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Til underretning for Folketingets Europaudvalg vedlægges Klima- og Energiministeriets besvarelse af spørgsmål nr. nr. 6-8 ad KOM (2008) 0019 vedrørende Kommissionens forslag til Rådets og Europa-Parlamentets direktiv om fremme af anvendelsen af vedvarende energi.

Per Boy Bolli

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Europaudvalget har i brev af 26. februar 2008 stillet mig følgende spørgsmål 7, som jeg hermed skal besvare.

Spørgsmål:

"Ministeren bedes – som lovet på mødet i Europaudvalget den 22. februar 2008 – fremsende en liste over potentialet i andre medlemslande for så vidt angår vedvarende energi."

Svar:

Kommissionen fremlagde i august 2006 et studie af VE-potentialerne i de forskellige medlemslande. Dette studie, "Economic analysis of reaching a 20% share of renewable energy sources in 2020", har siden været en del af grundlaget for byrdefordelingen i VE-direktivet.

Jeg har til Europaudvalgets orientering vedlagt Anneks 1 fra dette studie. På side 15-17 findes tabellerne nummereret 6, 7 og 8 med angivelse af de opgjorte potentialer for VE i de forskellige medlemslande.

Med venlig hilsen

Connie Hedegaard

Fraunhofer Institute Systems and Innovation Research

Energy Economics Group

ECOFYS

Economic analysis of reaching a 20% share of renewable energy sources in 2020

Annex 1 to the final report: **Methodological aspects & database for the scenarios of RES deployment**

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August 2006

by order of the:
European Commission
DG Environment
ENV.C.2/SER/2005/0080r

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A. 1. General methodology of the model Green-X

The computer model *Green*-X is an independent software tool developed under Microsoft Windows by EEG in the EC-funded project Green-X (5th FWP – DG Research, Contract N°: ENG2-CT-2002-00607).[1] Two major variants of the *Green*-X model are currently available:

- An extended variant with respect to the **intra-sectoral** coverage was developed, which **includes** besides RES-E **endogenous modelling of all conventional power generation options of the electricity sector** (incl. interconnections and according restrictions). Geographically this variant covers solely **the EU-15**. It allows a comparative, quantitative analysis of interactions between RES-E, conventional electricity and CHP generation, demand-side activities and GHG-reduction in the electricity sector, both within the EU-15 as a whole, as well as for individual member states.

- An extended variant with regard to the **geographical and sectoral coverage for RES**. It **covers** besides the EU-15 **all new member states (EU-10) as well as the EU candidate countries Bulgaria, Romania and Croatia.** It enables a comparative and quantitative analysis of the future deployment of RES in all energy sectors (i.e. electricity, (grid-connected and non-grid) heat and transport) based on applied energy policy strategies in a dynamic context. In this context, the impact of the conventional supply portfolio within each sector is described by exogenous forecasts of reference energy prices and corresponding CO_2 emission-factors etc., all set on country level.

For the purpose of this study, the modelling approach has been extended by the concept of a cross-sectoral quota: The key approach in the calculations is that the European energy market optimizes the additional generation costs for RES against the background of a RES target which can be set on a yearly base up to the year 2020. This overall optimization is modelled by comparing the difference between RES generation costs and conventional reference prices across all sectors (heat, electricity and biofuels), all technologies and all countries. Results are presented in terms of additional costs, that is, the total costs of generation per energy output minus the reference cost of energy production per unit of energy output. To avoid underestimation of the resulting cost with regard to an enhanced RES-deployment, negative additional cost are not counted – i.e. set to zero. The optimisation is conducted across all three sectors (RES-E, RES-H and RES-T). As biomass may play a role in all sectors, the allocation of biomass resources is a key issue. Consequently the overall optimization across sectors includes an integrated optimization of the distribution of biomass among the sectors.

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1 For more details see: http://www.green-x.at

Within the model *Green*-X, the most important RES-E (e.g. biogas, biomass, biowaste, wind on- & offshore, hydropower large- & small-scale, solar thermal electricity, photovoltaics, tidal & wave energy, geothermal electricity), RES-H technologies (e.g. biomass – subdivided into log wood, wood chips, pellets, district heating - , geothermal and solar heat) and RES-T options (e.g. traditional biofuels such as biodiesel and bioethanol, advanced biofuels as well as the impact of biofuel imports) are described for each investigated country by means of *dynamic cost-resource curves*. Dynamic cost curves are characterised by the fact that the costs as well as the potential for electricity generation / demand reduction can change each year. The magnitude of these changes is given endogenously in the model, i.e. the difference in the values compared to the previous year depends on the outcome of this year and the (policy) framework conditions set for the simulation year.

In most analysis conducted with the model *Green*-X an economic assessment takes place on the basis of the dynamic cost curves derived and scenario-specific conditions like selected policy strategies, investor and consumer behaviour as well as primary energy and demand forecasts. Within this step, a transition takes place from generation and saving *costs* to bids, offers and switch *prices*. It is worth mentioning that the policy setting influences the effective support, e.g. the guaranteed duration and the stability of the planning horizon or the kind of policy instrument to be applied.

Policies that can be selected are the most important price-driven strategies (feed-in tariffs, tax incentives, investment subsidies, subsidies on fuel input) and demand-driven strategies (quota obligations based on tradable green certificates (including international trade), tendering schemes). All the instruments can be applied to all RES technologies (and conventional options within the EU-15) separately for the various energy sectors. In addition, general taxes can be adjusted and the effects simulated. These include energy taxes (to be applied to all primary energy carriers as well as to electricity and heat) and environmental taxes on CO_2-emission as well as policies supporting demand-side measures. As *Green*-X is a dynamic simulation tool, the user has the possibility to change policy and parameter settings within a simulation run (i.e. by year). Furthermore, each instrument can be set for each country individually.

Note that in the least-cost analysis conducted in this study a policy neutral modelling approach has been chosen. This means that no specific support policies are assumed.

Modelling results are derived on a yearly basis by determining the equilibrium level of supply and demand within each considered market segment – e.g. tradable green certificate market (TGC, both national and international), electricity power market and tradable emissions allowance market. This means that the supply for the different technologies is summed up within each market and the point of equilibrium varies with the demand calculated.

A broad set of results with respect to RES can be gained on country and technology-level:

- total energy output by sector (RES-E, RES-H, RES-T), by country, by technology
- total installed capacity by sector (RES-E, RES-H, RES-T), by country, by technology
- share on gross domestic electricity / heat / transport fuel production or demand,
- average generation costs by sector (RES-E, RES-H, RES-T), by country, by technology
- import / export balance for the power sector (only for EU-15 countries),
- impact of simulated energy policy instruments on supply portfolio, generation costs, etc.
- impact of selected energy policy instruments on total costs and benefits to the society (consumer) – premium price due to RES-E / RES-H / RES-T strategy.

The latter option is not used in the RES2020 study.

Table 1: Main characteristics of the Green-X model

The most important RES-E included	Biogas, biomass, biowaste, wind on & -offshore, hydropower large & small-scale, solar thermal electricity, photovoltaics, tidal & wave energy, geothermal electricity
The most important RES-H included	Biomass, geothermal, solar thermal, heat pumps
The most important RES-T included	Biodiesel, bioethanol, Advanced bioethanol, BtL
Geographical aggregation	Country level, EU – 25
Included policies: Price-driven strategies (not used in the RES2020 study)	feed-in tariffs, tax incentives, investment subsidies, subsidies on fuel input
Included policies: Demand-driven strategies: (not used in the RES2020 study)	Quota obligations based on tradable green certificates, tendering schemes

A. 2. Development of the cost–resource curve for RES-E, RES-H and RES-T

A (static) cost-resource curve shows the correlation between electricity (respectively heat and biofuels) costs per unit and the cumulative amount of electricity (respectively heat and biofuels) production from one specific technology in one country per annum. Hence, the development of a cost-resource curve implies knowledge of the two items explained above:

- costs for electricity (or heat) per unit;
- total quantity of electricity (or heat) that can be generated per annum at certain cost levels. The cumulated sum of these amounts is equal to the totally available potential of a certain technology.

The procedure for deriving the dynamic cost-resource curves is exemplarily depicted in Figure 1 for the electricity sector. The starting point is the **input-database supply** for the first year under investigation.

The database contains information about already existing power plants (at the end of 2001) as well as possible new plants. The outputs of the database are cost-resource curves for each category containing information with respect to actual generation costs and the possible potential for electricity generation for the year under investigation.

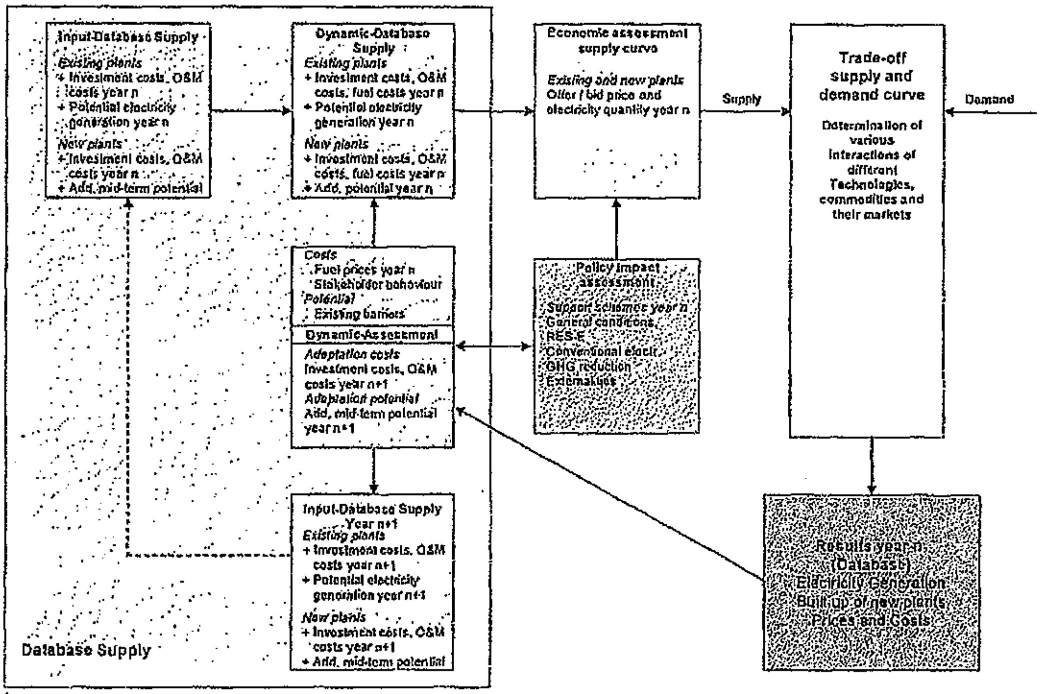

Figure 1 Overview of creating dynamic cost-resource curves for electricity generation

At the end of the simulation run for the year n-1, the input database for the following year will be created by adapting the input database for the year n.
This adapted input-database serves as a starting point for the dynamic cost-resource curve development for the next subsequent year.

Note that in the RES2020 study an overall optimisation is made across all sectors. Therewith one overall cost-resource curve is specified that includes all RES-E, -H and –T options.

A. 3. The data requirement

Information for the development of dynamic cost-resource curves must be available on different levels. In general, three levels of data are required in the model **Green-X**, namely: Country-, technology and band-level. The data requirements at each level will be briefly outlined below.

The interaction of country-specific, technology-specific and band-specific data is indicated in Figure 2 below.

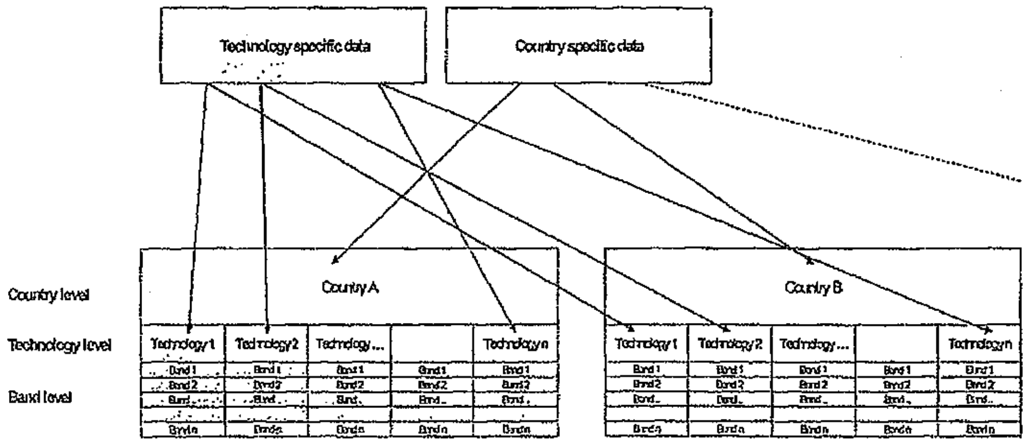

Figure 2 Overview of different levels of supply-side data

Country-specific data is characterised by the fact that these values and parameters are valid for all considered technologies in the specific region. Of course, variations occur in a dynamic context – i.e. from year to year. Country-specific data is summarised in Table 2.Despite the fact that the parameters are given exogenously, dynamic effects can be expected because values are available as time-series from 2002 to 2020 in the database.

Technology-specific data is valid and equivalent for all investigated regions. Of course, changes occur over time and data refers only to a certain technology, see Table 2.

Band specific data are introduced as it is assumed that most of the parameters (data) are not constant within a region and technology, respectively. I.e. they may vary depending on the sub-technologies (e.g. combined cycle or steam turbines), energy efficiency standards, the fuel input, the location of the plant, or the full-load hours. Therefore, it is

necessary to create several bands within each RES-E & RES-H category. Bands are characterised by the same economic, technical, social and geographical conditions.[2]
In the practical implementation, the supply-side database consists of two sub-bases, namely:

- Database: Existing plants
- Database: New plants

Aim of the input-database 'existing plants' is to provide generation costs for electricity or heat, respectively, as well as the potential for this generation from bands (plant) which are already in operation in the investigated year n. Possible new generation options of the year n are described in the database 'new plants'. The required band-specific information is summarised for both categories in Table 3.

Equivalent to the conditions at the other levels, parameters can differ over time.

Table 2: Summary of supply side country-specific data

Parameter	Aim
Country level	
Population, land size, GDP (per capita)	To receive comparative results among the countries
Fuel prices for renewable primary energy carriers	To calculate electricity generation costs
Conventional electricity / heat prices (for each sector)	Reference prices - To calculate additional costs for society due to the promotion of RES-E & RES-H
Specific GHG-emission by energy carrier	To derive additional generation costs due the CO_2-constraints and the consideration of externalities
Grid extension constraints	For dynamic parameter assessment
Market transparency	For dynamic parameter assessment
Investor behaviour / interest rate	For dynamic parameter assessment [3]
Willingness to accept new plants	For dynamic parameter assessment
Technology level	**Aim**
Lifespan of technology	To derive date of decommissioning of the plant
Payback time	To derive generation costs of a new plant
Dynamic cost development by technology (i.e. global projections with regard to development and technological learning)	To derive investment costs for the year n+1
Growth rate industry	For dynamic parameter assessment
Grid extension constraints	For dynamic parameter assessment
Market transparency	For dynamic parameter assessment
Investor behaviour / interest rate	For dynamic parameter assessment
Willingness to accept new plants	For dynamic parameter assessment

[2] Same fuel inputs, sub-technologies, energy efficiency standards, full-load hours, etc.

[3] Investor behaviour depends on various factors such as e.g. support scheme, planning horizon, technology.

Table 3 Summary band-specific data

Parameter	Valid for existing (Ex) / new (New) plants	Input (In) / output (Out) data	Aim
Technology parameter			
Construction year	Ex	In	To estimate date of decommissioning[4]
Full-load hours electr.	Ex and New	In	To calculate electricity generation costs
Full-load hours heat (in case of CHP / district heat)	Ex and New	In	To calculate generation costs (for electricity and heat)
Efficiency electricity generation	Ex and New	In	To calculate generation costs and emissions; this is a dynamic parameter which changes for new plants
Efficiency heat generation	Ex and New	In	To calculate generation costs and emissions; this is a dynamic parameter which changes for new plants
Fuel category	Ex and New	In	To calculate generation costs and emissions; link with fuel price (country database), mark if fuel switch possible

Table 4 provides an overview of the cost and potential parameters used to specify the cost/potential curves in the *Green*-X model.

[4] Date of decommissioning for a specific plant depends on the lifespan of the technology. If the year of decommissioning is reached, the plant will be deleted from the database.

Table 4 Parameters used to specify costs and potentials

Potential parameter			
Mid-term potential of electricity generation	New	In	Mid-term potential electricity generation
Dynamic restriction new plants	New	In	Link with dynamic restriction calculation tool
Potential of electricity generation year n:	Ex and New	Out	Value represents the maximum electricity generation of the band in year n
Cost parameter			
Investment costs	New[5]	In	To calculate generation costs; this is a dynamic parameter, i.e. investment costs are adapted year by year
Operation and maintenance costs	Ex and New	In	To calculate generation costs; this is a dynamic parameter, i.e. an adaptation of this parameter takes place year by year (link to investment costs)
Fuel category	Ex and New	In	To calculate generation costs and emissions; link with fuel price (country database)
Payback time	Ex and New		Parameter set at the technology level, but information necessary on band level for various calculations
Interest rate	New	In	Parameter set at the country and techn. level but information necessary on band level for various calculations
Short-term marginal generation costs	Ex	Out	Generation costs for existing plants, important input for economic assessment
Long-term marginal generation costs (year of construction)	Ex[6]	Out	To calculate profit of the investor
Long-term marginal generation costs (year of construction)	New	Out	Generation costs for new plants; important input for economic assessment

A. 4. Calculation of electricity, heat and biofuel generation costs

For calculating the generation costs a distinction must be made between already installed capacities and potentially new plants. For existing plants, only the running costs (short-term marginal costs) are relevant for the economic decision whether the plant should be used for electricity (or heat) generation or not, while for new capacities, the long-term marginal costs are important.

A further distinction has been applied in the following: Generation costs are explained separately for pure power & heat generation options, CHP and district heating.

[5] Note: Investment costs for existing plants must also be available for their date of construction.

[6] Note: Information must also be available for existing plant for their year of construction.

Existing plants

Yearly running costs consist of two parts: fuel costs and operation & maintenance (O&M) costs. Fuel costs depend on the fuel price of the primary energy carrier and the efficiency. O&M costs are set as annual expenditures.

Apart from all kinds of biomass (biogas, solid biomass, sewage and landfill gas), renewables have zero fuel costs, so running costs are determined by operation & maintenance costs only.

In the case of simultaneous electricity and heat generation, electricity generation costs are calculated by considering the revenues gained from the selling of the heat.

New plants

Generation costs pure power (or heat) generation

The calculation of the generation costs of electricity (respectively heat) of new plants consists of two parts, variable costs and fixed costs. In more detail, the generation costs are given by:

Fixed costs occur independently whether the plant generates electricity (respectively heat) or not. These costs are determined by investment costs (I) and the capital recovery factor (CRF).

Investment Costs and technological improvements

The investment costs differ by technology and energy source. As most RES-E technologies (with the exception of (large-scale) hydropower) are still not mature, investment costs decrease over time. This evolvement is taken into consideration in the toolbox *Green*-X, i.e. investment costs are adapted yearly.[7]

In principle, the model is prepared to include two different approaches on technology level: (i) standard cost forecasts or (ii) endogenous technological learning (local vs. global). Hence, default settings for RES-E & RES-H technologies are applied as indicated in Table 5.

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[7] The 'yearly' determination of the investment costs represents an important input to the data-tables described in the previous section. In more detail, the following parameter must be derived for each country and technology according to the given situation for the year n-1 and the year n:

- quantitative values for investment costs over time.
- quantitative values for the development of the efficiency over time.

Table 5: Overview of the methodology to dynamically derive investment costs by technology[8]

Dynamic cost development	Methodology to derive investment costs year n (default settings)
Biogas	learning curve approach
Biomass electricity (heat, CHP)	learning curve approach & forecast based on expert judgement (depending on technology)
Biofuels for transport	forecast based on expert judgement & learning cureve approach
Geothermal electricity (heat, CHP)	learning curve approach
Geothermal heat non-grid	learning curve approach
Small scale hydropower (<10 MW)	forecast based on expert judgement
Large scale hydropower (>10 MW)	forecast based on expert judgement
Landfill gas	learning curve approach
Sewage gas	learning curve approach
Photovoltaics	learning curve approach
Solar thermal electricity	learning curve approach
Solar thermal heat	forecast based on expert judgement
Tidal energy	forecast based on expert judgement
Wave energy	forecast based on expert judgement
Wind on-shore	learning curve approach
Wind off-shore	learning curve approach

Capital recovery factor CRF

The CRF allows investment costs incurred in the construction phase of a plant to be discounted. The amount depends on the interest rate and the payback time of the plant.

In general, *experience curves* describe how costs decline with cumulative production. 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:

$$C_{CUM} = C_0 * CUM^b$$

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.

For the standard calculation of generation costs these factors are set for all technologies as follows:

- payback time (PT) of all plants: 15 years
- interest rate (z) equals 6.5%

In the toolbox *Green*-X different interest rates are used. The interest rate depends on stakeholder behaviour and is a function of

- guaranteed political planning horizon
- promotion scheme (not used in the RES2020 study)
- technology
- market sector (i.e. private, residential, tertiary sector)
- kind of investor.

Note, as the generation costs are calculated per energy output, the fixed costs must also be related to the generation of energy. Hence, the fixed costs per unit output are lower if the operation time of the plant - characterised by the full load-hours - is high. In general, no taxes are included in the various cost-components.

Generation costs - CHP

Deriving the generation costs for CHP plants is similar to the calculation for plants only producing electricity. Beside the short-term marginal costs, i.e. the variable costs, fixed costs must be considered for new plants. Of course, equivalent to the case for existing plants, variable costs differ between CHP and conventional electricity plants, as the revenue from purchasing the heat power must be considered in the first case.

Generation costs - biofuels

Biofuel costs calculations take into account the current entire biofuel production chain until the distribution at the fuelling station. The production chains for biofuels include the cultivation and harvesting of biomass feedstock, transportation to the conversion plant, biofuels conversion and distribution.

A. 5. Assessment of the potentials for RES

The *Green*-X model differentiates between different types of potentials. Following types are of main importance:

- *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;
- *Mid-term potential*: The mid-term potential as indicated in Figure 3 is equal to the *realisable potential in the year 2020.*

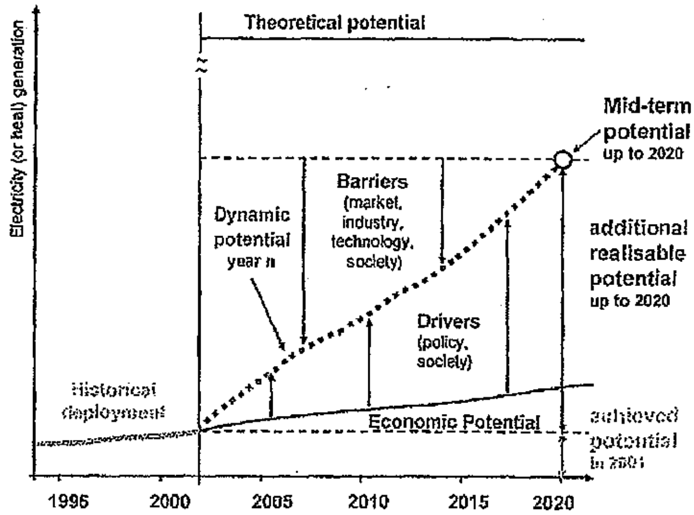

Figure 3 Methodology for the definition of potentials

Below, values are presented for the achieved potential for 2004 and the future potentials for 2020 for renewable electricity, heat and transport fuels.

RES such as hydropower or wind energy are energy sources characterised by a natural volatility. Therefore, in order to provide accurate forecasts of the future development of RES-E, historical data for RES is translated into generation potentials – the *achieved potential* at the end of 2004. This data was derived in a comprehensive data-collection – based on (Eurostat, 2006), (IEA, 2006) and statistical information gained on national level.

In addition, *future* potentials – the *additional realisable mid-term potentials* up to 2020 - were assessed taking into account the country-specific situation as well as overall realisation constraints.

We show in the following the sector specific generation potentials of the different RES technologies in the sectors electricity, heat and transport. As the biomass potential is endogenously allocated to the sector by the model, it can not be allocated to the sectors at this stage. At the end of this section we give an overview of the primary biomass potentials used in this analysis.

RES-E potentials

Table 6 provides an overview of the already achieved potential (at the end of 2004) and the additional realisable mid-term potential (up to 2020) for different RES-E options available in EU countries, separated in EU-15 and EU-10. In total EU-15 the already achieved potential for RES-E equals 441 TWh, whereas the additional mid-term potential (excluding biomass options / biogas solid biomass and biowaste) amounts to 696 TWh. Corresponding figures for the EU-10 are 18.9 TWh for the achieved potential and 37.3 TWh for the additional mid-term potential (excluding biomass options / biogas solid biomass and biowaste).

Table 6 Overview on electricity generation potentials for RES-E in the EU

RES-E - Electricity generation potentials (EU15)		AT Austria	BE Belgium	DK Denmark	FI Finland	FR France	DE Germany	GR Greece	IE Ireland	IT Italy	LU Luxembourg	NL Netherlands	PT Portugal	ES Spain	SE Sweden	UK United Kingdom	EU15 European Union (15)
Achieved potential (2004)																	
Biogas	GWh	218	121	238	60	677	3585	162	115	1244	17	325	0	670	105	4712	12247
(Solid) Biomass	GWh	2440	314	1288	9834	1764	2678	0	0	528	0	1036	1234	4442	3578	1613	30748
Biowaste	GWh	43	316	732	225	2442	2027	0	0	1666	23	1351	518	651	468	1003	11464
Geothermal electricity	GWh	7	0	0	0	21	0	0	0	5549	0	0	105	0	0	0	5682
Hydro large-scale	GWh	33587	137	0	12803	60820	12576	3280	703	35565	0	101	10697	29687	68856	4562	273374
Hydro small-scale	GWh	4338	192	31	1178	6219	7367	163	106	8467	100	1	697	4710	3284	515	37369
Photovoltaics	GWh	15	1	1	0	8	621	1	0	17	18	32	1	34	0	5	755
Solar thermal electricity	GWh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tide & Wave	GWh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind onshore	GWh	1273	195	5948	178	973	29516	1023	793	2649	73	2383	1171	18592	900	2027	67695
Wind offshore	GWh	0	0	1442	0	0	0	0	88	0	0	58	0	0	81	200	1870
RES-E TOTAL	GWh	41921	1275	9681	24278	72924	58370	4630	1805	55685	231	5287	14422	58786	77273	14637	441205
Additional realisable potential (up to 2020)																	
Geothermal electricity	GWh	11	0	0	0	158	0	221	0	1722	0	0	189	95	0	0	2395
Hydro large-scale	GWh	1459	4	0	1110	1815	2974	1356	95	10827	0	0	3358	15119	1063	130	39312
Hydro small-scale	GWh	5308	98	0	494	4723	2228	208	109	1971	0	8	1076	2630	1907	193	20953
Photovoltaics	GWh	972	581	497	600	5902	4840	1043	310	3691	5	1173	955	5104	1287	4321	31280
Solar thermal electricity	GWh	0	0	0	0	0	0	2634	0	7623	0	0	2418	17209	0	0	29885
Tide & Wave	GWh	0	150	2582	1545	13158	7725	4007	3930	3220	0	1026	7404	13229	3006	58895	119877
Wind onshore	GWh	3696	4123	2756	7679	55436	23803	7814	1959	25977	147	3169	5836	20707	8938	26439	198479
Wind offshore	GWh	0	3648	9381	4105	39920	76842	2635	3502	2396	0	19789	6599	14444	13544	66808	253611
RES-E TOTAL (excl. BM)	GWh	11447	8603	15216	15534	111111	118412	19917	9906	57428	152	25164	27835	88537	29743	156785	695790

RES-E - Electricity generation potentials (EU10)		CY Cyprus	CZ Czech Republic	EE Estonia	HU Hungary	LA Latvia	LT Lithuania	MT Malta	PL Poland	SK Slovakia	SI Slovenia	EU10 European Union (10)	BG Bulgaria	RO Romania
Achieved potential (2004)														
Biogas	TWh	141	2064	401	2213	481	736	55	7873	999	708	15670	135	5197
(Solid) Biomass	TWh	192	6382	3431	11277	3419	4199	32	28810	3303	1008	62053	747	15426
Biowaste	TWh	57	362	67	771	25	112	29	1644	254	383	3706	286	926
Geothermal electricity	TWh	0	0	0	0	0	0	0	0	0	0	0	129	98
Hydro large-scale	TWh	0	35	0	1090	678	224	0	45	414	4582	7067	801	5197
Hydro small-scale	TWh	4	610	39	78	158	109	0	767	500	356	2622	401	673
Photovoltaics	TWh	17	214	20	115	24	29	9	500	91	33	1054	158	275
Solar thermal electricity	TWh	0	0	0	0	0	0	0	0	0	0	0	0	0
Tide & Wave	TWh	239	0	1223	0	528	203	60	1112	0	0	3366	802	510
Wind onshore	TWh	627	4489	1246	1190	1232	1257	110	8482	557	299	19491	734	6693
Wind offshore	TWh	271	0	311	0	301	148	211	2451	0	0	3693	433	151
RES-E TOTAL	TWh	1158	5349	2839	2473	2923	1970	390	13358	1562	5271	37292	275	35146
Additional realisable potential (up to 2020)														
Geothermal electricity	TWh	0	0	0	0	0	0	0	0	0	0	0	129	98
Hydro large-scale	TWh	0	35	0	1090	678	224	0	45	414	4582	7067	801	5197
Hydro small-scale	TWh	4	610	39	78	158	109	0	767	500	356	2622	401	673
Photovoltaics	TWh	17	214	20	115	24	29	9	500	91	33	1054	158	275
Solar thermal electricity	TWh	0	0	0	0	0	0	0	0	0	0	0	0	0
Tide & Wave	TWh	239	0	1223	0	528	203	60	1112	0	0	3366	802	530
Wind onshore	TWh	627	4489	1246	1190	1232	1257	110	8482	557	299	19491	734	6693
Wind offshore	TWh	271	0	311	0	301	148	211	2451	0	0	3693	433	151
RES-E TOTAL (excl. BM)	TWh	1158	5349	2839	2473	2923	1970	390	13358	1562	5271	37292	184	13596

RES-H potentials

Table 7 shows the achieved potential in 2004 and the additional RES heat generation potentials (excluding biomass) for 2020 at member state level (EU-15 and EU-10 & Bulgaria, Romania). The already achieved potential in 2004 amounts to 40.9 Mtoe for the EU-15 and 8.4 Mtoe for the EU-10; whereas the additional potential until 2020 totals 63 Mtoe for the EU-15 and 7 Mtoe for the EU-10 (excluding biomass).

Table 7: Overview on heat generation potentials for RES-H in the EU

RES-H - Heat generation potential (EU15)		AT Austria	BE Belgium	DK Denmark	FI Finland	FR France	DE Germany	GR Greece	IE Ireland	IT Italy	LU Luxembourg	NL Netherlands	PT Portugal	ES Spain	SE Sweden	UK United Kingdom	EU15 European Union (15)
Achieved potential (2004)																	
Biomass heat	ktoe	2418	481	915	5319	9442	5142	920	191	2393	15	382	2480	3453	5085	703	39339
Geothermal heat (CHP & d.h.)	ktoe	19	3	1	0	113	17	13	1	169	0	0	9	8	23	2	376
Heat pumps	ktoe	85	7	13	46	77	88	0	0	12	0	31	0	0	263	1	625
Solar collectors	ktoe	87	2	10	0	29	221	128	0	18	0	15	6	54	6	25	600
RES-H TOTAL	ktoe	2608	492	940	5366	9660	5469	1061	192	2592	16	428	2494	3515	5377	731	40940
Additional realisable potential (up to 2020)																	
Geothermal heat (CHP & d.h.)	ktoe	78	22	381	0	42	605	22	24	884	0	22	15	64	14	16	2189
Heat pumps	ktoe	674	1157	431	490	4240	7237	484	288	4305	65	1224	275	1282	694	4839	27683
Solar collectors	ktoe	576	826	673	662	5882	6403	764	310	6033	37	1268	854	3322	803	4799	33214
RES-H TOTAL	ktoe	1327	2005	1486	1152	10165	14246	1270	622	11222	102	2515	1144	4668	1510	9653	63087

RES-H - Heat generation potential (EU10)		CY Cyprus	CZ Czech Republic	EE Estonia	HU Hungary	LA Latvia	LT Lithuania	MT Malta	PL Poland	SK Slovakia	SI Slovenia	EU10 European Union 10+	BG Bulgaria	RO Romania
Achieved potential (2001)														
Biomass heat	ktoe	0	793	492	564	1055	576	0	3865	265	430	8038	709	3047
Geothermal heat (CHP & d.h.)	ktoe	0	2	0	189	0	0	0	6	72	15	285	0	0
Heat pumps	ktoe	0	7	2	0	0	2	0	14	0	0	27	0	0
Solar collectors	ktoe	20	2	0	2	0	0	1	3	2	4	33	2	4
RES-H TOTAL	ktoe	20	803	494	755	1055	578	1	3888	339	449	8383	711	3050
Additional realisable potential (up to 2020)														
Geothermal heat (CHP & d.h.)	ktoe	0	23	0	46	0	39	0	116	50	102	376	108	189
Heat pumps	ktoe	17	450	59	446	103	163	2	1714	241	88	3283	121	1002
Solar collectors	ktoe	65	410	59	429	95	164	14	1771	216	126	3349	361	1185
RES-H TOTAL	ktoe	82	883	118	921	197	367	16	3601	507	316	7008	590	2376

RES-T potentials

Table 8 provides an overview on the achieved biofuel potentials on country-level. The achieved RES potentials for 2004 showed 1930 ktoe for the EU-15, and 171 ktoe for the EU-10.

Table 8 Overview on biofuel potentials (RES-T) in the EU

RES-T - Biofuel potential (EU15)		AT Austria	BE Belgium	DK Denmark	FI Finland	FR France	DE Germany	GR Greece	IE Ireland	IT Italy	LU Luxembourg	NL Netherlands	PT Portugal	ES Spain	SE Sweden	UK United Kingdom	EU15 European Union (15)
Achieved potential (2004)																	
Biofuel	ktoe	51	0	62	2	362	975	0	0	285	0	7	0	141	37	8	1930

RES-T – Biofuel potential (EU10)		CY Cyprus	CZ Czech Republic	EE Estonia	HU Hungary	LA Latvia	LT Lithuania	MT Malta	PL Poland	SK Slovakia	SI Slovenia	EU10 European Union 10+	BG Bulgaria	RO Romania
Achieved potential (2004)														
Biofuel	ktoe	0	110	0	1	8	6	0	24	23	0	171	0	0

Primary biomass potentials

A crucial input to the model is given by the primary potentials of solid biomass. These were determined in this project based on the analysis of the following sectors:

- Agricultural products
- Agricultural residues
- Forestry products
- Forestry residues
- Biodegradable waste
- Forestry imports

In the following Table 9 gives an overview on the potentials used in this project. Thereby for agricultural products it was assumed that 15% of the arable land will be used for energy crops. For the total area attributed to energy crops a pre-allocation to the individual crops was done as indicated in the table. This implies already a certain predetermination of the future conversion technologies (e.g. 1st versus 2nd generation biofuels).

Table 9 Overview on primary biomass potentials in the EU

Solid biomass - Primary potentials & corresponding fuel cost	Potentials (in terms of primary energy)			
	2005 Mtoe	2010 Mtoe	2015 Mtoe	2020 Mtoe
AP1 - rape & sunflower	4.6	4.7	3.4	2.2
AP2 - maize, wheat (corn)	14.3	14.5	9.2	3.9
AP3 - maize, wheat (whole plant)	0.0	11.1	22.2	33.3
AP4 - SRC willow	1.3	3.6	5.8	8.1
AP5 - miscanthus	1.3	3.3	5.2	7.1
AP6 - switch grass	1.8	6.5	11.2	15.9
AP7 - sweet sorghum	1.4	2.7	4.0	5.3
AR1 - straw	21.6	22.7	23.9	25.2
AR2 - other agricultural residues	2.3	2.4	2.6	2.7
FP1 - forestry products (current use (wood chips, log wood))	27.9	27.9	27.9	27.9
FP2 - forestry products (complementary fellings (moderate))	8.2	8.7	9.1	9.6
FP3 - forestry products (complementary fellings (expensive))	12.4	13.0	13.7	14.4
FR1 - black liquor	13.8	14.5	15.2	16.0
FR2 - forestry residues (current use)	14.3	14.3	14.3	14.3
FR3 - forestry residues (additional)	2.3	2.5	2.6	2.7
FR4 - demolition wood, industrial residues	6.7	7.1	7.4	7.8
FR5 - additional wood processing residues (sawmill, bark)	4.8	5.0	5.3	5.6
FR6 - forestry imports from abroad	2.5	3.1	3.9	4.9
BW1 - biodegradable fraction of municipal waste	11.8	13.2	14.8	16.7
Agricultural products	24.8	46.3	61.0	75.8
Agricultural residues	23.9	25.2	26.5	27.9
Forestry products	48.5	49.6	50.8	52.0
Forestry residues	42.0	43.4	44.9	46.4
Biodegradable waste	11.8	13.2	14.8	16.7
Forestry imports	2.5	3.1	3.9	4.9
Solid biomass - TOTAL	153.5	180.7	201.8	223.6

A. 6. Assessment of & overview on the economic data for RES

Assessment of economic data for RES-E & RES-H (electricity and grid-connected heat sector)

The assessment of the economic parameter and accompanying technical specifications of for the various RES-E technologies comprises a comprehensive literature survey and an expert consultation. With respect to existing plant, representing the already achieved potential at the end of 2001, also project specific information is taken into account. References of major relevance are discussed below.

A set of studies is listed which provide a comprehensive survey on RES-E technologies, thereby including detailed economic and technical data with respect to most common technologies. Namely these are, listed in chronological order: (DTI/ETSU, 1999) (DLR/WI/ZSW/IWR/Forum, 1999), (Neubarth et al., 2002), (Haas et al., 2001), (Resch et al., 2001), (Nowak et al., 2002), (Kaltschmitt et al., 2003), (BMU, 2004).

References with a focus on selected technologies are listed in the following by RES-E category:

- Biogas and Biomass: (Fischer et al., 2002), (Enquete, 2002), (EUBIONET, 2003)
- Geothermal energy: (BMU, 2002)
- Hydropower: (Lorenzoni, 2001)
- Photovoltaics: (Alsema, 2003), (Schäffer et al., 2004)
- Solar thermal electricity: (Quaschning, Ortmann , 2003)
- Wind energy: (Greenpeace, 2001), (Neij et al., 2003), (BTM, 1999-2003), (Beurskens, Noord, 2003)
- Tidal and wave energy: (Thorpe, 1999), (DTI/ETSU, 2001), (Michael, 2003)

Assessment of economic data for RES-H (non grid)

The assessment of the economic parameter and accompanying technical specifications of for the various RES-H technologies comprises a comprehensive literature survey and an expert consultation. In particular the following sources were consulted for the techno-economic assessment:

- Invert (2005)
- Jahrbuch Erneuerbare Energien (2004)
- ESTIF (2003)
- Kaltschmitt et al. (2003)
- DLR/WI/ZSW/IWR/Forum (1999)
- BMU (2004)

Assessment of economic data for RES-T (biofuels)

The assessment for potential and cost figures for biofuels was based on a comprehensive literature review and experts conversations among the biofuels industry members in Europe. For the agricultural and biofuels techno-economic assessment following sources were used and consulted:

CONCAWE (2003), Well-to-wheel analysis of future automotive fuels and powertrains in the European Context, Well Tank Report, Brussels, 2003. Available at: http://ies.jrc.cec.eu.int/Download/eh

Energy Research Centre of the Netherlands ECN (2003). An overview of biofuel technologies, markets and policies in Europe, 2003, Available at: http://www.ecn.nl/docs/library/report/2003/c03008.pdf

ESTO, IPTS, (2003), Trends in vehicle and fuel technologies: Scenarios for Future Trends" Ed. Luc Pelkmans (VITO), Panayotis Christidis, Ignacio Hidalgo, Antonio Soria. Report EUR 20748 EN, 2004. Available at; http://www.jrc.es

ESTO, IPTS, (2003). Biofuel production potential of EU-candidate countries – Final Report, EUR 20835, 2003, Available at: http://www.jrc.es/home/publications/publication.cfm?pub=1120;

European Commission, DG Energy and Transport (2003), European Energy and Transport Trends to 2030, January 2003. Available at http://europa.eu.int/comm/dgs/energy_transport/figures/trends_2030/index_en.htm

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

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

European Commission (2001), Green Paper towards a European strategy for the security of energy supply. Available at http://europa.eu.int/comm/energy_transport/doc-principal/pubfinal_en.pdf

European Commission (2001), White Paper: European Transport Policy 2010: Time to Decide. http://europa.eu.int/comm/energy_transport/library/lb_texte_complet_en.pdf

European Commission, DG Energy and Transport (2004). Promoting Biofuels in Europe: Securing a cleaner future for transport. Available at http://europa.eu.int/comm/energy/res/publications/doc/2004_brochure_biofuels_en.pdf

Energy scientific and technological indicators and references (2005), DG for Research and Sustainable Energy Systems, EUR 21611. ISBN: 92-894-9169-8

Friedrich S. (2004), A World wide review of the commercial production of Biodiesel – A technological, economic and ecological investigation based on case studies, Band 41, Institut fuer Technologie und Nachhaltiges Produktmanagement, Vienna 2004.

Hamelinck, C. (2004), Outlook for advanced biofuels, PhD Dissertation June 2004, Utrecht University, Department of Science, Technology and Society, Netherlands. ISBN: 90-393-3691-1

Henke, J., Klepper, G., Schmitz, N. (2004): Tax Exemption for Biofuels in Germany: Is Bio-Ethanol Really an Option for Climate Policy? Kiel Institute of World Economics 2004.

International Energy Agency IEA (2004). Biofuels for Transport. An international perspective. Paris, France, April 2004. ISBN 92-64-01512-4.

IEA, CADETT, (1998), Mini-review of Energy from Crops and Crops Residues. UK, January, 1998.

IPTS, (2002). Techno-economic analysis of Bio-diesel production in the EU: a short summary for decision-makers, EUR 20279, 2002. Available at http://www.jrc.es/home/publications/publication.cfm?pub=990

IPTS, (2002). Techno-economic analysis of Bio-alcohol production in the EU: a short summary for decision-makers, EUR 20280, 2002, http://www.jrc.es/home/publications/publication.cfm?pub=991

IPTS, (2003). Biofuel production potential of EU-candidate countries – Addendum to the Final Report, EUR 20836, 2003. Available at http://www.jrc.es/home/publications/publication.cfm?pub=1121

IPTS, (2004).The introduction of alternative fuels in the European transport sector: Techno-economic barriers and perspectives - Extended summary for policy makers. IPTS, Ed. Soria Antonio, et al.

Kaltschmitt, M., Hartmann, H. (2001). Energie aus Biomasse, Grundlagen, Techniken und Verfahren (In German). Springer Verlag 2001, ISBN: 3-54-64853-4.

Ryan, L.; Convery, F.; Ferreira, S.: Stimulating the use of biofuels in the European Union: Implications for climate change policy. Working Paper, University College Dublin, 2004.

Sustainable Energy Ireland (SEI) (2004), Liquid Biofuel Strategy for Ireland study prepared by Hamelinck Carlo; Van den Broek, Richard; Toro, Felipe; Ragwitz, Mario; Rice, Bernard. Available at: http://europa.eu.int/comm/energy/res/legislation/doc/biofuels/member_states/2004_liquid_strategy_study_ireland.pdf

Toro, F. (2004). Techno-Economic Assessment of Biofuel Production in the European Union. Master Thesis, Karlsruhe, TU Freiberg, 2004.

Wyman, Charles E., Handbook on Bioethanol: Production and Utilization. Applied Energy Technology Series, Taylor & Francis 1998, ISBN: 1-56032-553-4.

Economic data for RES-E

Table 10 gives an overview economic parameter and accompanying technical specifications on technological level by RES-E sub-category, referring to *new plant* of the database in accordance with the *additional realisable mid-term potential*. In case of (large- and small-scale) hydropower and wind onshore non-harmonised cost settings are applied, i.e. a country-specific[9] differentiation of investment- and where suitable also O&M-costs is undertaken, whilst for all other RES options harmonised cost settings are applied. In the latter case expressed ranges of the economic and technical parameter result from different plant sizes (small- to large-scale) and / or applied conversion technologies. Please note that all data – i.e. investment-, O&M-costs and efficiencies - refer to the default start year of the simulations, i.e. 2005, and are expressed in €$_{2005}$.

[9] Especially in case of hydropower the range of investment costs differs largely between and within the countries. These capital costs are site-specific, depending on the plant-size and geographic conditions as well as on additional (country-specific) efforts (acceptance barrier, planning process, etc.). The applied country-specific settings are based on (Lorenzoni, 2001).

Table 10 Overview on economic-& technical-specifications for new RES-E plant

RES-E sub-category	Plant specification	Investment costs	O&M costs	Efficiency (electricity)	Efficiency (heat)	Lifetime (average)	Typical plant size
		[€/kW$_{el}$]	[€/ (kW$_{el}$*yr.)]	[1]	[1]	[years]	[MW$_{el}$]
Biogas	Agricultural biogas plant	2550 - 4290	115 - 140	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant - CHP	2760 - 4500	120 - 145	0.27 - 0.33	0.55 - 0.59	25	0.1 - 0.5
	Landfill gas plant	1280 - 1840	50 - 80	0.32 - 0.36	-	25	0.75 - 8
	Landfill gas plant - CHP	1430 - 1990	55 - 85	0.31 - 0.35	0.5 - 0.54	25	0.75 - 8
	Sewage gas plant	2300 - 3400	115 - 165	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant - CHP	2400 - 3550	125 - 175	0.26 - 0.3	0.54 - 0.58	25	0.1 - 0.6
Biomass	Biomass plant	2225 - 2530	75 - 135	0.26 - 0.3	-	30	1 - 25
	Cofiring	550	60	0.37	-	30	-
	Biomass plant - CHP	2600 - 4230	80 - 165	0.22 - 0.27	0.63 - 0.66	30	1 - 25
	Cofiring - CHP	550	60	0.2	0.6	30	-
Biowaste	Waste incineration plant	4300 - 5820	90 - 165	0.18 - 0.22	-	30	2 - 50
	Waste incineration plant - CHP	4600 - 6130	100 - 185	0.14 - 0.16	0.64 - 0.66	30	2 - 50
Geothermal electricity	Geothermal power plant	2000 - 3500	100 - 170	0.11 - 0.14	-	30	5 - 50
Hydro large-scale	Large-scale unit	850 - 3650	35	-	-	50	250
	Medium-scale unit	1125 - 4875	35	-	-	50	75
	Small-scale unit	1450 - 5950	35	-	-	50	20
	Upgrading	800 - 3600	35	-	-	50	-
Hydro small-scale	Large-scale unit	800 - 1600	40	-	-	50	9.5
	Medium-scale unit	1275 - 5025	40	-	-	50	2
	Small-scale unit	1550 - 6050	40	-	-	50	0.25
	Upgrading	900 - 3700	40	-	-	50	-
Photovoltaics	PV plant	5080 - 5930	38 - 47	-	-	25	0.005 - 0.05
Solar thermal electricity	Large-scale solar thermal plant	2880 - 4465	163 - 228	0.33 - 0.38	-	30	2 - 50
Tidal energy	Tidal (stream) power plant - shoreline	2670	44	-	-	25	0.5
	Tidal (stream) power plant - nearshore	2850	49	-	-	25	1
	Tidal (stream) power plant - offshore	3025	53	-	-	25	2
Wave energy	wave power plant - shoreline	2135	44	-	-	25	0.5
	wave power plant - nearshore	2315	49	-	-	25	1
	wave power plant - offshore	2850	53	-	-	25	2
Wind onshore	Wind power plant	890 - 1100	33 - 40	-	-	25	2
Wind offshore	wind power plant - nearshore	1590	55	-	-	25	5
	wind power plant - offshore: 5...30km	1770	60	-	-	25	5
	wind power plant - offshore: 30...50km	1930	64	-	-	25	5
	wind power plant - offshore: 50km...	2070	68	-	-	25	5

Default ranges for fuel costs with respect to the various fractions of biomass are depicted in Table 11. These country-specific prices are mainly based on (EUBIONET, 2003-2005).. For biowaste as default a negative price of -4€/MWh was used, representing a revenue for the power producer, i.e. a 'gate fee' for the waste treatment. Again, these prices refer to start year of the simulation, i.e. 2005. Their future development is internalised in the overall model – linked to fossil fuel prices as well as the available additional potentials.

Table 11 Fuel price ranges for various fractions of solid biomass in EU countries

Solid biomass - Fuel cost	Fuel cost ranges (2005)		
	Minimum	Maximum	Weighted average
(expressed in € per MWh primary energy)	[€/MWh-p]	[€/MWh-p]	[€/MWh-p]
AP1 - rape & sunflower	32.3	40.4	37.2
AP2 - maize, wheat (corn)	26.6	33.2	30.6
AP3 - maize, wheat (whole plant)	29.8	29.8	0.0
AP4 - SRC willow	27.4	32.9	29.2
AP5 - miscanthus	27.1	34.1	30.0
AP6 - switch grass	17.9	31.9	25.9
AP7 - sweet sorghum	31.0	40.9	40.9
Agricultural products - TOTAL	17.9	40.9	31.9
AR1 - straw	12.2	14.7	13.4
AR2 - other agricultural residues	12.2	14.7	13.5
Agricultural residues - TOTAL	12.2	14.7	13.4
FP1 - forestry products (current use (wood chips, log wood))	17.8	22.3	20.6
FP2 - forestry products (complementary fellings (moderate))	19.1	23.8	21.7
FP3 - forestry products (complementary fellings (expensive))	25.8	32.3	29.4
Forestry products - TOTAL	17.8	32.3	23.0
FR1 - black liquor	5.6	7.7	6.0
FR2 - forestry residues (current use)	6.3	8.6	7.0
FR3 - forestry residues (additional)	12.5	17.1	13.9
FR4 - demolition wood, industrial residues	5.0	6.8	5.9
FR5 - additional wood processing residues (sawmill, bark)	6.3	8.6	6.9
Forestry residues - TOTAL	5.0	17.1	6.9
BW1 - biodegradable fraction of municipal waste	-3.8	-3.8	-3.8
Biowaste - TOTAL	-3.8	-3.8	-3.8
FR6 - forestry imports from abroad	16.0	16.8	16.8
Solid biomass - TOTAL	-3.8	40.9	16.4
... of which domestic biomass	-3.8	40.9	16.4

In order to give a better illustration of the current[10] economic conditions of the various RES-E options, electricity generation costs[11] are depicted in the following figures. Their calculation is based on the economic and technical specifications as depicted in

[10] As usual, costs refer to the starting year for model simulations, i.e. 2005 and, hence, are expressed in $€_{2005}$.

[11] Note that in the model *Green-X* the calculation of generation costs for the various generation options is done by a rather complex mechanism as described further in this report, respectively, 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.

Table 10, extended by missing parameters such as full load hours and fuel prices (in case of biomass), representing the broad range of resource-specific conditions among the EU-15 countries.

The Green-X tool differentiates between *long-run marginal generation costs* that are used for the simulation of investment decisions and *short-run marginal generation costs* which are the running costs that depict the operation decisions. These costs for the RES-E category are presented in Figure 4 and Figure 5. Thereby, for the calculation of the capital recovery factor two different settings are applied with respect to the payback time:[12] On the one hand, a default setting, i.e. a payback time of 15 years, is used for all RES-E options – Figure 4 (left), and on the other hand, the payback is set equal to the technology-specific life time (right). The broad range of costs for several RES-E represents, on the one hand, resource-specific conditions as are relevant e.g. in the case of photovoltaics or wind energy, which appear between and also within countries. On the other hand, costs also depend on the technological options available – compare, e.g. co-firing and small-scale CHP plants for biomass (small scale CHP is contained in the cost band "solid biomass" shown below).

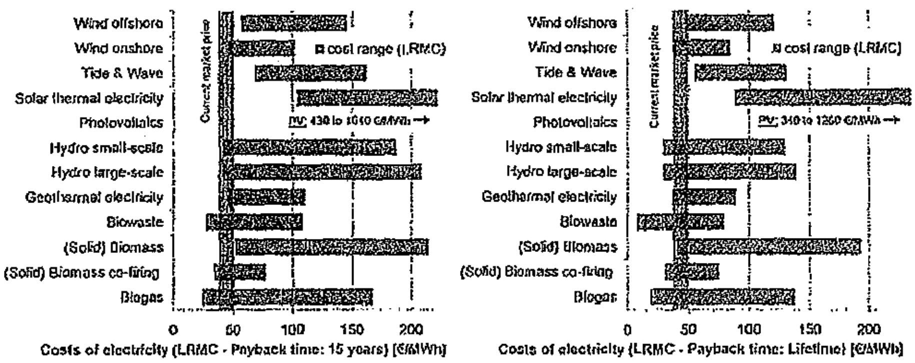

Figure 4 Long-run marginal generation costs (for the year 2005) for various RES-E options in EU countries – based on a default payback time of 15 years (left) and by setting payback time equal to lifetime (right).

[12] For both cases a default weighted average cost of capital (WACC) in size of 6.5% is used.

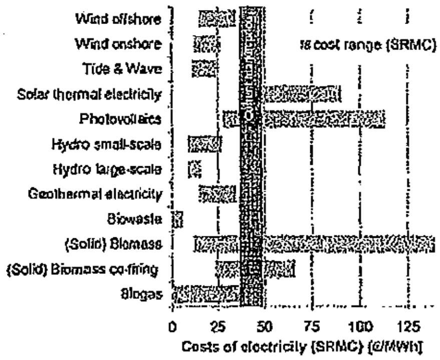

Figure 5 Short-run marginal generation costs (for the year 2002) for various RES-E options in EU countries

Figure 5 illustrates *short-run marginal generation costs*[13] by RES-E category. It is evident that for most RES-E options these short-run generation costs, i.e. the running costs, are low compared to conventional power generation based on fossil fuels. One exception in this context is biomass, where fuel costs and conversion efficiencies have a huge impact on the resulting running costs.

The current situation, without consideration of expected technological change, may be described as follows: RES-E options such as landfill and sewage gas, biowaste, geothermal electricity, (upgrading of) large-scale hydropower plant or co-firing of biomass are characterised by from an economic point-of-view comparatively low cost and by, in contrast, rather limited future potentials in most countries. Wind energy and in some countries also small-scale hydropower or biomass combustion (in large-scale plant) represent RES-E options with economic attractiveness accompanied by a high additional realisable potential. A broad set of other RES-E technologies are less competitive at present, compare e.g. agricultural biogas and biomass – both if utilised in small-scale plants, photovoltaics, solar thermal electricity, tidal energy or wave power – although, future potentials are in most cases huge.

[13] Short-run marginal costs are of relevance for the economic decision whether to operate an existing plant or not.

Economic data for RES-H

Table 12 gives an overview of economic parameters and accompanying technical specifications on technological level for grid- (i.e. district heating) and non-grid heating systems, referring to *new plant* of the database in accordance with the *additional realisable mid-term potential.*

Table 12 Overview on economic-& technical-specifications for new RES-H plant (grid & non-grid)

RES-H sub-category	Plant specification	Investment costs	O&M costs	Efficiency (heat)[1]	Lifetime (average)	Typical plant size
		[€/kW$_{heat}$][2]	[€/(kW$_{heat}$*yr)][2]	[1]	[years]	[MW$_{heat}$][2]
Grid-connected heating systems						
Biomass - district heat	Large-scale unit	350 - 380	16 - 17	0.89	30	10
	Medium-scale unit	390 - 420	17 - 19	0.87	30	5
	Small-scale unit	475 - 550	20 - 22	0.85	30	0.5 - 1
Geothermal - district heat	Large-scale unit	800	50	0.9	30	10
	Medium-scale unit	1200 - 1500	55	0.88	30	5
	Small-scale unit	2000 - 2200	57 - 60	0.87	30	0.5 - 1
Non-grid heating systems						
Biomass - non-grid heat	log wood	255 - 340	6 - 10	0.75 - 0.85*	20	0.015 - 0.04
	wood chips	340 - 610	6 - 10	0.78 - 0.85*	20	0.02 - 0.3
	pellets	390 - 530	6 - 10	0.85 - 0.9*	20	0.01 - 0.25
Heat pumps	ground coupled	900 - 1100	5.5 - 7.5	3 - 4[1]	20	0.015 - 0.03
	earth water	650 - 1050	10.5 - 18	3.5 - 4.5[1]	20	0.015 - 0.03
Solar thermal heating & hot water supply	Large-scale unit	400 - 420[2]	5 - 7[2]	-	20	100 - 200
	Medium-scale unit	540 - 560[2]	7 - 9[2]	-	20	50
	Small-scale unit	900 - 930[2]	13 - 15[2]	-	20	5 - 10

Remarks: [1] In case of heat pumps we specify under the terminology "efficiency (haet)" 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).

Economic data for RES-T (biofuels)

Table 13 gives an overview economic parameter and accompanying technical specifications on technological level for some selected RES-T plant, referring to *new plant* of the database. Please note that all data – i.e. investment-, O&M-costs and efficiencies - refer to the default start year of the simulations, i.e. 2005, and are expressed in $€_{2005}$.

Table 13 Overview on economic-& technical-specifications for new RES-T plant

RES-T sub-category	Fuel input	Investment costs	O&M costs	Efficiency (transport)	Efficiency (electricity)	Lifetime (average)	Typical plant size
		[$€/kW_{trans}$]	[$€/(kW_{trans}$*year)]	[1]	[1]	[years]	[MW_{trans}]
Biodiesel plant (FAME)	rape and sunflower seed	210 - 860	10.5 - 45	0.66	-	20	5 - 25
Bioethanol plant (EtOH)	energy crops (i.e. sorghum and corn from maize, triticale, wheat)	640 - 2200	32 - 110	0.57 - 0.65	-	20	5 - 25
Advanced bioethanol plant (EtOH+)	energy crops (i.e. sorghum and whole plants of maize, triticale, wheat)	1130 - 1510[1]	57 -76[1]	0.58 - 0.65[1]	0.05 - 0.12[1]	20	5 - 25
BtL (from gasifier)	energy crops (i.e. SRC, miscanthus, red canary grass, switchgrass, giant red), selected waste streams (e.g. straw) and forestry	750 - 5600[1]	38 - 280[1]	0.36 - 0.43[1]	0.02 - 0.09[1]	20	50 - 750

Remarks: [1] In case of Advanced bioethanol and BtL cost and performance data refer to 2010 - the year of possible market entrance with regard to both novel technology options.

A. 7. Calculation of the dynamic cost-resource curve

In general, in the model *Green*-X, dynamic effects will be considered covering the areas of:

- costs (and related performance parameters) for new plants
- available / realisable potential for existing and new plants, respectively.

The dynamic adaptation of the costs (investment costs and operation and maintenance costs) will take place at the end of one simulated year, i.e. the investment costs for the year n will be determined at the end of the year n-1.

The dynamic assessment of the potential will take place at two different stages in the model:

- The evaluation of the *available potential of* **existing plants** *for the year n* will be made - similar to the cost adaptation – at the end of the simulation run in the previous year.

- For **new plants,** the assessment of the *maximal realisable potential for the year n* takes place after the creation of the static cost-resource curve for the year n. The reason why this step cannot also be carried out at the end of the year n-1 (as done for all other dynamic assessment steps), is that not all required information for deriving the assessment parameters is available at that time – i.e. as policy settings can be changed year by year, actual settings for the year n must be used which, of course, are only available after the simulation for the year n is started. In more detail the following inputs must be available:
  - Input database supply
    - Input database – existing plants
    - Input database – new plants
  - Stakeholder behaviour
    - Investor
    - Society
  - Policy instruments
    - Supply-side strategies
    - Demand-side strategies

In the following, the development of the dynamic cost-resource curves will be explained in more detail for existing and new plant separately.

Dynamic cost-resource curve - existing plants

The following describes how to adapt the already achieved potential of existing plants. As mentioned before, in the actual model implementation this step takes place during the creation of the 'input database – existing plants' for the year n, i.e. at the end of the year n-1. The results of the simulation of one year show – among others – which potentially new plants have actually been implemented. Therefore the database of existing plants must be extended by these plants, i.e. the database for existing plants consists - after carrying out this step - of data for all plants already installed before the year n-1 plus those plants which were built in the year n-1. However, this also means that old plants, which are at the end of their lifespan in the year n, are still included in the adapted database. Hence, in a second step, a lifespan assessment must be carried out. All plants which have to be decommissioned in the year n have to be excluded from the 'input database – existing plants'.

In the database the lifespan of the plant (share) of each band of the technology will be compared with the construction year of the plant. If construction year plus technology-specific defined lifespan is smaller than year n, the plant will be decommissioned. This means this potential will be subtracted from the available potential of existing plants in the year n.[14] This procedure is schematically depicted in Figure 6.

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[14] Note: costs for replacing old plants with new ones is cheaper and acceptance is higher compared to the construction of totally new plants at new locations. Therefore, the potential

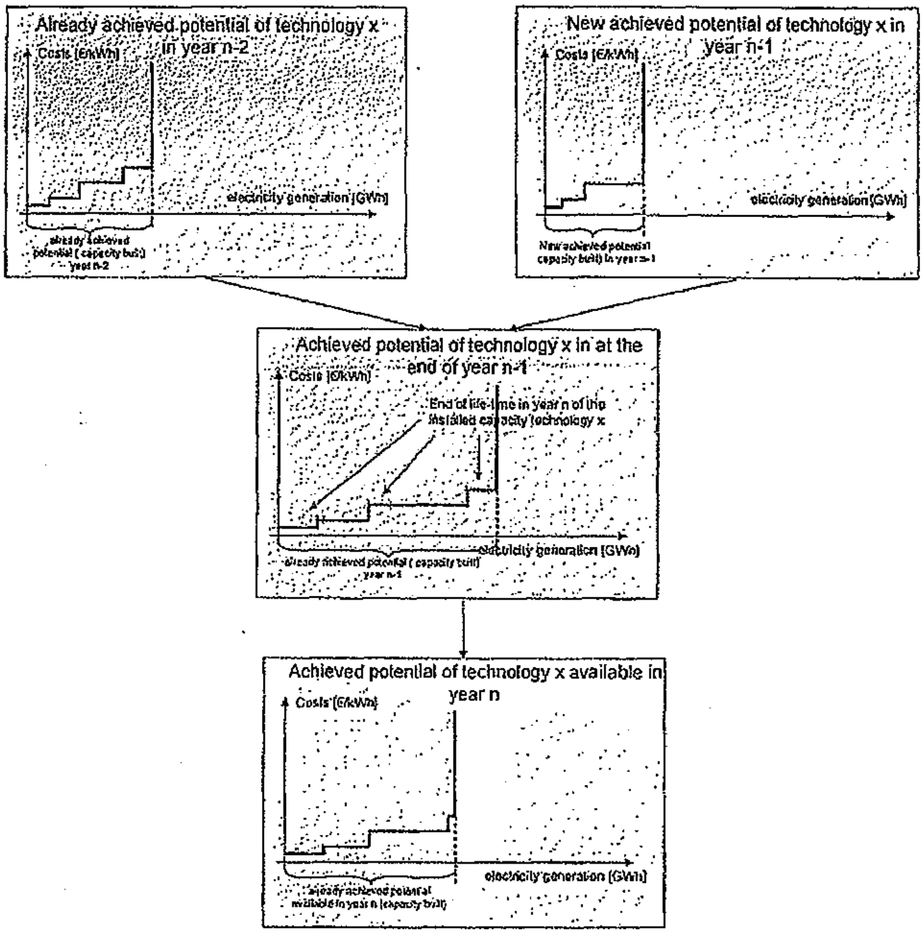

Figure 6 Schematic plot of the development of dynamic cost-resource curves for existing plant for the year n (incl. extension for new plant of the year n-1 and lifespan assessment of existing plants) (example for the electricity sector only)

Note: these steps will be carried out at the end of the simulation for year n-1

Dynamic cost-resource curve - new plants

The methodology to derive a dynamic cost-resource curve for the year n for potentially new plant is more complex than it is for existing plants, because – as already indicated in previous sections – this dynamic cost-resource curve for a certain year must be developed from the (static) cost-resource curve related to the additional mid-term potential.

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removed must be adequately considered in the dynamic parameter assessment in the following years.

Why is it necessary to start with the additional mid-term potential and derive the annual potential backwards in time from 2020 to year n ('top down') instead of assessing the additional potential for the next year directly by taking into consideration various available barriers and obstacles for the next year ('bottom up')? The motivation is given by practical reasons, namely,

- data with respect to the additional mid-term potential are available for various technologies, e.g. from projects like SAFIRE, ElGreen, etc. Therefore, compatibility with other studies is given and, hence, correction and adaptation are easily feasible,
- the potential for the year n depends on parameters (e.g. policy strategies) which will be set in the simulation for year n in year n and, hence, are not available as input parameters for the simulation process before the year n.

Nevertheless, in many cases, the results of this 'top-down' approach will be accompanied and compared with the 'bottom up' approach, i.e. deriving the additional potential for year n by starting from year n-1. With this 'two-fold' approach it is secured that the potential derived directly by the 'bottom up' approach (here the available potential is given by the minimum barrier for the next year) does not exceed the additional mid-term potential determined by the 'top-down' approach and evaluated in many international studies. Note, a depiction referring to the 'top down' approach is given in Figure 7.

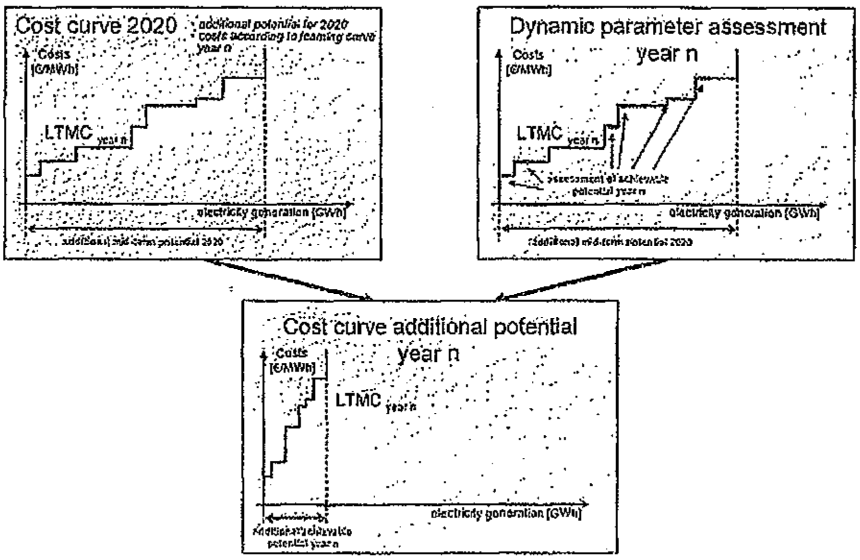

Figure 7 Schematic plot of the cost curve development for the year n and technology x

Dynamic cost-resource curves for the year n

The overall cost-resource curve for the year n can be derived by horizontal addition of the already achieved potential (existing plants) and the available additional potential (new plants). This procedure is shown in Figure 8.

In general, it can be said that the generation costs of RES are higher than those of conventional energy sources. Moreover, costs, as well as achievable potentials, differ widely among the specific technologies. The combination of the cost-resource curves for potentially new and already achieved plants represents the output of the database 'dynamic cost-resource curve'.

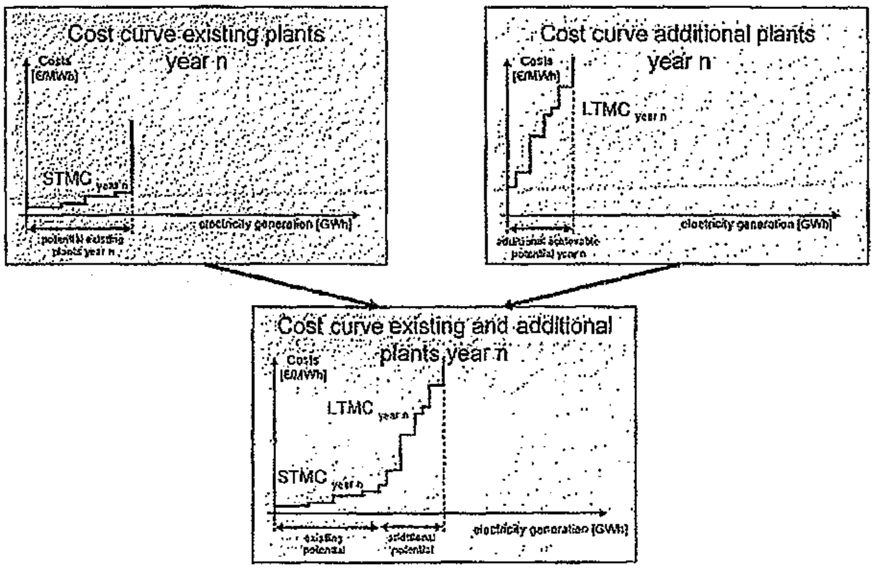

Figure 8 Combination of cost-resource curves for already achieved and additional potential for the year n and technology x (shown for electricity sector only)

Summing up, the future penetration of a certain technology depends on how it prevails over two categories of obstacles:

- Economic barriers – they are reflected by the net generation costs, i.e. inclusive policy strategies (if applicable).
- Other (non-economic) barriers as described above – they restrict the available potential of RES generation in year n.

Penetration of a technology will only take place if both categories of barriers can be overcome. So, on the one hand, it does not help to support a certain technology via a quota obligation, a guaranteed feed-in tariff or a tender scheme without preparing the framework conditions to overcome the other existing barriers, e.g. increasing the social acceptance by information campaigns, or decreasing administrative burdens for commissioning new plants, etc.. In other words, low (net) generation costs but high non-economic barriers still result in less additional penetration. On the other hand, providing a good environment at administrative, social, industrial and technical levels (i.e. admitting a huge potential) without economic incentives does not increase the future penetration rate of a certain technology. For instance, a high potential of electricity generation but high generation costs also results in a low market share.

A. 8. Data for the dynamic aspects

A *dynamic cost-resource curve* represents a tool to provide the linkage between the formal description of costs and potentials by means of *static cost-resource curves* (as presented in the previous sections of this chapter) and the dynamic cost assessment as e.g. done by application of *experience curves* as well as the implication of dynamic restrictions in accordance with *technology diffusion*.

Accordingly, data referring to these dynamic aspects will be presented in the following. First, data with respect to the dynamic cost (and performance parameter) assessment is outlined, followed by a description of the specifications for dynamic (non-economic) barriers.

Data for the dynamic cost assessment

With respect to **technological change**, the following dynamic developments of the electricity generation technologies are considered:

- Investment costs
- Operation & Maintenance costs
- Improvement of the conversion efficiency and related performance parameter

For most RES-E technologies the future development of investment cost is based on *technological learning*. As learning is taking place on the international level the deployment of a technology on the global level must be considered. For the model runs global deployment consists of the following components:

- Deployment within the EU 25 Member States is endogenously determined, i.e. is derived within the model.[15]
- Expected developments in the 'Rest of the world' are based on forecasts as presented in the IEA World Energy Outlook 2004 (IEA, 2004).

[15] For the case that only a single country is investigated, a default forecast would be taken as reference for the RES-E deployment on EU-25 level.

Table 14 Default settings with respect to the dynamic assessment of investment costs for RES-E & RES-H technologies

RES category	Applied approach	Assumptions
BIOGAS	EXPERIENCE CURVE (GLOBAL)	LR (LEARNING RATE) = 10 -12.5%
BIOMASS ELECTRICITY & CHP	EXPERIENCE CURVE (GLOBAL)	LR = 10 – 12.5% AS DEFAULT, COST DECREASE OF 1.5%/YEAR IN CASE OF CO-FIRING
BIOMASS DISTRICT HEATING	EXPERT FORECAST	COST DECREASE OF 1.5%/YEAR
BIOMASS NON-GRID	EXPERIENCE CURVE (EU25)	LR = 5 – 10% DEPENDING ON TECHNOLOGY
BIOFUEL FOR TRANSPORT	EXPERIENCE CURVE (EU25)	LR = 10%, EXPERT FORECAST UP TO 2012 IN CASE OF NOVEL TECHNOLOGIES
GEOTHERMAL ELECTRICITY	EXPERIENCE CURVE (GLOBAL)	LR = 8%
GEOTHERMAL HEAT	EXPERIENCE CURVE (GLOBAL)	LR = 5%
HYDROPOWER	EXPERT FORECAST	COST DECREASE OF 1.2%/YEAR
PHOTOVOLTAICS	EXPERIENCE CURVE (GLOBAL)	LR = 20% UP TO 2010, 12% AFTER 2010
SOLAR THERMAL ELECTRICITY	EXPERIENCE CURVE (GLOBAL)	LR = 18% UP TO 2010, 12% AFTER 2010
SOLAR THERMAL	EXPERIENCE CURVE (EU25)	LR = 5%
TIDAL & WAVE	EXPERT FORECAST	COST DECREASE 5%/YEAR UP TO 2010, 1%/YEAR AFTER 2010
WIND ON- & OFFSHORE	EXPERIENCE CURVE (GLOBAL)	LR = 9.5%

Default assumptions with respect to technological learning or the cost decrease, respectively, as depicted in Table 14 are based on a literature survey and discussions at expert level. Major references are discussed below:

Various studies have recently treated the aspects of technological learning with respect to energy technologies. In a general manner, covering a broad set of (RES-E) technologies, experience curves are discussed in (Grübler et al., 1998), (Wene C. O., 2000), (McDonald, Schrattenholzer, 2001) and (BMU, 2004). A focus on photovoltaics is given in (Alsema, 2003) and (Schäffer et al., 2004), whilst in case of wind energy (Neij et al., 2003) provides the most comprehensive recent survey. With respect to the future cost development of emerging new technologies like tidal and wave energy a stick to expert forecasts given by (OXERA Environmental, 2001) seems preferable.[16]

The **future development of biomass prices** as relevant for electricity and heat production based on biomass and biowaste is – as default – based on the following

[16] The currently implemented modelling approach accounts solely learning on the commercial market place. Efforts with respect to R&D, which do not result in additional deployment measurable in terms of MW installed, would otherwise neglected, but are of crucial relevance for technologies in the early phase of deployment – see (Grübler et al., 1998).

settings: On average an increase of 0.5-1.5% per year is projected, depending on fuel category and country.

Data with respect to dynamic barriers

Within the model *Green-*X dynamic barriers describe the impact of non-economic deficits on the deployment of a certain RES. They represent the key element to derive the dynamic potential for a certain year from the overall remaining additional realisable mid-term potential (up to the year 2020) for a specific RES. Thereby, the impact of three different types of several barriers can be investigated, e.g. technical, societal or market & administrative constraints.

As default, **technical and societal constraints** are considered only for onshore wind energy. Thereby, the simplified percentage approach has been adopted. More precisely the yearly realisable potential is restricted to a level of 50% of the remaining additional mid-term potential on band-level.

In contrast, the most important non-economic constraint, i.e. the combined indicator for **market & administrative barriers**, is well applied to all RES-E categories in each country. The application of this barrier results in a technology penetration following an 'S-curve' pattern – of course, only if financial incentives are set appropriate.
The required data in this respect is described below. Thereby, the following parameters have to be defined:

Econometric factors A, B and C:

They predefine the possible increase of market deployment over time for a certain technology on country-level. I.e. a high absolute value of A (e.g. 0.7) would allow a fast market deployment (of course, if the barrier level b_M is set high, too). In this context, the technology-specific figures are derived from the in-depth investigation of the historical development of RES-E in Europe undertaken within the project "*FORRES 2020*" (see (Ragwitz et al., 2004)). Hence, the chosen figures refer to best conditions as observed for several RES technologies in the past in European countries.

Barrier level b_M:

This parameter defines the country-specific conditions – i.e. how far these conditions differ from the technology-specific 'ideal case' (i.e. from the as above explained historical observed best conditions in a certain country). Thereby, a value of 0 indicates a 'very high barrier', whilst a value of 4 refers to a 'very low barrier', i.e. the 'ideal case'. An illustration of the default setting is given in Figure 9, which depicts the ranges on technology-level, referring to the electricity sector. These default settings refer to the current situation of the various RES-E options in the investigated countries as assessed within the project "*FORRES 2020*" (see (Ragwitz et al., 2004)).

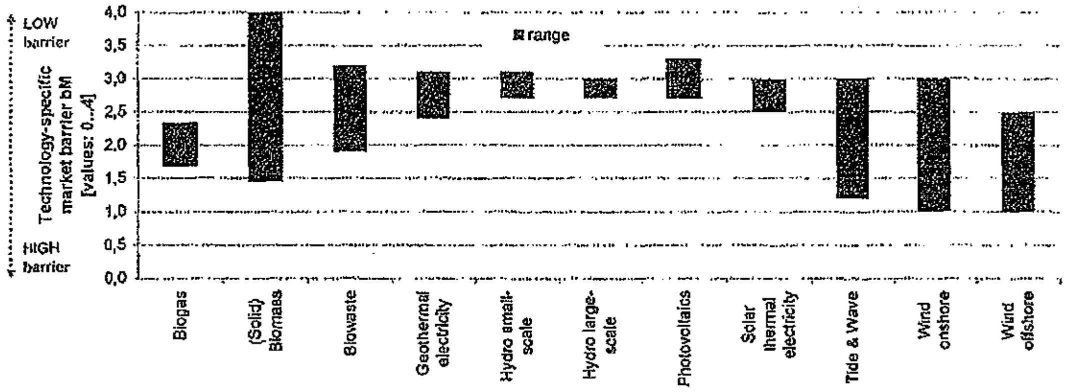

Figure 9 Model-settings of dynamic parameters: Country-specific ranges of applied market barrier level (bM) by RES-E technology

Lower boundary (minimum) for yearly realisable market potential $\Delta P_{M\ min}$:

A constant minimum level of the yearly realisable market potential is considered for each RES-E category on country level. Otherwise – if a technology enters a new market – no market potential would be available at the initial stage.

Similar to above, a depiction is given on country as well as on technology level: Figure 10 indicates ranges on technology-level, resulting from differing settings by country (referring to the electricity sector). Again, default settings take into account the current conditions for the various RES-E options in each country.

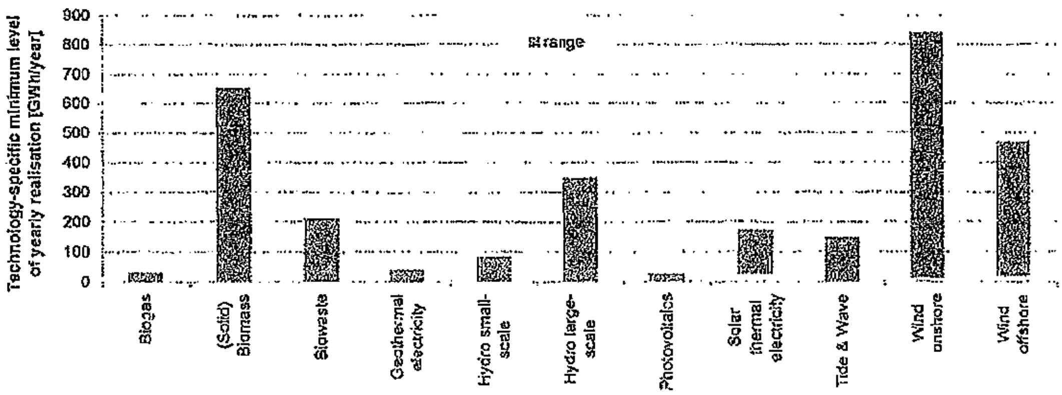

Figure 10: Model-settings of dynamic parameters: Country-specific ranges of applied minimum market potentials ($\Delta P_{M\ min}$) by RES-E technology

Annex 1b: Short characterisation of the model Green*Net*

The toolbox Green*Net*, developed by EEG, represents the core product of the overall project Green*Net* during its duration in the period 01/2003 to 12/2004.

The Green*Net* model allows to simulate different scenarios, which enable a comparative and quantitative analysis of strategies for an enhanced least-cost integration of RES-E within the liberalised electricity sector both for all considered EU countries (i.e. initially all EU15 countries and the new Member States Czech Republic, Hungary, Poland and Slovakia) as a whole as well as individual Member States for the period 2005 to 2020. It is important to mention that the geographical coverage has been recently extended within ongoing research activities[17] to the EU25 plus Bulgaria and Romania.

Similar to *Green*-X, the general modelling approach to describe both supply-side electricity generation technologies and electricity demand reduction options is to derive *dynamic cost-resource curves* for each generation and reduction option in the investigated region. Dynamic deployment of RES-E is policy-driven – where a similar pathway can be set as for the electricity sector within the *Green*-X model.

Of special interest within this project are the following model features:

Cost of system operation and grid extension in case of intermittent RES-E

Besides the policy settings, an additional feature is included in the overall simulation model, which is worth to mention: **The cost-allocation tool for system operation and / or grid extension costs in accordance with intermittent RES-E.** Within the toolbox Green*Net* such costs can be exemplarily determined for its most prominent representative: wind power.

Besides a variety of settings to determine the overall calculation procedure the user has the possibility to determine the allocation of the accordingly calculated cost. In general, they can either be applied to the consumer (society) or to the producer / investor. The later setting allows getting aware of a likely impact in terms of reduced wind installations, etc. In addition, trade-offs between policy instruments and this cost-allocation can be clearly expressed and determined.

An overview of the core elements of the Green*Net* model is given in Figure 11.

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17 Within the follow-up project Green*Net*-EU27 the extension of the geographical coverage of the model to all 10 new Member States, the candidate countries Bulgaria, Romania was recently undertaken – a further expansion to include Croatia as well as Switzerland and Norway is planned for the near future. For further information on these follow-up activities please visit: www.greennet-europe.org.

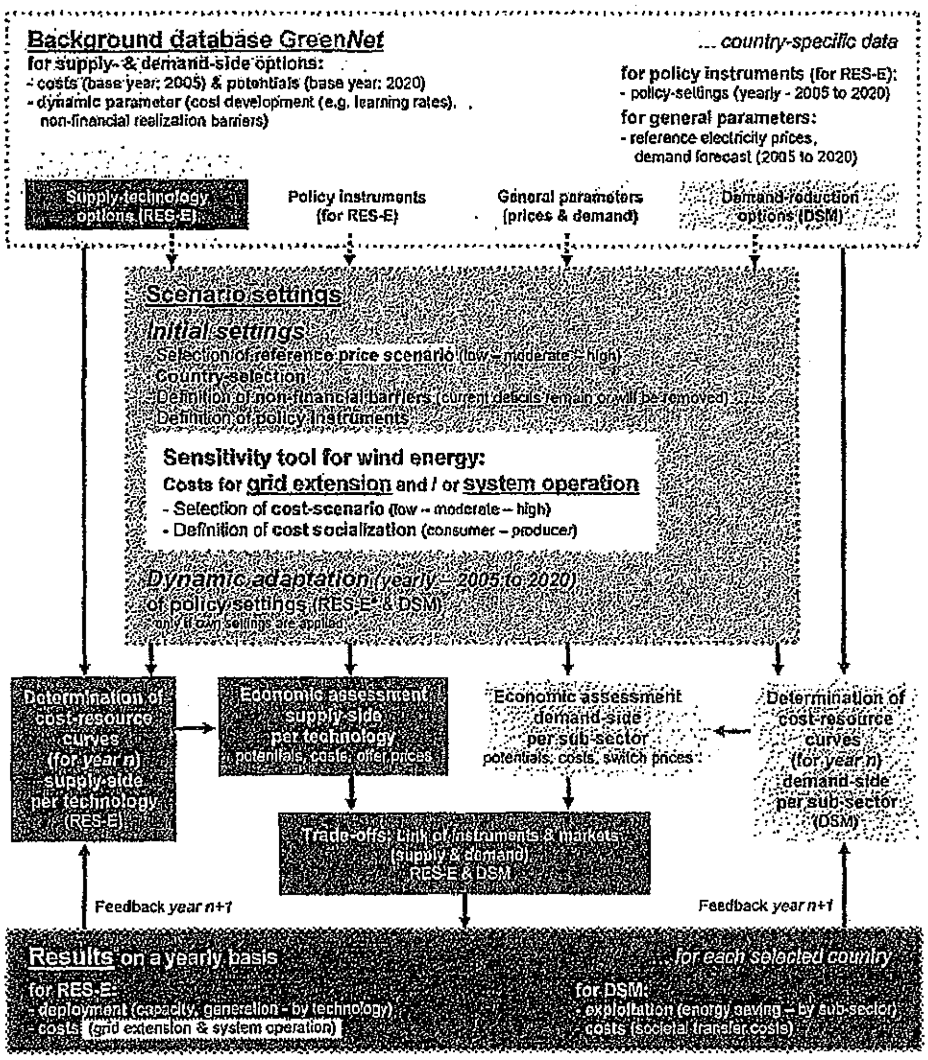

Figure II-2

Figure 11. Overview on the core elements of the model Green*Net*

The model Green*Net* aims to deliver a broad set of results. All results can be provided on a yearly basis on country-, EU- and / or technology-level.

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

- <u>*General results – including e.g.:*</u>
  - Installed capacity [MW]
  - Electricity generation [GWh]
  - National electricity consumption [GWh]
  - Wholesale market price electricity (yearly average price) [€/MWh]
  - Market price Tradable Green Certificates [€/MWh]

- Total electricity savings [GWh]

- *Impact on producer or society – including e.g.:*
  - Additional costs due to DSM strategy [M€, €/MWh]
  - Additional costs due to system operation [M€, €/MWh]
  - Additional costs due to grid extension [M€, €/MWh]