cells,
- production of PV modules.

Estimating the average cost structure for these cost components has to rely on several information sources. Whereas there is a lot of information on specific costs and their development over time, information on cost structures and their development is far more restricted. Furthermore material costs can fluctuate strongly. Therefore the cost structures assumed in this study should be regarded as approximations.

Three important components of PV module manufacturing, wafers, solar cells and PV modules, are considered as “global” components, for which we specifically analyse the regional production patterns and the country market shares, respectively. Regarding solar cells and PV modules, our estimation of market shares is based on a detailed market survey published in the magazine *Photon International*, where global production is presented by country and manufacturer. For wafers our estimate is based on information from the technical literature. As a result we arrive at the following market shares for the first reference year 2005 (Table 2-1). The results show that the market shares of EU countries vary between 26% and 31% of global production. Within the EU especially Germany and Spain have a strong position as manufacturing countries.

Table 2-1 Country market shares in global production of wafers, solar cells and PV modules in 2005

Country	Wafer production	Solar cells production	PV modules production
Germany	22%	19%	14%
Spain	6%	4%	8%
France		2%	1%
United Kingdom	3%	0%	0%
Other EU		1%	6%
Rest of the world	69%	74%	71%
Total	100%	100%	100%

Source: Photon International, own calculation

Similar analyses were performed for the other RES technologies considered in this project. The depth of the analysis depended on the relevance of the respective technologies.

Regarding the classification of cost components for other technologies, we identified two other cost components, for which it was necessary to consider specific regional production patterns and for which the necessary data is available: wind turbines and solar thermal collectors.

2.2 The input-output model based approach with MULTIREG

The starting point for the IO model based approach is the expenditure for renewable energy use, i.e. for installation of new plant capacities, end-of-life replacement of existing plant capacities and for operation and maintenance (O&M) of the existing plants. The expenditures are allocated to cost components and finally to economic activities, i.e. to the supply of goods and services needed to install new capacities or to operate existing capacities. In order to capture the indirect economic impacts triggered by the supply of the necessary goods and services usually input-output models are used. Demand side analysis is more comprehensive than supply-side analysis, since it includes all the indirect economic activities related to RES use. On the other hand it is less specific, since to some extent the use of input-output models implies the use of average sector production structures. To enhance specificity it is possible to combine IO analysis with techno-economic coefficients for the considered technologies (e.g. number of employees needed to operate a hydro power plant). It is also possible to use specific data from supply side analysis. Here it is necessary to give care to the compatibility of the data (e.g. in terms of system boundaries).

2.2.1 Assumptions, model description and specification

The IO model based approach starts with data on capacity development and annual capacity increase of the various RES technologies in the EU 27 countries and in selected countries of the rest of the world[8]. Furthermore specific investment costs, operation and maintenance costs and fuel costs (for biomass technologies) are given (see Figure 2-2). This capacity and cost data is available for the years 2005 to 2011. The cost of capacity replacement is a part of the total investment cost and was calculated for each year as the cost of replacing the capacities reaching the end of their economic lifetime in that year. The development of specific costs was derived from the Green-X database. Based on this data the annual investment costs, operation and maintenance costs and fuel costs are calculated.

In the case of some technologies, a part of the O&M costs are personnel expenditures for operating the plants. Value added and employment related to these direct operation costs are calculated directly by using country specific average values for labour costs and labour productivities. These cost components are not allocated to economic sectors. In some cases cost components do not lead to production activities (e.g. costs of wind parks for using land or the transfer component in insurance premiums). In accordance with conventions of national accounting, these cost components are not considered in the further economic modelling.

As described in the chapter above, the costs are subdivided into cost components and then allocated to economic sectors, thus deriving for each RES technology a vector of production by country and by economic sector.

This vector is the basis for calculating gross value added as the direct economic impact indicator and direct employment. In order to calculate indirect economic and employment impacts related to the deployment of RES technologies, the above mentioned vector of production is introduced as an additional final demand into the model MULTIREG, which then gives the induced economic output, gross value added and employment in all EU member countries and all industries as a result. In this calculation imports and exports between countries are accounted for at all levels of the supply chain.

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8 Basically the countries represented in the MULTIREG model are considered

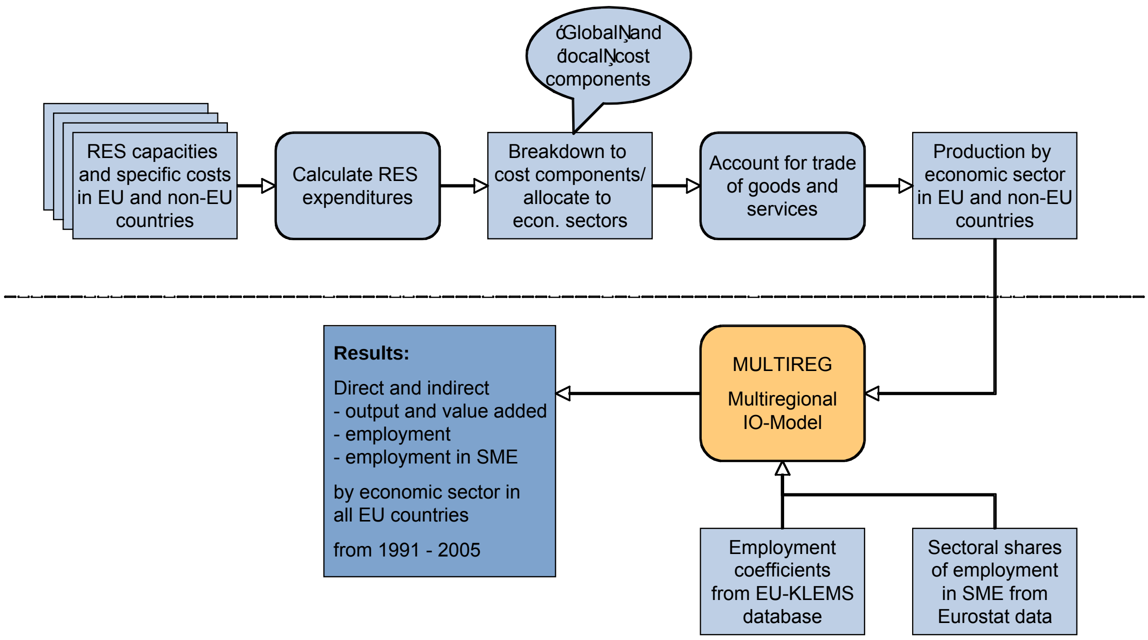

Figure 2-2 Overview of the modelling approach to calculate past and present economic and employment impacts of RES deployment

The MULTIREG model

MULTIREG is a static multi-country input-output (IO) model that covers all EU Member States and their main trade partners as well as trade between these countries with high sectoral detail (up to 59 sectors at the NACE 2-digit level). The model allows capturing economic interdependencies between industries of a country as well as across country boundaries. This ability to include effects across country boundaries is an essential feature for this study due to the high level of economic integration within Europe and with countries outside the EU. For this study the MULTIREG model is extended with sectoral employment data from the KLEMS database (working hours, employment, labour productivity, labour costs) to calculate employment impacts.

3 Future potentials for RES in Europe

Nowadays, a broad set of different renewable energy technologies exists. Obviously, for a comprehensive investigation of the future development of RES it is of crucial importance to provide a detailed investigation of the country-specific situation – e.g. with respect to the potential of the certain RES technologies in general as well as their regional distribution and the corresponding generation cost.

This section illustrates the consolidated outcomes of an intensive assessment process on Europe's RES potentials and accompanying costs that has been conducted within several studies in this topical area. This shall provide clarification on the pending question if sufficient RES are applicable to meet Europe's power demand in the absence of nuclear power. More precisely, a comparison will be provided that refers to 2030, indicating the demand for renewable sources according to the advanced scenario of the energy [r]evolution study as well as the applicable potentials.

The derived data on realisable mid-term (2030) potentials for RES fits to the requirements of the Green-X model, a specialised energy system model developed by TU Wien / EEG that allows to perform a detailed quantitative assessment of the future deployment of renewable energies on country-, sector- as well as technology level within the EU and its neighboring countries.[9] Within the course of this study Green-X will be used to complement the literature-based assessment of RES policy implications as well as of related costs / expenditures.

3.1 Classification of potential categories

We start with a discussion of the general background and subsequently present the status quo of consolidated data on potentials and cost for RES in Europe as applicable in the Green-X database. These figures indicate what appears to be realisable within the 2030 timeframe.

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9 The core strength of this tool lies on the detailed RES resource and technology representation accompanied by a thorough energy policy description, which allows assessing various policy options with respect to resulting costs and benefits. For a detailed model description we refer to www.green-x.at.

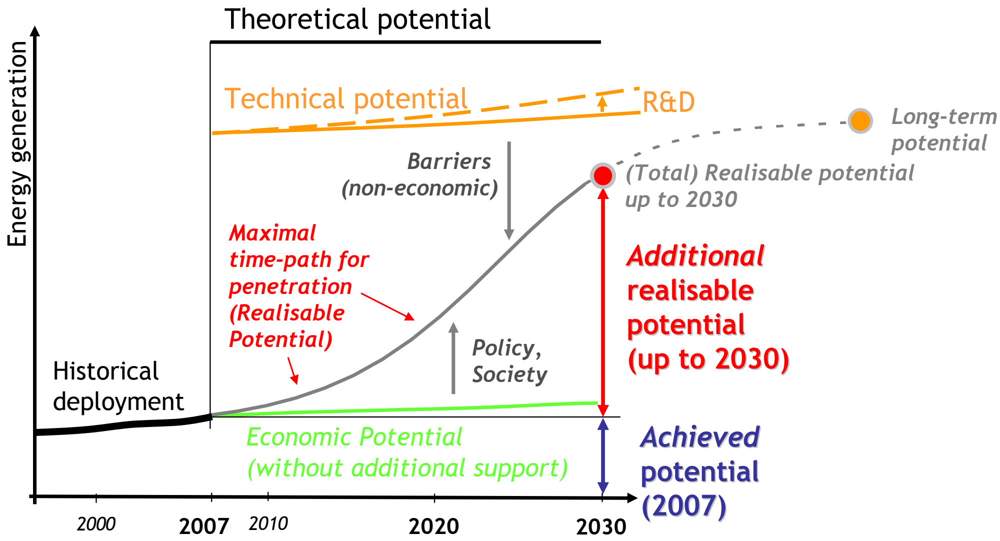

Figure 3-1 Definition of potential terms

The possible use of RES depends in particular on the available resources and the associated costs. In this context, the term "available resources" or RES potential has to be clarified. In literature, potentials of various energy resources or technologies are intensively discussed. However, often no common terminology is applied. Below, we present definitions of the various types of potentials as used throughout this report:

- *Theoretical potential:* To derive the theoretical potential, general physical parameters have to be taken into account (e.g. based on the determination of the energy flow resulting from a certain energy resource within the investigated region). It represents the upper limit of what could be produced from a certain energy resource from a theoretical point-of-view, based on current scientific knowledge;

- *Technical potential:* If technical boundary conditions (i.e. efficiencies of conversion technologies, overall technical limitations as e.g. the available land area to install wind turbines as well as the availability of raw materials) are considered, the technical potential can be derived. For most resources, the technical potential must be considered in a dynamic context. For example with increased R&D expenditures and learning-by-doing during deployment, conversion technologies might be improved and, hence, the technical potential would increase;

- *Realisable potential:* The realisable potential represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. Thereby, general parameters as e.g. market growth rates, planning constraints are taken into account. It is important to mention that this potential term must be seen in a dynamic context – i.e. the realisable potential has to refer to a certain year;

- *Realisable potential up to 2030:* provides an illustration of the derived realisable potential for the year 2030.
- *Long-term potential:* in this report, long-term potentials refer to the 2050 timeframe and consequently what can be realised until then. Obviously, this is closely linked (among other constraining factors) to infrastructural prerequisites.

Figure 3-1 (above) shows the general concept of the realisable potential up to 2030 as well as in the long-term (2050), the technical and the theoretical potential in a graphical way.

3.2 The Green-X database on potentials and cost for RES in Europe – background information

The input database of the Green-X model offers a detailed depiction of the achieved and feasible future deployment of the individual RES technologies in Europe – in particular with regard to costs and penetration in terms of installed capacities or actual & potential generation. Realisable future potentials (up to 2030 / 2050) are included by technology and by country. In addition, data describing the technological progress such as learning rates are available. Both serve as crucial input for the model-based assessment of future RES deployment. Note that an overview on the method of approach used for the assessment of this comprehensive data set is given in Box 1 (see section 1.3).

3.3 Mid-term (2030) realisable potentials for RES in the electricity sector – extract from the Green-X database[10]

Next, we take a closer look on the mid-term prospects for RES in the electricity sector, illustrating the identified potentials that can be principally realised in the 2030 timeframe. In the power sector, RES-E options such as hydropower or wind energy represent energy sources characterised by a natural volatility. Therefore, in order to provide an accurate depiction of the future development of RES-E, historical data for RES-E is translated into

10 Please note that the description of future RES potentials within the European Union as provided in this section refers to the EU27, excluding Croatia. Data for Croatia has been assessed and will be included in the graphical depiction and the explanatory notes at the final stage of this project.

electricity generation potentials[11] – the *achieved potential* at the end of 2005 – taking into account the recent development of this rapidly growing market. The historical record was derived in a comprehensive data-collection – based on (Eurostat, 2007; IEA, 2007) and statistical information gained on national level. In addition, *future* potentials – i.e. the *additional realisable mid-term potentials* up to 2030 – were assessed[12] taking into account the country-specific situation as well as overall realisation constraints.

Figure 3-2 depicts the achieved and additional mid-term potential for RES-E in the EU 27 at country level. For EU 27 countries, the already achieved potential for RES-E equals 503 TWh, whereas the additional realisable potential up to 2030 amounts to 2676 TWh (about 81% of 2005's gross electricity consumption). Obviously, large countries such as France, Germany, Spain or UK possess the largest RES-E potentials in absolute terms, where still a huge part is waiting to be exploited. Among the new Member States Poland and Romania offer the largest RES-E potentials in absolute terms.

Consequently, Figure 3-3 relates derived potentials to gross electricity demand. More precisely, it depicts the total realisable mid-term potentials (up to 2030), as well as the achieved potential (2005) for RES-E as share of gross electricity demand in 2005 for all Member States and the EU 27 in total. As applicable from this depiction, significant additional RES potentials are becoming apparent for several countries. In this context especially notable are Portugal, Denmark and Ireland, as well as most of the new Member States. If the indicated realisable mid-term potential for RES-E, covering all RES-E options, would be fully exploited up to 2030, almost all our electricity needs as of today (97% compared to 2005's gross electricity demand) could be *in principle*[13] covered. For comparison, by 2005 already installed RES-E plants possess the generation potential to meet about 15% of demand.

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11 The electricity generation potential with respect to existing plant represents the output potential of all plants installed up to the end of 2005. Of course, figures for actual generation and generation potentials differ in most cases – due to the fact that in contrast to the actual data, potential figures represent, e.g. in case of hydropower, the normal hydrological conditions, and furthermore, not all plants are installed at the beginning of each year.

12 A description of the potential assessment is given e.g. in (Resch et al., 2006) from a methodological point of view.

13 In practice, there are important limitations that have to be considered: not all of the electricity produced may actually be consumed since supply and demand patterns may not match well throughout a day or year. In particular this statement is getting more and more relevant for variable RES like solar or wind where curtailment of produced electricity increases significantly with increasing deployment. This indicates the need for complementary action in addition to the built up of RES capacities, including grid extension or the built up of storage facilities.

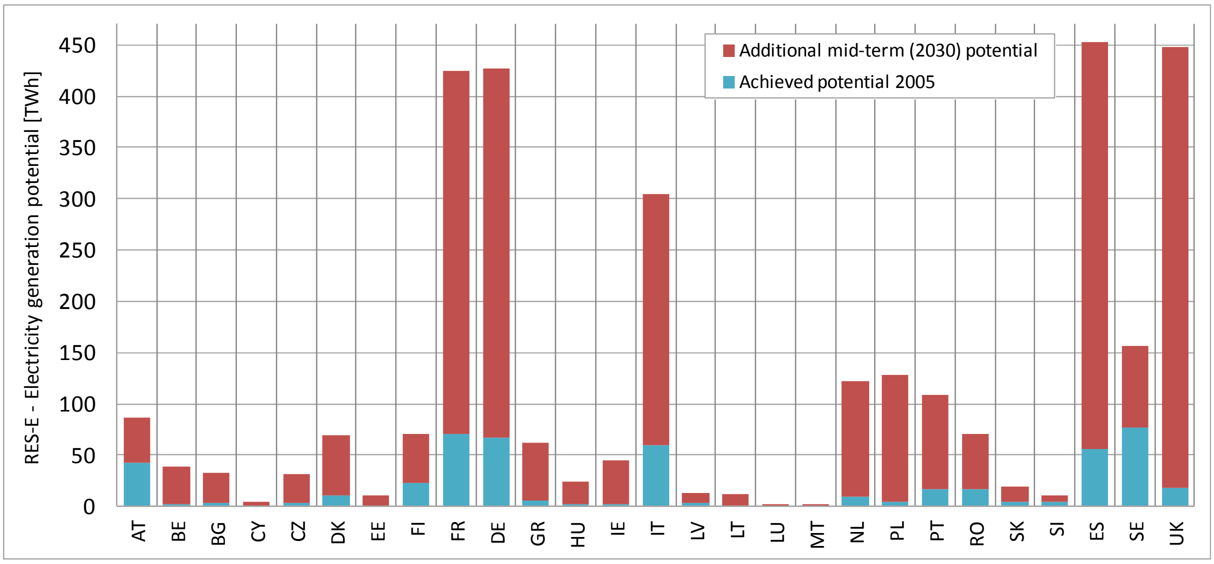

Figure 3-2 Achieved (2005) and additional mid-term potential 2030 for electricity from RES in the EU 27 on country level.

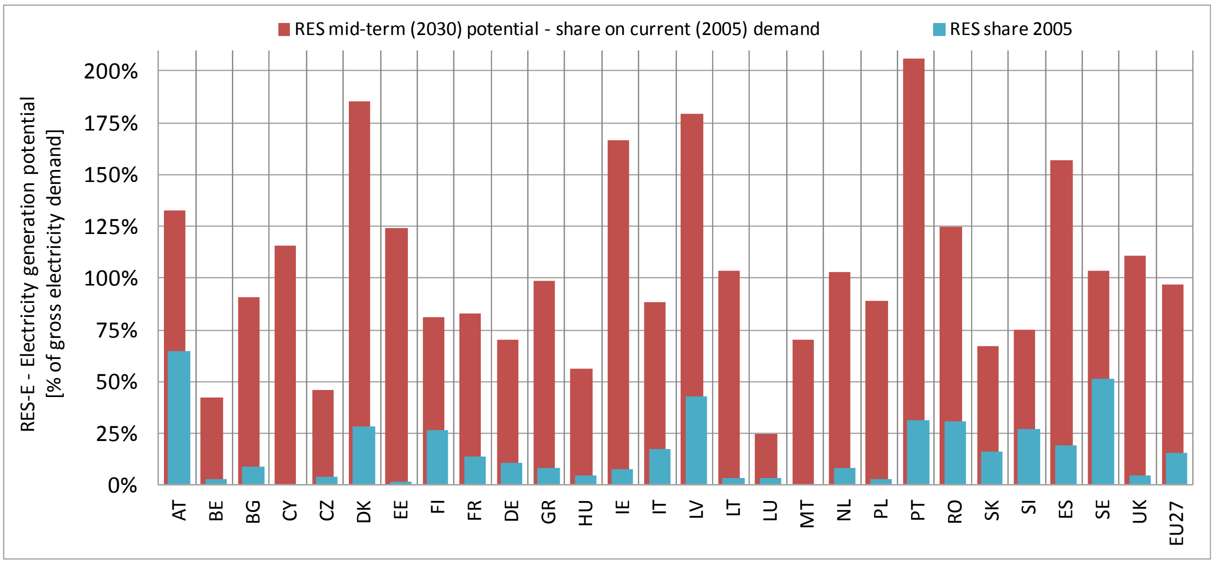

Figure 3-3 Total realisable mid-term potentials (2030) and achieved potential for RES-E in EU 27 countries as share of gross electricity demand (2005).

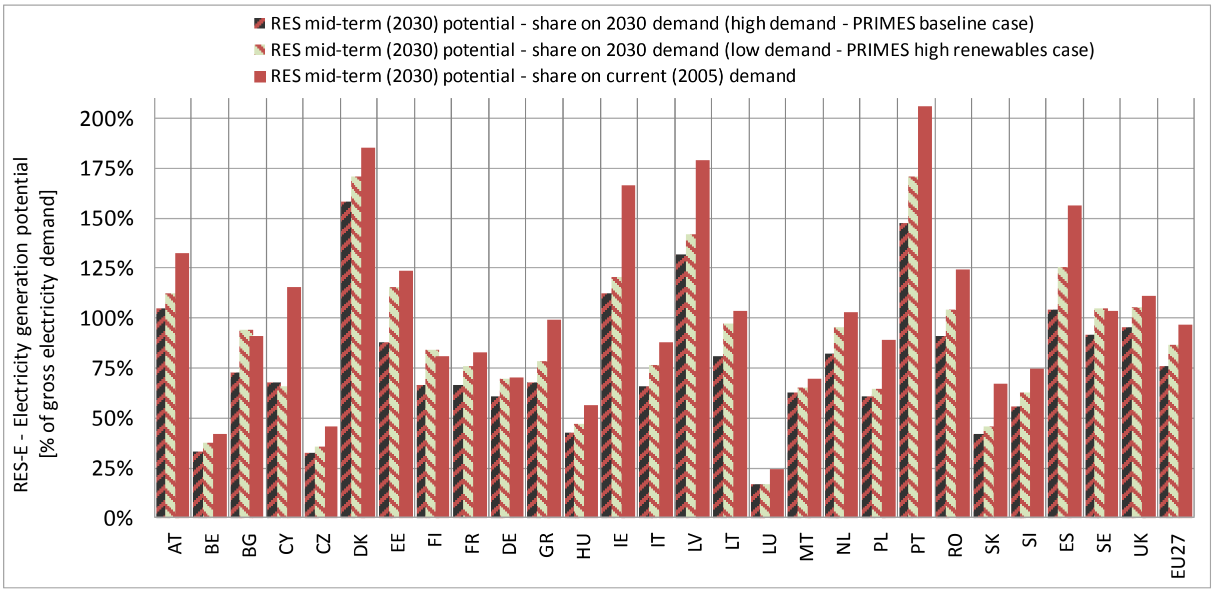

Figure 3-4 Total realisable mid-term potentials (2030) and achieved potential for RES-E in EU 27 countries as share of gross electricity demand (2005 & 2030) in a baseline and an efficiency demand scenario.

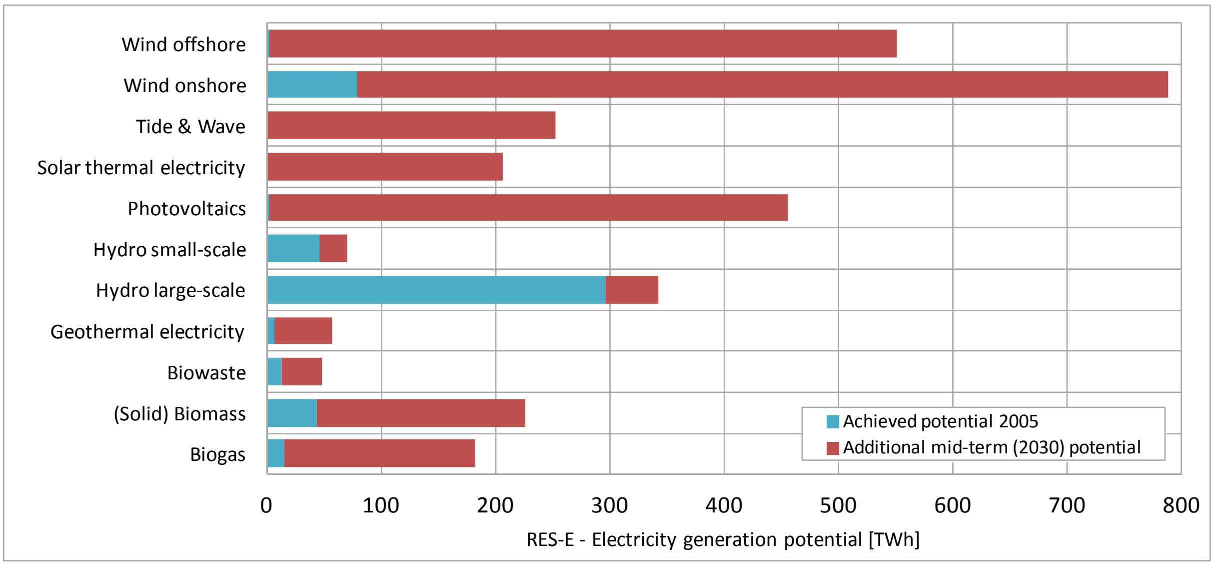

Figure 3-5 Total realisable mid-term potentials (2030) and achieved potential for RES-E in EU 27 countries on technology level.

Additionally, the above-mentioned relations of the total realisable mid-term potential (2030) to the gross electricity demand are addressed in Figure 3-4 with respect to different scenarios on the future development of the electricity demand. A strong impact of the electricity demand development on the share of renewables is noticeable: In a baseline demand scenario (according to PRIMES), a total achievable RES-E share of 76% in the year 2030 would appear feasible, whereas in a (moderate) efficiency demand scenario, 87% of the expected future electricity demand by 2030 could be generated by renewables. As already discussed in the previous figure, if the total realisable mid-term potential for RES-E was fully exploited up to 2030, 97% of current (2005) gross consumption could be covered, meaning even the efficiency demand scenario takes an increasing electricity demand into account.

4 Future renewable energy deployment

The core objective of this working task is to provide a detailed depiction of future RES opportunities up to 2050 within the European Union, considering deployment of RES technologies in EU Member States under different RES policy assumptions. Complementary to this, the assumed corresponding global RES deployment – i.e. more precisely the exploitation of RES technologies in the rest of the world (ROW) – and the related export opportunities for European economies are discussed then subsequently in section 5.

Scenario results based on Green-X model runs for the EU-28 will be included at a later stage. Since important input parameter for the RES-related modelling work is pending (i.e. data on energy demand and prices will be provided by forthcoming PRIMES scenarios from the impact assessment of Europe's 2030 strategy) the Green-X scenario calculations on RES deployment within Europe according to selected RES policy pathways could not be launched as originally envisaged.

4.1 Approach, assumptions, inputs and brief description of Green-X model

The Green-X model is used for a detailed quantitative assessment of the future deployment of renewable energies within the European Union on country-, sectoral- as well as technology level. A short characterisation of the model is given below, whilst a detailed description is included in the Annex of this report.

Short characterisation of the *Green*-X model

The Green-X model is used in this study to perform a detailed assessment on the future deployment of renewable energies in the European Union. The Green-X model is a well known software tool with respect to forecasting the deployment of RES in a real-world policy context. This tool has been successfully applied for the European Commission within several tenders and research projects on renewable energies and corresponding energy policies, e.g. FORRES 2020, OPTRES, RE-Shaping, EMPLOYRES, RES-FINANCING and has been used by Commission Services in the "20% RE by 2020" target discussion. It fulfils all requirements to explore the prospects of renewable energy technologies:

- It currently covers geographically the EU-27 (all sectors) as well as Croatia, Switzerland, Norway (limited to renewable electricity) and can easily be extended to other countries or regions.
- It allows investigating the future deployment of RE as well as accompanying generation costs and transfer payments (due to the support for RE) within each energy sector (electricity, heat and transport) on country- and technology-level on a yearly basis up to a time-horizon of 2030 (2050).

The modelling approach to describe supply-side generation technologies is to derive dynamic cost-resource curves by RE option, allowing besides the formal description of potentials and costs a suitable representation of dynamic aspects such as technological learning and technology diffusion.

It is perfectly suitable to investigate the impact of applying different energy policy instruments (e.g. quota obligations based on tradable green certificates, (premium) feed-in tariffs, tax incentives, investment subsidies) and non-cost diffusion barriers.

Within the Green-X model, the allocation of biomass feedstock to feasible technologies and sectors is fully internalised into the overall calculation procedure, allowing an appropriate representation of trade and competition between sectors, technologies and countries. Moreover, Green-X was recently extended to allow an endogenous modelling of sustainability regulations for the energetic use of biomass.

Within Green-X a broad set of results can be gained for each simulated year on a country-, sector and technology-level:

- RE generation and installed capacity,
- RE share in total electricity / heat / transport / final energy demand,
- Generation costs of RE (including O&M),
- Capital expenditures for RE,
- Impact of RE support on transfer costs for society / consumer (support expenditures),
- Impact of enhanced RE deployment on climate change (i.e. avoided CO2 emissions)
- Impact of enhanced RE deployment on supply security (i.e. avoided primary energy)

Green-X database:

The input database of the Green-X model provides a detailled depiction of the past and present development of the individual RES technologies - in particular with regard to costs and penetration in terms of installed capacities or actual & potential generation. Besides also data describing the technological progress such as learning rates is available which serves as crucial input to further macro-economic analysis.

Investigated cases

First, an overview is given on the investigated scenario paths and cases. Please note that, geographically, all Green-X scenarios refer to the European Union as of 2013, comprising

28 member states. Results on RES deployment and accompanying parameters such as additional generation cost, transfer cost due to RES support etc. are derived on a yearly basis covering the time horizon 2010 to 2050. Obviously, the RES policy pathway for the years up to 2020 appears well defined given the EU RES directive 2009/28/EC and the corresponding national 2020 RES targets and accompanying National Renewable Energy Action Plan's for the period up to then. Exploring the RES development beyond 2020 means to enter a terrain characterized by a higher level of uncertainty – both with respect to the policy pathway as well as with regard to potentials and cost for applicable RES technology options. The table below summarises the general settings of all scenarios agreed in particular with respect to ambition levels and targets for 2030.

Table 4-1 Overview of Green-X scenarios

Scenario Name	**Description**
No-policy scenario	Stop of all RES policies as of 2020, no new targets beyond 2020, No ETS
BAU-scenario	Continuation of current RES policies but no new targets for 2030 in alignment to PRIMES reference scenario (i.e. phase-out of RES support beyond 2020)
Policy case 1a (30% SNP)	Policy based on structure of energy and climate package, 30% RES target for 2030 (40% GHG); EE~ -29% in 2030
Policy case 1b (30% QUO)	EU green certificate scheme for RES-E, 30% RES target for 2030 (40% GHG),EE~ -33% in 2030;
Policy case 2a (35% SNP)	Policy based on structure of energy and climate package, 35% RES target for 2030 (45% GHG), EE~ -29% in 2030;
Policy case 2b (35% QUO)	EU green certificate scheme for RES-E, 35% RES target for 2030 (45% GHG)EE ~33% in 2030;

5 Scenarios on future global RES markets as basis for the macroeconomic modelling

Different scenarios have been defined for the deployment of and support policies for RES technologies in the EU (see previous section 4). Once quantitative outcomes are available, they will provide the scenario basis for the macroeconomic modelling. To form a sound basis for the subsequent macroeconomic modelling, these scenarios are combined with assumptions on

- RES deployment in the rest of the world (ROW) and
- projections on export opportunities for European economies.

Assumptions on RES deployment in the rest of the world are according to the IEA's World Energy Outlook 2013 (see section 5.1 below). The projections on export opportunities for European economies are calculated by the ISI Lead Market Model, relying on export shares in complementary economic sectors and patent share (from the ISI Lead Market database) and on present world market shares from MULTIREG (see section 5.2).

In addition to these scenarios, a number of sensitivity analyses are being carried out with regards to the global deployment of RES technologies, fossil energy prices and fossil energy demand, projections on the market development of RES technologies of European economies and technological learning (see section 5.3).

5.1 Global RES deployment based on the IEA world energy outlook

Prospects for RES technologies will be presented in this study at a global level, illustrating the feasible deployment of these technologies by means of scenarios depending on the applied energy policies. These future projections will be based on the IEA "World Energy Outlook 2013"[14] which is published in November 2013.

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14 International Energy Agency (2007). World Energy Outlook to 2030 – 2007 edition. International Energy Agency, Paris, France.

5.2 ISI Lead Market database as basis of the export projections for RES technology

5.2.1 Lead markets and RES technologies

Globally successful innovations have commonly been established first in one country or region before being adopted internationally (Beise 997-1018). Countries in which these innovations have evolved can be described as lead markets. It is said that they have a “first mover advantage.” A lead market therefore is the origin of the diffusion of a newly developed technological solution. It is a market in which the demand for such a technology is higher than in other countries, in which firms can grow and realise cost advantages or technological leadership, providing them an advantage on the international market for that technology.

Due to their special characteristics, lead markets provide the opportunity to keep those parts of an enterprise with a relatively high part of the value creation - like research and development - in one country in the long run. If environmental policy contributes to the development of a lead market it thus aligns itself with industry policy. In case of the successful diffusion of an environmentally sound technology, such as renewable energy technology, additionally positive effects for the environment are created.

Lead market ability of RES technologies

One prerequisite for an ambitious EU RES policy to lead to additional exports is the lead market ability of RES technologies. The potential to establish a lead market is given if the technology fulfils the following three criteria:

- high knowledge-intensity: In general, the technology intensity of renewable technologies can be judged as being above average or high tech, e.g. photovoltaics (see Grupp 1998).
- high innovation dynamics: It can be observed that the patent dynamics for renewable energy technologies show an impressive push, which has been characterised by substantially higher patent growth rates than the average increase in patents (Figure 5-1). This holds especially for on- and off-shore wind energy technologies, which have experienced a patent growth even above the average of RES technologies, followed by photovoltaics.
- high potential learning effects: e.g. the latest Japanese Delphi study reveals that above average learning effects are expected for renewable energy technologies.

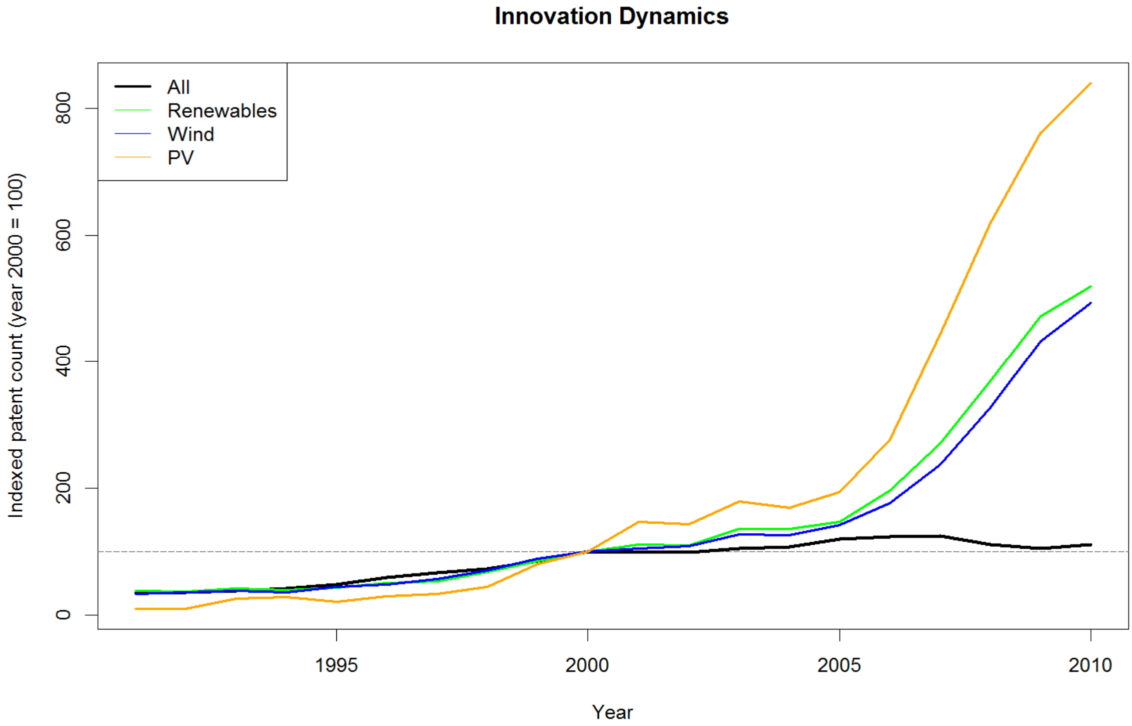

Figure 5-1 Innovation dynamics for renewable energy technologies
Source: calculations of Fraunhofer ISI

Comparative Lead Market Factors for RES technologies

The following factors have to be taken into account when assessing the potential of countries to be successful on international markets based on the innovation potential (Walz 2006; Walz and Krail 2011):

- Market conditions on the demand side
- Market conditions on the supply side
- System aspects of actors and their networks,
- Technological competences,
- Innovation friendliness of regulation.

A very important mechanism on the demand side is called price advantage by Beise (2004). With growing demand, economies of scale drive the costs of the technology down. Thus, it is the dynamic of the home market which drives this effect.

It follows from the discussion on lead market factors that the diffusion of the respective technologies is important for cost and price advantages. Thus, the diffusion patterns influence the cost advantages of countries based on both economies of scale and learning.

Furthermore, it can be expected that user-producer linkages are increasing if the diffusion of the technology in the (home) market is increasing too. Additional diffusion therefore also leads to the improvement of future technological capability.

There are also two factors on the supply side of the market: The transfer advantage is based on a kind of demonstration effect. If countries show a high level of successful technological applications, they will find it easier to export their products. The export advantage results from the degree to which the preferences in one country are similar to the preferences on the world market. Thus, countries which take the preferences of a wide spectrum of countries into account in designing their technologies will enjoy an export advantage compared to countries which are looking only towards one particular market. The export and transfer advantages are difficult to assess with indicators. However, it can be assumed that already existing export success also backs these two factors. Thus, there is a path dependency in the market performance, with past success making it easier to obtain future success. Clearly, the market shares found in the past also continue to influence the market shares in the future. In order to evaluate the export advantage Cleff et al. (2012) suggest using the distribution of exports to the largest markets at the overall exports of the country analysed.

Improving a country's position in quality competitiveness also depends on the structure of the innovation system. Powerful economic actors are required, which the innovations. In addition to size and skill of individual actors, functioning networks and coordination along the value chain are additional characteristics. It is widely held that innovation and economic success also depend on how a specific technology is embedded into other relevant industry clusters. Learning effects, expectations of the users of the technology and knowledge spillovers are more easily realized if the flow of this (tacit) knowledge is facilitated by proximity and a common knowledge of language and institutions. The results of Fagerberg (1995b) can be explained in this way. He found strong empirical evidence that the international competitiveness of sectors and technologies is greatly influenced by the competitiveness of interlinked sectors. By and large, renewable technologies have very close links to machinery and electronics. Thus, it can be argued that countries with strong production clusters in these two fields have a particularly good starting point for developing a first-mover advantage for renewable energy technologies, especially because success in these clusters also contributes to an export and transfer advantage. Figure 5-2 gives an indication of the competitiveness in these sectors by looking at the export shares for EU countries/regions and the rest of the world. It becomes clear that the EU countries play an important role. If one looks at the export specialisation of the countries, measured by the revealed comparative advantage (RCA), it becomes clear that Japan and the US are also showing positive specialisation on these complementary sectors. For the EU as a whole, there is no clear comparative advantage with regard to competitiveness of complementary clusters.

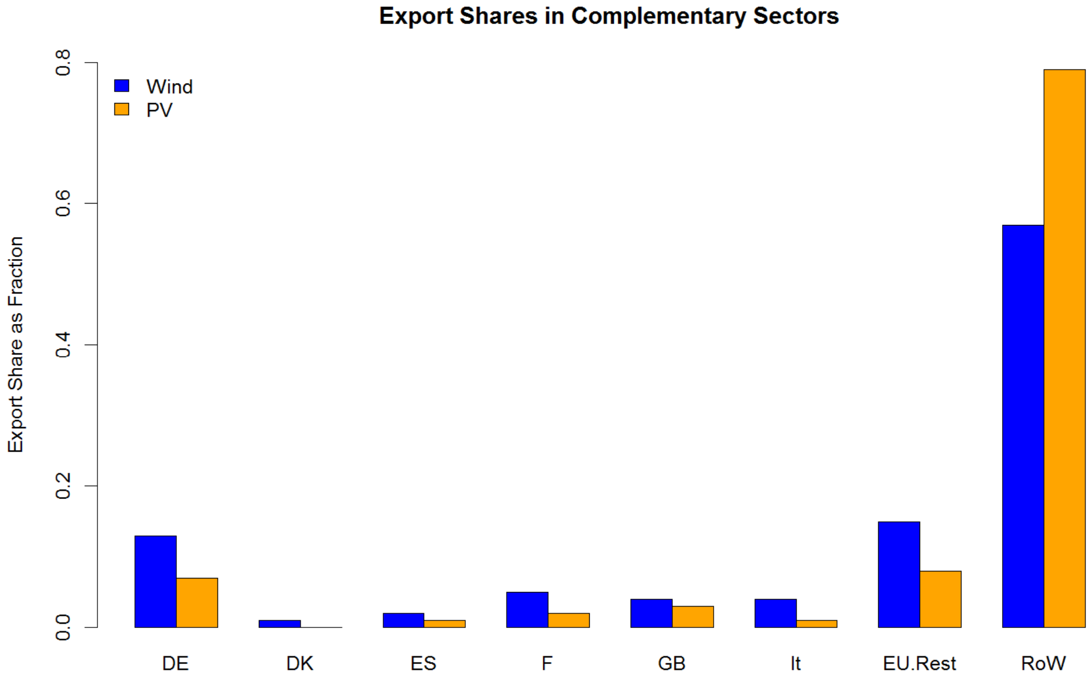

Figure 5-2 Shares of EU countries/ regions and the rest of the world (RoW) at world exports in complementary sectors to wind energy technologies and PV in 2006
Source: Calculations of Fraunhofer ISI

It has become increasingly accepted that international trade performance depends on technological capabilities (for an overview see Dosi and Soete 1990, Fagerberg 1995 or Wakelin 1997). Thus, indicators which measure technological capability are also important with regard to technological competitiveness. The empirical importance of these indicators for trade patterns has been repeated in various publications (Amable/Verspagen 1995; Wakelin 1998; Sanyal 2004; Lachenmaier and Wössmann 2006; Andersson and Ejermo 2008; Madsen 2008). Madsen (2008) underlines the importance especially of transnational patents.

A country has an additional advantage in developing future technologies if it has a comparatively high knowledge base. Thus, patent indicators such as share of patents or specialisation indicators such as the Relative Patent Advantage (RPA) are among the most widely used indicators to measure technological advantages. The data clearly shows that there are strong differences between wind energy technologies on the one hand and photovoltaics on the other. Europe clearly is the leader in the first, but must catch up at the latter.

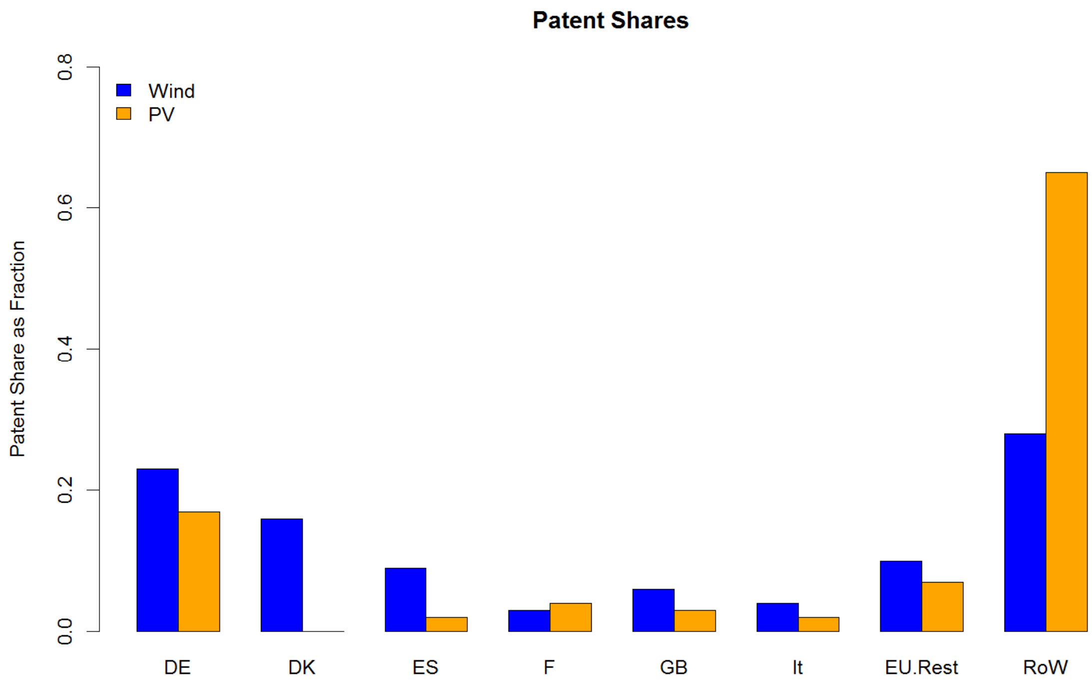

Figure 5-3 Shares of EU countries/ regions and the Rest of the World (RoW) at patents in wind energy technologies and PV in 2006
Source: Calculations of Fraunhofer ISI

Regulation which at the same time is innovation-friendly and sets the example for other countries to follow the same regulatory path is another important factor (Beise and Rennings 2005; Walz 2007). This relates to different aspects: First, the demand depends very much on the extent by which regulation leads to a correction of the market failures which consists in the externality of the environmental problems (Rennings; 2000). Second, the regulation should signal the direction of further innovations, and should be open to diverse technical solutions, which increase the chance that they fit into the preferences of importing countries. Third, the national regulation should set the standard for the regulatory regime, which other countries are likely to adopt.

The lead market factors differ with regard to availability of indicators to measure them. Thus, in addition to base the assessment of lead market potential on indicators it will be necessary to factor in qualitative assessment, based on expert judgements. Furthermore, some factors depend strongly on the diffusion of RES technologies, such as price and costs effects, or transfer advantage. Thus, there is a direct link to the scenarios for world market shares for RES technologies.

5.2.2 Scenarios for world market shares for RES technologies

It has been shown that especially wind energy technologies (on- and off-shore) and photovoltaics have a considerable above average innovation dynamics. Thus, for these three technologies, the scenarios for market shares will be explicitly built on the lead market considerations sketched out above. For the other renewable technologies, the market shares and exports of the base year, which are analysed in section 5, will be projected according to the results of the macro-models for the underlying sectors, which are modelled endogenously in both ASTRA-EC and NEMESIS.

For the three technologies wind on-shore, wind off-shore and photovoltaics, detailed market share scenarios will be developed. They follow the general scenario assumptions outlined in section 4.1. The underlying forces which influence market shares in the BAU and the ADP scenarios develop similarly for both the EU countries and the Rest of the World. Therefore, the market share scenarios do not differ between the EU and the Rest of the World. However, there clearly are uncertainties, e.g. with regard to the relative improvement in the innovation system for renewable energy in the EU compared to the Rest of the World, or with regard to the comparative advantage in the regulatory system.

In order to develop the scenarios, comparative lead market factors for the EU countries – in comparison to the Rest of the World – for the market share already achieved, diffusion of the three RES technologies in the home market, patent share and export share of the complementary sector will be used as a starting point. Based on the indicator values for these variables for each year in the projected period, the market share will be projected for each year. This dynamic projection scheme has the advantage that the phase of changes in the world market share is consistent with the changes in the underlying forces.

5.3 Sensitivity Analyses

To test the robustness of the model results and validate the scenario findings, a number of additional scenarios are analysed. While ultimately most assumptions could be tested, the sensitivity analyses focus on four major points:

- Global deployment of RES technologies
- Development of fossil energy prices and energy demand

- Development of market shares of EU in the global RES technology markets
- Technological learning

Table 5-1 shows the different cases for the sensitivity analyses. Cases in orange represent the assumptions in the main analyses, cases in white represent the sensitivity cases. The assumptions in the main analyses represent moderate assumptions on the different factors. The sensitivity analyses are used to model rather extreme cases to test the robustness of the results.

Table 5-1 Sensitivity analyses

Sensitivity	cases	models affected
Global RES deployment	IEA current policies	MULTIREG, ASTRA, NEMESIS
	IEA new policies	
	IEA 450ppm	
Fossil energy prices and energy demand	high prices/ high energy demand	Green-X, MULTIREG, ASTRA, NEMESIS
	moderate prices/ moderate demand	
	low prices/ low demand	
EU share in global RES markets	optimisitic	Lead Markets, MULTIREG, ASTRA, NEMESIS
	moderate	
	pessismistic	
Technological learning	high progress ratios	Green-X, MULTIREG, ASTRA, NEMESIS
	moderate progress ratios	

6 Future gross effects of RES

This section will be included after quantitative results from section 5 are available.

7 Net economic impact and net employment effects

7.1 Main inputs of the macroeconomic models

The inputs introduced in NEMESIS are the same as for the ASTRA-EC model:

- National RES investment and avoided investment by economic sector
- Exports and imports (including avoided for both) by economic sector
- Operation and maintenance costs and avoided operation and maintenance costs by economic sector
- Fuel demand and avoided fuel demand
- Electricity price variation by broad categories (households, industry and services)
- Agriculture and forestry demands.

The inputs by economic sector are then allocated to the economic sectors in the model, and the increase of electricity price is translated into the different price equations of the different economic sectors and categories for households.

In order to have a clearer idea of the impulses implemented in the NEMESIS and ASTRA-EC model we can calculate the ex-ante push as follows:

$$PUSH_{c,s} = INVNATRES_{c,s} - INVNATavoid_{c,s} + FUEDEM - FUEDEMAV$$
$$+ EXPRES_{c,s} - IMPRES_{c,s} + OPMAINRES_{c,s} - OPMAINavoid_{c,s} + AGRIRES$$

With:

- $PUSH_{c,s}$ the ex-ante push in country c and sector s
- $INVNATRES_{c,s}$ the national investment in RES
- $INVNATavoid_{c,s}$ the investment avoided by RES deployment
- $EXPRES_{c,s}$ the exports of RES by country c and sector s
- $IMPRES_{c,s}$ the imports of RES
- $OPMAINRES_{c,s}$ the operation and maintenance cost induced by RES deployment
- $OPMAINavoid_{c,s}$ the operation and maintenance cost avoided by RES deployment
- $FUEDEM - FUEDEMAV$ fuel demand minus avoided fuel demand
- $AGRIRES$ the additional demands for agriculture and forestry sectors

RES deployment will have several direct or indirect GDP and employment effects on European economies.

- Positive effects
  - At first, the investment push will act as a traditional Keynesian multiplier by increasing demand for the producing sectors, although countries benefit to a different extent from these new investments.
  - The operation and maintenance costs, that are often labour-intensive, are mainly of a national nature and all RES deploying countries will benefit from them.
  - The development of RES positively affects employment and growth in the agriculture and forestry sector. Most countries' agricultural and forestry sector stands to benefit, but to a varying degree depending on the significance of agriculture in the national economy.
- Negative effects
  - The avoided investments in conventional energy reduce the positive effect of the RES investments.
  - The development of RES implies an increase in energy prices (mainly for electricity); this price effect could have some limiting effects on consumption, investment and on competitiveness.
  - The fuel demand will also decrease, penalising some energy sectors such as the “refined oil” and gas “distribution” sectors.

7.2 NEMESIS model

7.2.1 Model approach and key assumption of NEMESIS

NEMESIS general overview

The NEMESIS model is based on detailed sectorial models for each of the EU-27 (Croatia, is on-going). Each model starts from an economic framework which is linked to an energy/environment module. The construction and the description of macro-economic pathway established by the NEMESIS model could be viewed as a "hybrid", *i.e.* "bottom-up" forces resulting from sectorial dynamics and interactions and "top-down" ones coming from macro-economic strength (labour force, international context, financial aspects, etc.). The sectorial interactions come not only from input/output matrix but also from more innovative exchange matrix: knowledge spillovers matrix based on patent data and fed by R&D investments.

Mechanisms

On the supply side, NEMESIS distinguishes 30 production sectors..Production in sectors is represented with CES production functions with 5 production factors: capital, low skilled labour, high skilled labour, energy and intermediate consumption. Interdependencies between sectors and countries are finally caught up by a collection of convert matrices describing the exchanges of intermediary goods, of capital goods and of knowledge in terms of technological spillovers, and the description of substitutions between consumption goods by a very detailed consumption module enhance these interdependencies. Furthermore, the energy/environment module computes (*i*) the physical energy consumption by ten different products through CES functions and (*ii*) CO_2 emissions.

On the demand side, representative households' aggregate consumption is dependent on current income, population structure, etc. Consistent with the other behavioural equations, the disaggregated consumption module is based on the assumption that there exists a long-run equilibrium but rigidities are present which prevent immediate adjustment to that long-term solution. Altogether, the total households aggregated consumption is indirectly affected by 27 different consumption sub-functions through their impact on relative prices and total income, to which demographic changes are added

For external trade, it is treated in NEMESIS as if it takes place through two channels: intra-EU, and extra-EU trades. The intra- and extra-EU export equations can be separated into two components, income and prices. The stock of innovations in a country is also included in the export equations in order to capture the role of innovation (quality) in trade performance and structural competitiveness.

The overall main mechanisms of the NEMESIS model are presented in Figure 7-1.

Main Output

Beyond economic indicators as GDP, prices and competitiveness, employment and revenues, NEMESIS energy/environment Module gives detailed results on energy demand by source and sector, on electricity mix and on CO_2 and GHG. The inclusion in the model of detailed data on population and working force, allows also the model delivering many social indicators as employment by sectors and skills, unemployment by skills, etc.

Main Uses

NEMESIS can be used for many purposes as short and medium-term economic projections; analysing Business As Usual (BAU) scenarios and economy long-term structural change, research and innovation policies, energy supply and demand, environment and more generally sustainable development. NEMESIS is regularly used to study BAU as well as alternative scenarios for the EU in order to reveal future economics, environmental and societal challenges (projections of sectorial employment, short and medium-term economic path, long-term economic path, etc). It is also used for policies assessment in terms of research and innovation (Horizon 2020, FP7, 3% GDP RTD objective, etc), environment and energy policies (European climate mitigation policies, nuclear phasing-out in France, etc).

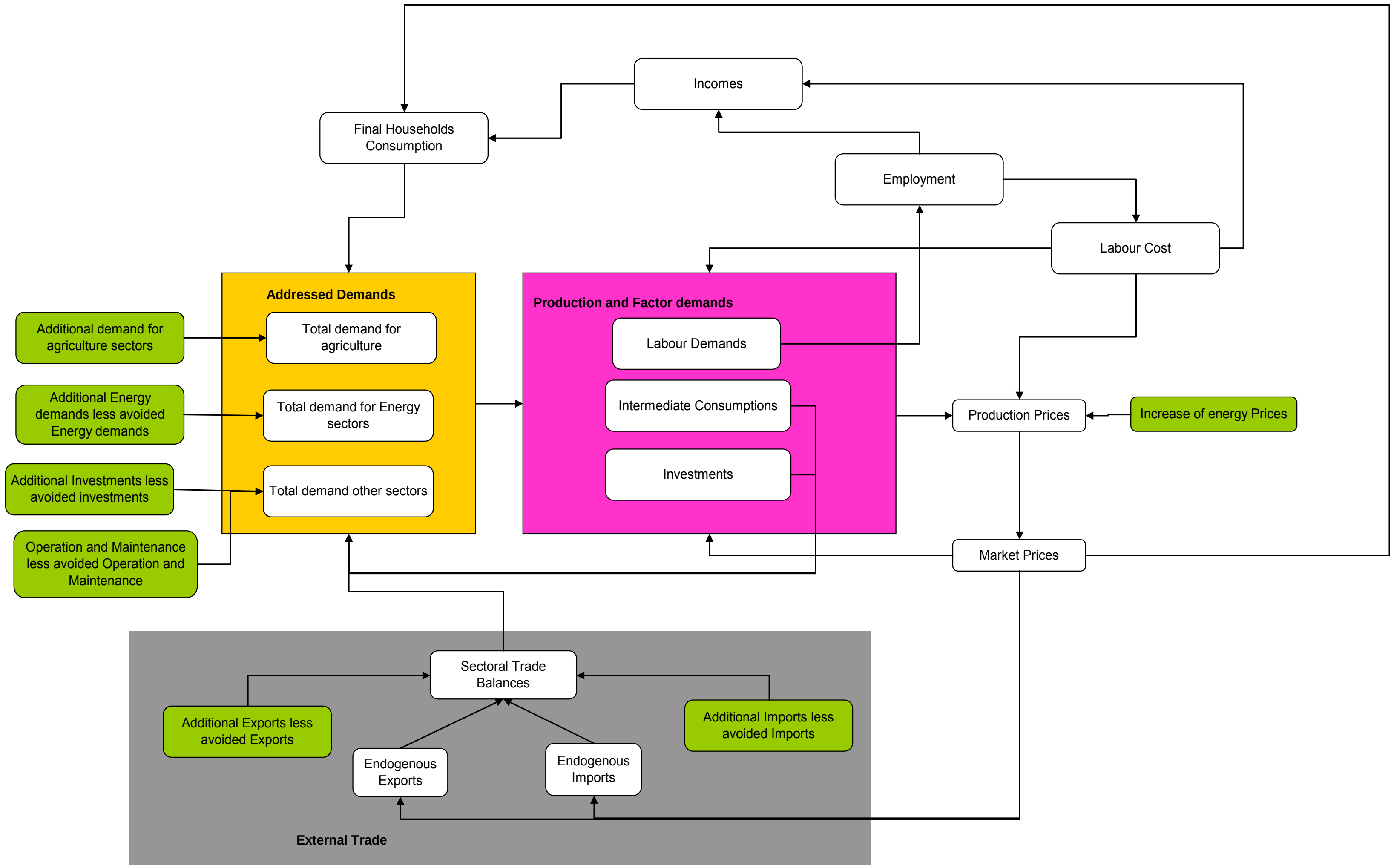

Figure 7-1 The NEMESIS model and its links with bottom-up models

Within the Employ-RES project, a bridge had to be constructed between the NEMESIS model, the Green-X and MULTIREG models. These interactions are shown in Figure 7-1 above. The deployment of RES technologies will impact the NEMESIS model in many ways that can be separated into direct and indirect effects.

Direct effects

At first, the additional investment demands for RES from the Green-X output will act the part of a traditional Keynesian multiplier, increasing the demand in national production sectors mainly for sectors producing investment goods. This positive effect will be reinforced by the additional operation and maintenance due to RES deployment. This deployment will also benefit the agriculture and forestry sectors due to the increasing biomass demand. Regarding the energy sectors, the development of RES technologies will lower the demand for conventional fuels.

However, the development of RES technologies will also result in decreased investment in conventional technologies as well as reduced operation and maintenance for these technologies, hence limiting the initial positive effects.

The direct impact of RES deployment on external trade can be split into two different effects. The first concerns the imports and exports of the global components of RES technologies that are produced by only a few countries. This global component trade is exogenous in the NEMESIS model. The second effect concerns the trade of local components of RES technologies; this part remains endogenous in the model.

Finally, RES deployment will have an impact on the electricity price, increasing the production cost.

Indirect effects

The additional demand in some production sectors will radiate throughout the whole economy in two different ways. At first, in order to produce this demand, firms will have to increase their production factor demands (investment, intermediate consumption), which in turm will lead to a second round effect. Moreover, the increased labour demand will increase households' final consumption in two ways: first by increasing employment, and second, depending on the initial national conditions, by increasing wages and salaries.

The increase in national demand will also be exported to other European economies through external trade.

The total effect of the deployment policies in the different member states will depend on their starting conditions such as,

- existence of sectors producing RES technologies,
- initial conditions on the labour market,
- the agriculture and forestry sector's potential to produce biomass,
- the external trade structure,
- national competitiveness,
- the different elasticities of substitution between the production factors,
- the substitution elasticities in the different consumption categories for households.

The total effect of the deployment policies also depends on the assumption about the evolution of external trade. The study integrates two different assumptions about external trade in each scenario: one with a moderate assumption (ME) and another with an optimistic assumption (OE).

This section presents the main NEMESIS results of the different RES policies. The results of the NEMESIS model are highly dependent on the primary impulses received from the Green-X model. The main difficulty in interpreting such results is that the impulses introduced in the model are very dynamic, and as a consequence, the traditional behaviour and causality chains of the model are sometimes difficult to interpret.

The results of the NEMESIS model will be presented as follows:

- ...

In order to present the results of the model more clearly, we will also portray the basic impulses introduced in the NEMESIS model for each scenario. The macro model results are presented at European level first, then at member state level and at a sectoral level.

7.2.2 Impulses for the policy scenarios

The objective of this study is to analyse and compare different RES policies scenarios. This section describes the methodology and scenarios used in the model to accomplish this objective.

As shown in Figure 7-1, the implementation of RES policies in the NEMESIS model requires inputs from the Green-X and MULTIREG models; these include:

- Additional investments in RES technologies.
- Exports of RES technologies.
- Additional demand in agriculture.

- Additional operation and maintenance costs for RES technologies.
- Avoided imports of fossil energy.
- Imports of RES technologies.
- Avoided investment in conventional technologies.
- Avoided operation and maintenance costs for conventional technologies.
- Electricity price increase.

7.3 ASTRA-EC model

7.3.1 Main model approach and key assumptions

ASTRA-EC stands for Assessment of Transport Strategies. The model has been continually developed since 1997 and is used for the strategic assessment of policies in an integrated way, i.e. by considering the feedback loops between the transport system and the economic system. Since 2004, it has been further extended by a number of studies and linked with energy system analysis, e.g. to analyse the economic impacts of high oil prices (Schade et al. 2008) and of the German climate strategy (Jochem/Jäger/Schade et al. 2008).

The model is based on the System Dynamics methodology, which, similar to NEMESIS, can be seen as a recursive simulation approach. It follows system analytic concepts which assume that the implemented real systems can be conceived as a number of feedback loops that are interacting with each other. These feedback loops are implemented in ASTRA-EC and model covers the time period from 1995 until 2050. The spatial coverage extends over the EU27 countries, plus Norway and Switzerland. Each country is further disaggregated into a maximum of four functional spatial zones based on their settlement characteristics and classified into metropolis zones, high-, medium- and low-density zones. A detailed description of ASTRA-EC can be found in Schade (2005) with extensions described in Krail et al. (2007).

ASTRA-EC-EC consists of different modules, each related to one specific aspect, such as the economy, the transport demand, the vehicle fleet. The main modules cover the following aspects:

- Population and social structure (household types and income groups),
- Economy (including input-output tables, government, employment and investment),
- Foreign trade,

- Transport (including demand estimation, modal split, transport cost and infrastructure networks),
- Vehicle fleet (road),
- Environment (including pollutant emissions, CO2 emissions, fuel consumption).

An overview on the modules and their main linkages is presented in Figure 7-2. From the figure, it is apparent that modules are not independent, but linked together in manifold ways. A short description of the modules and their main links is provided below followed by a closer look at the two modules most relevant for EMPLOY-RES II.

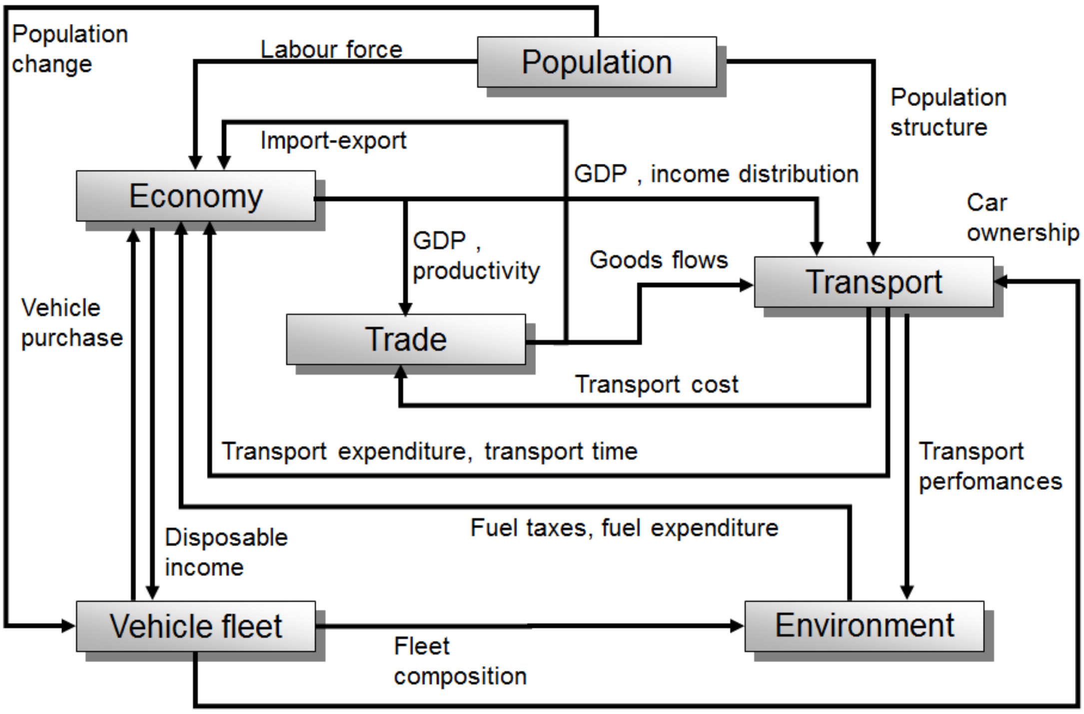

Figure 7-2 Overview of the ASTRA-EC model modules
Source: TRT/ Fraunhofer ISI

The economic modules implemented in ASTRA-EC reflect the view of the economy as constructed of several interacting feedback loops (e.g. income – consumption – investment – final demand – income loop, the trade – GDP – trade loop etc.). These feedback loops are comprised of separate models which do not refer to only one specific economic theory. Investments are partially driven by consumption following Keynesian thought, but exports are added as a second driver of investment. Neoclassic production functions are used to calculate the production potential of the 29 national economies. Total factor productivity (TFP) is endogenised following endogenous growth theory by considering sectoral investment and freight travel times as drivers of TFP.

7.3.2 Relevant Modules for the project

The following two sections briefly describe the modules/models relevant for the economic analysis applying ASTRA-EC in the project.

7.3.2.1 Macro economy

The macroeconomics module (MAC) provides the national macroeconomic framework. The macroeconomics module is made up of six major elements. The first is the sector interchange model that reflects the interactions between 25 economic sectors of the 29 national economies. Demand-supply interactions are considered by the second and third element. The second element, the demand side model, depicts the four major components of final demand: consumption, investments, exports-imports and government consumption.

The supply-side model reflects the influence of three production factors: capital stock, labour and natural resources as well as the influence of technological progress that is modelled as total factor productivity. Endogenised Total Factor Productivity (TFP) depends on sectoral investments, freight transport times and sectoral labour productivity changes weighted by sectoral value added. Investments are involved in a major positive loop since they increase the capital stock and total factor productivity (TFP) of an economy which leads to a growing potential output and GDP that in turn drive income and consumption which feeds back into an increase of investments again. However, this loop may also be influenced by other interfering loops that could disrupt the growth tendency:

1. In ASTRA-EC, the existence of the ‘crowding out’ effect is accepted so that increasing government debt could have a negative impact on investment.
2. Exports, e.g. influenced by RES policy, energy and transport cost, could also change, which in turn would affect investments.
3. Different growth rates between the supply side (potential output) of an economy and the demand side (final demand) change the utilisation of capacity. If demand grows slower than supply, utilisation would be reduced which would also have an effect on investment decisions. Ultimately, investments could decrease.
4. Substantial changes of energy prices could cause inflation, thus reducing real disposable income.

The employment model constitutes the fourth element of MAC based on value-added as the output from the input-output table calculations and labour productivity. The fifth element of MAC describes government behaviour. As far as possible government revenues and expenditures are differentiated into categories that can be modelled endogenously by ASTRA-EC and one category covering other revenues or other expenditures. Categories that are endogenised include VAT and fuel tax revenues, direct taxes, import taxes, social contributions and revenues of transport charges on the revenue side as well as unemployment payments, transfers to retired persons and children, transport investments, interest payments on government debt and government consumption on the expenditure side.

The micro-macro bridges form the sixth and final element comprising the MAC. These link micro- and meso-level models of ASTRA-EC, for instance the transport module or the vehicle fleet module, to components of the macroeconomics module. This means that expenditures for bus transport or rail transport of one origin-destination pair (OD) become part of the final demand of the economic sector for inland transport within the sectoral interchange model. This element also includes the linkages with bottom-up models, e.g. the changes of the energy system modelled by GreenX in EMPLOY-RES II.

7.3.2.2 Trade

The Foreign Trade Module (FOT) is divided into two parts: trade among the 29 European countries (INTRA-EU model) and trade between the 29 European countries and the rest-of-the world (RoW) that is divided into nine regions (EU-RoW model with Oceania, China, East Asia, India, Japan, Latin America, North America, Turkey, Rest-of-the-World). Both models are differentiated into bilateral relationships by country pair and sector.

The INTRA-EU trade model depends on three endogenous and one exogenous factors. World GDP growth exerts an exogenous influence on trade. Endogenous influences are provided by: GDP growth of the importing country of each country pair relation, the relative change of sector labour productivity between countries and the averaged generalised cost of passenger and freight transport between countries. The latter is chosen to represent an accessibility indicator for transport between countries. In EMPLOY-RES II, the RES trade of selected technologies (e.g. wind turbines) stimulated by the policies is fed in exogenously into the trade model as the trade patterns of these RES technologies differ significantly from the modelled sectoral trade, e.g. of the machinery sector, while for other technologies (e.g. boilers for biomass), the trade patterns are derived directly from the ASTRA-EC model.

The EU-RoW trade model is mainly driven by the relative productivity between the European countries and the rest-of-the-world regions. Productivity changes together with GDP growth of the importing RoW-country and world GDP growth drive the export-import relationships between the countries. RES exports stimulated by ambitious RES policies in Europe and estimated by the lead market model in EMPLOY-RES II are added exogenously to the ASTRA-EC trade model.

The resulting sectoral export-import flows of the two trade models are fed back into the macroeconomic module as part of final demand and national final use, respectively.

7.3.3 Treatment of RES-Deployment

ASTRA-EC incorporates micro-macro-bridges from the bottom-up transport system models to the economy. For the EMPLOY-RES II project, the micro-macro-bridges from the bottom-up energy system model to the economy also have to be established. This was achieved by linking ASTRA-EC with the Green-X and MULTIREG models. These linkages and their further take-up in the economic models of ASTRA-EC are presented in Figure 7-3.

Broadly speaking, the impacts from the energy system and thus from RES policies can be divided into those on (1) consumer demand, (2) the production of goods and services, and (3) the trade balance of the 29 economies. Consumer demand is directly affected by the higher energy prices via the budget effect (more money spent on energy and thus less money for other sectors) and the substitution effect (prices of goods and services change differently as a reaction to higher energy prices and, depending on energy content and elasticities, the sectoral consumer demand will be restructured, i.e. if energy prices increase, more energy-intensive goods and services will be substituted by less energy-intensive ones).

The production of goods and services reacts in two ways: first, the adaptation of the energy system estimated by Green-X leads to additional investments in RES energy technologies and to avoided investments in conventional energy technologies. Second, changes of energy prices affect the exchange of intermediate goods in the input-output-table. The latter impact is then felt on the value-added of each sector, employment and finally the GDP from the supply side, while the direct impacts on the consumer side and to some extent also the additional demand for investment goods also affect the GDP on the demand side.

Thirdly, the direct impacts on the trade balance have to be considered. These are twofold: First, reductions of energy imports in the energy sector have a positive impact on the demand side of GDP, as well as increase the value-added of the energy sector. Second, trade of RES technologies within the EU and from the EU to the rest of the world alter the national trade balances.

Figure 7-3 illustrates the bottom-up inputs of the energy sector from the Green-X and MULTIREG models that provide the micro-macro bridges from the energy sector to the macro economy.

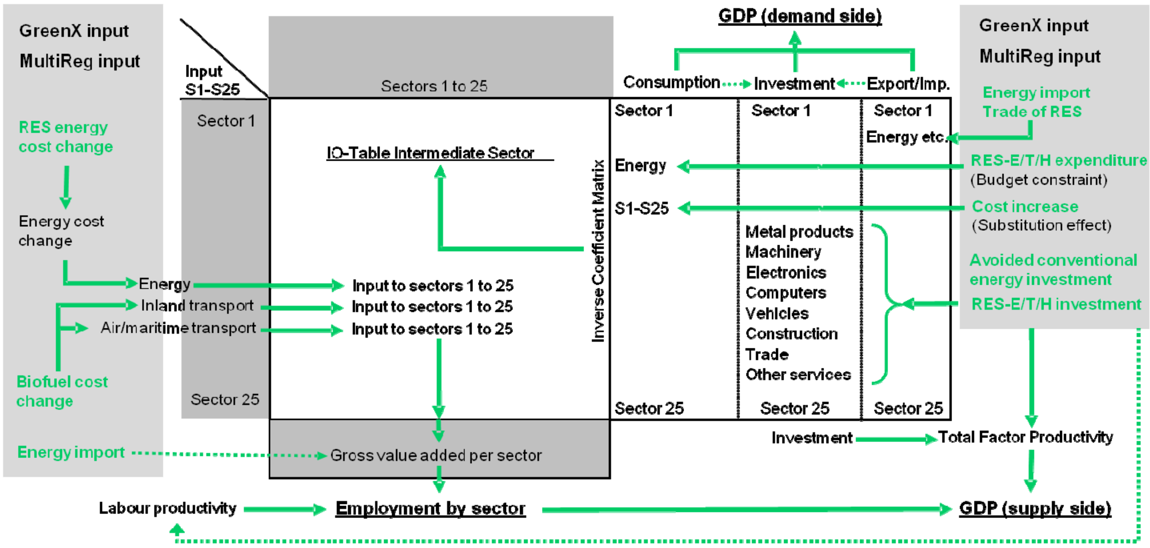

Figure 7-3 Inputs to ASTRA-EC from the bottom-up analysis of RES policies from the GreenX and MULTIREG models
Source: Fraunhofer ISI

The economic outcome of the RES policies in the different countries depends on the countries' specific characteristics with respect to renewable technologies and their specific economic characteristics which are reflected in the ASTRA-EC model or the bottom-up inputs into ASTRA-EC. Among the important characteristics are:

- The existence of a domestic industry producing renewable technology.
- The potential to produce biomass.
- The competitiveness to export renewable technology.
- The existing energy system and cost of energy in a country.
- The elasticity of consumers and industry in responding to energy price changes.
- The level of (un-)employment which affects the reaction of the labour market.
- The productivity effect of investments in renewables compared with the productivity effect of other investments.

- The inter-industry structure, in particular the input-output relations of the energy sector and the major sectors producing renewable technologies, i.e. machinery, electronics, construction, computers and metal products.
- The trade relationships among EU countries, i.e. growth in one EU country can lead to growth in other countries via imports.

8 Comparison of the model results and conclusions about the economic effects

9 General conclusions of the study