The toolbox *Green-X*

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Short characterisation of the toolbox *Green*-X[1]

Country/Area coverage	EU-15 Member States Note, all detailed results are available on country-level. In an extended version the 10 new Member States, the candidate countries Bulgaria and Romania as well as Swiss and Norway are available. A further extension is planned for other neighbouring States such as e.g. Balkan countries.
Requested Inputs	As model inputs two major items are requested: **Primary energy prices** and **policy instrument settings** – both in a dynamic context. Furthermore, a **default forecast of the electricity demand** on country-basis is needed. Optional, if to be considered, a demand forecast for (grid-connected) heat is of need. In addition, **dynamic parameters** (with impact on technology-specific market penetration and cost development) can be adapted. In more detail, the following inputs are requested: Regarding **primary energy prices**: **Forecasts (up to 2020) of primary energy prices** are of need for all fuel-based supply-side generation options **on a country-level**. Thereby, the following classification has been applied: • Fossil fuels - including: – Fuel oil – Natural gas – Brown coal / lignite – Hard coal • Biomass fractions – including: – Forestry products (wood) – Forestry residues (bark, sawmill by-products) – Agricultural products (energy crops) – Agricultural residues (straw etc.) – (Biogenic fraction of) waste (MSW+ISW) – Biogas – Landfill gas

[1] Please note, the following characterisation of the toolbox ***Green*-X** refers to the extended version which will be available at the end of the research project in October 2004.

Up to now, a preliminary version of the model is available and has been used within this study to carry out the analysis with its clear focus on renewable energy sources! In more detail, the sub-tool calculating the impact of various promotion strategies on the development rates of RES-E, the cost assessment (generation costs, costs for customers) of various strategies is available at present. Other sub-tool of the model ***Green*-X**, like analysing interactions of RES-E with the conventional power market, demand-side measures, CHP strategies, complex climate change strategies, and electricity flows (import / export balances) within a liberalised power market considering grid restrictions are not applied for this analysis. However, a detailed investigation can be offered in a later stage.

- Sewage gas

Note, default figures are available for biogenous fuels in the database of the model ***Green*-X**.

Regarding **policy instrument settings**: These settings represent, beside the supply-side and demand-side structural database, the major input for the dynamic simulation model. In more detail, instruments are categorized as follows:

- General taxes – including:
  - Energy taxes (to be applied to: electricity, heat, lignite / brown coal, hard coal, gas, fuel oil)
  - Environmental taxes (on emissions of: CO_2, SO_2, NO_x, dust)
- Promotion instruments for RES and conventional options in the field of electricity generation - including:
  - Price-driven strategies (Feed-in tariffs, tax incentives, investment subsidies, subsidies on fuel input)
  - Demand-driven strategies (Quota obligations based on tradable green certificates (incl. international trade), tendering schemes, voluntary green pricing)

  Note, all instruments can be applied to all RES and conventional options separately. In addition, separate settings can be selected for combined heat and power. With respect to nuclear power plant pre-defined phase-out scenarios can be also investigated.
- Demand-Side-Measures (DSM): Instruments to reduce the demand for electricity (i.e. quota obligations, tax incentives, investment subsidies) can be applied on a sectoral level
- Climate Policy: Trading of emission allowances on both national and international level can be analysed.

Note, all instruments can be set for each country individually. Furthermore, all settings can be changed in a dynamic context (i.e. for each year of the simulation). Of course, all default settings refer to actual implemented energy policy strategies (business-as-usual).

With respect to the **electricity demand** a default forecast of the gross national electricity demand has to be provided as model input for the whole investigation-period (i.e. up to 2030). By applying DSM-strategies, default figures will be endogenously adapted.

In addition, **dynamic parameters** with impact on the market penetration of RES and conventional generation options can be selected on a country- and / or technology-level. Among these are e.g. settings describing the dynamic cost development (i.e. learning rates etc.) on a technology level.

Model Outputs and Links

The model ***Green-X*** aims to deliver a broad set of results on a national level as well as per technology for the electricity and – if requested – also for the grid-connected heat sector.

In more detail, model outputs can be categorized as follows:

- General results – including:
  - Installed capacity [MW]
  - Total fuel input electricity generation [TJ, MW]
  - Total electricity generation [GWh]
  - National electricity consumption [GWh]
  - Import / export electricity balance [GWh, % of gen.]
  - Total CO_2-emissions from electricity gen. [Mt-CO_2]
  - Market price electricity (yearly average price) [€/MWh]
  - Market price Tradable Green Certificates [€/MWh]
  - Market price Tradable Emission Allowances [€/t-CO_2]
- Impact on **producer** – including:
  - Total electricity generation costs [M€, €/MWh]
  - Total producer surplus electricity gen.[M€, €/MWh]
  - Total profit electricity generation [M€, €/MWh]
  - Marginal gen. costs per techn. electricity gen.[€/MWh]
- Impact on **consumer** – including:
  - Additional costs due to supply-side promotion strategy [M€, €/MWh]
  - Additional costs due to DSM strategy [M€, €/MWh]
  - Additional costs due to CO_2-strategy total [M€, €/t-CO_2]
  - Additional costs due to CO_2-strategy on electricity price [M€, €/MWh]

Note, as mentioned above all results can be provided on a country- and – if expedient – also on a technology-level.

Short description of model functionality

The toolbox ***Green-X*** consists of:

- A **database**, allowing dynamic changes and calculating potentials and costs of RES-E, CHP and conventional power
- A **dynamic computer model *Green-X*** integrating RES-E, CHP generation, conventional electricity production and the most relevant demand-side activities

The computer model, which forms the essential part of the overall toolbox, allows a comparative and quantitative analysis of interactions between RES-E, CHP, DSM activities and GHG-reduction within the liberalised electricity sector both for the EU as a whole and individual Member States over time by simulating different scenarios. Figure 1 gives an overview on the core elements of the toolbox.

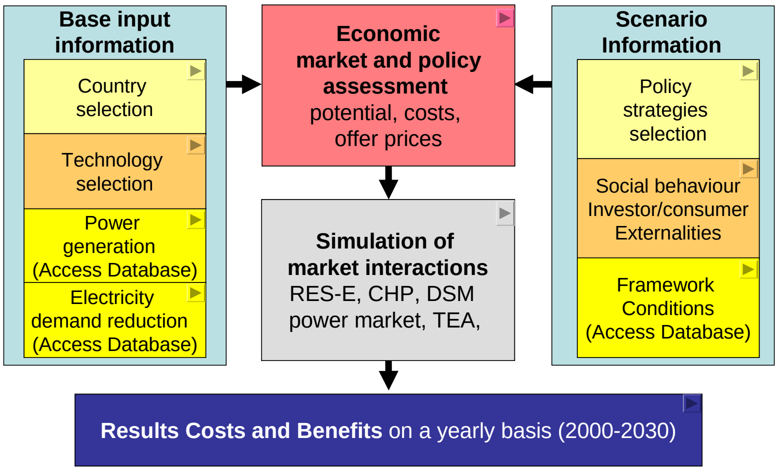

Figure 1 Overview on the toolbox ***Green*-X**

Within ***Green*-X** the general modelling approach to describe **supply-side** generation technologies in case of electricity (and heat) production is to derive *dynamic cost-resource curves* for each generation option in the investigated region.

In principle, the approach consists of two parts:

- The development of *static cost-resource curves* (which describe the relationship between (categories of) technical available potentials (of e.g. wind energy, hydropower) and the corresponding (full) costs of utilisation of this potential) for each RES and conventional generation option on a country-level;
- The *dynamic assessment*, including a dynamic assessment of costs as well as of potential restrictions, in order to derive annual dynamic cost-resource curves.

In more detail, within the first part of deriving static cost-resource curves a clear distinction between already existing plant, i.e. the achieved potential, and new generation options, i.e. the additional mid-term potential, is undertaken.

In the following, the approach will be described for new generation options only.

As mentioned before, static cost-resource curves describe available potentials and the according costs. Thereby, for new plants the economic conditions are described by *long-run marginal costs*. With respect to the potentials, *realisable additional mid-term potentials* have been assessed for each RES and conventional generation category by country. They represent the maximal additional achievable potential up to the year 2030 assuming that all existing barriers can be overcome in a dynamic context and all driving forces are active.

Dynamics are reflected within the model ***Green*-X** on an annual basis. Hence, in order to derive dynamic cost-resource curves for each year, a dynamic assessment of the previous described static cost-resource curves is undertaken. It consists of two parts: The *dynamic cost assessment* and the application of *dynamic restrictions*.

In this context, regarding the dynamic adaptation of costs – in particular investment costs and operation- & maintenance costs – the chosen approach differs by technology. Generally, the model is prepared to include two different approaches: Standard cost forecasts or endogenous technological learning. Default settings have been applied as follows:

- For conventional power generation technologies – as well as some RE technologies – it was decided to adopt well-accepted expert judgements.
- For a set of RE technologies like, e.g. wind power or PV, it was decided to adopt the approach of technological learning. Learning rates were assumed at least for each decade separately.

Next, to derive realisable potentials for each single year of the simulation, dynamic restrictions are applied to the predefined overall mid-term potentials. Thereby, a complex procedure is used which differs by considered restriction. Default figures which can be adapted within the model, are derived from an in-depth assessment of the historical development of the various RES and conventional generation options and their according barriers, which are categorized as follows:

- Industrial barrier: Implemented by application of a growth rate of industry, which limits the annual available potential on an international level;
- Social barrier: For some technologies (e.g. wind) social acceptance is considered as constraint on a national and/or band-level;
- Market and administrative constraints: A high level of bureaucracy (i.e. long leap times) or the existence of a less-transparent market is translated to annual limitation of the available potential on a country-level;
- Technical barrier: Grid constraints are implemented as annual band-specific restriction.

With respect to the **demand-side** in the model ***Green*-X** DSM and their impact on the overall demand for electricity (and e.g. associated GHG emission-reductions) will be considered. In this context, assumptions on the total electricity demand have to be set exogenously.

With respect to the database in principle the same scheme is applied as described for the supply-side. For the practical implementation, however, differences occur. For example, the dynamic parameter assessment on the demand-side is less complex – e.g. existing barriers and obstacles are exogenously given and are not derived within the simulation process (endogenous parameters).

The **general modelling approach** is to derive an **equilibrium between supply and demand** within each considered market segment on a yearly basis. In this context, as already mentioned above, policy instrument settings modify the dynamic cost-resource curves for concerned supply and demand categories.

As ***Green*-X** represents a dynamic simulation tool, the user has the possibility to change policy and parameter settings within a simulation run (i.e. by year). In addition, intermediate results are also accessible.

Basis Principle

The general modelling approach to describe supply-side generation technologies in case of electricity and heat production is to derive so-called *dynamic cost-resource curves* for each generation option in the investigated region. So, for the interesting reader, the basic principle of *static* and *dynamic cost-resource curves* as well as *experience curves* will be explained in the following.

Experience curves

Forecasting technological development is a crucial activity, especially for a long time horizon. Considerable efforts have been made recently to improve the modelling of technology development in energy models. A rather 'conventional' approach relies exclusively on exogenous forecasts based on expert judgements of technology development (e.g. efficiency improvements) and economic performance (e.g. described by investment and O&M-costs). Recently, within the scientific community, this has often been replaced by a description of technology-based cost dynamics which allow endogenous forecasts, at least to some extent, of technological change in energy models: This approach of so-called technological learning or experience / learning curves takes into account the "learning by doing" effect:

In general, experience curves describe how costs decline with cumulative production. In this context, the later is used as an indication for the accumulated experience gained in producing and applying a certain technology. In many cases empirical analysis have proven that costs decline by a constant percentage with each doubling of the units produced or installed, respectively. In general, an experience curve is expressed as follows:

$$C_{CUM} = C_0 * CUM^b \qquad (1)$$

where:

C_{CUM} Costs per unit as a function of output

C_0 Costs of the first unit produced or installed

CUM Cumulative production over time

b Experience index

Thereby, the *experience index (b)* is used to describe the relative cost reduction – i.e. *(1-2^b)* – for each doubling of the cumulative production. The value *(2^b)* is called the *progress ratio (PR)* of cost reduction. Progress ratios or their pendant, the *learning rates (LR)* – i.e. *LR=1-PR* – are used to express the progress of cost reduction for different technologies. Hence, a progress ratio of 85% means that costs per unit are reduced by 15% for each time cumulative production is doubled.

In Figure 2 the characteristic run of an experience curve is illustrated: As indicated, by plotting such a curve on a log-log scale, a straight line occurs. Thereby, the gradient of the line reflects the according learning rate.

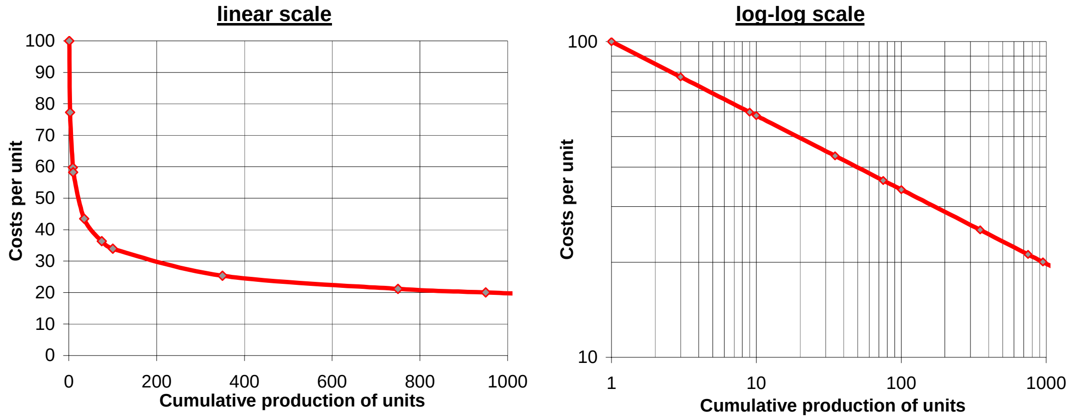

Figure 2 Characteristic run of an experience curve: On a linear (left-hand side) and on a log-log scale (right-hand side)

Note: Parameter settings: LR=15%, C_0=100.

Static cost-resource curves

In general, renewable energy sources are characterised by a limited resource, and – if no cost dynamics are considered – costs rise with increased utilization, as e.g. in case of wind power sites with the best wind conditions will be exploited first, and as a consequence if best sites are gone, rising generation costs appear. On proper tool to describe both costs and potentials represents the (static) cost-resource curve.

In principle, a *static cost-resource curve* describes the relationship between (categories of) technical available potentials (of e.g. wind energy, hydropower, biogas) and the corresponding (full) costs of utilisation of this potential at this point-of-time (Note, no learning effects are included in static cost-resource curves!).

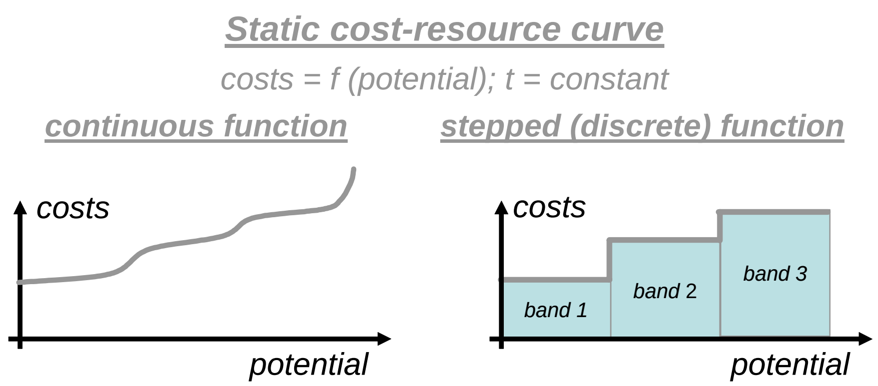

Figure 3 Characteristic run of a static cost-resource curve: Continuous (left-hand side) and stepped function (right-hand side)

On the left-hand side of Figure 3 a theoretically ideal continuous static cost-resource curve is depicted, taking into account that every location is slightly different from each other and, hence, looking at all locations e.g. for wind energy in a certain geographic area a continuous curve emerges after these potentials have been classified and sorted in a least cost way. The stepped function as shown on the right-hand side of Figure 3 represents a more practical approach as in real life the accuracy as needed for a continuous design is impossible. Thereby, sites with similar economic characteristics (e.g. in case of wind, sites with same range of full-load hours) are described by one band and, hence, a stepped curve emerges.

Dynamic cost-resource curves

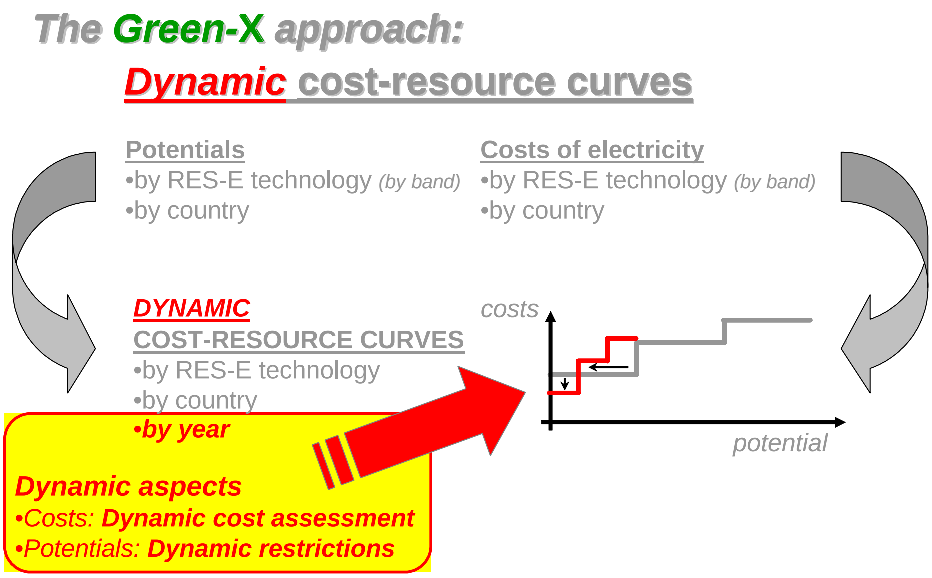

Figure 4 Method of approach regarding dynamic cost-resource curves for RES-E (for the model **Green-X**)

A *dynamic cost-resource curve* represents a tool to provide the linkage between both approaches described before, i.e. the dynamic cost assessment as e.g. done by application of experience curves and the formal description of costs and potentials by means of static cost-resource curves.

In the following, the method of approach regarding dynamic cost-resource curves as developed for the model **Green-X** will be described in more detail. Thereby, Figure 4 gives an overall illustration.

- In principle, the approach consists of two parts:
  - The development of *static cost-resource curves* for each RES category in the investigated region;
  - The *dynamic assessment*, including a dynamic assessment of costs as well as of potential restrictions, in order to derive dynamic cost-resource curves. Hence, these dynamics are reflected in the model **Green-X** on a yearly basis.

In more detail, within the first part of deriving static cost-resource curves as used for the model **Green-X** a clear distinction between already existing plant, i.e. the achieved potential, and new generation options, i.e. the additional mid-term potential, is undertaken.