DISSERTATION

Dynamic cost-resource curves for electricity from renewable energy sources and their application in energy policy assessment

ausgeführt zum Zwecke der Erlangung des akademischen Grades
eines Doktors der technischen Wissenschaften

unter der Leitung von

ao. Univ. Prof. Dr. Reinhard Haas
und
Univ. Prof. Dr. Nebojša Nakićenović
Institut für Elektrische Anlagen und Energiewirtschaft (E373)

eingereicht an der Technischen Universität Wien
Fakultät für Elektrotechnik und Informationstechnik

von

Dipl.-Ing. Gustav Resch
Matr. Nr.: 9125046
Anzengrubergasse 10/21
1050 Wien

Wien, im April 2005

Acknowledgements

This PhD summarises my experience gained within the last four years of research undertaken at the Energy Economics Group (EEG), Institute for Power Systems and Energy Economics. The involvement in national as well as international research activities allowed me to finally come up with this set of written stuff.

Of major impact in this context I have to name the recently finished project *"Green-X – Deriving optimal promotion strategies for RES-E in a dynamic European electricity market"*, a research project within the 5th Framework Programme of the European Commission, DG Research, which allowed me and my colleagues Claus Huber and Thomas Faber to put our ideas into practice. Moreover, a set of "side-activities", i.e. the participation in other projects, on international as well as on national level, crucially helped to intensify our knowledge as well as to get a critical and fruitful feedback. Learning or experience, respectively, represents a well addressed topic in my thesis – therefore I have to address at this initial stage also my start-up activity at EEG – the European research project *"ElGreen – a joint European Green Electricity Market"* gave me the opportunity to take a first breath on the European stage (i.e. the smoke in Brussels).

To get more personnel, my special thanks addresses my colleagues at EEG - among all others namely

Prof. Reinhard Haas, the referee of my thesis, who gave me helpful inputs and a critical review, sometimes even at fruitful late-night discussions.

My colleagues Claus Huber and Thomas Faber, forming my main partners at EEG in above listed projects. Only our intensive cooperation allowed to us to succeed in these activities; and they always brought me "back on track" when sometimes becoming lost in certain side issues. I hope they do not mind if a lot of their brains is also packed into this thesis!

Prof. Nebojša Nakićenović as second referee – his sound experience in modelling of technological change I have to honour hereby greatly.

Last but not least my colleague Hans Auer, to whom I have to acknowledge my possibility to work at EEG – ringing me up by phone when I was a student and asking "Are you interested in joining us when you have finished your master thesis…?" Thereby, I have to name also my former girlfriend Helga Pokstefl, who replied in my absence "Yes – he will …".

Hence, my personnel acknowledgment addresses in an equal manner

My parents Erika and Gustav (senior) Resch, who gave me the opportunity to spend a set of years in studying (at least) electrical engineering. Their kindness as well as their appreciation of whatever I undertook helped me a lot and gave me protection.

My partner Demet Suna, who assisted me with her patience and love, not only in the final stage of completing this thesis! Her peer-review of this work accompanied by not taking me too serious helped me a lot.

Finally, I also have to address my friends outside the university, who applied a lot of understanding, as I was recently too often too busy for joint activities.

Kurzfassung

Der Ausbau erneuerbarer Energien wird national und international als wesentlicher Bestandteil einer Nachhaltigkeitsstrategie angesehen. Das Ziel der Europäischen Union ist es, den Anteil erneuerbarer Energien an der Stromerzeugung massiv zu erhöhen. Die Effizienz und auch die Effektivität des Ausbaues hängen entscheidend vom Förderinstrument selbst (z.B. Einspeisetarif, Quotensystem), aber vor allem von dessen konkreter Ausgestaltung ab.

Technologien zur Nutzung (neuer) erneuerbarer Energien im Bereich der Stromerzeugung sind gekennzeichnet durch, einerseits, ein zumeist hohes Kostensenkungspotenzial und, andererseits, begrenzte Ressourcen. In dieser Arbeit wird die konträre Rolle dieser beiden Effekte analysiert und die Folgen für die zeitliche Ausgestaltung von entsprechenden Förderstrategien diskutiert. Ein neuer Ansatz im Bereich der Modellierung energiepolitischer Instrumente – die Entwicklung *dynamischer Kosten-Potenzialkurven* – wird aufgezeigt, der einen Brückenschlag zwischen bestehenden Methoden darstellt. Wie in der Abbildung unterhalb skizziert, umfasst dies:

die formale Beschreibung von Kosten und Potenzialen erneuerbarer Energien mittels *statischer Kosten-Potenzialkurven*;

die Modellierung *technologischen Wandels*, d.h. der dynamischen Kosten- und Effizienzentwicklung, wie beispielsweise mittels *Lernkurven* beschrieben;

Aspekte der *Technologiediffusion* durch Berücksichtigung *nicht-ökonomischer dynamischer Barrieren*.

Abbildung: Skizze des methodischen Ansatzes dynamischer Kosten-Potenzialkurven für erneuerbare Energien (anhand des Modells ***Green-X****)*

Nach eingehender Beschreibung der formalen Grundlagen wird die gewählte Modellimplementierung anhand des entwickelten Prognosemodells ***Green-X***, das die Simulation energiepolitischer Instrumente erlaubt, beschrieben. Im Weiteren erfolgt eine umfassende Darstellung der erstellten Datenbasis bezüglich Potenziale und Kosten erneuerbarer Energietechnologien in den EU15 Mitgliedsstaaten.

Anhand von Beispielen wird die Anwendung des Modells im Bereich der Evaluierung energiepolitischer Instrumente aufgezeigt. Hierbei wird einerseits eine Förderinstrumentendiskussion auf europäischer Ebene durchgeführt, und andererseits die Erstellung von Entwicklungsprognosen für erneuerbare Energien auf nationaler Ebene exemplarisch am Beispiel Österreich diskutiert.

Die wichtigsten Erkenntnisse, die aus der Anwendung des Modells gezogen werden können, sind:

Die *Berücksichtigung der Dynamik ist essentiell*, da sich die Ergebnisse bzgl. der Effekte von Förderinstrumenten wesentlich von denen einer statischen Analyse unterscheiden. Von besonderer Bedeutung sind:

- die technologische Diffusion,
- die dynamische Entwicklung vorhandener, nicht ökonomischer Barrieren,
- sinkende Investitionskosten aufgrund von Lerneffekten und daher veränderte finanzielle Rahmenbedingungen und
- die nicht-lineare dynamische Zielsetzung für Erneuerbare über die Zeit.

Dynamische Kosten-Potenzialkurven erweisen sich als ein aussagekräftiges Werkzeug, das es erlaubt eine Vielzahl an Ergebnissen sowohl in Hinsicht auf *Effizienz* (Kosten) als auch *Effektivität* (Potenzialausschöpfung) energiepolitischer Instrumente abzuleiten. Die gleichzeitige Berücksichtigung von Ressourcenbeschränkungen als auch dynamischer Kostenentwicklungen erlaubt folglich eine verbesserte dynamische Ausgestaltung von Förderinstrumenten – zumindest im betrachteten Bereich der Energietechnologien basierend auf finiten erneuerbaren Energiequellen.

Die *konkrete Ausgestaltung der Förderinstrumente stellt das wichtigste Kriterium* für eine effiziente Förderung dar. Ähnliche Effekte bezüglich der Ausbaurate erneuerbarer Energien, der Investitionssicherheit, der Kosten für die Gesellschaft usw. lassen sich durch verschiedene Instrumente erreichen, wenn deren Rahmenbedingungen ähnlich gesetzt werden. Selbstverständlich bleiben gewisse Unterschiede erhalten, wie der Vergleich von Einspeisetarifen und handelbaren Zertifikatssystemen zeigt. Bei Beschränkung auf die *direkten Förderkosten zeigen die Analysen klare Vorteile bei Einspeisetarifsystemen*.

Um langfristig einen signifikanten Ausbau zu erreichen, ist es notwendig *ein breites Technologieportfolio aufzubauen*. Eine breite Förderung führt dazu, dass

- *Erfahrungen mit derzeit noch wenig ausgereiften Technologien gemacht werden können*, was zu einer Erhöhung der Akzeptanz und auch zur Kostenreduktion bei diesen Technologien aufgrund von technologischem Lernen führen kann.
- *Kostengünstige Optionen wie beispielsweise die Wasserkraft* einen (wesentlichen) Beitrag *zur Erreichung bestehender und künftiger Zielvorgaben* leisten können.

Durch eine *Koordination der Förderinstrumente auf europäischer Ebene* lässt sich die Gesamteffizienz erhöhen. Eine Koordination der Maßnahmen ist jedoch nicht automatisch mit einer vollen Harmonisierung der Förderinstrumente gleichzusetzen. Die Einigung auf einheitliche Rahmenbedingungen wie kontinuierliche Förderpolitik, stabile Planungshorizonte für Investoren, Beschränkung der Förderdauer, spezielle Förderstrategien für neue Kapazitäten (kein Gießkannenprinzip) und die Förderung von Wettbewerb genügt weitgehend, um eine effiziente und effektive Entwicklung der Stromerzeugung aus erneuerbaren Energien in Europa zu gewährleisten.

Abstract

Increasing the share of *electricity from renewable energy sources (RES-E)* has a high priority in the energy policy of many countries world-wide. Within the European Union the 'White Paper on Renewable Sources of Energy' (European Commission, 1997) as well as the 'Directive on the promotion of electricity produced from renewable energy sources' (European Parliament and Council, 2001) set essential goals to almost double the share of RES-E by 2010.

The developed modelling concept of *dynamic cost-resource curves* allows the linkage between three approaches of particular importance in the field of renewable energy sources, but also energy technologies in a general manner, namely *static cost-resource curves*, *technological change* and *technology diffusion*. In more detail, as illustrated in the *figure* below, it comprises:

- Renewable energy sources are characterised by a limited resource, and – if cost dynamics are not considered – costs rise with increasing 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. One proper tool to describe both costs and potentials represents the *static cost-resource curve.*
- The extension of above formal description of resource conditions is provided by including aspects of *technological change* and *technology diffusion*:
  - Costs and other performance issues are adapted dynamically on technology level. Thereby, two different approaches can be applied: Standard cost forecasts or endogenous technological learning.
  - Of importance in the context of technology diffusion is to apply dynamic realisation restrictions. Consequently, 'S-curve' patterns are applied to describe the impact of market and administrative restrictions, representing the most important in the set of dynamic non-economic barriers for the deployment of a certain RES-E.

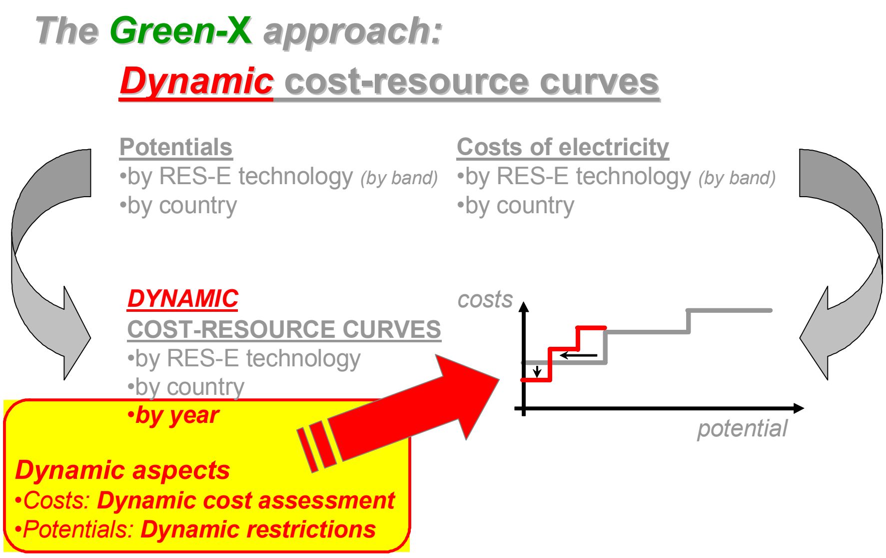


Figure *Method of approach regarding dynamic cost-resource curves for RES-E (for the model **Green-X**)*

This concept is applied within the development of the dynamic computer model ***Green-X***. Thereby, data requirements with respect to dynamic cost-resource curves are discussed, and an in-brief depiction of the developed database for RES-E, referring geographically to EU-15 countries, is given. The application of the concept respectively the model in the assessment of RES-E policies is illustrated exemplarily: An evaluation of energy policy instruments on EU-15 level is undertaken, and, in addition, the assessment of RES-E deployment on national level is discussed considering Austria as an example.

Main conclusions are:

- *Considering dynamics is essential* for the assessment of energy policy instruments and RES-E deployment. The impact of policy instruments significantly varies from a static viewpoint. Of special importance is:
  - Technological diffusion due to changes of existing barriers over time
  - Decreasing generation costs and hence lower necessary financial incentives
  - Non-linear dynamic target /quota setting
- The *dynamic cost-resource curve* approach represents a *proper tool* in this respect:
  - Due to the *combined consideration of resource restrictions and dynamic cost developments, dynamic cost-resource curves assist in deriving the optimal time-path for policy instruments*.
  - In addition, *they assist policy makers in deriving efficient and effective promotion instruments for RES-E*. Through their application results can be gained with respect to both costs (i.e. efficiency) and penetration (i.e. effectiveness).
- From a societal point-of-view *the use of the full basket of available RES-E technologies is highly recommended*. The effects of neglecting some technologies – especially 'cheap' options such as hydropower – increase both generation costs and transfer costs for consumer.
- *The design of an effective strategy is by far the most important success criteria.* The effects on RES-E deployment, investor stability, conventional power generation and its emission and prices are similar if the design of the instrument is similar too. Of course, as the instrument differs, the effort, the efficiency and complexity of reaching a similar impact varies among the support schemes too.
- By focusing on transfer costs for consumer *the comparison of the single promotion instruments* leads to the following findings:
  - A *quota obligation based on TGCs* is less efficient from a societal point-of-view compared to other instruments analysed, as, first, a higher risk must be born by the generator, and, second, efficiency gains are absorbed by producers (high producer surplus) and not by consumers;
  - *Feed-in tariffs* (and also e.g. tender schemes) are useful in promoting a more homogeneous distribution among different technologies by setting technology specific guaranteed tariffs. By implementing such a policy, the long-term technology development of various RES-E options, which are currently not cost-efficient, can be supported.
- *Coordination and harmonisation of support mechanisms* between the Member States leads to *lower transfer costs for consumers*. Of course, a necessary pre-condition to reach an international agreement is that *a 'fair' burden sharing concept is developed, considering both national and international benefits from RES-E generation*.
- The *achievement of most policy targets for RES-E* as well as the accompanying societal costs are closely *linked to the future development of the electricity demand*. Therefore, besides setting incentives on the supply-side for RES-E, accompanying demand-side measures help to minimise the overall societal burden.

Content

Figures

Tables

List of Abbreviations

A .... quadratic factor yield from the econometric analysis
a .... econometric factor, technology specific
α .... calculated factor - expressing the dynamic additional realisable potential as percentage figure
α_{SC} .... calculated factor - expressing the dynamic additional realisable potential (on country level) as percentage figure
B .... linear factor yield from the econometric analysis
b .... experience index *or* econometric factor, technology specific
$\beta_{G\ max}$ .... slope of grid restriction (band level)
$\beta_{G\ min}$ .... slope of grid restriction (band level)
β_S .... slope of social restriction (band level)
β_{SC} .... slope of social restriction (country level)
b_G .... barrier level – grid assessment
b_M .... barrier level market / administrative constraint assessment
b_S .... barrier level – social acceptance assessment
c .... econometric factor, technology specific
C .... constant factor yield from the econometric analysis
C .... generation costs per kWh
C_{CUM} .... costs per unit as a function of output
C_{FIX} .... fixed costs
C_{FIX} / q_{el} .... fixed costs per energy unit
C_{FUEL} .... fuel costs per energy unit
$C_{O\&M}$ .... operation and maintenance costs per energy unit
CRF .... capital recovery factor
CS .... consumer surplus
CUM .... cumulative production over time
$C_{VARIABLE}$ .... running costs per energy unit
C_0 .... costs of the first unit produced or installed
D .... demand curve
$\Delta P_{G\ n}$ .... realisable potential - grid constraint (year n, band level)
$\Delta P_{S\ n}$ .... realisable potential - social constraint (year n, band level)
$\Delta P_{M\ n}$ .... realisable potential (year n, country level)
$\Delta P_{M\ min}$ .... lower boundary (minimum) for realisable potential (year n, country level)
$\Delta P_{M\ ne}$ .... realisable potential econometric analysis (year n, country level)
ΔP_n .... realisable potential (year n, band level)
$\Delta P_{n\ ->\ 2020}$ .... additional mid-term potential (year n till 2020, band level)
$\Delta P_{stat2020}$ .... static additional mid-term potential (i.e. from 2002 to 2020)
η_{el} .... efficiency for electricity generation
η_{heat} .... efficiency for heat generation
FIT .... feed-in tariff
GC .... generation costs
H .... full-load hours

I........................investment costs per kW
LR ....learning rate *or* experience rate
LTMC...............long-term marginal cost
MC ....marginal cost
P ....payback time of the plant [a]
p_c......................electricity price
p_{FUEL}.................fuel price for primary energy carrier
p_{HEAT}.................heat price
PR....................progress ratio
PS ....producer surplus
PV ....photovoltaics
q_{el} ....quantity of electricity generation
R_{HEAT} ....revenues gained from selling of heat
S ....supply curve
STMC...............short-term marginal cost
z ....interest rate
p_F ....feed-in tariff
p_I ....investment subsidy
p_Q ....penalty
$P_{stat\ long\text{-}term}$ ....static long-term potential (country level)
p_T ....tax incentive
PT ....payback time
q_o......................quota obligation
RES ....renewable energy source(s)
RES-E.............electricity from renewable energy sources *or* renewable energy source for electricity generation
ST ....support time
TEA..................tradable emission allowance
TGC ....tradable green certificate
WACC..............weighted average cost of capital
WTP.................willingness to pay
X_n ....calculated factor - expressing the dynamic achieved long-term potential as percentage figure
$\chi_{M\ max}$................absolute amount of market restriction assuming very low barriers
$\chi_{M\ min}$ ....absolute amount of market restriction assuming very high barriers
χ_G ....slope of grid restriction (band level)
$\chi_{S\ max}$ ....absolute amount of social restriction (band level)
$\chi_{S\ min}$.................absolute amount of social restriction (band level)

1. Introduction

Generating *electricity from renewable energy sources (RES-E)* has a high priority in the energy policy strategies on national and European level as well as on a global scale. Challenging goals for this 'new' kind of electricity generation have been set recently, e.g. national targets for Austria are given by the *'Eco Electricity Act' (BMWA, 2002)* or on European level by the *'Directive on the promotion of electricity from RES' (European Parliament and Council, 2001)* as well as the *'White Paper on Renewable Sources of Energy'* (European Commission, 1997)[1]. In order to achieve these goals, increased co-operation is needed within and between countries. In addition, financial incentives for the development of new industries also play a key role.

The great importance of RES-E is due to the considerable associated benefits, namely:

- reduction of greenhouse gas emissions;
- increases in local employment and income;
- enhanced local tax revenues;
- a more diversified resource base;
- avoided risks of disruption in fossil fuel supply and associated price instability;
- provision of infrastructure and economic flexibility by modular, dispersed and smaller scale technologies;
- the potential to greatly reduce, and perhaps eventually eliminate pollution associated with electricity services;
- a significant contribution towards *sustainability*[2].

However, to facilitate a breakthrough for RES-E, several barriers have to be overcome. It is well known that at present most RES-E options require financial support in order to penetrate the electricity market. Moreover, besides the economic deficits, also a set of non-economic barriers are of relevance. They include administrative and legislative obstacles as well as problems arising from lack of awareness. Also there are social and environmental barriers, which may result from a lack of experience with planning regulations, which curtail the public acceptance of a new technology. To overcome these deficits, careful energy policy strategies have to be applied. Currently, a wide range of strategies is implemented in different countries.

Nevertheless, which of the different instruments is most effective for increasing the dissemination of RES-E is still a topic of very controversial discussions. To assist the analysis which promotion strategy works best to facilitate the deployment of RES-E several projects (e.g. the European Commission funded projects "Organising a joint green electricity market - ElGreen" (Huber et al., 2001) or "Renewable energy burden sharing – REBUS" (Voogt et al., 2001)) have been carried out. A common feature of all these studies is the fact that the investigations are undertaken from a static point-of-

---

[1] *"The Commission takes the view that a doubling of the share accounted for by these energy sources by 2010 (from 6% to 12%) could be an ambitious but realistic objective."* (European Commission, 1997)

[2] In relation to energy systems, i.e. the exploitation of primary energy resources for energy utilization, sustainability is commonly quoted as the ability of the particular production system to sustain the production level over long times, i.e. for continuing future generations. Accordingly, this implies that the sustainable system will not cause significant ecological damage.

The original definition of sustainability goes back to Bruntland Commission (1987): *"Meeting the needs of the present generation without compromising the needs of the future generations"*.

view, i.e. by focussing on a certain target year[3]. Such static models may assist in finding proper strategies, but a 'fine tuning' of these instruments longs for a more detailed reflection.

This underlines the need for a dynamic approach enabling a setting of the correct 'time path' for selected effective and efficient energy policy instruments. Thereby, aspects of technological change and technology diffusion as well as the characteristics of the specific renewable resources have to be taken into account.

1.1. Objective

The core objective of this thesis is to **develop a modelling framework allowing an assessment of the future deployment of RES-E in the 'real world'.**

Derived objectives are:

- to describe **the potential & the accompanying cost of the various RES-E options** in a brief and suitable manner for model implementation;

  With respect to resource restrictions a practicable approach has to be developed – in accordance with the envisaged time-horizon of scenarios. In addition, the formal description of RES-E has to address the determining economic parameters for (new) supplier on liberalised power markets.

- to model the **impact of policy instruments**;

  As energy policy represents the key driver for RES-E deployment, the developed concept has to allow an in-depth evaluation of possible policy settings by applying criteria such as *effectiveness* and *efficiency*.[4]

- to address **dynamic aspects** in a proper way, including:
  - Future **technological changes** – e.g. a reduction of investment costs or efficiency improvements for a certain technology due to technological learning as observed in the past for several technologies – and the related uncertainties have to be considered.
  - **Technology diffusion** as well as the impact of **non-economic barriers** has to be taken into account to be able to derive a picture of a likely future as close as possible to reality.

It is important to stress that the overall time-horizon of forecasts to be undertaken is 2020 to 2030. Looking roughly 20 years ahead represents in energy modelling, especially on global scale, a (short to) mid-term projection. Such a distinction might be of crucial importance, as it justifies e.g. the claimed accuracy with respect to the modelling of policy instruments and excuses missing dynamic aspects which become important the farer looking into the future.[5]

---

[3] The term 'static' means in this case the implying of a leap in time. Thereby, the period between the starting point and the target year is neglected.

[4] Effectiveness of an energy policy instrument for RES-E may be judged in terms of installed MW or resulting GWh, whilst (economic) efficiency refers to the resulting cost burden (for consumer etc.).

[5] Compare e.g. Grübler et al. (1998): Besides above mentioned dynamic aspects, network effects and technological interdependence are mentioned as important attributes for technological change. The neglect of this issue may be justified due to the time-horizon of likely network changes in size of 50 to 100 years – at least twice as long as envisaged herein.

1.2. Main literature

In my search for solutions to meet above raised objectives, the following references gave helpful inputs and addressed topics of relevance:

In the assessment of potentials for renewable energy sources (Neubarth et al., 2002) and (Haas et al., 2001) gave helpful methodological inputs. With respect to accompanying economic aspects, a set of studies have to be listed which provide a comprehensive survey on RES-E technologies: (DTI/ETSU, 1999), (DLR/WI/ZSW/IWR/Forum, 1999), (Nowak et al., 2002), (Kaltschmitt et al., 2003) and, recently, (BMU, 2004).

(Grübler et al., 1998) addresses important aspects of technological change and dynamic aspects with respect to energy technologies in a conceptual manner. Various studies have recently focussed on the aspects of technological learning. In this context, (Wene, 2000), (McDonald, Schrattenholzer, 2001) and with a particular focus on wind energy (Neij et al., 2003) have to be mentioned.

With respect to energy policy modelling in the field of RES-E much of the work as presented herein is based on the past experience gained within the previous research project "Organising a joint green electricity market - ElGreen". However, the model developed therein neglects dynamic aspects and, consequently, underpins the 'static point-of-view'. For a detailed description see (Huber et al., 2001). In addition, aspects of energy policy modelling are also treated well in (Voogt et al., 2001) and (Uyterlinde et al., 2003). A focus on aspects of importance for the various policy instruments is given in (Huber, 2000).

1.3. Structure of the thesis

An inventory of the state-of-the-art of RES-E is undertaken in chapter 2. As starting point the global context and in brief the historical development within Europe, in particular the EU-15 countries, is described. Thereby, accompanying energy policy instruments, i.e. commonly named as promotion strategies will be discussed as well. An outlook on future targets as set on European level ends this chapter.

Next, the applied method of approach is discussed in chapter 3. An introduction on the main issues of relevance in this context and a description of basic principles indicates the starting position. Next, the developed methodology – i.e. the concept of dynamic cost-resource curves – is explained briefly.

In chapter 4 the application of this concept, i.e. the model implementation, is illustrated with the computer model ***Green-X***. Accordingly, an overview on the developed tool is given first, accompanied by a brief description of the model framework.

Chapter 5 illustrates data requirements with respect to dynamic cost-resource curves. Principal aspects will be discussed with respect to the assessment of potentials and cost of RES-E as well as an in-brief depiction of the developed database of ***Green-X*** – referring geographically to EU-15 countries. Requirements and the according data on dynamic aspects, i.e. technological change and dynamic barriers, are represented as well.

Next, the application of the concept respectively the model ***Green-X*** in the assessment of RES-E policies is illustrated in chapter 6. Thereby, examples refer to the evaluation of energy policy instruments and to the assessment of RES-E deployment (based on policy assumptions) at the European respectively the national level.

Finally, conclusions and recommendations are derived in chapter 7.

2. Inventory – State-of-the-art of electricity from renewable energy sources

2.1. Classification of RES-E

Initially, in order to increase the legibility of this thesis and to avoid any misinterpretation, an overview is given on to some extend differing classifications of RES-E. Explanatory notes are given below.

Table 2.1 Overview on classifications applied for the various RES-E

Detailed classification (in accordance with 'RES-E Directive' & sub-categories of ***Green-X***)	**Common classification**	**IEA classification**
Agricultural biogas[6]	**Biogas**	**Bioenergy** (incl. all waste fractions)
Landfill gas		
Sewage gas		
Forestry products (wood)	**Solid biomass**	
Forestry residues (bark, sawmill by-products etc.)		
Agricultural products (energy crops)		
Agricultural residues (incl. vegetal and animal substances, e.g. straw)		
Biodegradable fraction of waste (MSW+ISW)	**Biowaste**	
Geothermal electricity	**Geothermal electricity**	
Small scale hydro power (<10 MW)	**Small hydro**	**Hydro**
Large scale hydro power (>10 MW)	**Large hydro**	
Photovoltaics	**Photovoltaics**	
Solar thermal electricity	**Solar thermal electricity**	
Tidal energy	**Tidal & wave**	
Wave energy		
Wind on-shore	**Wind onshore**	
Wind off-shore	**Wind offshore**	

Notes:

- The resource definition, representing the most detailed classification (left), is done in accordance with the 'RES-E directive' (European Council and Parliament, 2001), subject of discussion in the following section 2.4.2. A similar categorization is applied in the computer model ***Green-X*** and the accompanying database, which will be introduced briefly in chapter 4 and 5, respectively.
- The common classification will be used for most graphical representations, e.g. of results, databases, etc.. This compared to above rough categorisation simplifies the comparison with other sources

[6] Fuel sources are in this case farm slurries, usable agricultural residues (i.e. from sugar beet production), residues from pasture and the separated biodegradable fraction of municipal wastes.

- The classification in accordance with the International Energy Agency (IEA) appears of relevance when discussing issues on global level as done in the following section 2.2.

2.2. The global dimension

Electricity generation from renewable energy sources amounted 2927 TWh in 2002 on global-scale, equal to a share of 18% of total electricity production. Compared to 1971 this represents a decrease by -5% on total generation. Hence, as illustrated in Figure 2.1 (left) in absolute terms an increase of roughly 1860 TWh could be observed, equal to an average yearly growth of 3.3%. Hydropower represents the dominating RES-E technology, holding a share of 89% on total RES-E generation in 2002, see Figure 2.1 (right). However, over the last decade a huge growth of other RES-E options occurred, in particular bioenergy (incl. biomass and waste incineration) and wind power increased their share, especially in Europe.

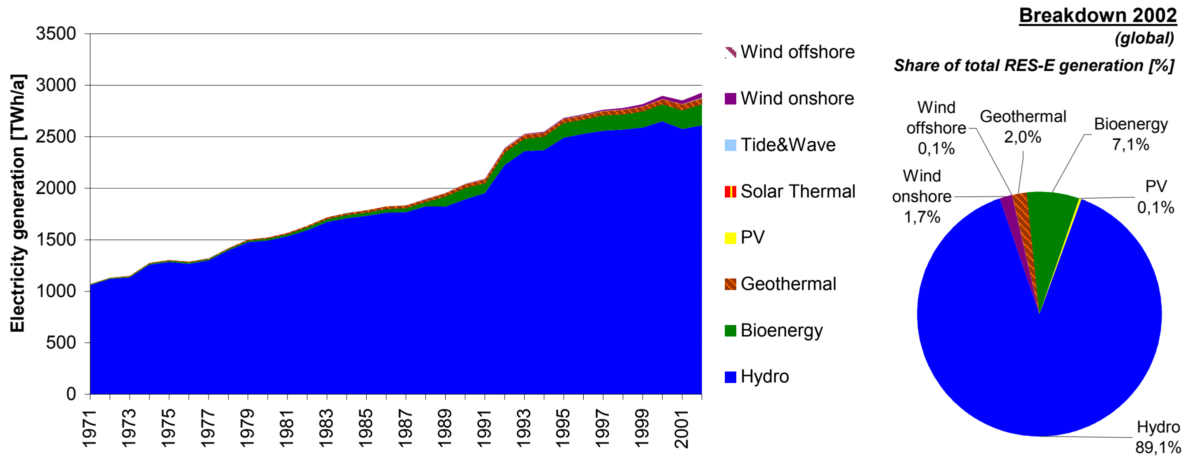


Figure 2.1 Electricity generation from RES on global scale from 1972 to 2002 (left) & breakdown of RES-E generation by technology in 2002 (right)
Source: IEA (2003, 2004)

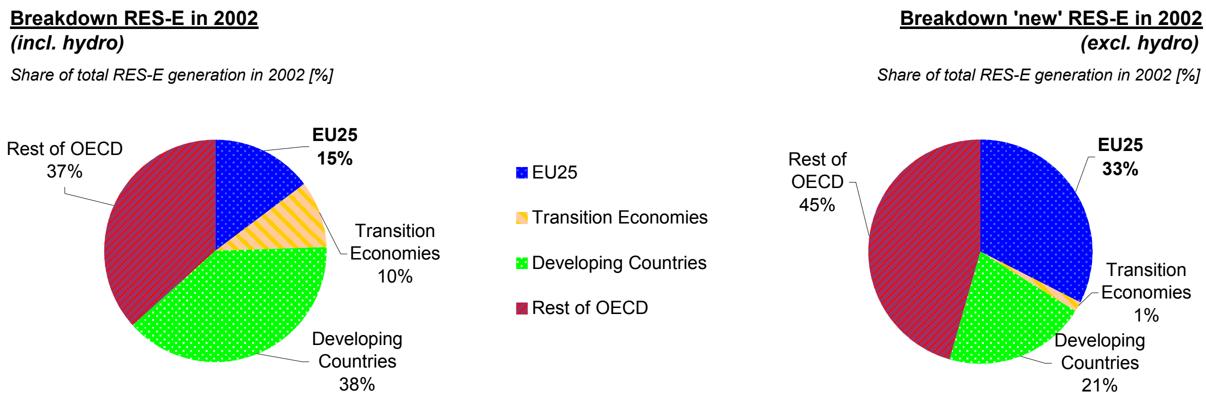


Figure 2.2 Breakdown of RES-E generation by region in 2002 – incl. (left) & excl. hydropower (right)
Source: IEA (2004)

Figure 2.2 indicates the European (EU-25) contribution on global RES-E generation in 2002. Comparing total RES-E generation by region (left), 15% refer to the European Union (EU-25), whilst for 'new' renewables, i.e. RES-E excluding hydropower (right), a share of 33% occurs. In case of wind power an uneven higher percentage is kept by Europe – EU-15 countries in total have been holding a share of more than two thirds of global cumulative installed capacity since 1999, which underpins the strong activities set on European level in the past.

2.3. Historical development in EU-15 countries

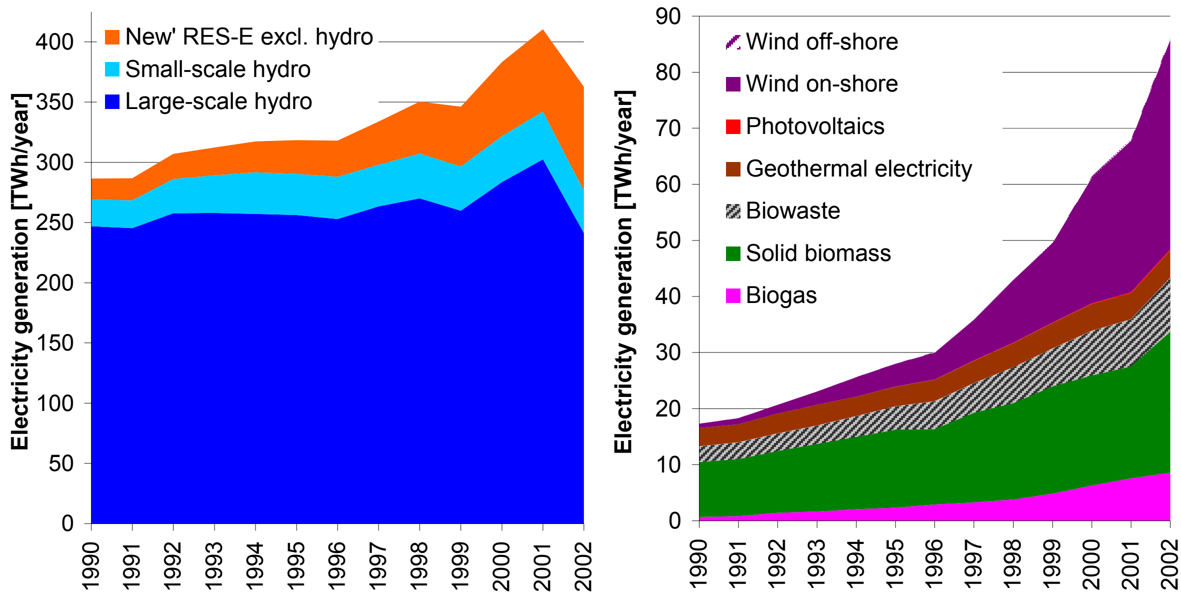


Figure 2.3 Electricity generation from RES in EU-15 countries from 1990 to 2002 – including (left) & excluding (right) hydro
Source: Own investigations; Eurostat, 2003.

The historical development of RES-E[7] is shown in Figure 2.3 (left) for the EU-15 in total, covering the period 1990 to 2002. As can be seen, large-scale (> 10 MW) hydropower is the dominant source. Such plant was mostly established before the post-1970's 'new renewables'. Therefore, the indicated fluctuations in yearly generation are mainly caused by its natural volatility.[8] In contrast, 'new' RES-E such as biomass or wind are starting to play a role. In this context, Figure 2.3 (right) illustrates the historical development of 'new' RES-E[9], again on EU-15 level. Of interest are the high yearly growth rates of emerging new technologies such as wind power[10].

---

[7] Based on EUROSTAT data, which are only up-to-date until 2002. For many RES, e.g. wind-onshore and PV, more recent data from sector organisations and national statistics have been used. Generally EUROSTAT data were modified, where alternative data proved to be more accurate.

[8] Compare, e.g. the decrease of electricity generation from hydropower on EU-15 level from 2001 to 2002 as depicted in Figure 2.4 (left). In contrast to generation, installed capacity has grown slightly in the same period.

[9] In general, definitions of RES-E sources are made in accordance with EU's 'RES-E Directive' (European Council and Parliament, 2001), see next section for a brief discussion on it. The

The following figures provide some insights on the country-specific situation: Figure 2.4 compares for each EU-15 country in 2002 (i) the total electricity consumption, and (ii) the amount of RES-E generation. In Figure 2.5 the countries are ranked by the share of RES-E. Only in two countries, namely Austria and Sweden, RES-E generation is larger than a third of total consumption, while in other Member States RES-E holds a much lower proportion.

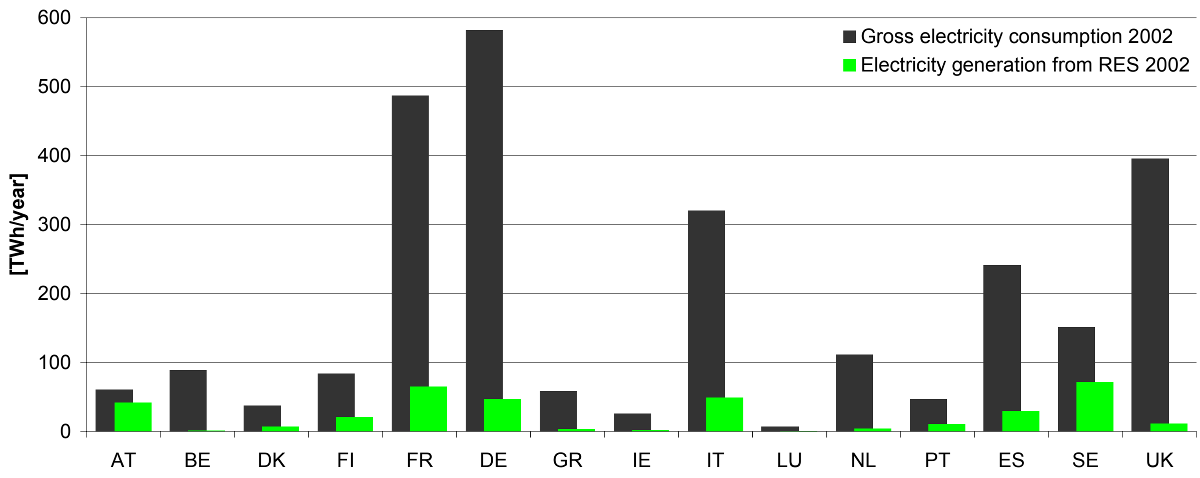


Figure 2.4 Electricity generation from RES versus total electricity consumption in EU-15 countries in 2002
Source: Own investigations; Eurostat, 2003.

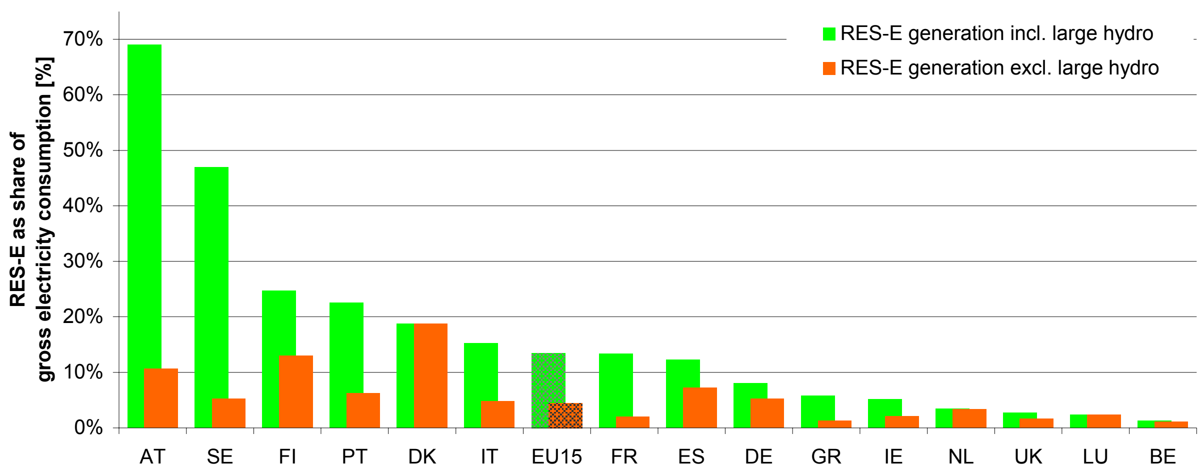


Figure 2.5 EU-15 countries ranked by the share of RES-E (with and without large hydro) on total electricity consumption in 2002
Source: Own investigations; Eurostat, 2003.

---

assessed technologies include hydropower (large and small), photovoltaic, solar thermal electricity, wind energy (onshore, offshore), gaseous & solid biomass, biodegradable fraction of municipal waste, geothermal electricity, tidal and wave energy.

[10] Wind energy represents the RES-E source with the highest yearly growth rates of about 38% in electricity production over the last ten years.

Finally, Figure 2.6 shows a breakdown of RES-E production (excl. large-scale hydropower) by country for 2002. Of interest, are (i) the large proportions of wind power in Denmark, Spain and Germany, (ii) the significant contribution of geothermal power in Italy, (iii) the high contribution of biomass in Finland and Sweden, and (iv) the dominance of small-scale hydropower in Austria, France and Italy.

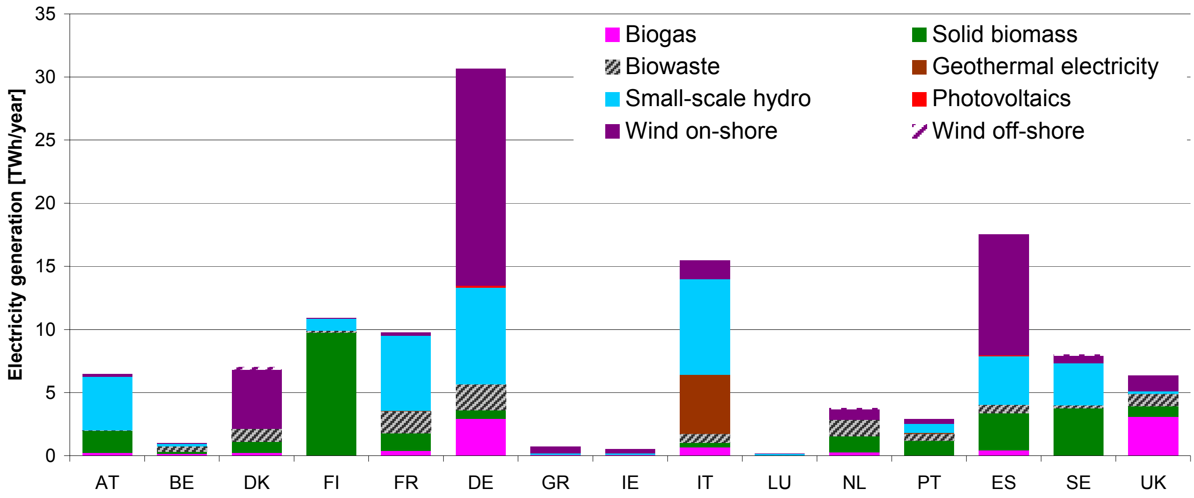


Figure 2.6 Electricity generation from RES (excl. large hydro) in EU-15 countries in 2002
Source: Own investigations; Eurostat, 2003.

2.4. The role of energy policy – a survey on promotion instruments for RES-E in the EU-15[11]

Recent growth of especially 'new' RES-E, as indicated in section 2.3, has arisen from considerable technical research, development and demonstration. However, it is well known that most RES-E options require public support in order to penetrate the electricity market. This has been recognised at the EU level and by the individual Member States, which have been promoting RES-E for many years.

2.4.1. Classification of promotion instruments

Promotion instruments can be classified according to different criteria (i.e., whether they affect demand for or supply of RES-E or whether they support capacity or generation). For a common terminology to be applied at least within this thesis, Table 2.2 provides a classification of these instruments, covering at least all currently applied strategies referring to the promotion of RES-E deployment. Accordingly, a brief explanation of the terminology is provided below for instruments of high relevance.

[11] Note, a comprehensive review of promotion strategies for RES-E as applied in Europe, also from a historical point-of-view, is given in (Resch et al., 2005a).

Table 2.2 Classification of promotion strategies

		Direct		Indirect
		Price-driven	**Quantity-driven**	
Regulatory	Investment focussed	• Investment subsidies • Tax incentives	• Tendering system	• Environmental taxes
	Generation based	• Feed-in tariffs • Rate-based incentives	• Tendering system • Quota obligation (RPS) based on TGCs	
Voluntary	Investment focussed	• Shareholder Programs • Contribution Programs		• Voluntary agreements
	Generation based	• Green tariffs		

- Investment subsidies establish an incentive for the development of RES-E projects as a percentage over total costs, or as a predefined amount of € per installed kW. The levels of these incentives are usually set technology-specific.
- Feed-in Tariffs (FITs) are generation based price-driven incentives. Thereby, the feed-in tariff represents the price per unit of electricity that a utility or supplier or grid operator is legally obligated to pay for electricity from RES-E producers. Thus, a federal (or provincial) government regulates the tariff rate. It usually takes the form of either a total price for RES-E production, or an additional premium on top of the electricity market price paid to RES-E producers. Besides the height of the tariff its guaranteed duration represents an important parameter for an appraisal of the actual financial incentive. FITs allow technology-specific promotion as well as an acknowledgement of future cost-reductions by implementing decreasing tariffs (compare e.g. the German Renewable Energy Act).
- Production tax incentives are generation-based price-driven mechanisms that work through payment exemptions of electricity taxes applied to all producers. Hence, this type of instrument differs from premium feed-in tariffs in terms of the cash flow for RES-E producers: It represents a minus cost instead of an additional income.
- Tendering systems are quantity-driven mechanisms. The financial support can either be investment-focussed or generation-based. In the first case, a fixed amount of capacity to be installed is announced and contracts are given following a predefined bidding process, which offers winners a set of favourable investment conditions, including investment subsidies per installed kW. The generation based tendering systems work in a similar way. However, instead of providing up-front support, they offer a support in size of the 'bid price' per kWh for a guaranteed duration.
- Quota obligations based on Tradable Green Certificates (TGCs) are generation-based quantity-driven instruments. Thereby, the government defines targets for RES-E deployment and obliges any party of the electricity supply-chain (e.g., generator, wholesaler, consumer) with their fulfilment. Once defined, a parallel market for renewable energy certificates is established and their price is set following demand and supply conditions (forced by the obligation). Hence, for RES-E producer financial support may arise from selling certificates in addition to the income from selling electricity on the power market.

Besides above described regulatory instruments voluntary approaches have appeared increasingly with on-going market liberalisation. They are mainly based on the willingness of consumers to pay premium rates for renewable energy. Nevertheless, so far in terms of effectiveness – i.e. actual installations resulting from their appliance – their impact on total RES-E deployment is negligible.

2.4.2. Status quo of RES-E promotion & future targets

At the **EU level**, the 'Directive of the European Parliament and the Council on the promotion of electricity from renewable energy sources in the internal electricity market (RES-E Directive)' (European Parliament and Council, 2001 – Directive 2001/77/EC) was approved in 2001, underlines the political willing to increase the share of renewables in the European internal electricity market. It appeared as a supplementary Directive to the 'Liberalisation Directive' 96/92/EC aiming to concern renewable energy sources and to attach equal weight to the environmental aspects.

The main issues of the 'RES-E Directive' – of particular relevance for later discussions – are outlined in more detail:

► Definition of RES-E

The 'RES-E Directive' includes the following definitions[12]:

- *'renewable energy sources'* shall mean renewable non-fossil energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases);
- *'biomass'* shall mean the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste.

► Indicative national targets for RES-E

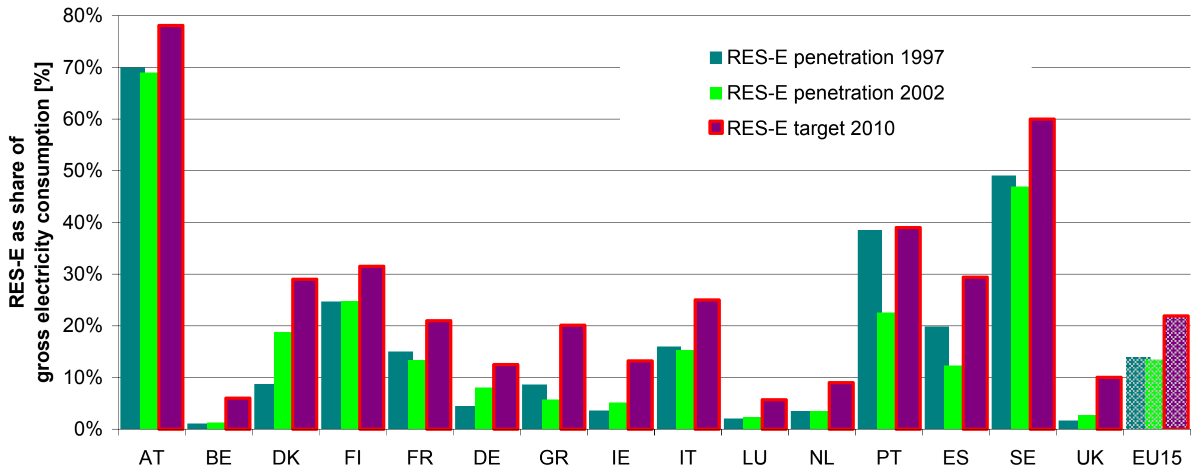


Figure 2.7 Comparison of historical (1997) & present penetration (2002) and future targets according the 'RES-E Directive'
Source: European Parliament and Council, 2001; Own investigations; Eurostat, 2003

[12] These definitions are taken from Article 2 ('Definitions') of the 'RES-E Directive', see (European Parliament and Council, 2001).

Article 3 as well as the Annex of the adopted 'RES-E Directive' refers to the national indicative targets for RES-E. The overall indicative target for the penetration of RES-E is to achieve a share of 22% in EU-15's electricity consumption by 2010. Therefore, Member States are obliged to set and fulfil national targets in accordance with the reference values listed in the Annex of the Directive.[13]

It is important to mention that:

- national targets are *'indicative'* and not *'regulatory binding'*;[14]
- targets refer to gross electricity consumption of the year 2010 – expressed as to be achieved percentage.

For most countries of the European Union, these targets represent a huge challenge, as indicated on Figure 2.7 (above).

► Harmonisation of support systems

The Directive states that, taking account of the wide diversity of promotion schemes between Member States, it is too early to set a Community-wide framework regarding support schemes". By 27th October 2005 the Commission should present a report on the experience gained with the application and coexistence of different support schemes in the Member States. In particular, Article 4.2 states: *"This report shall, if necessary, be accompanied by a proposal for a Community framework with regard to support schemes for electricity produced from renewable energy sources. Any proposal for a framework should … include sufficient transitional periods for national support systems of at least seven years …".*

In accordance with above, promotion policies **at the national level** will continue to be of crucial relevance for the further penetration of RES-E – at least in the short to medium term. In the following, currently implemented promotion strategies for RES-E in the EU-15 countries are depicted. Table 2.3 gives a brief overview on this topic – listing countries, promotion strategies and the technologies addressed.

[13] In Article 3 (2) of the 'RES-E Directive' (European Parliament and Council, 2001) it is outlined, that the EU Member States have to adopt and publish a report setting national indicative targets for future consumption of electricity produced from renewable energy sources in terms of a percentage of electricity consumption for the next 10 years. This has to be done not later than 27 October 2002 and every five years thereafter. To set these targets until the year 2010, the Member States shall take account of the reference values in the Annex of the Directive. Furthermore, they have to ensure that these targets are compatible with the climate change commitments according to the Kyoto Protocol.

[14] However, in Article 3 of the 'RES-E Directive' it is stated that *"if (…) national indicative targets are likely to be inconsistent"* the European Commission *"shall address national targets, including possible mandatory targets, in the appropriate form."*

Table 2.3 Current promotion strategies for RES-E in EU-15 countries *(status: end of 2004)*

	Major strategy	RES-E TECHNOLOGIES CONSIDERED			
		Large Hydro	**Small Hydro**	**'New' RES (Wind on- & offshore, PV, Solar thermal electricity, Biomass, Biogas, Landfill gas, Sewage gas, Geothermal)**	**Municipal Solid Waste**
Austria	**FITs**	No	Renewable Energy Act 2003. (Ökostromgesetz). Technology-specific FITs guaranteed for 13 years for plants which get all permissions between 1 January 2003 and 31 December 2004 and, hence, start operation by the end of 2006. Investment subsidies mainly on regional level.		FITs for waste with a high biodegradable fraction
Belgium	**Quota/TGC + guaranteed electricity purchase**	No	Federal: The Royal Decree of 10 July 2002 (operational from 1st of July 2003) sets minimum prices for RES-E. Except for offshore wind it will be implemented by the regional authorities: Wallonia: Quota obligation (based on TGCs) on electricity suppliers – increasing from 3% in 2003 up to 12% in 2010. Flanders: Quota obligation (based on TGCs) on electricity suppliers – increasing from 3% (no MSW) in 2004 up to 6% in 2010. Brussels region: No support scheme yet implemented.			
Denmark	**FITs**	No	Act on Payment for Green Electricity (Act 478): Fix settlement prices instead of former high FITs. Valid for 10 years. Tendering plans for offshore wind.		No
Finland	**Tax Exemption**	No	Tax refund: 4.2 € /MWh (plant <1MW)	Mix of tax refund and investment subsidies:Tax refund of 6.9 €/MWh for Wind and of 4.2 €/MWh for other RES-E. Investment subsidies up to 40% for Wind and up to 30 % for other RES-E.	Tax refund (2.5 €/MWh)
France	**FITs**	No	FITs for RES-E plant < 12 MW guaranteed for 15 years (20 years PV and Hydro). Tenders for plant >12 MW. FITs in more detail: Biomass: 49-61 €/MWh, Biogas: 46-58 €/MWh, Geothermal: 76-79 €/MWh, PV: 152.5-305 €/MWh; Landfill gas: 45-57.2 €/MWh; Wind[15]: 30.5-83.8 €/MWh; Hydro[16]: 54.9-61 €/MWh. Investment subsidies for PV, Biomass and Biogas (Biomass and Biogas PBEDL 2000-2006).		FIT: 25.8-47.2 €/MWh
Germany	**FITs**	Only refurbishment	German Renewable Energy Act: FITs guaranteed for 20 years[17]. In more detail, FITs for new installations (2004) are: Hydro: 37-76.7 €/MWh; Wind[18]: 55-91 €/MWh; Biomass & Biogas: 84-195 €/MWh; Landfill-, Sewage- & Mine gas: 66.5-96.7 €/MWh; PV & Solar thermal electricity: 457-574 €/MWh; Geothermal: 71.6-150 €/MWh		No
Greece	**FITs + investment subsidies**	No	FITs guaranteed for 10 years (at a level of 70-90% of the consumer electricity price)[19] and a mix of other instruments: a) Law 2601/98: Up to 40% investment subsidies combined with tax measures; b) CSF III: Up to 50% investment subsidies depending on RES type		No
Ireland	**Tender**	No	Tendering scheme – currently AER VI with technology bands and price caps for small Wind (<3 MW), large Wind (>3 MW), small Hydro (<5 MWp), Biomass, Biomass CHP and Biogas. In addition, tax relief for investments in RES-E.		No
Italy	**Quota/TGC**	Quota obligation (based on TGCs) on electricity suppliers: 2.35% target (2004), increasing yearly up to 2008; TGC issued for all (new) RES-E (incl. large Hydro and MSW) – with rolling redemption[20]; penalty in size of 84.2 €/MWh (2004) but market distortions appear[21]. Investment subsidies for PV (Italian Roof Top program).			
Luxembourg	**FITs**	No	No	FITs[22] guaranteed for 10 years (PV: 20 years) and investment subsidies for Wind, PV, Biomass and small Hydro. FITs for Wind, Biomass and small Hydro: 25 €/MWh, for PV: 450 €/MWh.	No
Netherlands	**FITs + tax exemption**		Mixed strategy: Green pricing, tax exemptions and FITs. The tax exemption for green electricity amounts 30 €/MWh and FITs guaranteed for 10 years range from 29 €/MWh (for mixed Biomass and waste streams) to 68 €/MWh for other RES-E (e.g. Wind offshore, PV, Small Hydro).		No
Portugal	**FITs + investment subsidies**	No	FITs (Decree law 339-C/2001 and Decree law 168/99) and investment subsidies of roughly 40% (Measure 2.5 (MAPE) within program for Economic Activities (POE)) for Wind, PV, Biomass, Small Hydro and Wave. FITs in 2003: Wind[23]: 43-83 €/MWh; Wave: 225 €/MWh; PV[24]:224-410 €/MWh, Small Hydro: 72 €/MWh		No
Spain	**FITs**	Depending on the plant size[25]	FITs (Royal Decree 2818/1998): RES-E producer have the right to opt for a fixed price or for a premium tariff[26]. Both are adjusted by the government according to the variation in the average electricity sale price. In more detail (only premium, valid for plant < 50 MW): Wind: 27 €/MWh; PV[27]: 180-360 €c/kWh, Small Hydro: 29 €/MWh, Biomass: 25-33 €/MWh. Moreover, soft loans and tax incentives (according to "Plan de Fomento de las Energías Renovables") and investment subsidies on a regional level		Premium FIT: 17 €/MWh
Sweden	**Quota/TGC**	No	Quota obligation (based on TGC) on consumers: Increasing from 7.4% in 2003 up to 16.9% in 2010. For Wind Investment subsidies of 15% and additional small premium FITs ("Environmental Bonus"[28]) are available.		No
United Kingdom	**Quota/TGC**	No	Quota obligation (based on TGCs) for all RES-E: Increasing from 3% in 2003 up to 10.4% by 2010 – penalty set at 30.5 £/MWh. In addition to the TGC system, eligible RES-E are exempt from the Climate Change Levy certified by Levy Exemption Certificates (LEC's), which cannot be separately traded from physical electricity. The current levy rate is 4.3 £/MWh. Investment grants in the frame of different programs (e.g. Clear Skies Scheme, DTI´s Offshore Wind Capital Grant Scheme, the Energy Crops Scheme, Major PV Demonstration Program and the Scottish Community Renewable Initiative)		No

15 Stepped FIT: 83.8 €/MWh for the first 5 years of operation and then between 30.5 and 83.8 €/MWh depending on the quality of site.
16 Producers can choose between four different schemes. The figure shows the flat rate option. Within other schemes tariffs vary over time (peak/base etc.).
17 The law includes a dynamic reduction of the FITs (for some RES-E options): For biomass 1%/year, for PV 5%/year, for wind 2%/year.
18 Stepped FIT: In case of onshore wind 87 €/MWh for the first 5 years of operation and then between 55 and 87 €/MWh depending on the quality of site.
19 Depending on location (islands or mainland) and type of producer (independent power producers or utilities)
20 In general only plant put in operation after 1st of April 1999 are allowed to receive TGCs for their produced green electricity. Moreover, this allowance is limited to the first 8 years of operation (rolling redemption).
21 GRTN (Italian Transmission System Operator) influences strongly the certificates market selling its own certificates at a regulated price – namely at a price set by law as the average of the extra prices paid to acquire electricity from RES-E plant under the former FIT-programme (CIP6).
22 Only valid for plants up to 3 MW (except PV: limited to 50 kW).
23 Stepped FIT depending on the quality of the site.
24 Depending on the size: <5kW: 420 €/MWh or >5kW: 224 €/MWh.
25 Hydropower plant with a size between 10 and 50 MW receive a premium FIT of 6-29 €/MWh depending on the plant size.
26 In case of a premium tariff, RES-E generators earn in addition to the (compared to fixed rate lower) premium tariff the revenues from the selling of their electricity on the power market.
27 Depending on the plant size: <5kW: 360 €/MWh or >5kW: 180 €/MWh
28 Decreasing gradually down to zero in 2007

As indicated on Table 2.3, a broad set of countries has implemented investment subsidies for technologies in their early phase of development, such as tidal stream and wave energy, photovoltaics, solar thermal electricity or offshore wind.

Feed-in tariffs have traditionally been the most widespread mechanism for promoting renewables production. Countries like Germany, Spain, recently Austria, and from an historical point-of-view Denmark, all characterised by a huge success in deploying RES-E, have set comparatively high (feed-in) incentive-levels, mainly accompanied by long-term stable frameworks.

Tax incentives are applied in Finland, Netherlands and the UK. In Finland the tax break works almost as a feed-in scheme, reducing the real cost of RES-E. In the Netherlands and the UK, the tax break represents only small part of a broader scheme. In the first case, the tax reduction provides a "minus cost" of about 20 €/MWh to RES-E producers, which in combination with the feed-in system represents the basic incentive for renewables. In the case of the UK, the Climate Change Levy provides some 6.3 €/MWh exemption to RES-E producers in addition to the revenues from the TGC system.

Tendering systems have been for instance largely applied in the UK through the NFFO-scheme, which was in place until 2001. Currently only Ireland and France have such a system in application, in the later case it is dedicated to large-scale wind projects (on- & offshore). According to recent discussions also Denmark envisages to adopt this type of instrument for offshore wind projects.

Finally, quota obligations based on Tradable Green Certificates (TGCs) are applied in the UK (replacing the NFFO tendering system), Belgium, Italy and Sweden.

Reasons for this apparent variety appear to be manifold – likely explanations may include:

- Technology and country specificity – different stages of development and costs, differing local resource conditions.
- Political willingness and coherence – countries which have undergone past liberalisations are embedded into market oriented policies (UK, Ireland) and often prefer quantity-driven schemes such as quota obligations based on TGCs; and,
- Unlevelled electricity markets – Important differences appear when analysing the individual electricity markets (on country-level) in terms of their work-arrangements, institutional set-ups and fiscal schemes (e.g. heterogeneous energy tax levels).

3. Method of approach

3.1. Introduction

In a first step, before discussing the developed concept of dynamic cost-resource curves in detail, it is necessary to provide an introduction of supply- and demand-aspects in a general manner first, and later on focussing on the particular characteristics of RES-E in the electricity market.

3.1.1. The partial equilibrium approach

The partial equilibrium approach refers to the Equivalence Theorem drawn from economics: *A supply-demand equilibrium is reached when the sum of producers' and consumers' surpluses is maximized.*

Figure 3.1 provides an illustration for the case where only one commodity is exchanged. Point E, representing the equilibrium, occurs as the intersection of the (inverse) supply and the (inverse) demand curves. Consumer surplus, as indicated by the pale red area, is the difference between how much consumer pays and the higher price that would have been paid for smaller quantities. In contrast, the producer surplus, i.e. the pale green area, is the difference between the price received and the lower price as accepted for smaller quantities.

Obviously, the area between the two curves is maximized at point E, representing the intersection of both curves. Producer and consumer surpluses in sum are often called the net social surplus, which is a proxy for welfare.

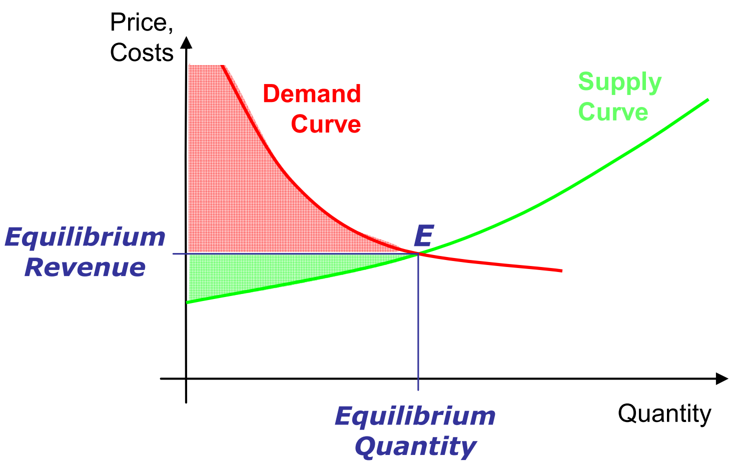


Figure 3.1 Illustration of a supply-demand equilibrium

The implementation of the Equivalence Theorem in energy modelling requires e.g. in case of optimisation models based on linear programming (e.g. MARKAL as described in (ECN, 1997)) some sort of simplifications, i.e. a linearization of demand by piecewise linear mathematical functions.

3.1.2. Supply- and demand aspects for RES-E in the electricity market

Based on above explanations, issues of relevance for RES-E in the electricity market are discussed in the following. From a simplified static point-of-view Figure 3.2 depicts the principal relationships. Note Initial demand, before setting any promotional strategy[29] uses q_0 of electricity from RES generation. Supply-side policies, e.g. rebates, shift the supply curve downwards (S′). As a consequence, the total amount of electricity generation from RES increases from q_0 to q_2[30]. A demand-side strategy, e.g. a quota, shifts the demand curve upwards (D″), leading to electricity output q_3[31]. In the case of a voluntary demand characterised by the willingness to pay (D′) electricity output will increase up to q_1.

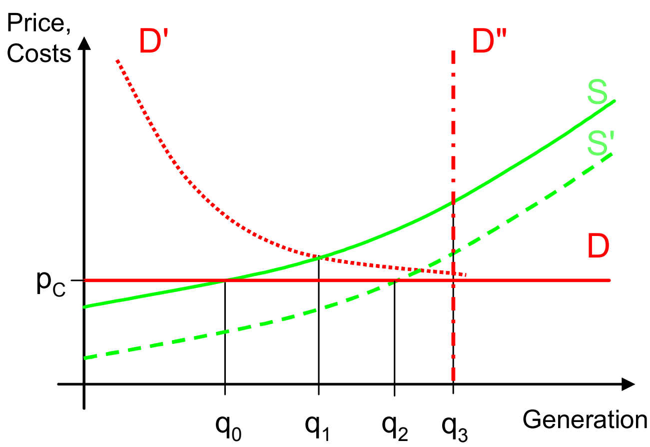


Figure 3.2 Different amounts of electricity from RES depending on energy policies

The **major influences on the supply-side** are:

► <u>Costs and potentials for RES-E</u>

The supply-side is determined by the unit costs of electricity and the resulting potentials. In a liberalised and competitive market these costs have a major influence on the energy source chosen for electricity generation.

As long as an overcapacity of power plants exists to meet electricity demand, no new power plant is necessary to meet the demand. Accordingly, competition between the different generators is only determined by the variable costs of a plant. With future demand growth and plant replacement, new capacity has to be constructed. Competition between different 'new' generators is influenced by the total costs of electricity generation.

In both cases costs depend on the applied conversion technology and the applied energy source, respectively. By looking closer at a certain energy source another

[29] From the industrial economic point-of-view the demand for RES-E is given due to the price for conventional electricity p_C.

[30] This amount is given by the intersection of the demand-curve D with the supply curve S'.

[31] Another demand-side option would be to introduce an indirect promotion instrument, i.e. increasing the price for conventional electricity due to an energy/CO_2 tax. In this case demand for RES-E increases, too.

important correlation appears; namely the correlation between costs of electricity generation and the availability of capacity. Because every energy source, fossil, nuclear or renewable, used for electricity generation has limitations, costs depend on previous exploitation and installed capacity. For example, electricity generation costs from wind increase if the best sites have already been used.

Hence, strategies for a forced market penetration of RES-E in a future electricity market must be based on a detailed analysis of costs and potentials for electricity generation from different RES. Such an analysis is presented in chapter 5 in detail.

► Price-driven strategies (Promotion instruments for RES-E on the supply-side)

To overcome the crucial barrier of high costs a variety of promotion instruments have been implemented in the past. Some of these are setting incentives on the supply side – the so called price-driven instruments[32]. The mechanism of promotion instruments on the supply-side will be explained in detail in section 4.3.1.

Demand for RES-E is determined by a number of factors, including:

► The industrial economic point-of-view

The price for conventional electricity is set by supply and demand for electricity in general. According to specific market conditions across Europe, this price differs by country and by region. These differences will continue to change due to the ongoing liberalisation process.

Under the assumption that no other promotional instrument exists, the price of conventional electricity would determine the market penetration of RES-E, see Figure 3.2 (demand D). In this case only the quantity of green electricity would be produced that could be generated to lower or equal costs than the according conventional price level.

► Willingness to Pay for electricity from RES

Voluntary approaches to promote RES-E (e.g. 'Green tariffs') are based on consumers' *willingness to pay* voluntarily more for 'green' electricity compared its 'grey' counterpart. Figure 3.3 shows the results of a recent *Eurobarometer* survey on "Energy: Issues, Options and Technologies - Science and Society" (The European Opinion Research Group, 2002). This survey confirms the existence of a market for 'green energy' amongst consumers, especially in northern Europe. It can be observed that in Denmark, Luxembourg, Netherlands, Finland and Sweden, the percentage of people who voluntarily sought green electricity is larger than in other countries, so their demand for RES-E is large compared with other countries. Nevertheless there usually exist important divergences between real demand and the aspiration shown in surveys. Therefore, Figure 3.3 should be understood as an indication of attitudes rather than as quantifiable demand data.

[32] An overview on price-driven promotion strategies is given in section 2.3 of this thesis, for further details see e.g. (Resch et al., 2005a).

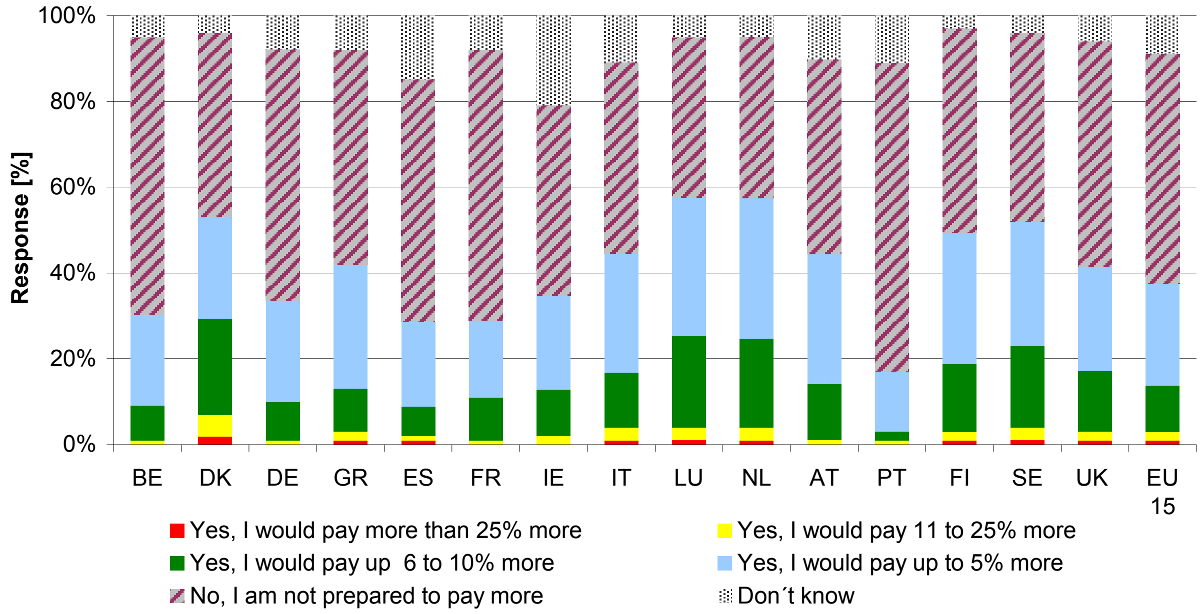


Figure 3.3 *Results of the survey relating willingness to pay more for energy produced from renewable sources: "Would you be prepared to pay more for energy produced from renewable sources than for energy produced from other sources? (If yes) How much more would you be prepared to pay?"*
Source: European Opinion Research Group (2002).

There is an important interaction between regulatory and voluntary approaches, with huge impact on the latter one (see e.g. Menges (2003)). This interaction relates to the existing asymmetrical relationship between both approaches, which explains the e.g. the relatively poor 'readiness' of German consumers, facing a high regulatory demand for RES-E, to pay more for green electricity, despite their well-known environment awareness.

► Quantity-driven strategies (Promotion instruments for RES-E on the demand-side)

To promote RES-E, a mandatory demand could be set by the government. Assuming, a quota for RES-E is introduced, a mandatory (inelastic) demand for electricity from RES results, for illustration see Figure 3.2 (demand D"). This inelastic demand, characterised by the vertical line, occurs because obliged actors are required to pay a high price for electricity from RES in order to fulfil the quota q_Q. If the amount of green electricity exceeds the quota level, nobody demands an additional quantity. The principal mechanism of promotion instruments encouraging an increased demand for RES-E will be explained in detail in section 4.3.2.

3.2. From *'static'* to *'dynamic'* – the concept of dynamic cost resource curves for RES-E

Based on the depiction of principal relationships of importance from a static point-of-view, the developed methodology of dynamic cost-resource curves with respect to electricity generation from renewable energy sources will be explained in the following. This concept refers to three basic principles, which are subject of explanation below.

3.2.1. Basic principles

► 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*[33].

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!).

On the left-hand side of Figure 3.4 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 3.4 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.

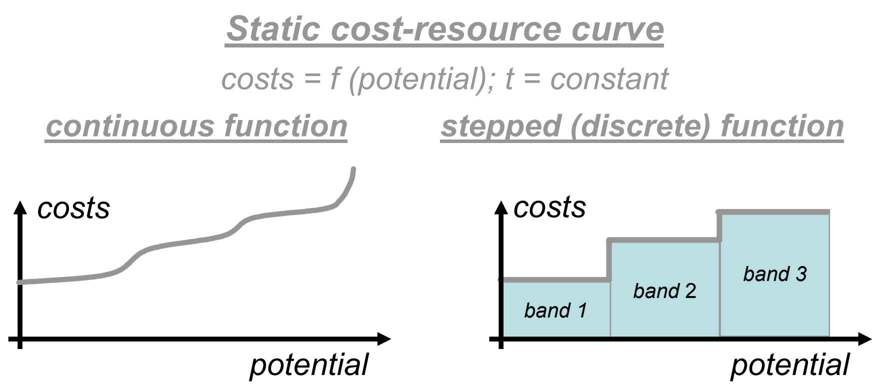


Figure 3.4 Characteristic run of a static cost-resource curve: Continuous (left) and stepped function (right)

[33] For 'static cost-resource curves' as explained above in literature no common terminology is applied. Other names commonly applied to this term are 'supply curves' or 'cost curves'. Nevertheless, with respect to (renewable) energy sources the term 'static cost-resource curves' gives – at least in the opinion of the author - a clear and unambiguous wording.

► 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 that a decline of costs depends on accumulation of actual experience and not simply on the passage of time.

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:

$$C_{CUM} = C_0 * CUM^b \qquad (3.1)$$

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.

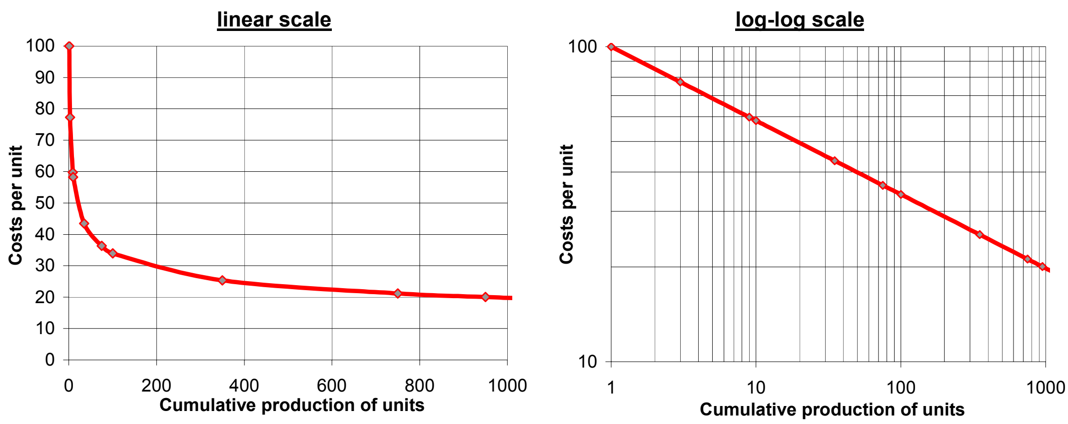


Figure 3.5 Characteristic run of an experience curve: On a linear (left) and on a log-log scale (right)

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

In Figure 3.5 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.

As described in (Grübler et al., 1998): *"… such straight-line plots should not be misunderstood to imply that 'linear' progress can be maintained indefinitely. The potential for cost reduction becomes increasingly exhausted as the technology matures."*

Mechanisms for the often called 'learning by doing' are manifold, including experience gained at different levels (i.e., of individuals in performing routine tasks, of organisations with respect to logistics, plant management) as well as economics of scale. For a brief discussion of this topic with respect to energy technologies in a general manner see (Grübler et al., 1998)[34] or (Wene C.O., 2000) and in particular focussing on wind energy (Neij et al., 2003).

► Technology diffusion

Additionally to experience curves, another approach is of importance in the discussion of technology dynamics, aiming to identify general patterns by which technologies diffuse through competitive markets:[35] In accordance with general diffusion theory, penetration of a market by any new commodity typically follows an 'S-curve' pattern, see Figure 3.6. It points to relatively modest growth in the early stage of deployment[36], whilst the costs of technologies are gradually reduced to an economically competitive level. As this is achieved for more competitive technological concepts, there will be accelerating growth[37] in deployment over the medium term. This will finally be followed by a slowing down in deployment[38], corresponding to nearly full penetration of the market.

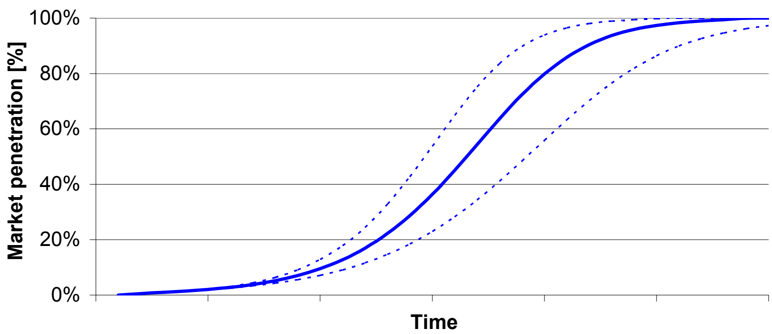


Figure 3.6 'S-curve' pattern: Market penetration of a new commodity

---

[34] Thereby, the authors state that a learning curve (as discussed above) related to cumulative production or installation refer solely to the commercial marketplace. Consequently, learning due to RD&D expenditures are neglected, which is of crucial importance in case of emerging new technologies in their early phase of market penetration. Hence, they suggest a different approach by referring to cumulative investments – for further details see (Grübler et al., 1998).

[35] For a brief discussion of this topic see (Grübler et al., 1998).

[36] As long as the market is immature, high relative growth rates but low growth in absolute terms (i.e. capacity increase) can be observed.

[37] Hence, also for successful technologies relative growth rates usually decrease constantly. In contrary, with increasing market maturity yearly installations measured in absolute terms still increase as long as approximately half of the overall long-term potential is exploited.

[38] I.e. growth measured in both relative and absolute terms decreases.

3.2.2. The concept of dynamic cost resource curves for RES-E

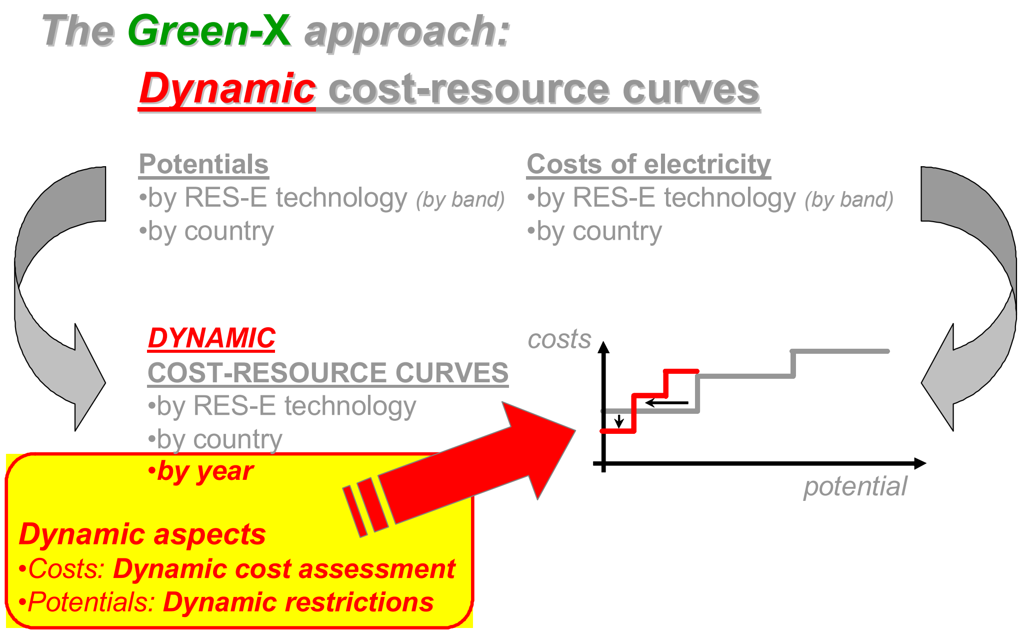


Figure 3.7 Method of approach regarding dynamic cost-resource curves for RES-E (for the model ***Green-X****)*

A *dynamic cost-resource curve* represents a tool to provide the linkage between all three approaches described in the previous section, i.e., the formal description of costs and potentials by means of *static cost-resource curves*, the dynamic cost assessment as e.g. done by application of *experience curves*, and the implication of dynamic restrictions in accordance with *technology diffusion*.

In the following, the method of approach regarding dynamic cost-resource curves as developed for the model ***Green-X*** will be described. Thereby, Figure 3.7 gives an overall illustration. As mentioned above, the approach comprises the following parts:

► The development of static cost-resource curves for each RES-E category in each investigated country.

As mentioned before, static cost-resource curves describe available potentials and the according costs. Accordingly, an assessment of potentials and costs has to be undertaken according to model specific requirements – i.e. for ***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.

In case of new plants the economic conditions are described by long-term *marginal costs*, whilst for existing plants short-term marginal costs, including solely fuel and O&M costs, are of determinant.

With respect to the potentials, for new options the *additional realisable mid-term potentials* were assessed for each RES-E category on country-level, representing the maximal additional achievable potential up to the year 2020 under the assumption, that all existing barriers can be overcome and all driving forces are active. In addition, existing plants are described by their generation potentials, referring to normal climatic conditions in case of RES-E with natural volatility (e.g. hydropower, wind energy).

► <u>The dynamic assessment, including a dynamic assessment of costs as well as of potential restrictions</u>

Dynamics have to be reflected in a suitable periodic manner – e.g. within the model ***Green-X*** this is done on a yearly 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.

Within ***Green-X*** costs[39] – in particular investment costs and operation- & maintenance costs – are adapted dynamically on technology level. Thereby, two different approaches can be applied: Standard cost forecasts or endogenous technological learning. Default settings are applied as follows:

- For conventional power generation technologies – as well as some RES-E technologies –well-accepted expert judgements are adopted.
- For most of RES-E technologies, e.g. wind power or PV, the approach of technological learning is applied. In this context, technology-specific learning rates are assumed at least for each decade separately[40], as default referring to the global development[41].

Next, to derive realisable potentials for each single year of the simulation, dynamic restrictions have to be applied to the predefined overall mid-term potentials. Generally spoken, this can be done by applying a restriction in accordance with the technology diffusion theory, following an 'S-curve' pattern. Within ***Green-X*** such an approach is chosen to describe the impact of market and administrative restrictions, representing the maturity of the market. Thereby, it represents the most important in the set of dynamic parameter describing the impact of non-economic barriers on the deployment of a certain RES-E. Note, besides market and administrative barriers also other restrictions can be included. In the model ***Green-X*** for instance industrial, social and technical restrictions are considered additionally. Important in this respect is to apply them on the 'correct' level: E.g. technical restrictions refer to characteristics within a certain region, whilst industrial barriers, indicating the production capacity of an industry (e.g. the manufacturing of wind turbines), refer to the international level.

---

[39] Note, besides the above mentioned cost parameters, dynamics are also considered with respect to other performance issues – i.e. efficiency improvements and in case of wind turbines an up-scaling of potentials (and achievable full load hours, respectively) in accordance with increasing hub-heights (due to rising turbine sizes).

[40] In many cases experience has shown that the rate of technological learning is often closely linked to the development stage of a certain technology – i.e. at an early stage of development, if a technology is 'brand new', high learning rates can be expected and later, as the technology matures, a slowdown occurs – compare e.g. (Grübler et al., 1998) or (Wene, 2000).

[41] As learning is usually taking place on the international level, the deployment of a technology on the global level must be considered.

3.3. Evaluation criteria for energy policy instruments

The assessment of energy policy instruments for RES-E represents a core application of above described dynamic cost-resource curves.[42] Examples on this will follow in chapter 6 of this thesis. However, such an evaluation requires well defined criteria, which are outlined below.

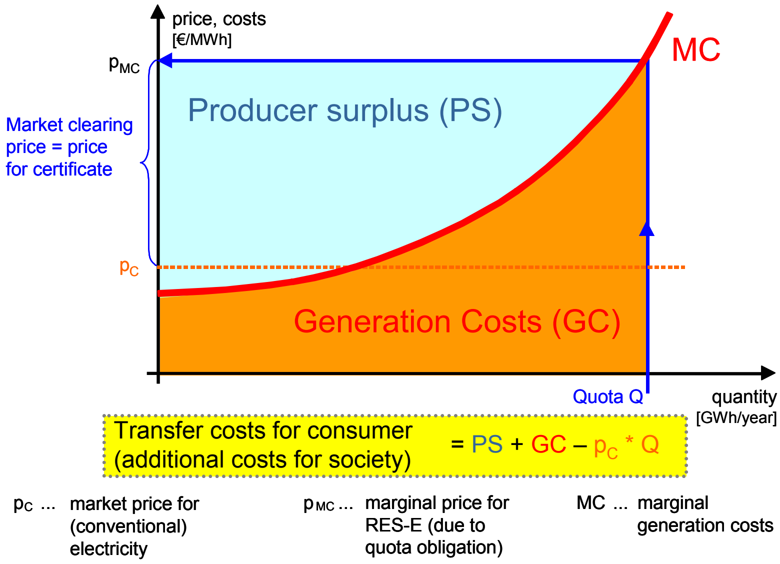


Figure 3.8 Basic definitions of the cost elements (illustrated for a TGC system)

Energy policy instruments for RES-E have to be *effective* for increasing the penetration of RES-E and *efficient* with respect to minimising the resulting public costs (*transfer cost for consumer / society*)[43] over time. Accordingly, this implies a fulfilment of the following conditions:

► Minimise generation costs

This aim is fulfilled if total RES-E generation costs (GC) are minimised. In other words, the system should provide incentives for investors to choose technologies, sizes and sites so that generation costs are minimised.

► Lower producer profits

If such cost-efficient systems are found, – in a second step – various options should be evaluated with the aim to minimise transfer costs for consumer / society. This means that feed-in tariffs, subsidies or trading systems should be designed in a way

---

[42] The linkage of policy instruments and dynamic cost-resource curves is to a high degree model specific, depending on the actual model implementation of both issues. A detailed discussion of the applied approach as undertaken within the model ***Green-X*** is subject of section 4.3.

[43] *Transfer costs for consumer / society* (sometimes also called additional / premium costs for consumer / society) are defined as direct premium financial transfer costs from the consumer to the producer due to the RES-E policy compared to the case that consumers would purchase conventional electricity from the power market. This means that these costs do not consider any indirect costs or externalities (environmental benefits, change of employment, etc.).

that public transfer payments are also minimised. This implies lowering producer surplus (PS)[44].

In some cases both goals – minimise generation costs and producer surplus – may not be reached together so compromise solutions must be found. For a better illustration of the used cost definitions the various cost elements are expressed in Figure 3.8.

[44] The producer surplus is defined as the profit of the green electricity generators. If for example, a green producer receives a feed-in tariff of 60 € for each MWh of electricity he sells and his generation costs are 40 €/MWh, the resulting profit would be 20 € for each MWh. The sum of the profits of all green generators defines the producer surplus.

4. Model implementation – the computer model *Green-X*[45]

This chapter aims to illustrative in brief the model implementation of the developed concept of dynamic cost-resource curves for RES-E as done for the model computer ***Green-X***. First, a concise overview on the developed computer model is given, including an illustration based on screenshots. Next, a comprehensive description of the formal framework behind the model follows. Thereby, a focus is given on issues of relevance in the modelling of RES-E deployment – i.e. their description by dynamic cost-resource curves and the modelling of energy policy instruments. Accordingly, other topics such as the modelling of the demand-side or the conventional power market are neglected.

4.1. Short characterisation of the model *Green-X*

The ***Green-X*** computer model is an independent computer programme, developed by the Energy Economics Group (EEG), Vienna University of Technology, which allows to simulate different scenarios, enabling a comparative and quantitative analysis of the interactions between RES-E, CHP, DSM activities and GHG-reduction within the liberalised electricity sector both for the EU as a whole and individual EU 15 Member States[46] over time. Figure 4.1 gives an overview of the core elements of the ***Green-X*** model.

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 cost curves are characterised by the fact that the costs as well as the potential for electricity generation / demand reduction can change year by 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.

Based on the derivation of the dynamic cost-resource curve an economic assessment takes place considering the scenario specific conditions like selected policy strategies, investor and consumer behaviour as well as primary energy and demand forecasts.

Within this step, a transition from generation and saving *costs* to bids, offers and switch *prices* takes place. It is worth to mention that the policy setting, e.g. the guaranteed duration and the stability of the planning horizon or the kind of policy instrument, which will be applied, influences the effective support.

---

[45] The model ***Green-X*** has been developed within the recently completed (September 2004) research project *Green*-X, a joint European research project funded within the 5th framework program of the European Commission, DG Research. For details on model or project please visit the project web-site www.green-x.at or see (Huber et al., 2004). Furthermore, an in-depth description of the application of this tool is given in (Faber et al., 2004).

[46] In the near future, it is planned to extend the geographical coverage of the model to the 10 new Member States, the candidate countries Bulgaria and Romania as well as Switzerland and Norway. A possible further extension to other neighbouring countries such as, e.g. the Balkan states and Turkey seems likely later-on.

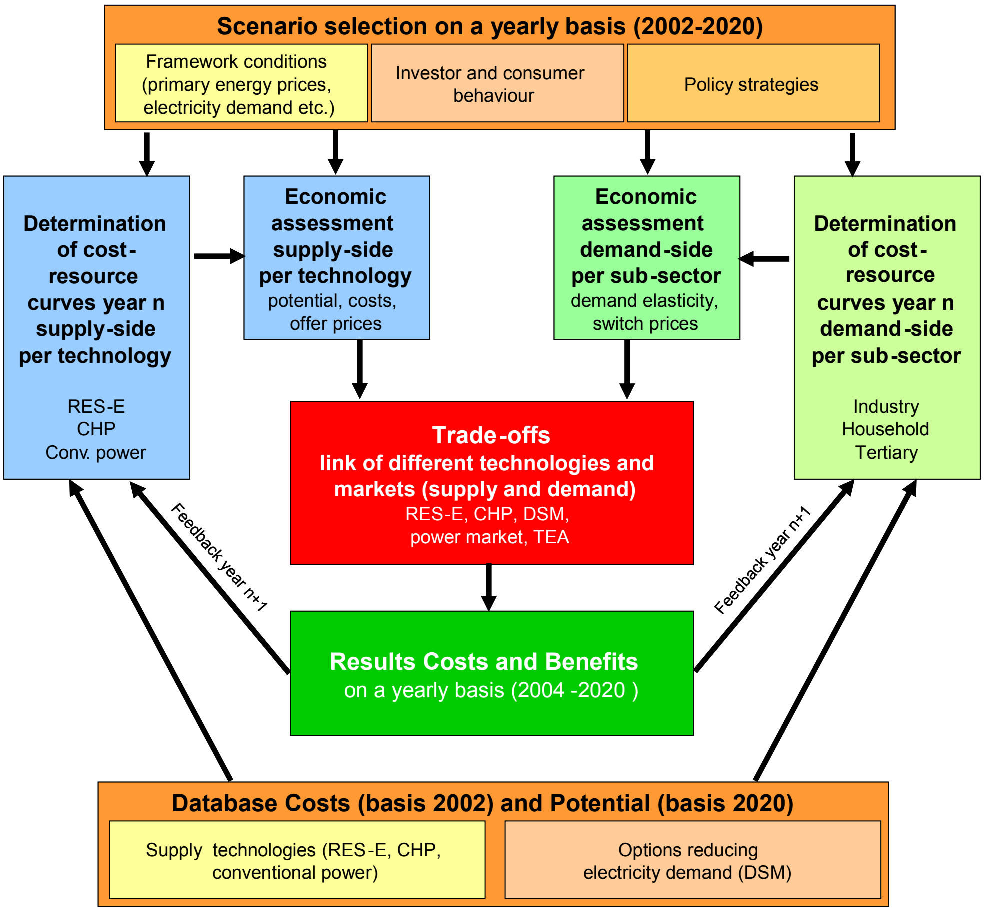


Figure 4.1 *Overview on the computer model* ***Green-X***

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 instruments can be applied to all RES and conventional options separately for both combined heat power and power production only. In addition, general taxes including energy taxes (to be applied to all primary energy carriers as well as to electricity and heat) and environmental taxes on CO_2-emissions, policies supporting demand-side measures and climate policy options (trading of emission allowances on both the national and international level) can be adjusted and the effects simulated.[47] 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). Furthermore, all instruments can be set for each country individually.

The results on a yearly basis are derived 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, tradable emissions permit market. This means that the different technologies are collected within each market and the point of equilibrium varies with the calculated demand.

[47] Thereby, various instrument-specific parameters can be defined, such as for example, in the case of a quota obligation the reference point of the quota (as share of total demand or generation), the imposed penalty in the case of non-compliance with the quota, etc.

In more detail, the ***Green-X*** model provides the following outputs for each Member State and for the European Union as a whole as well as for each technology on a yearly base up to 2020:

- *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 generation compared to baseline (BAU, Kyoto-target, etc.) [%]
  - Market price electricity (yearly average price) [€/MWh]
  - Market price Tradable Green Certificates [€/MWh]
- *Impact on producer, including:*
  - Total electricity generation costs [M€, €/MWh]
  - Total producer surplus for electricity generation [M€, €/MWh]
  - Marginal generation costs per technology for electricity generation [€/MWh]
- *Impact on consumer, including:*
  - Additional transfer costs due to promotion of RES-E [M€, €/MWh]
  - Additional transfer costs due to DSM strategy [M€, €/MWh]
  - Additional transfer costs due to CO_2-strategy [M€, €/MWh]
  - Total transfer costs due to the selected support schemes and policy options [M€]

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

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.

For illustration of the computer model ***Green-X***, some screen shots are copied Figure 4.2 to Figure 4.9.

Figure 4.2 Starting page ***Green-X***

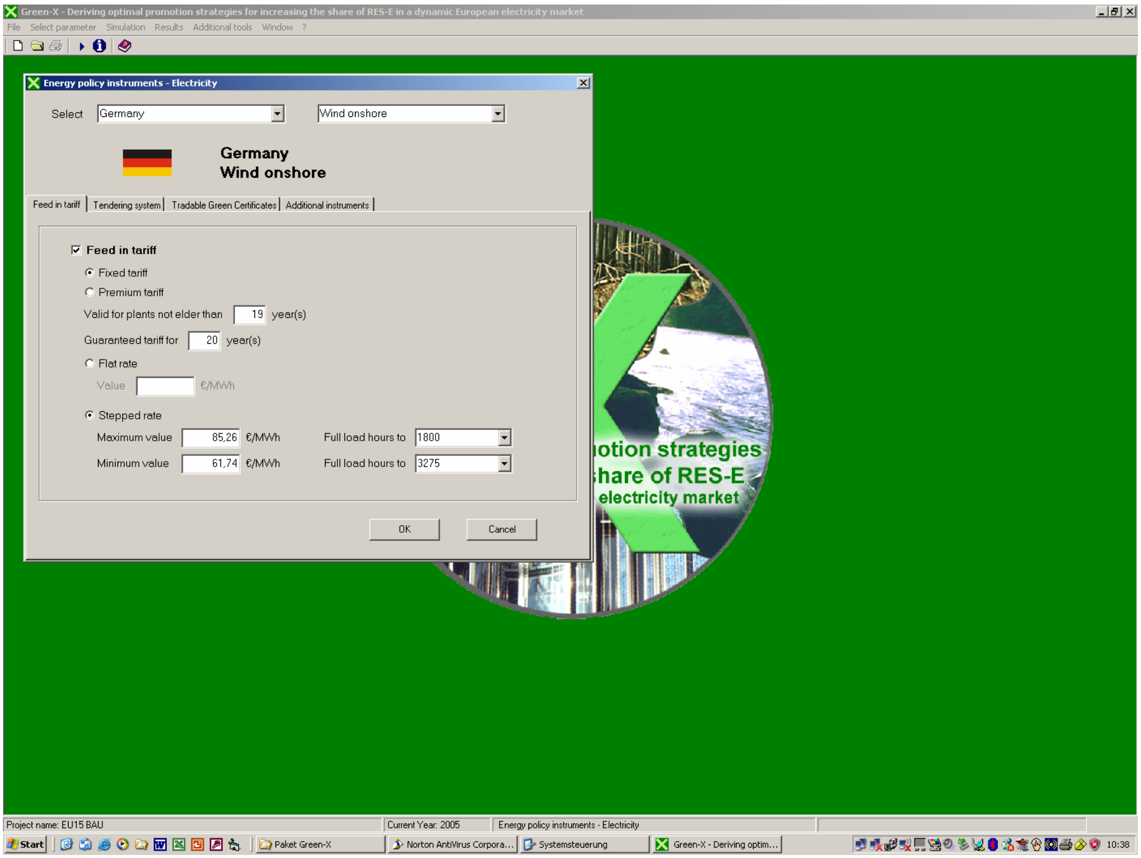


Figure 4.3 Design options in the case of a feed-in tariff

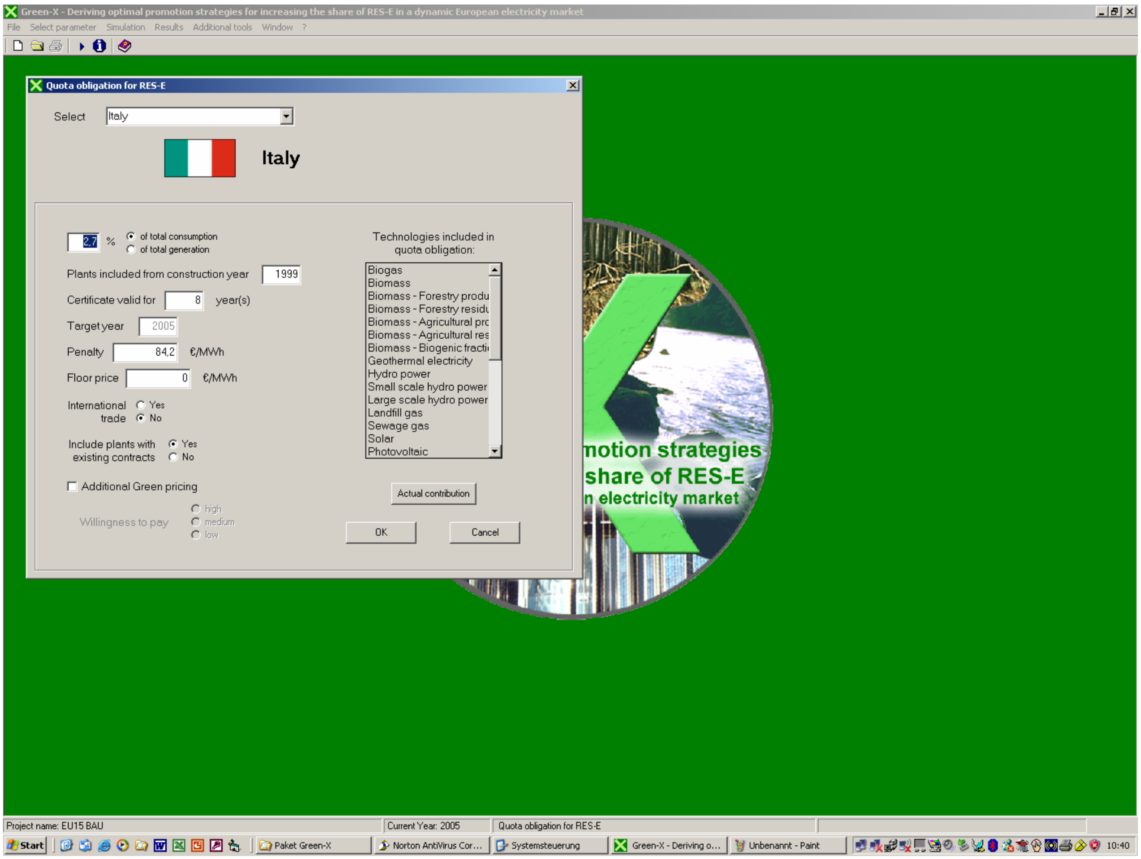


Figure 4.4 Design options in the case of a quota obligation

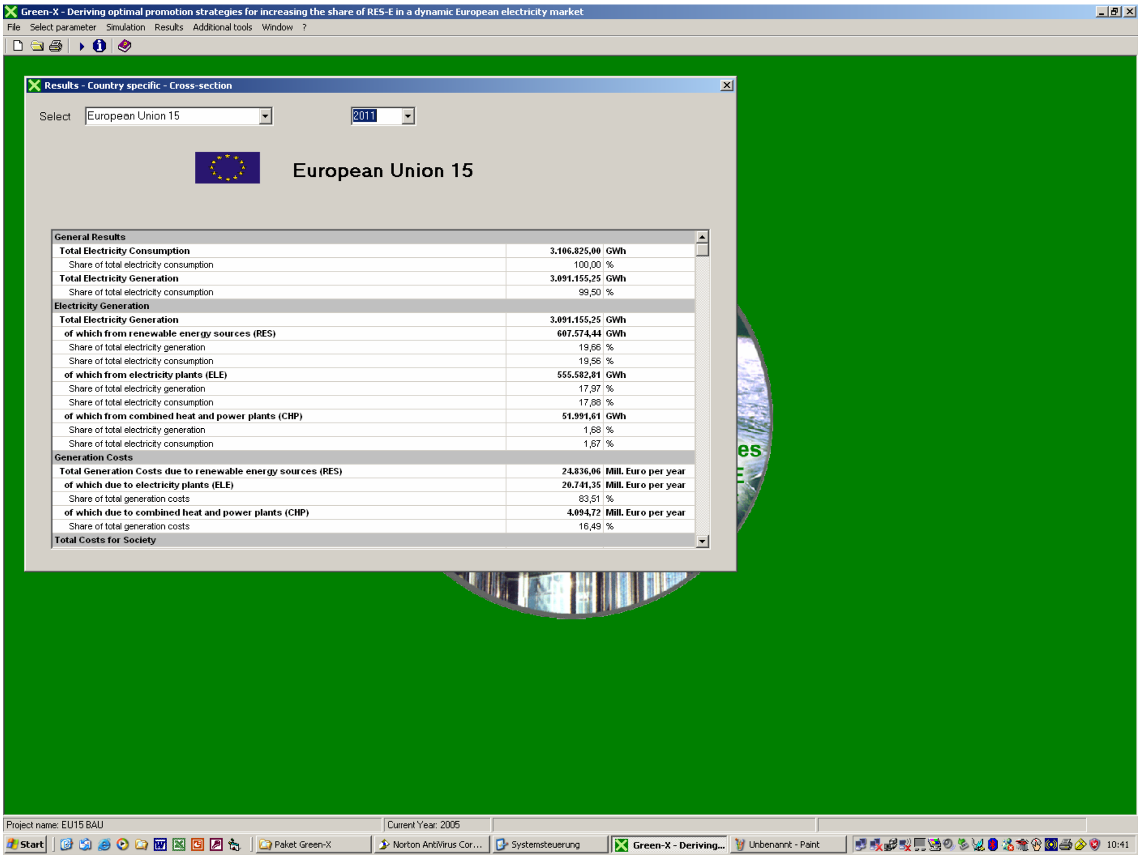


Figure 4.5 Result table - country specific results

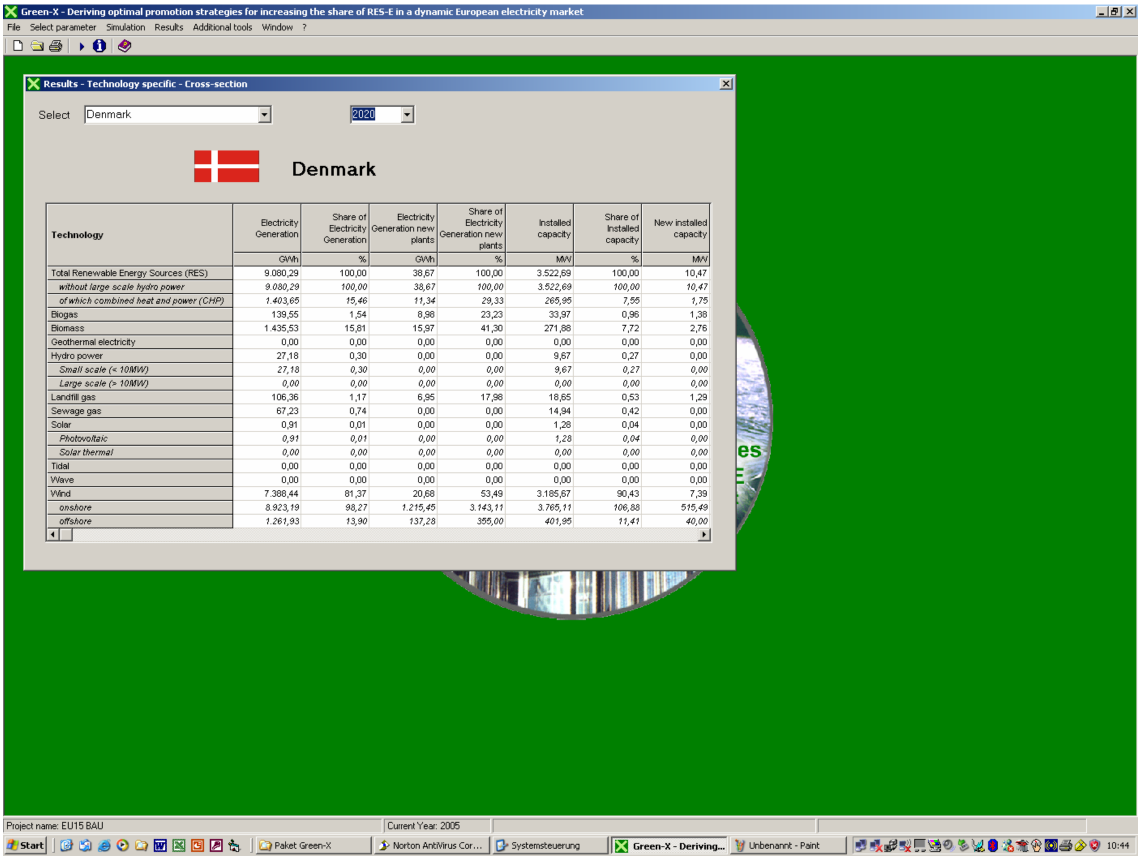


Figure 4.6 Result table - technology specific results on country level

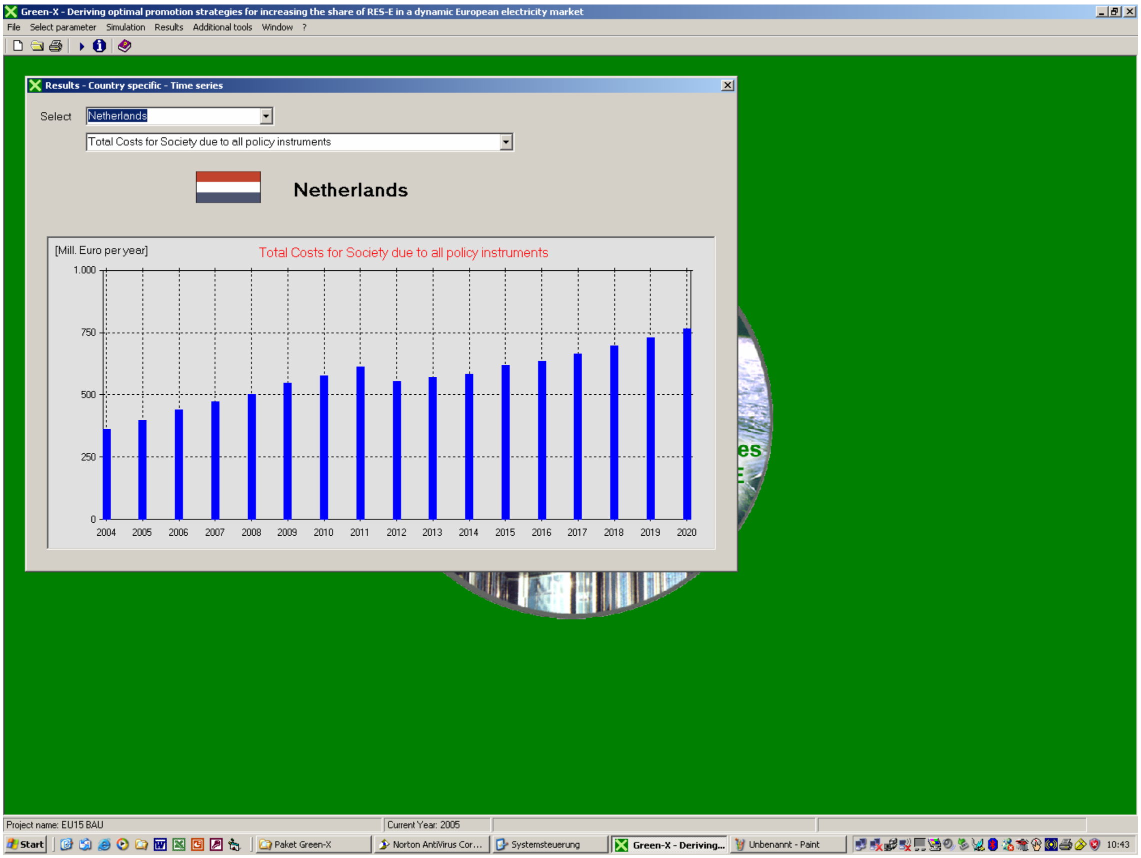


Figure 4.7 Result figure – time series total costs for society

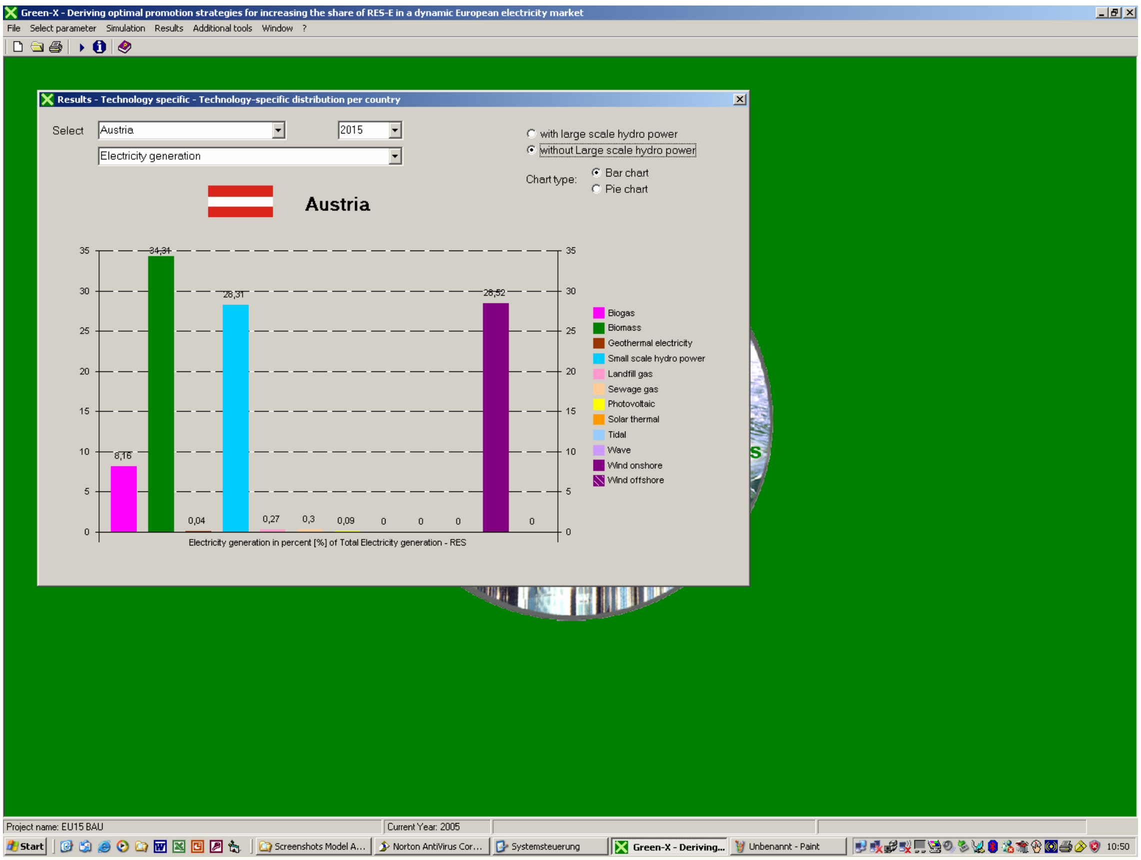


Figure 4.8 Result figure – technology specific distribution per country

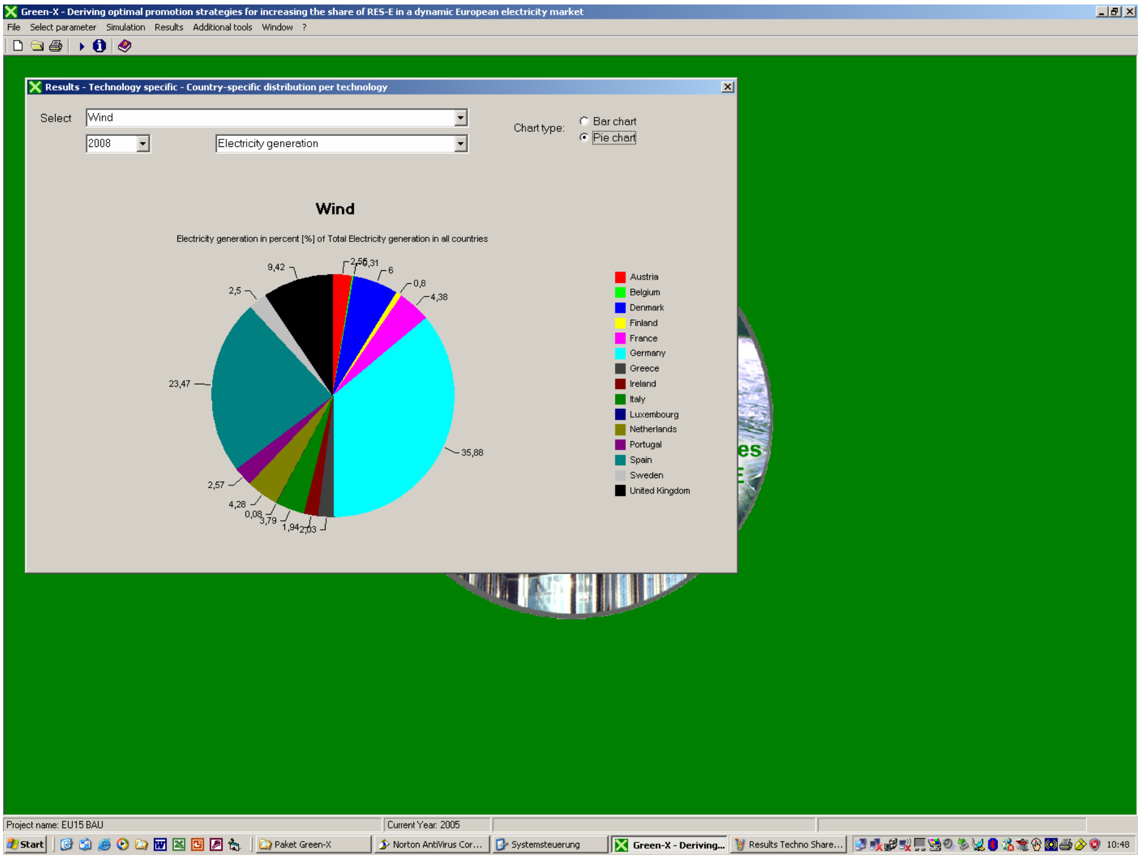


Figure 4.9 Result figure – country specific distribution per technology

4.2. Formal framework of the model ***Green-X***

This section is split into two major parts. Initially, a description of the methodology applied to set up the empirical database for the supply-side is given. Later on, the modelling of energy policy instruments is explained in brief. Other topics, not of core relevance with respect to RES-E, such as the modelling of the demand-side or the conventional power market are neglected.[48]

4.2.1. Development of supply-side cost-resource curves for RES-E

In the model ***Green-X*** the supply-side for RES-E technologies are described by generation costs and related potentials on yearly bases, i.e. by dynamic cost-resource curves. The subject of this section is to describe the development of these cost-resource curves, which takes place in three steps. Firstly the calculation of electricity generation costs from RES will be explained, followed by an analysis of the potentials. Finally, the methodology used for the specification of cost-resource curves is outlined.

The procedure for deriving the dynamic cost-resource curves is depicted in Figure 4.10. 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)

[48] For a brief discussion of these issues see (Ragwitz et al., 2003).

as well as possible new plants. Key information for existing plants includes investment costs, operation and maintenance (O&M) costs and electricity generation of the plant per year. For new plants, investment costs, O&M costs, efficiency as well as the additional potential of electricity generation in the end year 2020 – the so called *mid-term potential* - of the technology are most relevant.

Most of the data can be used as output variables without any change; however, some adaptation is required. These parameters are, e.g. the primary energy (fuel) prices, interest rate – the value depends on stakeholder behaviour following a certain support scheme for RES-E – and potential for electricity generation which is available for this year. The breakdown of the available additional potential 2020 for the subsequent year will be conducted with the help of a dynamic assessment, by considering the existing industrial, technical, market and societal barriers and obstacles. The outputs of the database are cost-resource curves for each category containing information with respect to the actual generation costs and the possible potential for electricity generation for the year under investigation.

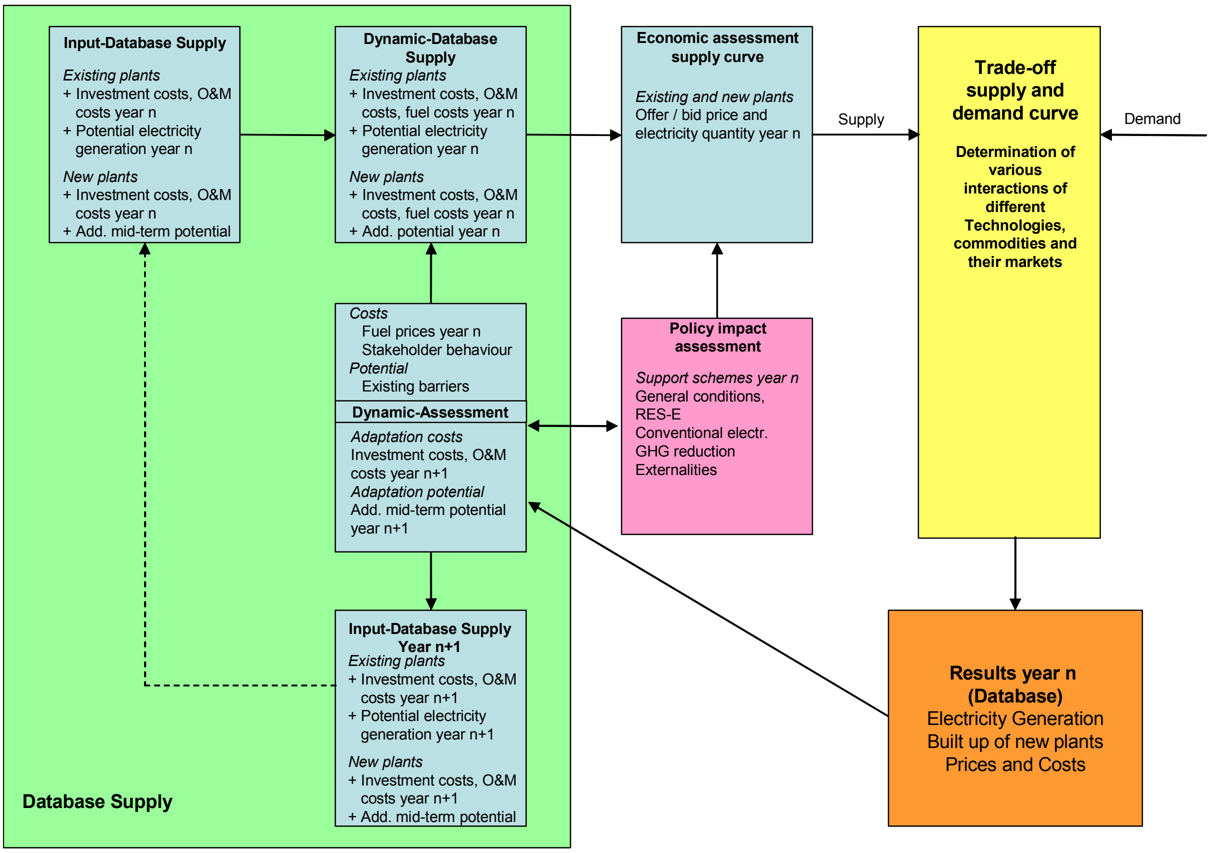


Figure 4.10 Overview of creating dynamic cost-resource curves for electricity generation

For the analysis of the interactions of different promotion schemes and among different markets and market conditions, a further adaptation of the dynamic cost-resource curve is necessary – i.e. an economic assessment of the supply curve, which will be influenced by the conditions of various support instruments. The results of this analysis, however, are offer prices and not costs, i.e. a transition from generation costs to bids and offers takes place during this step.

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. Changes are necessary for

- investment costs,
- operation & maintenance costs,
- efficiencies (and related parameter)
- database on existing plant – all new plant have to be added and old decommissioned plant have to be removed
- database on new plant (options) – the remaining additional mid-term potential must be reduced if parts of this potential have actually been exploited in the year under examination.

This adapted input-database serves as a starting point for the dynamic cost-resource curve development for the next subsequent year.

4.2.2. Data requirements

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.

► Country level

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 4.1.

Table 4.1 Summary of supply side country-specific data

Parameter	**Aim**
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 prices (for each sector)	Reference prices - To calculate additional costs for society due to the promotion of RES-E
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 [49]
Willingness to accept new plants	For dynamic parameter assessment

[49] Note investor behaviour depends on various factors such as support scheme, planning horizon, technology, and country.

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.

► <u>Technology level</u>

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 4.2.

Table 4.2 Summary of supply side technology-specific data

Parameter	**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

► <u>Band level</u>

In the toolbox ***Green-X*** 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 category. Bands are characterised by the same economic, technical, social and geographical conditions.[50]

In general, the core database of the toolbox ***Green-X*** contains information on the band level. 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 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 4.3.

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

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

Table 4.3 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[51]
Full-load hours electr.	Ex and New	In	To calculate electricity generation costs
Full-load hours heat (in case of CHP)	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
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[52]	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[53]	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

[51] 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.

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

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

► <u>Summary on supply-side data categories</u>

The interaction of country-specific, technology-specific and band-specific data is indicated in Figure 4.11 below.

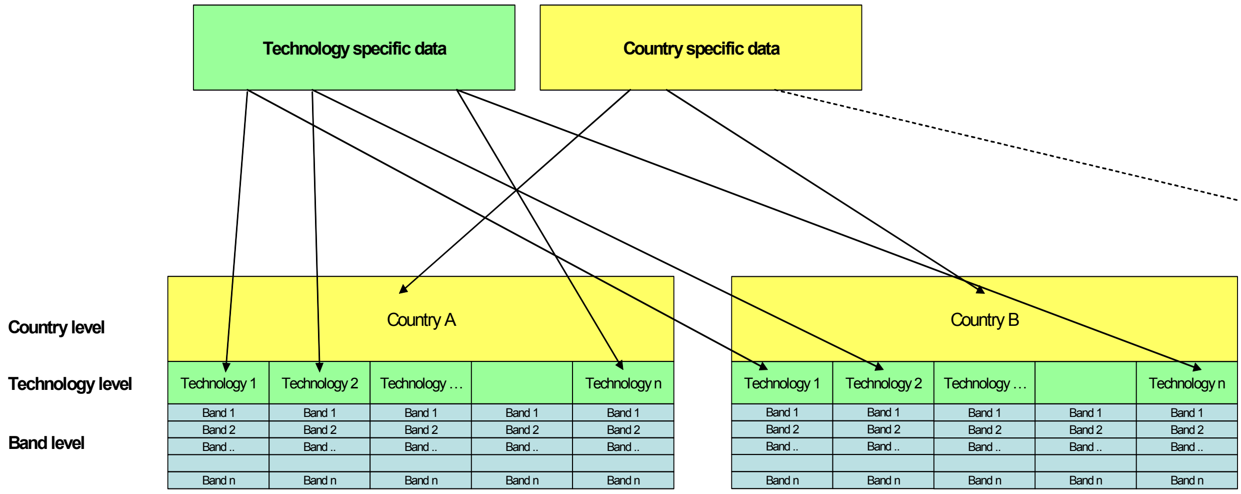


Figure 4.11 Overview of different levels of supply-side data

4.2.3. Calculation of electricity 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 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 generation options and CHP. Of course, within the model the same equations (i.e. the extended ones as necessary in case of CHP) have been applied.

4.2.3.1. Existing plants

<u>Generation costs – pure power generation</u>

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. Therefore, running costs for RES-E are in most cases low compared to fossil-based power generation opportunities.

Analytically, the generation costs for existing plants are given by:

$$C = C_{VARIABLE} = C_{FUEL} + \widetilde{C}_{O\&M} = \frac{p_{FUEL}}{\eta_{el}} + \frac{C_{O\&M}}{H} * 1000 \quad (4.1)$$

where:

C .... Generation costs per kWh [€/MWh]
$C_{VARIABLE}$ .... Running costs per energy unit [€/MWh]
C_{FUEL} .... Fuel costs per energy unit [€/MWh]
$\widetilde{C}_{O\&M}$ .... Operation and maintenance costs per energy unit [€/MWh]
$C_{O\&M}$ .... Specific annual operation and maintenance costs [€/(kW*yr)]
p_{FUEL} .... Fuel price primary energy carrier [€/$MWh_{primary}$]
η_{el} .... Efficiency electricity
H .... Full-load hours [h/yr]

Generation costs - CHP

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.

$$C = C_{VARIABLE} = C_{FUEL} + \widetilde{C}_{O\&M} - R_{HEAT} = \frac{p_{FUEL}}{\eta_{el}} + \frac{C_{O\&M}}{H} * 1000 - p_{HEAT} \frac{\eta_{heat}}{\eta_{el}} \cdot \frac{H_{heat}}{H_{el}} \quad (4.2)$$

where:

C .... Generation costs per kWh [€/MWh]
$C_{VARIABLE}$ .... Running costs per energy unit [€/MWh]
C_{FUEL} .... Fuel costs per energy unit [€/MWh]
$\widetilde{C}_{O\&M}$ .... Operation and maintenance costs per energy unit [€/MWh]
$C_{O\&M}$ .... Operation and maintenance costs per energy unit [€/(kW*yr)]
R_{HEAT} .... Revenues gained from selling of heat [€/MWh]
p_{FUEL} .... Fuel price primary energy carrier [€/$MWh_{primary}$]
p_{HEAT}................... Heat price [€/MWh_{heat}]
η_{el} .... Efficiency electricity generation [1]
η_{heat} .... Efficiency heat generation [1]
H .... Full-load hours [h/yr]

4.2.3.2. New plants

Generation costs - pure power generation

The calculation of the generation costs of electricity consists of two parts, variable costs and fixed costs. In more detail, the generation costs are given by:

$$C = C_{VARIABLE} + \frac{C_{FIX}}{q_{el}} = \left(C_{FUEL} + \frac{C_{O\&M}}{H} * 1000 \right) + \frac{1000 * I * CRF}{H} \qquad (4.3)$$

where:

C .... Generation costs per kWh [€/MWh]
q_{el} .... Quantity of electricity generation [MWh/yr]
$C_{VARIABLE}$ .... Running costs per energy unit [€/MWh]
C_{FIX} .... Fixed costs [€]
C_{FIX} / q_{el} .... Fixed costs per energy unit [€/MWh]
C_{FUEL} .... Fuel costs per energy unit [€/MWh]
$C_{O\&M}$ .... Operation and maintenance costs per energy unit [€/(kW*yr)]
I.......................... Investment costs per kW [€/kW]
CRF.................... Capital recovery factor: $CRF = \frac{z * (1+z)^{PT}}{\left[(1+z)^{PT} - 1\right]}$
z .... Interest rate (weighted average cost of capital) [1]
P......................... Payback time of the plant [yr]
H .... Full-load hours [h/yr]

A more detailed description of the running costs is given in the previous sub-section. Fixed costs occur independently whether the plant generates electricity or not. These costs are determined by investment costs (I) and the capital recovery factor (CRF).

► Investment Costs I

The investment costs differ by technology and energy source. In general, investment costs per unit capacity for RES-E are higher than for conventional technologies based on fossil fuels. Also, of course, differences occur between RE technologies, e.g. investment costs per unit capacity for small hydropower plants are generally more than double those for wind turbines. 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.[54]

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 technologies are applied as indicated in Table 4.4.

[54] 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 4.4 Overview of the methodology to dynamically derive investment costs by technology

Dynamic cost development	**Methodology to derive investment costs year n (default settings)**
Biogas	learning curve approach
Biomass	learning curve approach
Geothermal electricity	learning curve approach
Small scale hydropower (<10 MW)	learning curve approach
Large scale hydropower (>10 MW)	learning curve approach
Landfill gas	learning curve approach
Sewage gas	learning curve approach
Photovoltaics	learning curve approach
Solar thermal electricity	learning curve approach
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. 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
- 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 electricity generation q_{el}, compare e.g. equation (4.3) or (4.4). 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.

$$C = C_{VARIABLE} + \frac{C_{FIX}}{q_{el}} = \left(C_{FUEL} + \frac{C_{O\&M}}{H_{EL}} * 1000 - R_{HEAT} \right) + \frac{1000 * I * CRF}{H_{EL}} \qquad (4.4)$$

where:

- C .... Electricity generation costs per kWh [€/MWh]
- q_{el} .... Quantity of electricity generation [MWh/yr]
- $C_{VARIABLE}$ .... Running costs per energy unit [€/MWh]
- C_{FIX} .... Fixed costs [€]
- C_{FIX} / q_{el} .... Fixed costs per energy unit [€/MWh]
- C_{FUEL} .... Fuel costs per energy unit [€/MWh]
- $C_{O\&M}$ .... Operation and maintenance costs per energy unit [€/(kW*yr)]
- R_{HEAT} .... Revenues gained from sales of heat[55] [€/MWh]
- I.......................... Investment costs per kW [€/kW]
- CRF.................... Capital recovery factor: $CRF = \frac{z * (1+z)^{PT}}{\left[(1+z)^{PT} - 1\right]}$
- z .... Interest rate (weighted average cost of capital) [1]
- PT .... Payback time of the plant [yr]
- H_{EL} .... Full-load hours electricity generation [h/yr]

4.2.4. Determination of the additional mid-term potential for RES-E in 2020

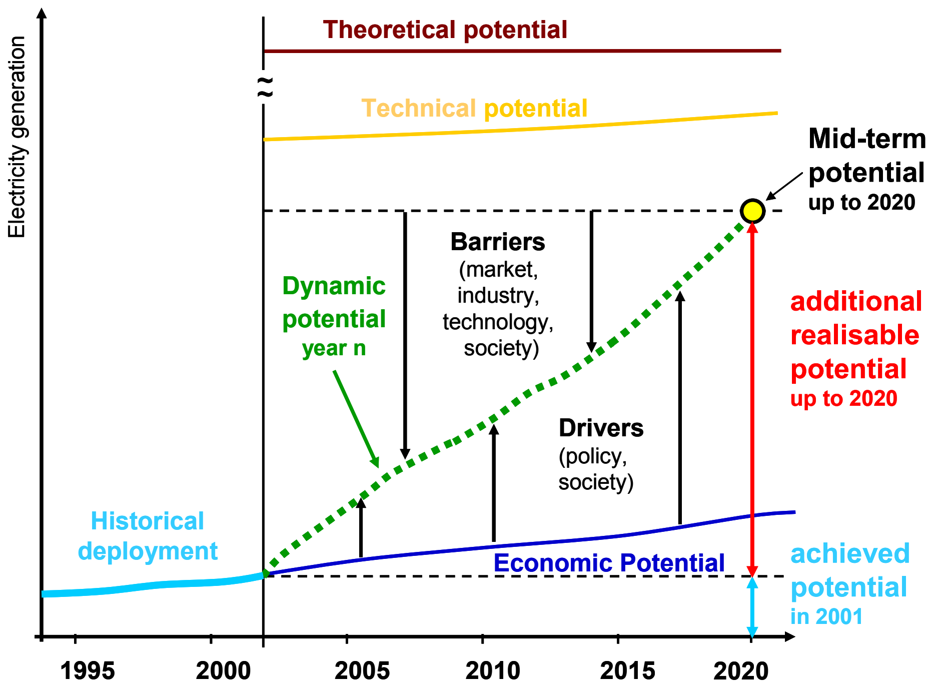


Figure 4.12 Methodology for the definition of potentials

[55] The calculation of the revenues gained from sales of heat is described in equation (4.2).

Remark: Definition of potential terms

- *Theoretical potential*: For deriving the theoretical potential general physical parameters have to be taken into account (e.g. based on the determination of the energy flow resulting from a certain energy resource within the investigated region). It represents the upper limit of what can be produced from a certain energy resource from a theoretical point-of-view – of course, based on current scientific knowledge;
- *Technical potential*: If technical boundary conditions (i.e. efficiencies of conversion technologies, overall technical limitations as e.g. the available land area to install wind turbines) are considered the technical potential can be derived. For most resources the technical potential must be seen in a dynamic context – e.g. with increased R&D conversion technologies might be improved and, hence, the technical potential would increase;
- *Realisable potential*: The realisable potential represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active. Thereby, general parameters as e.g. market growth rates, planning constraints are taken into account. It is important to mention that this potential term must be seen in a dynamic context – i.e. the realisable potential has to refer to a certain year;
- *Mid-term potential*: The mid-term potential as indicated in Figure 4.12 is equal to the realisable potential in the year 2020.

The starting point for deriving the dynamic potential is the determination of the additional mid-term potential for electricity generation for a specific technology in a specific country.[56] As described above, it represents the *'maximal additional achievable potential assuming that all existing barriers can be overcome and all driving forces are active'*. The so-called dynamic potential represents the maximal achievable potential for the year n. This means advantage must have been taken of all existing promotion strategies, both on the investor and the consumer side. To illustrate this more clearly, the connections between the different potential terms are depicted in Figure 4.12.

In the toolbox ***Green*-X** the additional mid-term potential for electricity generation refers to the year 2020. The methodology for the analysis of the potential varies significantly from one technology to another.

- In most cases a 'top-down' approach is used (e.g. for wind energy, photovoltaics). In a first step the technical potential for one technology (in one country) for 2020 has to be derived by determining the total useable energy flow of a technology. Secondly, based on step one, the mid-term potential for the year 2020 is determined by taking into consideration the technical feasibility, social acceptance, planning aspects, growth rate of industry and market distortions. The additional mid-term potential is given by the mid-term potential minus existing penetration plus decommissioning of existing plants.[57]

[56] Note: While the additional mid-term potential represents an important input parameter in the database, the additional annual potential (dynamic potential) is one of the essential output parameters of the cost-resource curve development.

[57] To use the potential in the database of the toolbox ***Green*-X**, the additional mid-term potential obtained on the technology level (in one country) must be broken down to the band level.

- For a few technologies, a 'bottom-up' approach has been more successful (e.g. for geothermal electricity), i.e. by looking at every single site (or band) where energy production seems possible and by considering various barriers, the additional mid-term potential is derived. The accumulated value of the single band yields the additional potential for one technology (in one country). [58]

One specific problem occurs with respect to biomass. The total primary energy potential for biomass is restricted. The actual distribution among the different options - pure electricity generation, CHP generation, heat generation or biofuel - depends on the net economic condition. As for the economic assessment, various support schemes must be considered, the final decision as to which options will actually be implemented is only feasible after including this step. To solve this problem, the values and the different options are linked in the database.

4.2.5. Development of the static cost-resource curve for RES-E

A (static) cost-resource curve shows the correlation between electricity costs per unit and the cumulative amount of electricity 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 per unit;
- total quantity of electricity 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.

As already described, cost curves for one technology (and country) are divided into different bands, see Figure 4.13.

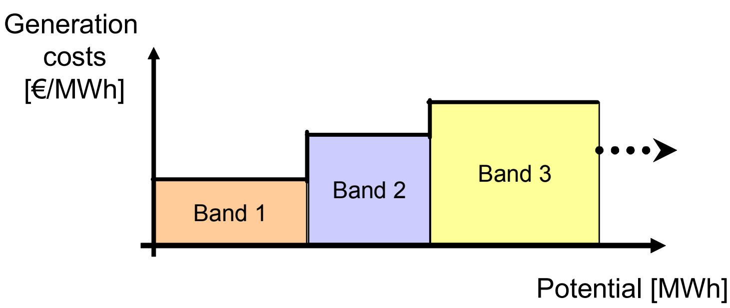


Figure 4.13 Relation between costs and potential for one technology

Bands are characterised by

- same fuel input, e.g. solid biomass: forestry products (wood) – forestry residues (bark, sawmill by-products) – agricultural products (energy crops) – agricultural residues (straw etc.),

[58] For the toolbox ***Green-X*** the addition of the single band is not necessary as the information must be available on band level.

- same sub-technology and energy efficiency categories, e.g. photovoltaics systems: façade integrated systems – roof system,
- same range of full-load hours, e.g. wind energy onshore: 2600 h/yr – 2500 h/yr – 2400 h/yr – 2100 h/yr – …. – 1500 h/yr.

Table 4.5 gives an overview of the band characteristics of the implemented RES-E technologies.

Table 4.5 Summary of the band characteristics of different technologies

Technology	**Band characteristic**
Biogas	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
(Solid) Biomass	Fuel input (fuel price), plant size/type (efficiency, investment-, O&M costs), full-load hours
Biowaste	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Geothermal electricity	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Small scale hydropower (<10 MW)	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Large scale hydropower (>10 MW)	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Photovoltaics	Plant size (inv.-, O&M costs), Application (full-load hours)
Solar thermal electricity	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Tide & Wave energy	Plant type (investment-, O&M costs), full-load hours
Wind on-shore	Full-load hours
Wind off-shore	Plant type (investment-, O&M costs), full-load hours

To obtain a rising curve, bands are put in ascending order with respect to costs, i.e. cheapest first and most expensive last. Figure 4.14 depicts a characteristic run of a cost-resource curve. It can be seen that it is helpful to show a separate development of the cost-resource curve for already existing and potential new plant.

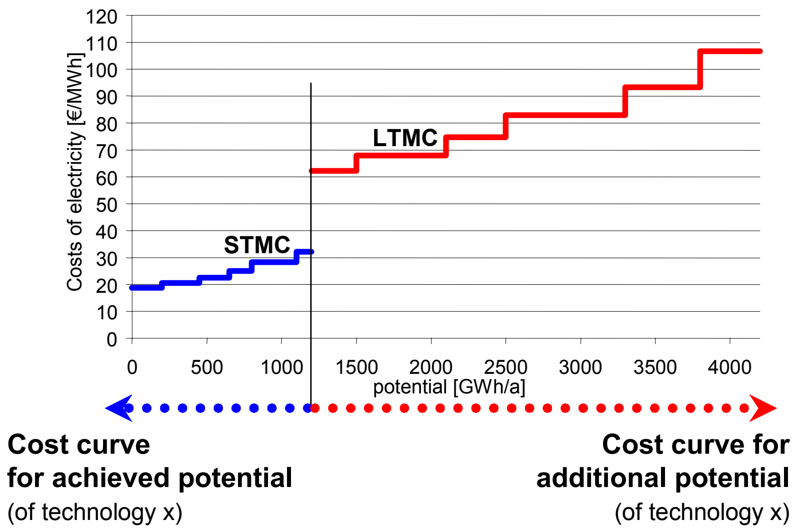


Figure 4.14 Cost-resource curve for achieved and additional potential of technology x

4.2.5.1. Cost-resource curve – existing plants

A characteristic cost-resource curve referring to already installed plant is depicted in Figure 4.15. In this example 4 different categories are used to describe the existing plant - bands B1 (efficient plant / good size) to B4 (inefficient plant / bad size). For each band the short-term marginal generation costs (STMC) and the long-term marginal generation costs (LTMC) are shown sorted by rising STMC.

The calculation of the STMC follows equation (4.1) explained above.[59] The LTMC are derived according to equation (4.3)[60], i.e. all cost parts, both investment and running costs, have to be taken into account. Note that the investment costs for existing plants refer to the year of installation and not to the year n – of course, as usual they are expressed in $€_{2002}$.

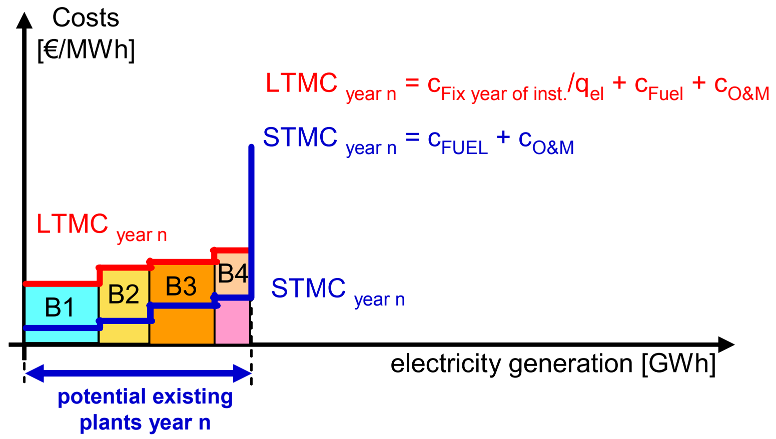


Figure 4.15 Cost-resource curve for already achieved potential of technology x

As already mentioned, only the short-term marginal generation costs (STMC) are relevant for the economic decision whether or not to produce electricity with a certain capacity - represented in the model by the band. This is because, for existing plants, the investments in the capacity are already (irreversibly) sunken.[61]

Nevertheless the long-term marginal generation costs are still important for the calculation and evaluation of important results, e.g. the derivation of the producer's profit. More precisely, as long as investments for a plant are not fully depreciated, the actual investment costs influence (significantly) the actual full generation costs and, hence, the producer's profit.

4.2.5.2. Costs-resource curve – new plants

► <u>Cost-resource curve – pure power generation</u>

As already mentioned, the electricity generation cost level for new installations is determined by the long-term marginal costs. The costs are derived according to

---

[59] Equation (4.2) in the case of a CHP plant.

[60] Equation (4.4) in the case of a CHP plant.

[61] It is assumed that the capacity cannot be rebuilt and sold to a third party.

equation (4.2) and (4.4), respectively. In contrast to already existing plants, the investment costs decrease over time e.g. according to the derived learning curve of the technology for the year n. The stepped curve as depicted in Figure 4.16 indicates the different cost / potential levels (bands). For instance, in the case of wind energy, sites with similar wind characteristics (mean wind speed and roughness class) are described by one band with one average load factor (or full-load hours), resulting in one specific cost level. In the example shown in Figure 4.16, seven different bands (characterised by different full-load hours) are defined – starting with best wind conditions (high achievable full-load hours - band B1) through to poor (band B7).

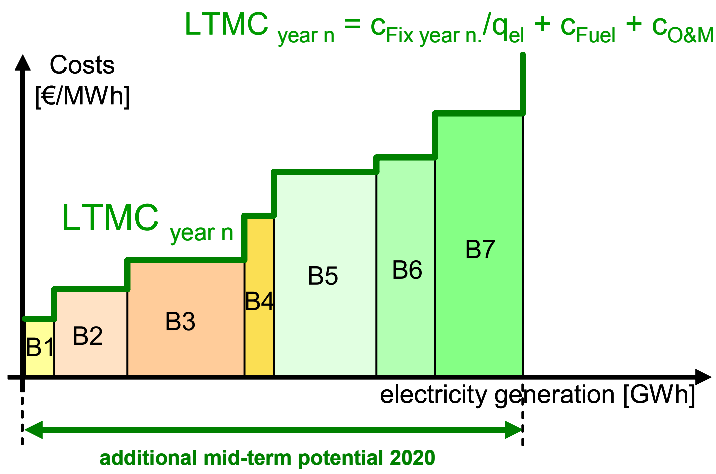


Figure 4.16 Cost-resource curve for additional mid-term potential of technology x

► <u>Cost-resource curve - CHP</u>

Some resource categories such as biomass can be used for both pure power generation and combined heat and power production. Therefore, information with respect to the mix of 'pure' electricity generation to combined heat and electricity production is of high relevance. In the model ***Green-X***, the ratio of CHP plants to pure electricity generation plants depends on the competitiveness of each technology. To keep the simulation time in an acceptable frame, it is assumed that the electricity to heat generation ratio is constant within one band. The power-to-heat ratio, however, differs among the bands of a certain CHP technology.

4.2.6. Development of the <u>dynamic</u> cost-resource curve for RES-E

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, see also Figure 4.17. The methodology used to derive the new investment costs has been already described in Chapter 4.2.3.2.

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.

4.2.6.1. 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.[62] This procedure is schematically depicted in Figure 4.17.

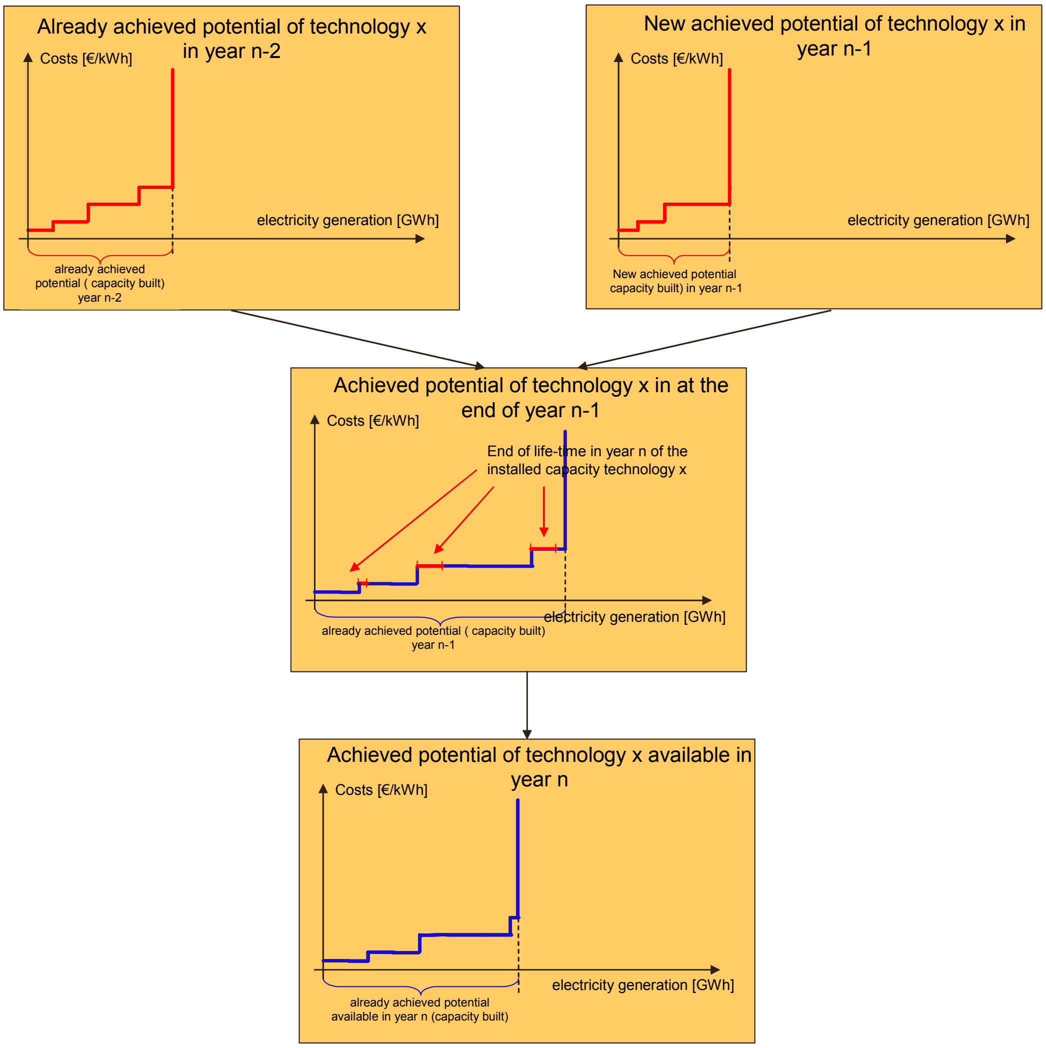


Figure 4.17 *Schematic plot of the development of dynamic cost-resource curves for existing plant for the year n (incl. extension for new plant of the year n-1 and lifespan assessment of existing plants)*
Note: these steps will be carried out at the end of the simulation for year n-1

4.2.6.2. 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.

[62] 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 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 RES-E 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 4.18.

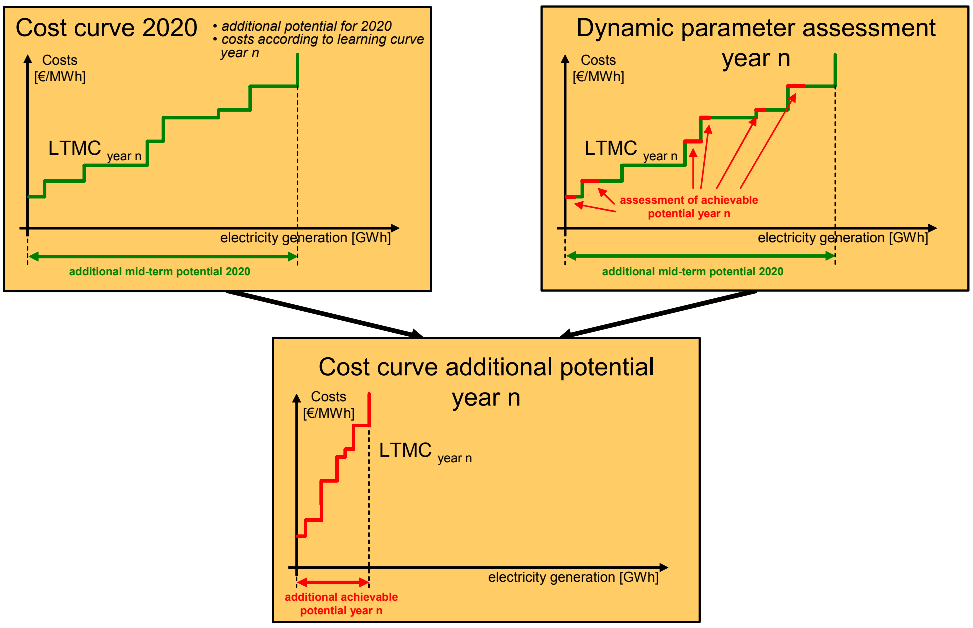


Figure 4.18 Schematic plot of the cost curve development for the year n and technology x

Note, a brief description of the dynamic parameter assessment is given in section 4.2.7.

4.2.6.3. 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 4.19.

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

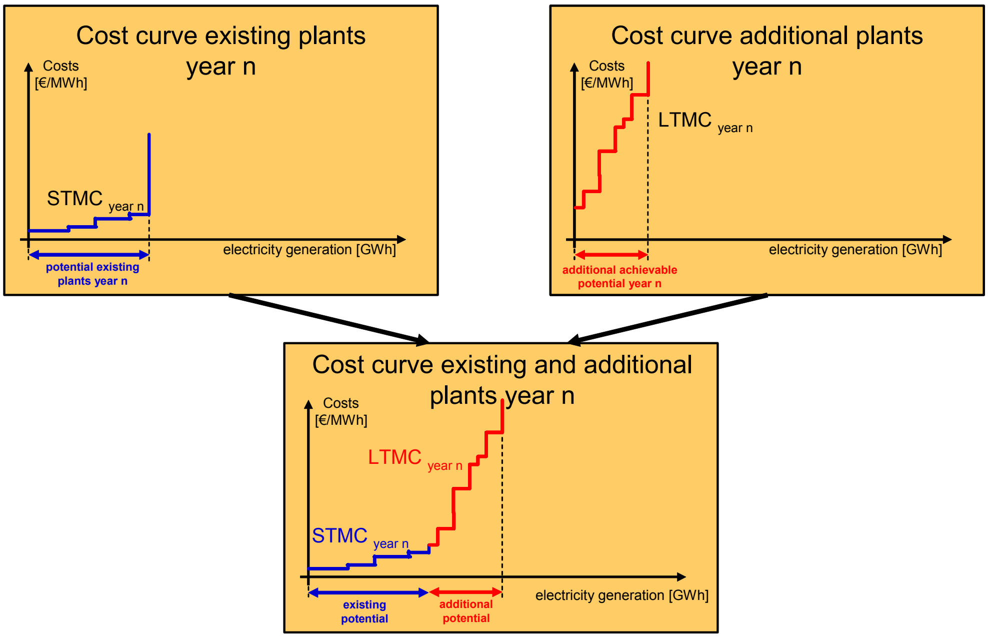


Figure 4.19 Combination of cost-resource curves for already achieved and additional potential for the year n and technology x

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.
- Other (non-economic) barriers as described above – they restrict the available potential of electricity 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. A high potential of electricity generation but high generation costs also results in a low market share.

4.2.7. Dynamic parameter assessment (new plant)

The *dynamic parameter assessment* represents the key element within the model **Green-X** to derive the dynamic potential for a certain year – i.e. the year n – from the overall remaining additional realisable mid-term potential (up to the year 2020) for a specific RES-E.

In a first step, the restricting factors of the dynamic potential for the year n must be analysed compared to the given additional mid-term potential, i.e. existing barriers must be determined. Secondly, the additional potential for the year n can be derived by applying a dynamic parameter assessment. More precisely, for each band, the available potential for the next year compared to the overall remaining mid-term potential (for the period up to the year 2020) will be evaluated.

4.2.7.1. Classification of dynamic barriers

In general, various barriers are taken into consideration – namely these are:

► Industrial barriers: *Growth rate of Industry*

In general, the availability of a certain RES-E technology in one country depends on the total global demand. I.e. if the (policy-driven) demand for a certain technology as e.g. wind power plant would increases rapidly on an international level, then a bottleneck situation might occur with respect to the industrial production of wind turbines. As a result less capacity could be built also on a country-level.

► Market barriers: *market and policy distortions*

Potential investors of RES-E projects have to get aware of the overall 'policy-driven demand' due to the promotion of certain RES-E. Thereby, confidence must be raised, that the overall planning horizon can be seen as stable and that the envisaged technology is proven. Market barriers are closely linked to administrative barriers described below and, hence, are described within the model **Green-X** by one RES-E specific indicator on a country-level.

► Administrative barriers: *high bureaucracy*

Often RES-E project developers face a high level of bureaucracy (i.e. a broad set of required procedures and permissions) during their project implementation process. In general, administrative barriers are linked to the RES-E specific market maturity within a country.

► Resource availability:

In general, the availability of a specific resource must be seen in a dynamic context. Thereby, the potential can either increase or decrease over time. E.g. in case of solid biomass, where the available potential of energy crops depends on land use regulations, higher available area potentials lead to a delayed increase of the according energy potential over time due to the time gap (delay) between cultivation and harvesting. In contrary, recent developments regarding waste treatment regulations as e.g. given by the EU-directive on the landfill of waste (European Commission, 1999) highly limit the realisable potential of this energy source in the future. Hence, the realisable potential would decreases over time. Note, in general the dynamic parameter 'resource availability' has to be considered in the overall potential assessment.

► Social barriers: *Social acceptance of additional RES-E generation*

Social acceptance represents an important parameter influencing the penetration of RES-E. In general, a decreasing social acceptance can be observed if penetration of a specific RES-E increases. Compare e.g. the case of large-scale hydropower in Austria: As hydropower represents a well-exploited resource planned new large-scale projects faced huge public acceptance problems in the near past. Social acceptance problems occur also in case of wind energy on local level with increasing penetration. Thereby, the involvement of local actors determines in many cases the success of certain projects.

Hence, in many cases social acceptance is also influenced by the applied policy strategy, e.g. the acceptance of big wind projects (e.g. in countries with best wind conditions as this is the case for Austria) is more restricted knowing that most of the electricity generated will be exported (e.g. due to an international TGC market) rather than be consumed locally or at least domestically.

► Technical barriers: *technical feasibility – i.e. grid restrictions or necessary grid extension, respectively*

For the integration of certain RES-E, namely e.g. wind power (characterised by high capacities and low load-factors), the existing grid represents an important barrier. If a weak grid exists on a local level, grid extension is necessary to integrate large amounts of RES-E in the future. Hence, grid restrictions lead to longer project leap times and are considered within the model ***Green-X*** as RES-E specific dynamic limitations of the yearly realisable potential on a local (i.e. band) level

The above described barriers influence the penetration of RES-E on different levels. According to the applied distinction of the supply-side database for RES-E as described in section 4.2.2, their impact is considered in the toolbox ***Green-X*** in the following way:

- industrial constraints (growth rate of industry) .... international level
- market constraints (market transparency, maturity of market,..) ... country level
- administrative constraints (bureaucracy) .... country level
- technical constraints (grid constraints) .... band level
- societal constraints (social acceptance to built new plants) .... band level

Table 4.6 gives an overview of the analysis of barriers and their consideration.

Table 4.6 Summary: characterisation of dynamic barriers

Dynamic parameter & their characterisation		**Techno-logy - specific**	**Inter-national level**	**Country level**	**Band-level**	**Link to policy**	**Impact on costs**	**Impact on poten-tials**	**Methodology to implement**
Industrial constraints	Growth rate of industry	X	**X**					X	EU-wide limitation of annual installations
Market constraints	Investors behaviour	X		**X**		X	X		Increased interest rate
	Market trans-parency	X		**X**			(X)*	X	Joint econometric approach
Admini-strative constraints	Bureaucracy	X		**X**		X	(X)*	X	
Technical constraints	Grid constraints (i.e. extension necessary)	X		X	**X**		(X)*	X	Band-specific assessment
Societal constraints	'Willingness to accept'	X		X	**X**	X		X	Band-specific assessment

Note: * ... Results gained from stakeholder questioning

4.2.7.2. Model implementation of the dynamic parameter assessment

General approach:

For each RES-E category a procedure as described in the following is applied to derive the realisable potential for each year of the simulation. Note, in principle, a 'bottom-up' approach is used, i.e. the assessment starts at the *band level*.

In a first step for each band the maximal realisable potential will be calculated. This amount represents the minimum of the following terms – see also equation (4.5):

- the amount of RES-E that can be integrated in the year n by band under consideration of grid restrictions,
- the amount of RES-E that can be integrated in the year n by band under consideration of social acceptance barriers,
- the remaining additional mid-term potential (for the period up to 2020).

$$\Delta P_n = \textit{Minimum}\ [\Delta P_{n \text{-> } 2020};\ \Delta P_{G\ n};\ \Delta P_{S\ n}] \qquad (4.5)$$

With: ΔP_n .... realisable potential (year n, band level)
$\Delta P_{n \text{-> } 2020}$ .... additional mid-term potential (year n till 2020, band level)
$\Delta P_{G\ n}$ .... realisable potential - grid constraint (year n, band level)
$\Delta P_{S\ n}$ .... realisable potential - social constraint (year n, band level)

This procedure is depicted in Figure 4.20. The red lines represent the overall remaining additional mid-term potential (see left-hand-side top), the blue lines the additional potential which is available for the next year (year n) considering band specific restrictions (right-hand-side, top). Note, the actual availability can vary between the single bands.[63] By adding the additional potential of each band (for year n), the dynamic cost-resource curve on band level (for year n) can be constructed. In the example, the blue lines (right-hand-side, top) are summed up – forming the available cost-resource curve (for the year n) under consideration of band-specific restrictions, see left-hand-side (down) in Figure 4.20.

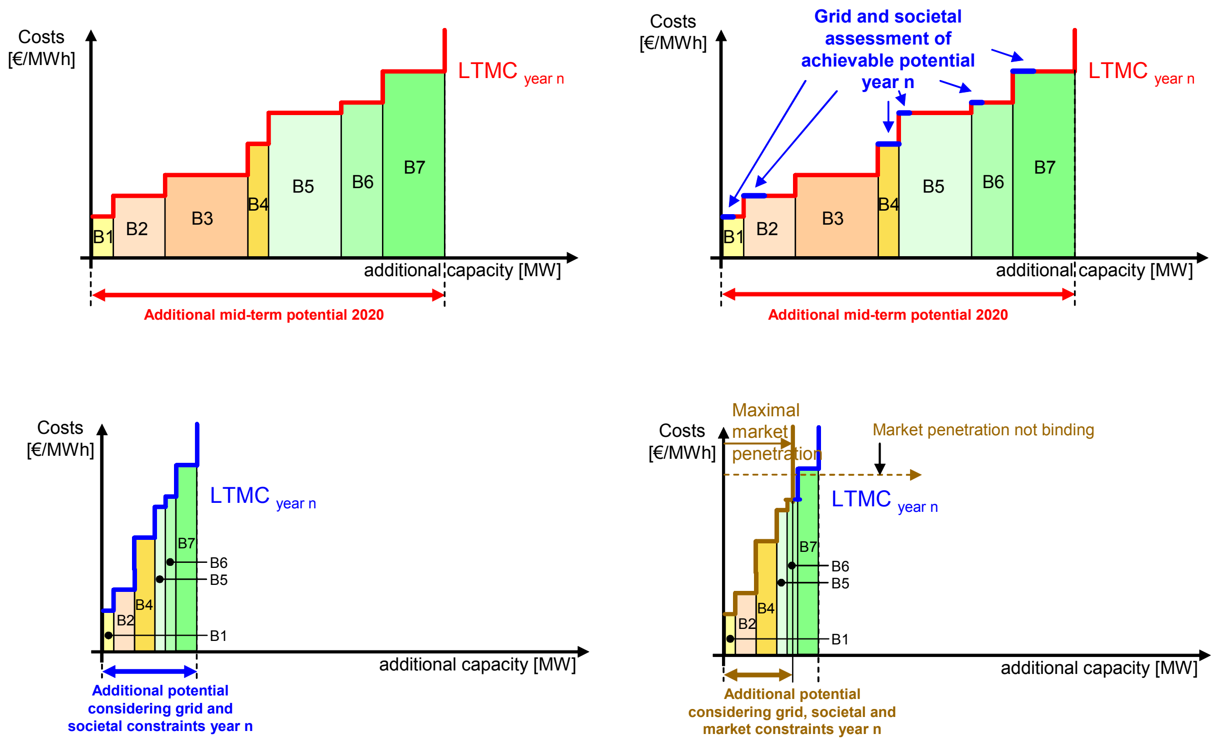


Figure 4.20 Dynamic parameter assessment – to derive the dynamic cost-resource curve for the additional realisable potential in year n for technology x

In a second step restrictions have to be applied on a country-level. I.e. the additional realisable potential (in year n), resulting from band-restrictions as described above, must be possibly further limited by application of constraints acting on a country-level. Here, it is assumed that most cost efficient bands would be achieved first. This means that those bands with the lowest costs (in general bands on the left-hand side of the cost-resource curve) would be favourably used. All (parts of a) bands fulfilling the following constraint will be considered for the achievable potential for the year n:

$\sum \Delta P_{n\,i} < \Delta P_M$ *from í = 1 to m, band 1 = band with the lowest costs,* (4.6)

band m = band with the highest costs

With: $\Delta P_{n\,i}$ ..... realisable potential (year n, band level i)

ΔP_M realisable potential - market and administrative constraint (year n, country level)

[63] E.g. in Figure 4.20 no additional potential for band 3 is available for the next year. Note: the cost level of the individual bands remains uninfluenced by the dynamic parameter assessment because the costs (referring to the mid-term as well as the dynamic potential) already refer to the year n.

This procedure is schematically depicted on the right-hand-side (down) in Figure 4.20: The brown lines represent the remaining dynamic cost-resource curve (for the year n) under consideration of band-specific as well as country-specific restrictions.

It is worth mentioning that the market barriers must not be binding in any case, i.e. under the assumption of strong grid and / or social restrictions the market barrier actually does not restrict the additional available potential (for the year n).

In general, all parameters describing the dynamic barriers can be set for each RES-E category individually. Note, default settings have been applied based on the assessment of dynamic parameters as undertaken within this project. Nevertheless, users of the toolbox ***Green-X*** have the possibility to adjust the barriers according to their own assessment.

Thereby, the following common categorization is used to describe the impact of a specific barrier:

very high barrier	level number	 0
high barrier	level number	 1
medium barrier	level number	 2
low barrier	level number	 3
very low barrier	level number	 4
'%-approach'[64]	level number	…. 5

In the following, the modelling approach to derive the dynamic realisable potential for each barrier category (grid, social and market/administrative constraints) will be explained in detail:

Market and administrative constraints (impact on country-level)

Market and administrative restrictions shall be seen as one combined indicator for the maturity of the market, taking also into account required planning procedures. For the model ***Green-X*** it represents the most important in the set of dynamic parameter describing the impact of non-economic barriers on the deployment of a certain RES-E.

The maturity of the market is one of the key issues influencing the penetration of a technology in the future. In accordance with general diffusion theory, penetration of a market by any new commodity typically follows an 'S-curve' pattern – see section 3.2.1. The evolution is characterised by a growth, which is nearly exponential at the start and linear at half penetration before it saturates at the maximum penetration level. With regards to the technical estimate of the logistic curve, a novel method has been employed by a simple transformation of the logistic curve from a temporal evolution of the market penetration of a technology to a linear relation between annual penetration and growth rates. This novel procedure for estimating the precise form of the logistic curve is more robust against uncertainties in the historic data. Furthermore, this method

[64] Note, if the level number '5' is chosen, the default approach for each barrier-category as described next will be replaced by a simplified mechanism: In this case the yearly realisable potential is defined as share of the overall additional realisable mid-term potential.

allows the determination of the independent parameters of the logistic function by means of simple linear regression instead of nonlinear fits involving the problem of local minima, etc.[65]

Analytically the initial function, as resulting from econometric assessment has a similar form to equation (4.7). However, for model implementation a polynomic function is used, see equation (4.8) – which represents the derivation of equation (4.7). This translation facilitates the derivation of the additional market potential for the year n if the market constraint is not binding, i.e. the grid or social constraint is more restrict.

As absolute growth rate is very low in the case of an immature market, a minimum level of the yearly realisable additional market potential has to be guaranteed – as indicated by equation (4.9)

$$X_n = \frac{a}{\left\{1 + b * e^{\left[-c*(\text{year}n - \text{start year} + 1)\right]}\right\}} \tag{4.7}$$

$$\Delta P_{Mne} = P_{\text{stat long-term}} * \left[A * X_n^{\ 2} + B * X_n + C\right] * \left[\chi_{M\min} + \frac{\chi_{M\max} - \chi_{M\min}}{4} * b_M\right] \tag{4.8}$$

$$\Delta P_{Mn} = \text{Max}\left[\Delta P_{M\,min}; \Delta P_{M\,ne}\right] \tag{4.9}$$

where: $\Delta P_{M\,n}$ .... realisable potential (year n, country level)

$\Delta P_{M\,min}$ .. lower boundary (minimum) for realisable potential (year n, country level)

$\Delta P_{M\,ne}$ ... realisable potential econometric analysis (year n, country level)

$P_{\text{stat long-term}}$ .. static long-term potential (country level)

a .... econometric factor, technology specific

b .... econometric factor, technology specific

c .... econometric factor, technology specific

A quadratic factor yield from the econometric analysis

B linear factor yield from the econometric analysis

C constant factor yield from the econometric analysis (as default 0, considering market saturation in the long-term)

X_n .... calculated factor - expressing the dynamic achieved long-term potential as percentage figure: In more detail …

$$X_n = \frac{\text{dynamic achieved potential (year n, country level)}}{\text{total long - term potential (country level)}}$$; X_n [0, 1]

$\chi_{M\,max}$ ... absolute amount of market restriction assuming very low barriers; $\chi_{M\,max}$ [0, 1]; to minimise parameter setting $\chi_{M\,max} = 1$

$\chi_{M\,min}$ .... absolute amount of market restriction assuming very high barriers; $\chi_{M\,min}$ [0, $\chi_{M\,max}$]

b_M........ **barrier level market / administrative constraint assessment (level 0 - 5)** [66]**;**
selectable by the user

---

[65] Note that a detailed description of this concept will be given in (Ragwitz et al., 2005).

[66] Note, if the level number '5' is chosen, the default approach as described next will be replaced by a simplified mechanism: In this case the yearly realisable potential is defined as share of the dynamic additional realisable mid-term potential on band level. Hence, it can be chosen separately how much of the remaining potential can be exploited each year.

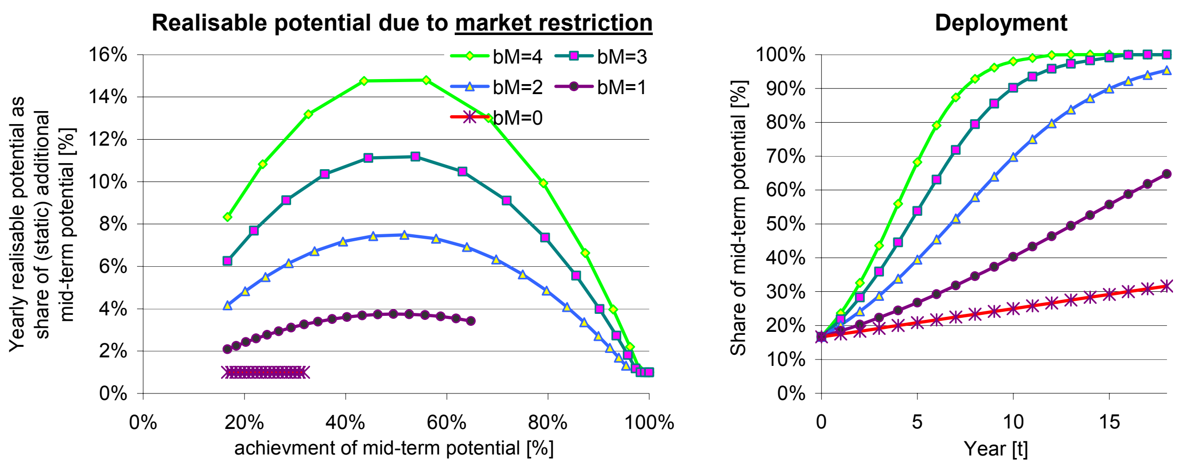


Figure 4.21 Impact of dynamic barriers on the derivation of the yearly realisable potential: Modelling approach for market & administrative constraints

Figure 4.21 illustrates the applied approach: On the left-hand side resulting yearly realisable potential in dependence of applied barrier level and on the right-hand side related deployment – in case that no other constraint would exist – is depicted. In more detail, the following settings have been used:

b_M = 0 … 4 (variation from 0 to 4)

$\chi_{M\ max}$ = 1.00

$\chi_{M\ min}$ = 0.00

B = -A = 0.5

C = 0

(Initial exploitation of the RES-E potential on country level: $X_0 =$ 17%)

Technical / Grid constraints (impact on band-level)

As already mentioned band-specific constraints consist of technical and societal barriers. For both barriers, in general, existing obstacles increase with the exploitation of the band. This means that the barriers are more restricted if the already achieved potentials are high.

Barriers exist with respect to the existing grid and their extension, respectively. If the potential of a band (representing a specific geographical area) is less exploited, it is assumed that only few problems to integrate RES-E into the (existing) grid exist compared to the situation of an extensive exploitation.

Analytically this fact is characterised by setting the 'barrier assessment (b_G)' at the 'slope' of the linear function (β_G), see equation (4.10).

$$\Delta P_{Gn} = \Delta P_{stat2020} * \chi_G * \left\{1-(1-\alpha)*\left[\beta_{G\max} - \frac{\beta_{G\max}-\beta_{G\min}}{4} * b_G\right]\right\} \quad (4.10)$$

where: ΔP_{Gn} ..... realisable potential - grid constraint (year n, band level)

$\Delta P_{stat2020}$ static additional mid-term potential (i.e. from 2002 to 2020) (band level)

α .... calculated factor - expressing the dynamic additional realisable potential as percentage figure: In more detail …

$$\alpha = \frac{\text{dynamic additional mid-term potential (year n, band level)}}{\text{total mid-term potential (band level)}}\ ;\ \alpha\ [0,\ 1]$$

$\beta_{G\max}$.... slope of grid restriction (band level) - assuming very low barriers, $\beta_{G\max}$ [0, 1]

$\beta_{G\min}$ .... slope of grid restriction (band level) - assuming very high barriers, $\beta_{G\min}$ [0, $\beta_{G\max}$]

χ_G .... slope of grid restriction (band level); χ_G [0, 1]

b_G .... barrier level – grid assessment (level 0-5)[67]; selected by the user

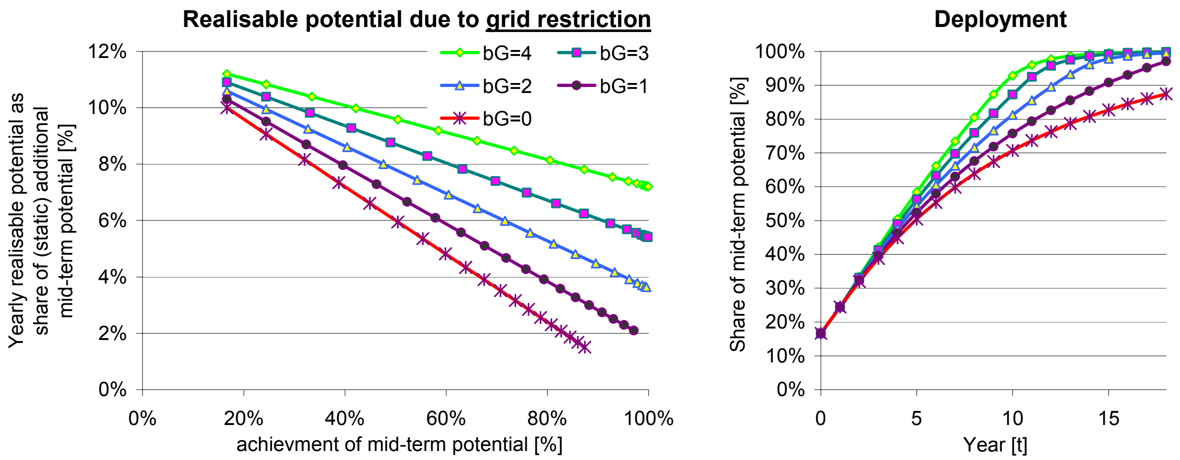


Figure 4.22 Modelling approach for technical /grid constraints: Impact of dynamic barriers on the derivation of the yearly realisable potential (left-hand side) and resulting deployment (right-hand side)

Figure 4.22 illustrates the applied approach: On the left-hand side resulting yearly realisable potential in dependence of applied barrier level and on the right-hand side related deployment – in case that no other constraint would exist – is depicted. Thereby, the following settings have been used:

b_G = 0 … 4 (variation from 0 to 4)
$\beta_{G\max}$ = 1.00
$\beta_{G\min}$ = 0.40
χ_G = 0.12
(Initial exploitation of the RES-E potential on band level: $\alpha = 17\%$)

[67] Note, if the level number '5' is chosen, the default approach as described next will be replaced by a simplified mechanism: In this case the yearly realisable potential is defined as share of the dynamic additional realisable mid-term potential on band level. Hence, it can be chosen separately how much of the remaining potential can be exploited each year.

Societal constraints (impact on band-level)

Social acceptance of RES-E generation represents an important restricting of the available potential in reality. Similar to the technical restriction, the barrier raises with the exploitation of the potential. Hence, in contrast to the technical constraint, it is assumed that social acceptance depends on both, the exploitation of a specific RES-E on local (i.e. band level) as well as on country level. This fact will be considered in **Green-X**:

- On band level the 'barrier assessment (b_S)' affects the absolute amount of the restriction (χ_S). In addition, by setting a steep slope (i.e. high value for β_S), a high decrease in the social acceptance with increasing exploitation of its potential is assumed for the specific RES-E category on a local level.
- The social acceptance on country level is modelled by the parameter β_{SC}, which – similar to β_S – describes the decrease in social acceptance with increasing utilisation of the specific RES-E in the whole country.

$$\Delta P_{Sn} = \Delta P_{stat2020} * \left[\chi_{S\min} + \frac{\chi_{S\max} - \chi_{S\min}}{4} * b_S \right] * \left[1 - \beta_S * (1-\alpha)\right] * \left[1 - \beta_{SC} * (1-\alpha_{SC})\right] \quad (4.11)$$

where: ΔP_{Sn} ..... realisable potential - social constraint (year n, band level)

$\Delta P_{stat2020}$ static additional mid-term potential (i.e. from 2002 to 2020) (band level)

α .... calculated factor - expressing the dynamic additional realisable potential (on band level) as percentage figure: In more detail …

$$\alpha = \frac{\text{dynamic additional mid-term potential (year n, band level)}}{\text{total mid-term potential (band level)}} \; ; \; \alpha \, [0,1]$$

β_S .... slope of social restriction (band level); β_S [0, 1]

$\chi_{S\,max}$.... absolute amount of social restriction (band level) - assuming very low barriers;
$\chi_{S\,max}$ [0, 1]

$\chi_{S\,min}$ .... absolute amount of social restriction (band level) - assuming very high barriers;
$\chi_{S\,min}$ [0, $\chi_{S\,max}$]

α_{SC}....... calculated factor - expressing the dynamic additional realisable potential (on country level) as percentage figure: In more detail …

$$\alpha_{SC} = \frac{\text{dynamic additional mid-term potential (year n, country level)}}{\text{total mid-term potential (country level)}} \; ; \; \alpha_{SC} \, [0,1]$$

β_{SC} .... slope of social restriction (country level); β_{SC} [0, 1]

b_S .... barrier level – social acceptance assessment (level 0-5)[68]; selected by the user

[68] Note, if the level number '5' is chosen, the default approach as described next will be replaced by a simplified mechanism: In this case the yearly realisable potential is defined as share of the dynamic additional realisable mid-term potential on band level. Hence, it can be chosen separately how much of the remaining potential can be exploited each year.

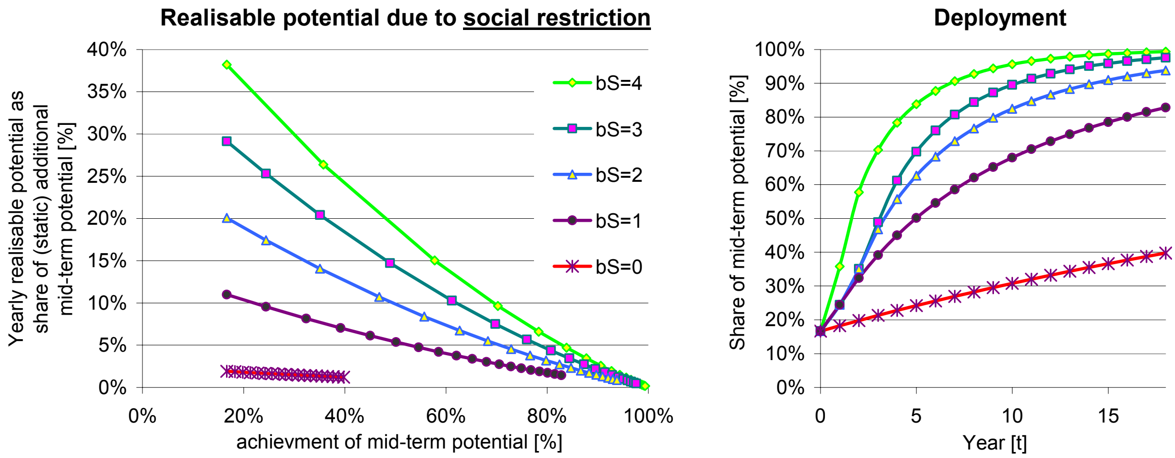


Figure 4.23 *Impact of dynamic barriers on the derivation of the yearly realisable potential: Modelling approach for social constraints*

Figure 4.23 illustrates the applied approach: On the left-hand side resulting yearly realisable potential in dependence of applied barrier level and on the right-hand side related deployment – in case that no other constraint would exist – is depicted. In more detail, the following settings have been used:

b_s = 0 … 4 (variation from 0 to 4)

β_S = 1.00

$\chi_{S\ max}$ = 0.50

$\chi_{S\ min}$ = 0.025

β_{SC} = 0.50

(Initial exploitation of the RES-E potential on country as well as band level: $\alpha = \alpha_{SC}$ = 17%)

4.3. Economic assessment – the linkage of dynamic cost-resource curves with promotion instruments

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

- *Economic barriers* – they are reflected by the 'net' generation costs, i.e. derived by considering the impact of policy strategies.
- *Non-economic barriers* as described in the previous section, which they restrict the available potential of electricity 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 provide only financial support without preparing the framework conditions to overcome the other non-economic barriers such as administrative, societal or technical constraints.

On the other hand, providing a good environment at administrative, social, industrial and technical levels (i.e. admitting a huge potential) without setting economic incentives does not increase the future penetration rate of an emerging not fully competitive technology. A high potential of electricity generation accompanied by high generation costs also results in a low market penetration.

In the model ***Green*-X** the impact of the support schemes and the policy framework on the economic cost for an investor and an enterprise is analysed in the so called *economic assessment*. Thereby, costs will be adapted according to possibly applied promotion schemes. Note, the costs correspond after the economic support assessment to the market conditions, i.e. they represent the offered prices / bids on the market. In other words, a transition from generation costs to offer prices takes place by applying the economic assessment.

In general it can occur that the revenue - the received income from the sell of the RES-E - which is necessary to built up a new plant - differs to the long-term marginal generation costs (LTMC) for a certain plant. The reason is that the period, where an additional support from the RES-E can be claimed, is shorter than the pay-back time of the plant. In this case an adaptation of the 'fix' costs is necessary.

The consequence of a shorter support time is that the offer price is above the LTMC concerning the pay-back time (PT). The reason is that only in this shorter period a higher revenue can / must be earned. However, the offer price is lower that the LTMC concerning the support time (ST), because additional revenues after this period (SP-PT) can be expected.

Note: A clear distinction between a guaranteed duration of the support time[69] and uncertainty about the stability of the promotion strategy[70] must be made. While the guaranteed duration can be directly considered in the determination of the offer price, the uncertainly about stability of the policy instrument is taken into account only indirectly. More precisely, the necessary rate of return (capital recovery factor) is higher

[69] For example: A tender contract is guaranteed over 10 year. However, after this period no additional (public) support can be expected.

[70] For example: A tax relief is currently implemented as support instrument. As such a policy scheme cannot be legally binding for a certain period, uncertainty about the duration when the investor / customer can claim this additional income exist, e.g. this tax can exist only one year, to the next elections or the next 15 years.

in this case, due to the higher risk associated with the uncertainty of the additional income.

In this context, Figure 4.24 provides an illustrative depiction of the economic assessment referring to the case discussed above.

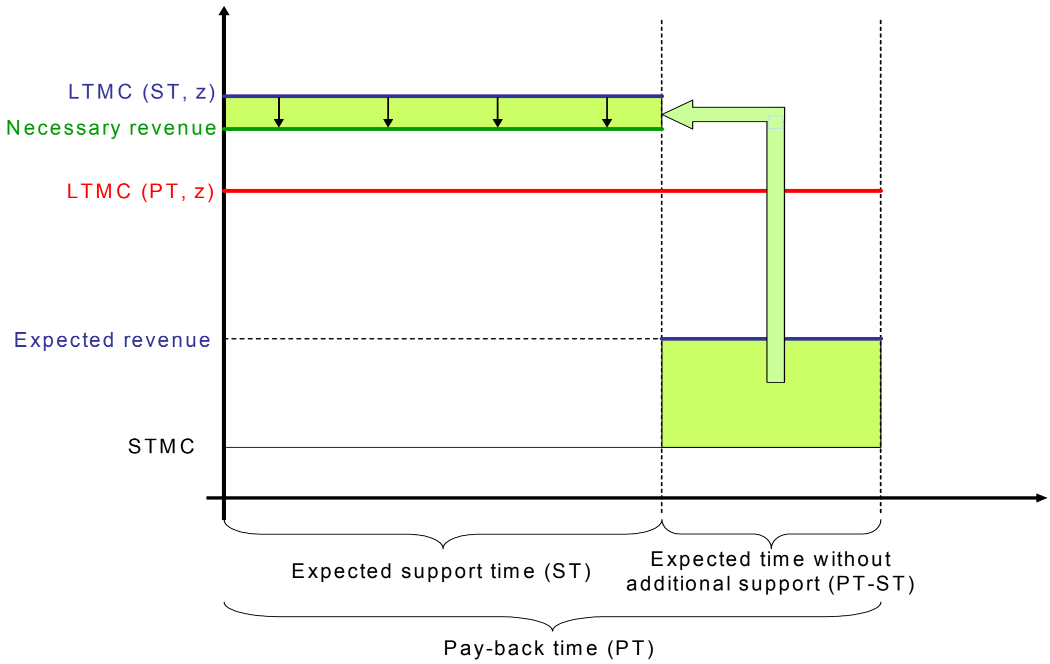


Figure 4.24 Determination of the offer price

In the following, the mechanism of the various types of promotion instruments is explained in detail. However, the so far most comprehensive discussion in this respect is given in (Huber et al., 2000).

4.3.1. Price driven instruments

Price driven strategies are characterised for expanding the RES capacity by setting an incentive on the supply side. This means these instruments benefit the marginal costs of producers. Due to price mechanism the economic costs, which are necessary for promotion of each unit of electricity generated from RES (kWh), can be estimated in relative certainty. However, a general disadvantage is - in contrast to mandatory quantity-driven instruments - that neither a minimum penetration of RES capacity nor an upper ceiling in the expansion of RES-E can be guaranteed, so the total amount of RES-E is uncertain. Below, most important price-driven instruments are discussed.

4.3.1.1. Feed-in tariff

In general, feed-in tariffs permit independent producers of RES-E to feed (export) electricity into the grid and to receive therefore a minimum price (the feed-in tariff), usually for a specified period of time. Such tariffs should relate to the long-term marginal generation costs and are set by a regulatory authority.[71] Usually the feed-in tariffs differ between various technologies, depending on the different production costs. One core argument for feed-in tariffs is to reduce the financial risk of independent power producers by guaranteeing them secure revenue over a specified period, e.g. 10 or 15 years.

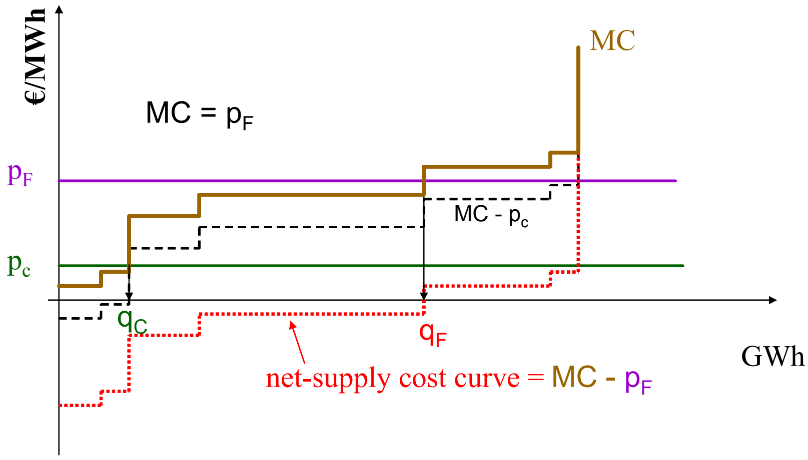


Figure 4.25 Feed-in Tariff

How such schemes encourage individual producers is explained by the following example. Suppose the long-term marginal cost (MC) for a technology is given as in Figure 4.25 (no footnote). Assuming the price for conventional electricity, e.g. on the spot market, is given by p_C. Without a promotional strategy, the amount q_C will be generated. This quantity is characterised by the intersection of p_C with the MC-curve, p_C = MC.[72] If the generator of RES-E receives the feed-in tariff p_F instead of the conventional electricity price p_C, he will try to increase his generation from q_C to q_F. This amount is shown by the intersection of feed-in tariff with the MC-curve (p_F = MC). The same result is given by the intersection of (MC – p_F) with the x-axis, i.e. MC – p_F = 0. (MC – p_F) is the net marginal costs of both producing RES-E and of receiving the feed-in tariff (dotted line).

The amount of electricity generated from RES depends on the height of the feed-in tariff and the guaranteed duration of this payment. If the tariff as well as guaranteed duration is set high enough, the instrument gives a strong incentive to invest in RES.[73] If it is low, only a moderate expansion can be expected.

[71] Nevertheless, feed-in tariffs should also reflect a 'reasonable profit' in order to make it particular attractive to invest.

[72] The same result occurs if the net marginal cost curve – defined as the cost curve after subtracting all net revenues received from subsidies and from selling the conventional electricity on the market (dashed line in Figure 4.25) - intersects the x-axis, i.e. MC – p_C = 0. Every amount on the left hand side of this point yields positive revenue and, thus, will be produced. Every amount on the right hand side of this intersection yields in a net loss and so this amount will not be generated.

[73] Consider, for example, the large proportion of wind energy in Germany, Denmark and, increasingly, Spain due to past and present high feed-in tariffs.

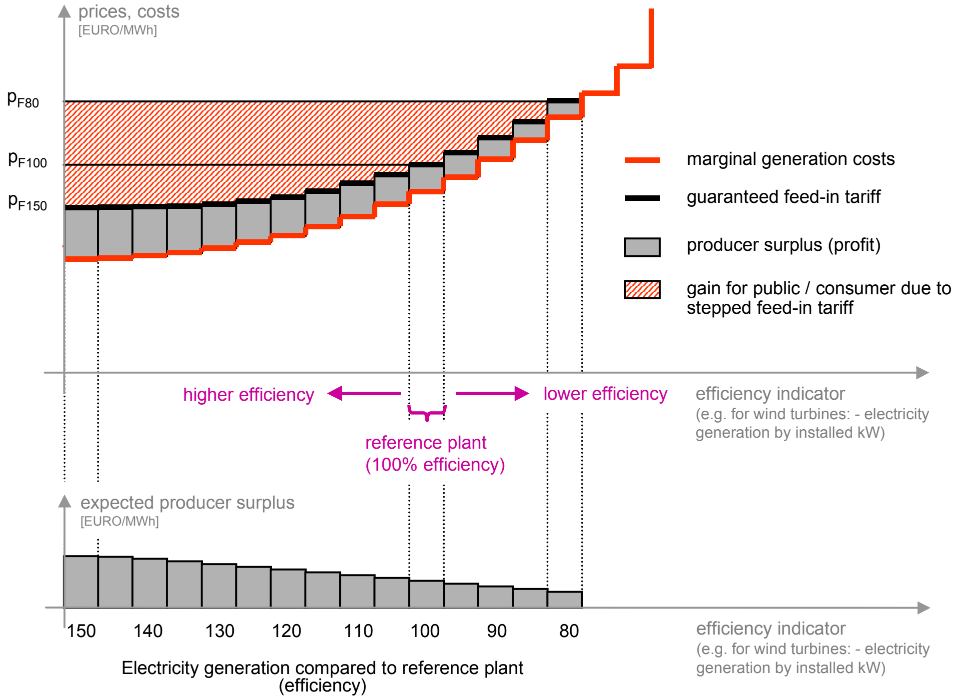


Figure 4.26 Optimal incentive-compatible feed-in system

In the last years a special design of a feed-in tariff has been developed, the so called 'stepped' feed-in tariff. In practise this kind of tariff scheme is used for wind energy in Germany, France and Portugal.

A stepped feed-in tariff is characterised by lower subsides as the actual generation increases. The decline in the guaranteed price, however, must be less than the total revenue that can be gained if an efficient plant and location is chosen, otherwise investors have no incentive to implement the most efficient technologies and locations. This means that profits must be higher at cost efficient locations compared to less efficient ones.[74] The principle of this scheme is depicted in the lower part of Figure 4.26.

Given the fundamental objective of minimising total costs to society, next a stepped feed-in tariff scheme should be analysed in more detail. In Figure 4.26, the public gain is characterised by the hatched line. Under such conditions this scheme is similar to a tendering system, but with the difference that the subsidised price for RES-E is given by the government and not by the market itself. Under the assumption of a 'perfect' market, the feed-in tariffs set by the government will still lead to inefficiency as compared to tendering. Considering, however, strategic bidding and the much higher administration costs of the tendering scheme, a feed-in tariff seems to be the more efficient solution.

One important condition for such a scheme is the measurable and standardised unit or baseline used for differentiation. If the costs for electricity generation are mainly based on the full-load hours, the latter can be such a suitable baseline. In this case, there is less dependence on specific, not standardised, criteria such as fuel costs or the special conditions of the location. Unfortunately, not every renewable energy technology fulfils this constraint.

---

[74] E.g. wind energy: 20% expected profit for locations with 2400 full-load hours and 14% for locations with 1800 expected full-load hours. In the former German feed-in tariff scheme ('Erneuerbare Energien-Gesetz') the incentive compatibility constraint is fulfilled.

- For wind energy this criteria is fulfilled, i.e. a stepped feed-in tariff is easy to implement.
- In the case of biomass, where costs depends on the specific fuel input (bark or wood chips from forest residues) an evaluation of the fuel mix must be made. This causes an increase of the administration costs and hence to a less efficient system. However, in principle, an incentive compatible scheme can be implemented.[75] Similar problems exist with applying this scheme to hydro power, where generation costs depend on full-load hours and investment costs, which both depend on the specific characteristics.

If one major political and societal objective is to promote a homogeneous distribution of a RES technology (e.g. wind plants should not only be located near the shore) the 'stepped' feed-in tariff must be adjusted so the producer's profits from generating electricity is independent of the generation costs, see Figure 4.27.[76] Furthermore, by granting a 'marginal' higher profit if investor choose an efficient plant, a compromise between cost efficiency (and the disadvantage of location hot spots) and homogeneous distribution (and the disadvantage of economic inefficiency) can be adjusted.

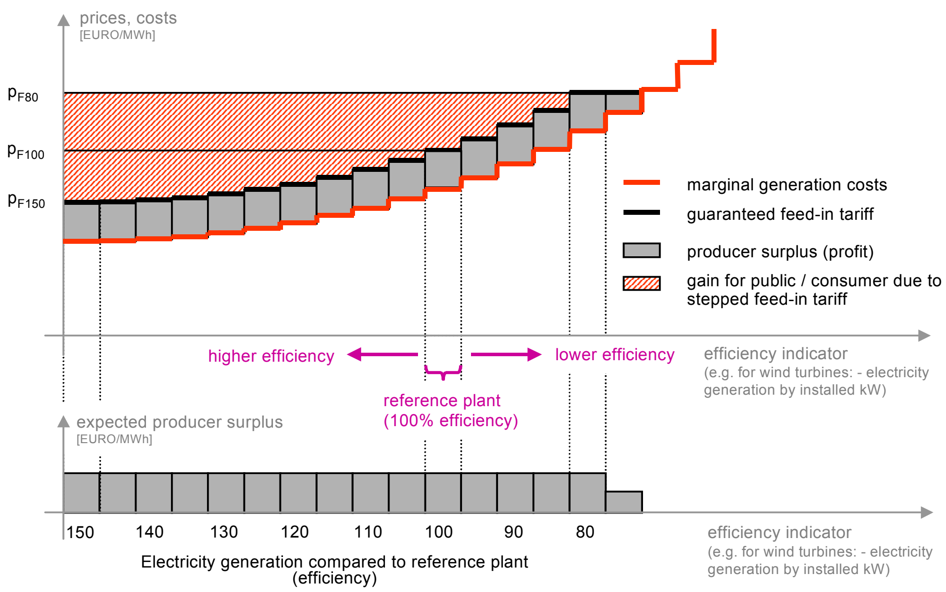


Figure 4.27 Feed-in system creating a homogeneous distribution

In addition, feed-in tariffs are a useful tool to promote a more homogeneous distribution among different technologies by setting technology specific guaranteed tariffs. Implementing such a policy, the long-term technology development of various RES, which are currently not cost-efficient, can be supported. The reason is that due to the application of non-mature technologies a dynamic process can be started (i.e. stimulation of the learning-curve) which could lead to a significant decrease in future generation costs. However, this positive effect of feed-in tariffs must be compensated by economic distortions among the RES. By applying a stepped feed-in tariff, producer surplus

[75] In this case, different feed-in tariffs must be created in parallel, depended on the fuel input.

[76] E.g. wind energy: 12% expected profit for locations with 2400 full-load hours and 12% for locations with 1800 expected full-load hours. Hence, plants will be built on cost efficient and less cost efficient locations to the same amount.

between the technologies can be adjusted in a way that a homogeneous distribution appears.[77]

The influence of a stepped feed-in tariff on the RES-E penetration is depicted in Figure 4.28. As already mentioned, the guaranteed price p_F varies according to the generation costs (low price for high efficient plants) and high tariff in the case of higher generation costs. As the single efficiency indicators are represented by the different band in the model ***Green-X***, for each band an 'individual' feed-in tariff exists. The net-supply cost curve can be derived by subtracting the guaranteed tariff from the marginal generation costs MC – p_F. The producer will generate electricity from those plants (bands) having negative net generation costs. In the case that the stepped feed-in tariff is well designed, all plants (band) on the left of the intersection of the net-supply generation cost curve with the x-axis and MC = p_F and, respectively will be used, see Figure 4.28. If, however, the slope of the tariff is to steep, producer have no incentive to generate electricity from efficient plants.[78] This situation is depicted in Figure 4.29.

Note, in the model ***Green-X*** stepped feed-in tariffs are only applied for wind-energy.

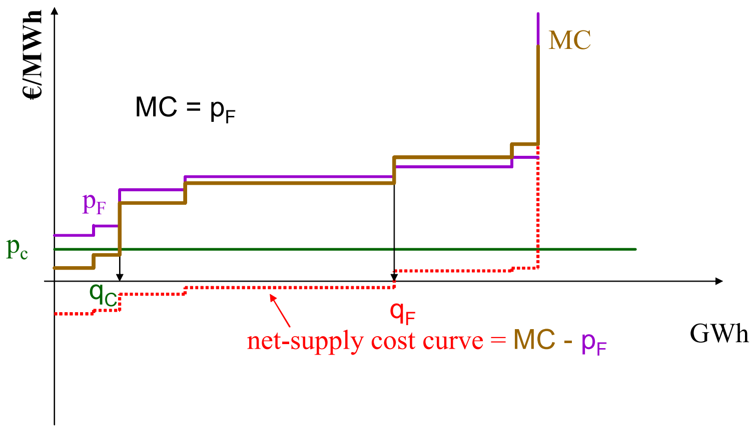


Figure 4.28 Stepped Feed-in Tariff

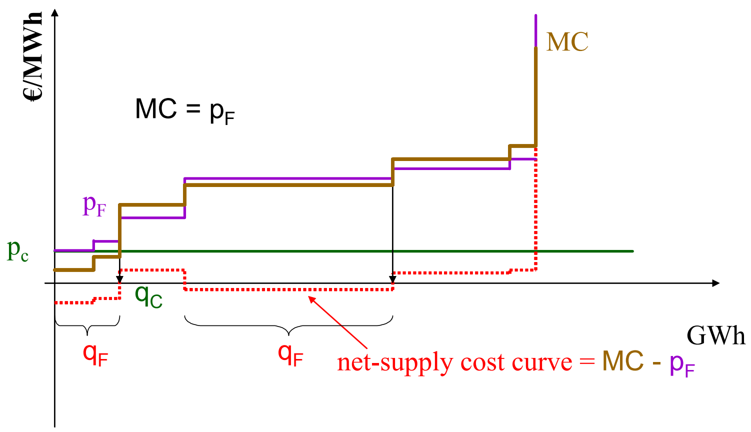


Figure 4.29 Stepped Feed-in Tariff with steep slope

[77] In more detail, the value of the subsidised feed-in tariff depends on the slope of the marginal cost curve of different technologies.

[78] The floor price for a feed-in tariff in one band is limited by the market price p_C.

4.3.1.2. Tax Incentives

Fiscal instruments can be linked in different ways for the promotion of RES-E, e.g.

- exemption of electricity generated from RES from energy taxes (tax relief),
- a decrease in the VAT of rate,
- an exemption (or lower rate) of income or business taxes for capital investments in RES-E technologies,
- introduction (or increase) of an energy tax or CO_2 emission caps for conventional electricity,
  - other tax refunds.

All options improve the competitiveness of electricity generated from RES-E. The first two options affect the amount of electricity generated from RES-E and, by using a tax relief per kWh generated, both new and old RES-E installations benefit. The other options are similar to investment subsidies (see below) and only new installations are affected. In the case of an energy tax (or CO_2 emission-cap) for conventional electricity the benefit to RES-E is indirect due to higher generation costs for electricity generated at conventional power plants. Tax incentives may differ between various technologies for the generation of RES-E or may be homogeneous. In the model ***Green-X*** both of the above mentioned kinds of instruments will be considered, i.e. both generation based (per kWh) and capacity based (per kW installed) tax incentives.

One disadvantage of the latter option and all other promotion strategies which are based on installed capacity instead of electricity generated - as already mentioned - is that in principle it gives no incentive to operate the plant as efficient as possible. The decision of the producer to ensure whether the RES plant is in operation or not depends on the short-term marginal costs of the facility, see left-hand-side of Figure 4.30. In general these costs consist of fuel costs, maintenance costs, wages etc. If these costs are higher than the revenue from the operation of the plant[79] (this can be the case if there are fuel costs, e.g. for biomass) generation of RES-E does not take place. In other words, if the price for conventional electricity is lower than the running costs of the plant, it is rational to produce no electricity. This fact leads to a high inefficiency (at least with respect to the granted subsidy).[80] Hence, promotion instruments based on installed capacity, i.e. per kW, are in general less suitable strategies for the sustained generation of RES-E.[81] If subsidies are based on actual generated electricity, then the situation is quite different (see right-hand-side of Figure 5-18). As the public support diminishes, the short-term net marginal costs of RES-E generation are secured unless much lower prices for conventional electricity occur.

With respect to the optimisation, a tax incentive per kW installed is equivalent to case of investment subsidies per kW. Therefore, for a discussion about the impact of tax incentives per kW see chapter below.

[79] In the case of subsidies per kW, the revenues derive from the sale of the electricity on the conventional electricity market.

[80] For plant with low running costs e.g. wind or hydro plant, this situation is not likely to have an impact, except for example in the case where a break in operation might result in high maintenance costs.

[81] Note: This will not always be the case where the electricity is generated and used on a decentralised basis, e.g. with building integrated PV, a rebate may nevertheless provide an optimal solution.

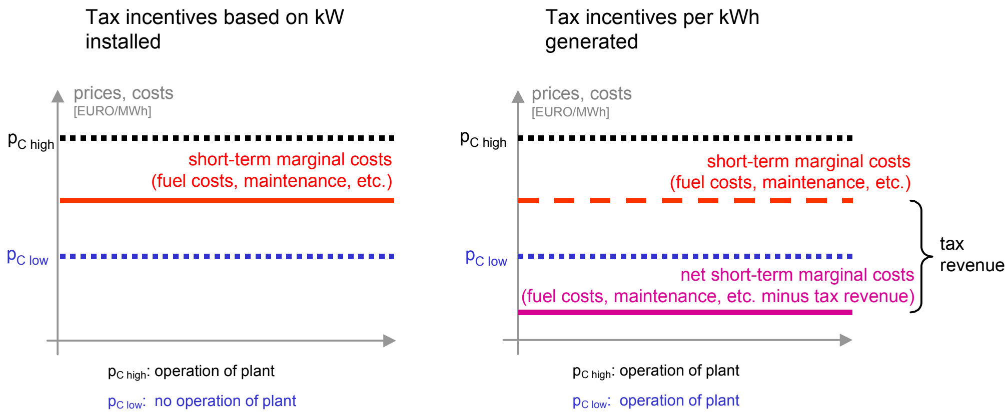


Figure 4.30 Comparison of the effects of subsidies per installed capacity (kW) and per electricity generated (kWh)

What are the results of the individual optimisation assuming a tax incentive per kWh? The initial value without any promotion instrument is given by q_C, i.e. the intersection of the net marginal cost curve (dashed line) with the x-axis; $MC - p_C = 0$. Receiving a tax relief per kWh, p_T, the net marginal cost curve is reduced by the amount of p_T.[82] For producers it is optimal to increase generation of electricity from RES to the amount q_T. At this point net marginal revenue equals zero, $MC - p_C - p_T = 0$.[83] Again, every kWh generated on the left hand side results in (positive) surplus for producers.

The distinction between a feed-in tariff and a tax incentive per kWh electricity output is that in the first case the price fluctuations for conventional electricity are included in the promotion system. This means that risk associated with price uncertainty must not be borne by producer of RES-E. On positive side, in contrast to feed-in regulation, no distortions between independent power producer and utilities exist in the case of a tax incentive.

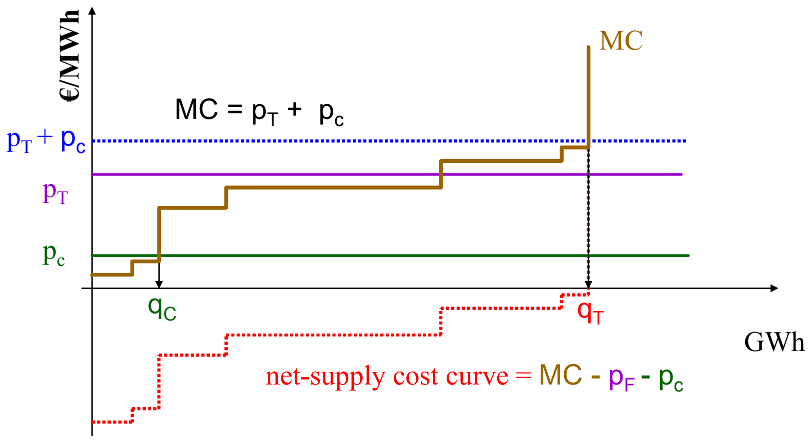


Figure 4.31 Tax Incentive per kWh

[82] The net marginal cost curve is given by the dotted line in Figure 4.31.

[83] In contrast to the case of the feed-in tariff, both revenues p_C and p_T must be considered, because in this case both incomes can be claimed.

4.3.1.3. (Investment) subsidies (per kW)

In the 1990's investment subsidies were a core instrument to increase the penetration of RES-E technologies in many countries. Recently, however, this kind of instrument has become less relevant, except in the promotion of emerging new RES-E technologies on R&D stage.

Subsidies can be granted either per unit of electricity generated or by capacity installed. The case of subsidies per electricity output is (from the optimisations point of view) equivalent to the case of tax incentives (per kWh). For a detailed discussion see chapter before. In the following investment costs granted per installed capacity are analysed.

One advantage of such subsidies is that they can be adjusted with respect to the kind of technology, the generating capacity and the location of installation. Hence, a fine tuned promotional programme for different technologies can be created.[84] One disadvantage – as already mentioned - is that no sufficient incentive can be set to guarantee that the plants remain in operation over total expected lifetime

In the following only the case of investment subsidies per installed capacity will be considered. As all relevant parameter of the optimisation are related to kWh (and not to kW) a conversion is necessary. This means that subsidies per kW must be converted into revenues per electricity generated[85]. The connection between investment subsidy per kW (S_{inst}) from plant i and revenue per kWh ($p_{I\,i}$) is given by equation (4.12), where η_i represent the efficiency, h_i the full-load hours of plant (band) i, and c is a constant.

$$p_{I\,i} = c * S_{inst\,i} / (\eta_i * h_i) \tag{4.12}$$

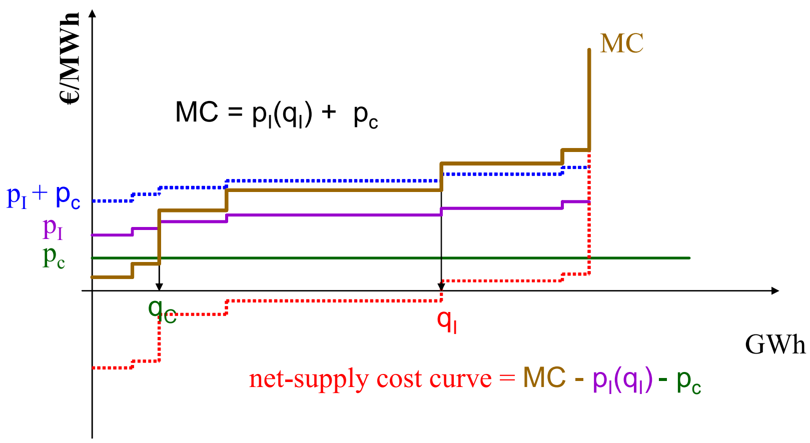


Figure 4.32 Investment Subsidies per kW (converted into kWh)

Assuming fixed investment subsidies per kW, revenues per kWh increase with respect to lower efficiency and less full-load hours. Since these factors, namely lower efficiency and less full-load hours, corresponds to higher marginal generation costs, converted investment subsidies per kWh can be understood as a function of installed capacity, $p_I = f(q_I)$. In general, the curve rises - similar to a stepped feed-in tariff - with respect to

[84] This advantage has been paid by the disadvantage of less economic efficiency and competitive distortions between different technologies.

[85] In the case of a capacity driven instrument (instead of a price driven strategy) a conversion into given electricity output must be made.

a higher amount of capacity installed, see Figure 4.32. The optimal output q_I is given by the intersection of the net marginal cost curve [86] with the x-axis, i.e. $MC - p_C - p_I(q_I) = 0$, and the total revenue from the sale of the electricity with the marginal generation cost curve $p_C - p_I(q_I) = MC$, respectively.

4.3.2. Quantity-driven instruments

As well as having the 'push' of supply-side inducements for more RES-E, there can be 'pull' from the demand-side. Quantity driven instruments are characterised by the fact that the expansion of RES-E is caused by a higher demand. In practice, such specified demand assures at least a minimal amount of RES-E. The disadvantage of this system is - contrary to price-driven instruments - that the price, which must be paid to reach this penetration, is uncertain.

4.3.2.1. Quota System (mandatory)

A mandatory demand may be set by government via quota obligations (i.e. legally enforceable orders to producers for specified amounts of RES-E to be sold) to promote electricity generation from RES. Quota systems usually operate in a liberalised electricity market The main objective of a legally enforceable quota system is to secure the penetration of a pre-defined amount of renewable energy. In general two different approaches exist:

- Non-tradable quotas: Renewable Portfolio Standards and Obligations
- Tradable quotas: Electricity or emissions (e.g. CO_2) based certificates

The advantage of tradable green certificates (TGCs) is to facilitate the fulfilment of the quota obligation, and to increase the economic efficiency of the promotion strategy.

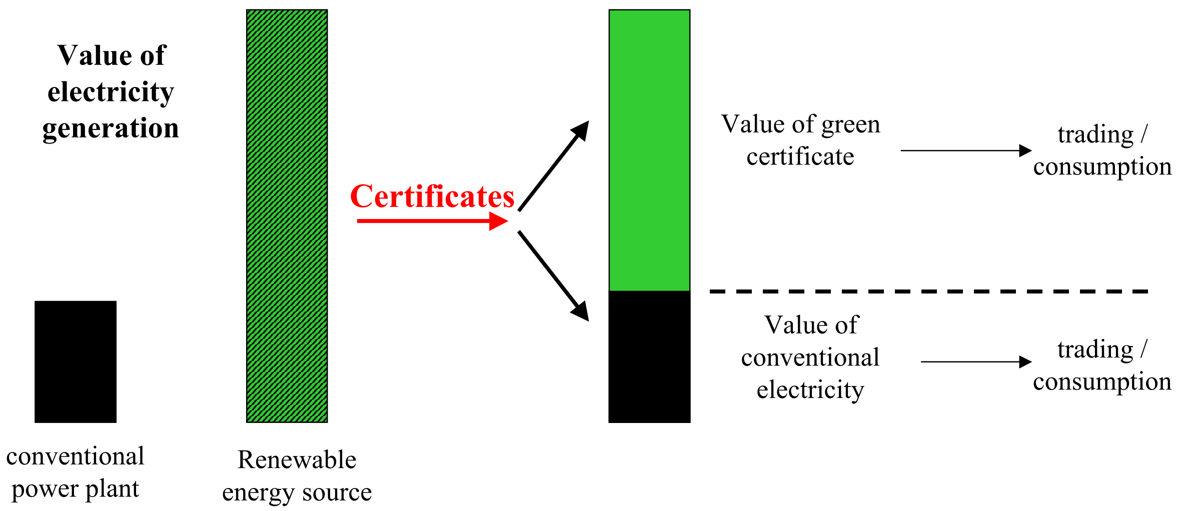


Figure 4.33 Splitting of the value of electricity generated from RES into two part due to the tradable certification system

[86] This cost curve (dotted line) is equal to the marginal costs for generation (MC) minus price for conventional electricity (p_C) minus revenues per kWh due to the investment subsidy (p_I).

A TGC is used to represent the 'added value' or 'greenness' of one pre-defined unit of electricity produced from RES.[87] If only a TGC system operates, each producer of RES-E is producing two goods, see Figure 4.33:

- physical electricity, which is fed into the grid (exported) and sold at market prices for conventional electricity
- TGC, which represent the added value of the 'greenness'

Due to a quota obligation imposed by the government, 'artificial' (inelastic) demands for TGC may be created, see vertical line in Figure 4.34. The obligated bodies can be any of the 'actors' in the electricity chain, namely generators, transmission or distribution companies, brokers, suppliers or consumers. To fulfil the obligation, each obligated actor may be allowed to either himself produce RES-E or buy TGCs.

Despite the advantage of tradable quotas non-tradable quotas can also be considered in the model ***Green-X*** under the following assumption

- allocation of the obligation is set that the fulfilment can be reached by actors own effort, or
- market transparency is high that bilateral trade between major RES-E producer and obliged actors is feasible.[88]

In addition, a quota obligation can be imposed for one (RES-E) technology – this was e.g. the case for small scale hydro power in Austria – or for a group of technologies. In this case the share of all in the basket included technologies can be chosen according to economic (and political) considerations, i.e. just the total amount (or percentage value) of all technologies is determined by the quota.

Single Quota

Optimisation within a single quota system is depicted in Figure 4.34. As already mentioned, two goods will be supplied; conventional electricity and TGCs. If the revenue from selling physical electricity into the grid is subtracted from the marginal costs of electricity generation, the marginal cost curve for providing TGC can be determined, i.e. the dashed line MC – p_C.[89] The total demand for TGCs is given by the quota obligation q_Q. In Figure 4.34 this demand is represented by $WTP_{\Delta Q}$. The inelastic demand, characterised by the vertical line, can be interpreted as follows: obliged actors are willing to pay a high amount for each TGC below the quota obligation q_Q, because they have to fulfil the quota. (The limit is in fact the 'fine' or 'penalty' paid for non-compliance; such a 'fine' becomes a price cap; see below). If, however, the obligated actors hold more TGCs than necessary to fulfil the mandatory obligation, nobody demands additional TGCs, and, thus, the price for TGC drops to zero.[90]

---

[87] For details see e.g. (Huber, 2000).

[88] In the case that both assumptions are fulfilled the same result occurs that introducing a TGC system, neglecting transparency costs.

[89] An important assumption for any TGC system in this connection - also assumed in the model ***Green-X*** - is that every generator of RES-E has the possibility to sell his electricity by feeding it into the grid. This means that a non-discriminating access to the system is guaranteed.

[90] In this static consideration, banking and borrowing of TGCs can not be taken into account. However, if the opportunity of banking and borrowing is possible, the demand curve would be more flat, i.e. $WTP_{\Delta Q}$ decreases in response to a higher number of TGCs in the market. Details with respect to banking and borrowing are discussed in (Huber, 2000).

In the optimum, the price for TGCs, p_Q, and the offered amount, q_Q; are given by the intersection of the net supply curve for TGCs, MC – p_C, and the demand curve for TGCs, $WTP_{\Delta Q}$. Due to the inelasticity in demand the offered amount of TGC_S is equivalent to the quota obligation. The marginal generation costs for electricity generated from RES are - according the supply of two goods - equivalent to the price for conventional electricity plus the price for TGCs, MC = p_C + p_Q.

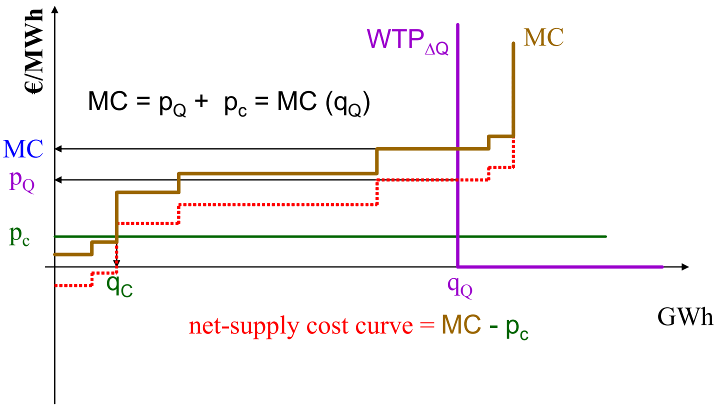


Figure 4.34 Quota System

Quota for more technologies

A methodological distinction between a single quota and a quota for more technologies is necessary if in addition to the quantity driven instrument price driven strategies for single technologies exist. In the following such a case is described.

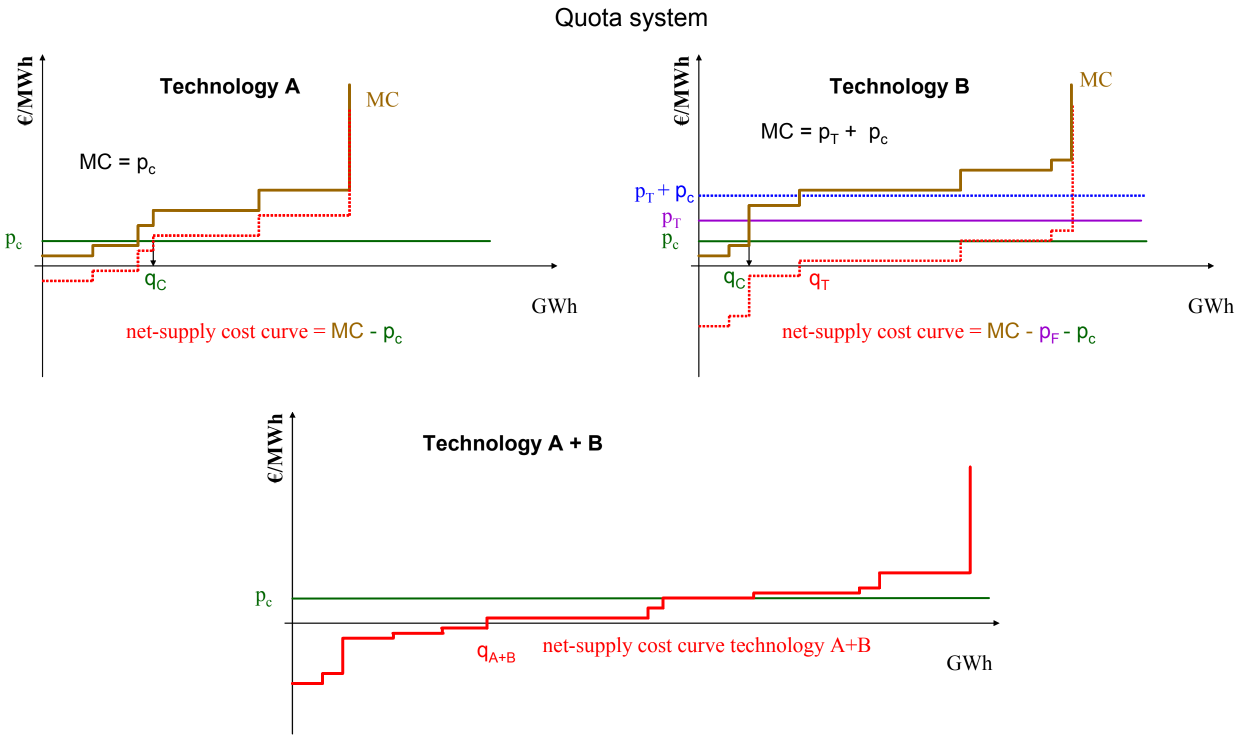


Figure 4.35 Determination of common net supply curve for technologies A and B under the assumption of no additional strategy for technology A and a tax incentive per kWh (p_T) for technology B.

In a first step the net-supply cost curves for those technologies (which are permitted to generate TGCs for fulfilling the quota obligation and / or green pricing activity) must be determined for each technology. This formal procedure is depicted in the upper part of Figure 4.35, for this graphical example for technology A a tax relief is granted in addition to the quota system. Next, the net marginal supply curve for all permitted technologies must be determined. This can be managed by horizontal addition of the single net supply curves, see lower part of Figure 4.35.

The price for TGCs, p_Q, can be determined at the intersection of the net marginal supply curve for all considered technologies with the demand curve, see upper part of Figure 4.36. Knowing the market price for TGC, in a third step, the intersection of p_Q with the net marginal supply cost curve of each permitted yields the quantity of electricity production per technology in each country. This step is depicted in the lower part of Figure 4.36.

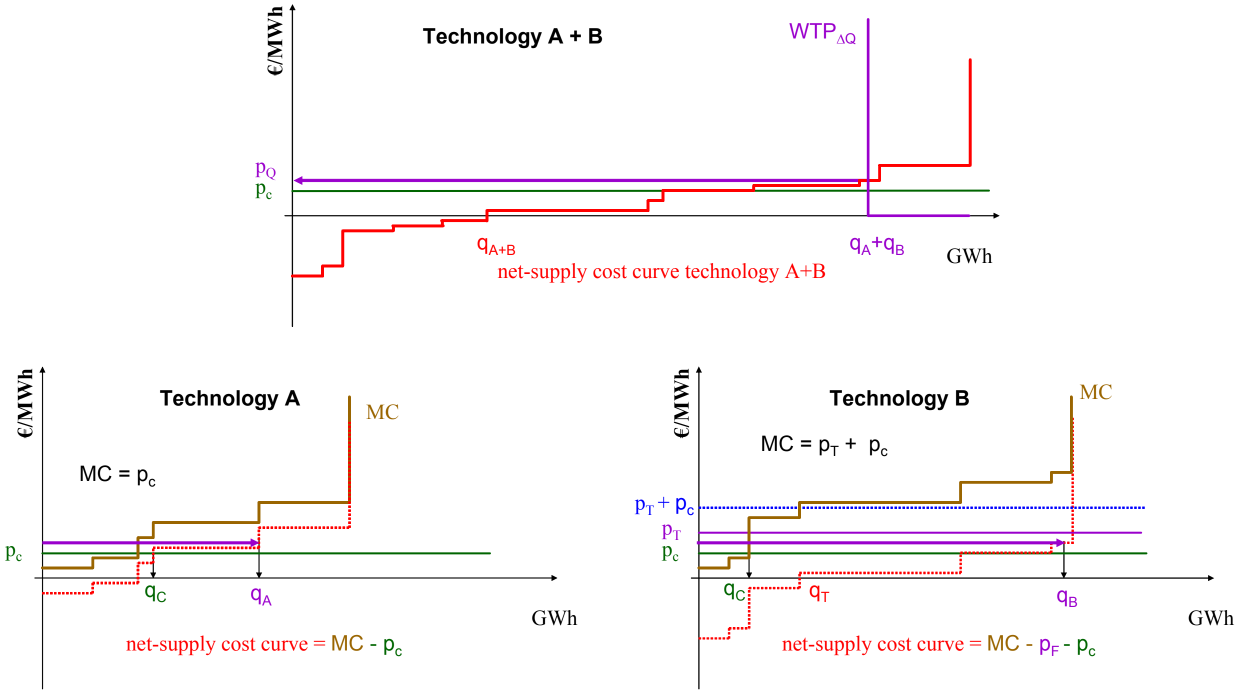


Figure 4.36 Development of total electricity generation for all considered technologies included in the quota obligation; under the assumption of no additional strategy for technology A and a tax incentive per kWh (p_T) for technology B.

Penalty

In practice, at least as long as the market for TGC is not mature, a ceiling price for TGC will be set. This maximum price can be interpreted as penalty per kWh in the case of non fulfilment of the quota obligation. How the optimisation looks like under this restriction is shown in Figure 4.37.

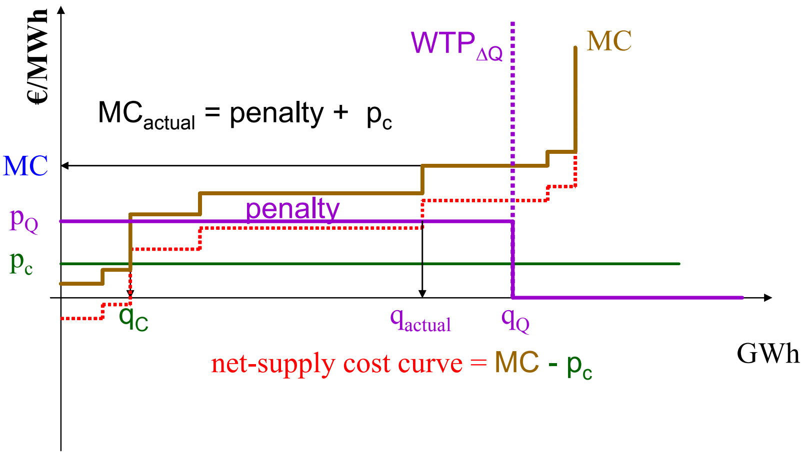


Figure 4.37 Quota System with price cap (penalty)

If the penalty, however, is set too low[91], obligated actors are not willing to fulfil the quota obligation, because it is cheaper to pay the penalty than the higher price for the TGCs p'_Q. Thus, the upper price for TGCs is restricted by the penalty, p_Q = penalty. The intersection of the penalty (which can be interpreted as new demand curve in the range $q \in [0, q_Q]$) with the supply curve for TGCs, yields the actual level of electricity generated due to the quota obligation, q_{actual}. Summing up, the actual price as well as the amount of electricity generated can be influenced by setting a price cap for TGCs.

4.3.2.2. Green pricing (voluntary)

Voluntary approaches are based on the 'willingness to pay (WTP)' of private individuals, and commercial or industrial companies, compare section 2.4. Voluntary demand might come from

- consumers who are willing to pay higher prices for electricity generated from RES (green tariff),
- the government itself, which may, furthermore, organise tenders for TGC on a regular basis or
- the possibility that government or another actor may buy TGCs to secure a fixed minimum price.

Nowadays 'green pricing' is the most common voluntary instrument to promote electricity from RES. Thus, in the following the mechanism behind this type of instrument is analysed.

Consumers can choose to buy either electricity at a utility 'green tariff', or from a 'green' electricity supplier. Of course, this option is just feasible if the customer is eligible, which will be assumed in the model. Usually the core feature of this promotional instrument is that participants are willingly to pay a premium price per kWh above the regular tariff rate. The extra payments to the suppliers are passed to the renewable electricity generators to meet extra costs of generation. Currently, the customers willingness to pay for green electricity differs from country to country in Europe and is influenced by a

[91] This is the case, if the resulting price for TGCs without a price ceiling is higher than the implemented ceiling price, p'_Q < penalty in Figure 4.37.

number of factors which primarily reflect consumer environmental awareness and the specific market conditions like the degree of market opening. Due to the voluntary nature of the system, and in contrast to TGC, 'green labels'[92] need not necessarily be harmonised or standardised. Nevertheless, a jointly agreed EU labelling system[93] would lead to greater transparency and thereby greater confidence for customers.

In the model, a linear decreasing demand curve for 'green pricing' is assumed, represented by $WTP_{\Delta GP}$ in Figure 4.38. This means that few customers are willing to pay a high premium price for 'green' electricity and that more participants accept lower additional costs. In addition, in the model it has been assumed that the willingness to pay curve is never negative. This can be interpreted as the improbability of anyone paying higher costs for conventional electricity than electricity generated from RES.[94]

The marginal costs with a premium green tariff are given by the marginal generation costs minus the revenue received from selling conventional electricity, $MC - p_C$ (dotted line in Figure 4.38). The demand curve is given by WTP for 'green pricing', $WTP_{\Delta GP}$. The intersection of supply and demand yields the premium price for electricity generated from RES, p_{GP}, and the corresponding demand, q_{GP}.

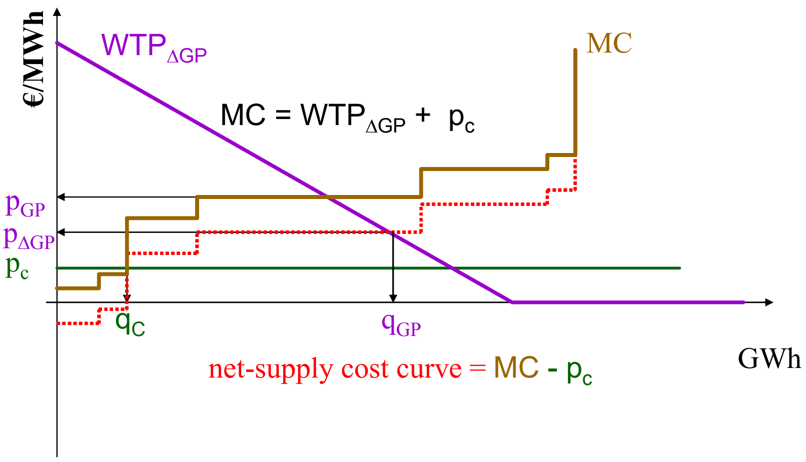


Figure 4.38 Green Pricing

---

92 'Green labels' are being used in several European countries to accredit green tariffs. They provide consumers with reassurance that the accredited tariffs do indeed utilise renewable energy and have beneficial environmental impact. Markets with a 'Green label' often witnessed a higher level of consumer uptake, than those without such a system in place. This indicates the fact that consumers need confirmation and a guarantee that the electricity they purchase (for a higher price) comes from RES.

93 Article 5 of the 'RES-E Directive' (European Parliament and Council, 2001) refers to the labelling of renewable energy generation sources, so that for example it can be assured that renewables are not sold twice. Such a system should be implemented within the next two years in all EU Member States. Nevertheless, it does not call for a labelling system on supply. For more details see (White et al., 2003).

94 Most customers are indifferent to secure of electricity, i.e. the premium price equals zero.

5. Database on dynamic cost-resource curves for RES-E in EU-15 countries

For electricity generation a broad set of different technologies based on RES exist today. Obviously, for a comprehensive investigation of the future development of RES-E it is of crucial importance to provide a detailed investigation of the country-specific situation – e.g. with respect to the potential of the certain RES in general as well as their regional distribution and the according costs of electricity generation.

The data as presented in this chapter aims to fulfil above mentioned constraints. It has been derived initially in 2001 based on a detailed literature survey and a development of an overall methodology with respect to the assessment of specific resource conditions of several RES-E options. In the following, comprehensive revisions and updates have been undertaken, taking into account reviews of national experts etc.. The finally derived data fits to the requirements of the model ***Green-X*** as described in the previous chapter and includes besides potentials and costs from a static point-of-view, both forming so-called static cost-resource curves, data as required for the description of dynamic aspects. Geographically it refers to the EU-15, containing data for RES-E divided into 11 categories (with in total 17 sub-categories) on country-level.

For a better illustration of the derived data, initially potential- and economic-data is presented separately: First, an overview on the derived data with respect to potentials for RES-E is given, followed by a RES-E specific description of the applied approach with respect to the data assessment. Next, the according economic data for RES-E (i.e. investment and O&M costs, resulting generation costs) is depicted. Later on, the development of static cost-resource curves is illustrated and finally, data referring to dynamic aspects is described.

General remarks:

► (Additional) realisable mid-term potential

Indicated future potentials represent (additional) *realisable mid-term potentials*. According to the categorisation as depicted in the formal framework of the model ***Green-X***, see section 4.2.4, this potential term refers to *'the maximal (additionally) achievable potential in the year 2020 assuming that all existing barriers can be overcome and all driving forces are active'*. It represents the upper boundary of that what can be realised for a certain RES-E category on country level – where only maximal market growth rates and planning constrains act as restriction.[95]

► Calculation of costs of electricity

In the model ***Green-X*** the calculation of electricity generation costs for the various generation options is done by a rather complex mechanism as described in the sections 4.2.3 and 4.3, respectively, internalized within the overall set of modelling

[95] But it has to be mentioned, that future potentials as presented in the following represent the perspective as gained at the starting point of the simulations (2002). Efficiency improvements or up-scaling as in case of wind energy is not taken into account, as such aspects are calculated endogenously in a model run. Accordingly, a slight increase of the future potentials can occur – depending on the applied dynamic settings.

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. The later parameters depend on a set of user input data as policy instrument settings, etc. Nevertheless, for a better illustration of the data presented in the following, marginal electricity generation costs are exemplarily depicted. Thereby, for long-run marginal generation costs (as applied for new plant) a default capital recovery factor is used – based on the following settings:

- Weighted average cost of capital (WACC): 6.5%
- Pay-back time PT: 15 years

► Cost-data with respect to CHP-plant

In case of CHP, investments costs, etc. refer only to the power plant – i.e. costs for district heating network are not included. Hence, the assumed heat price in default size of 20 €/MWh must be seen as price according to the defined hand-over point. It indicates the additional revenue for the power producer due to the selling of heat, but, of course, does not indicate the final consumer price for heat.

5.1. Potentials for RES-E

The following depiction aims to illustrate to what extend renewable energy sources may contribute in the electricity sector within the EU-15 up to the mid-term (i.e. the year 2020) by considering the specific resource conditions in the investigated countries. Indicated potentials for RES-E refer to the cost-resource curve-database of the model ***Green-X***. As explained before[96], *realisable mid-term potentials* are derived. Thereby, in accordance with the general approach, a clear distinction between existing RES-E plant installed up to the end of 2001 – i.e. the *achieved potential* (2001)– and new RES-E options – the *additional mid-term potential* (up to 2020) – is undertaken.

5.1.1. Overview on derived potentials for RES-E

RES-E such as hydropower or wind energy represent 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-E is translated into electricity generation potentials[97] – the *achieved potential* at the end of 2001. This data was derived in a comprehensive data-collection – based on (Eurostat, 2003), (IEA, 2003) and statistical information gained on national level.[98]

---

[96] See *general remarks* (above) for a concise definition or visit section 4.2.4 for a brief explanation.

[97] The *electricity generation potential* with respect to existing plant represents the output potential of all plants installed up to the end of 2001. Of course, figures for actual generation and generation potentials differ in most cases – due to the fact that in contrast to the actual data, potential figures represent, e.g. in case of hydropower, the normal hydrological conditions, and furthermore, not all plants are installed at the beginning of each year.

[98] Thereby, each band of the database for existing plant represents the generation potential of past annual installations within a country. In principle, it contains a set of information on costs (investment costs, O&M costs), potential (generation, full load-hours) and, of course, the construction year (derived by linking of time-series for annual installations – described by their electricity generation potential and the according capacity – with time-series for costs).

In addition, *future* potentials – the *additional realisable mid-term potentials* up to 2020 - were assessed[99] taking into account the country-specific situation as well as overall realisation constraints.

Figure 5.1 provides an overview on the different RES-E options available in EU-15 countries. Thereby, the already achieved potential at the end of 2001 and the additional realisable mid-term potential (up to 2020) are indicated by country (left) as well as by RES-E category (right). In total EU-15 the already achieved potential for RES-E equals 386 TWh, whereas the additional mid-term potential amounts to 1078 TWh. Hydropower represents the currently dominant but also already most exploited renewable energy source within Europe. The largest future potential is found in the sector of wind energy followed by solid biomass and biogas – but promising future options also include tidal and wave or solar thermal energy.

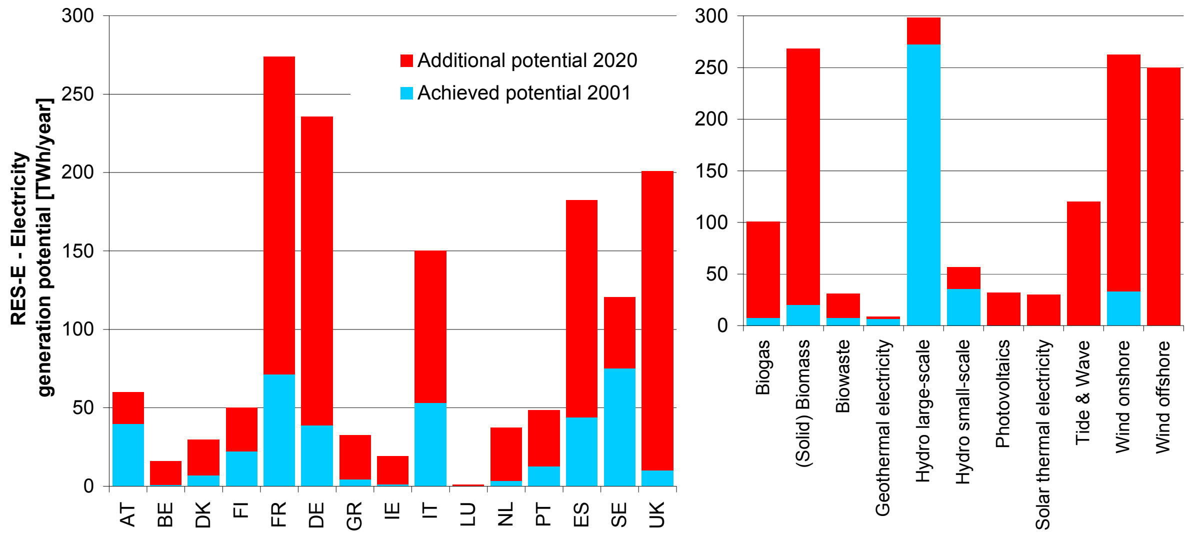


Figure 5.1 *Achieved (2001) and additional realisable mid-term potentials (2020) for* RES-E in the EU-15 – by country (left) and by RES-E category (right)

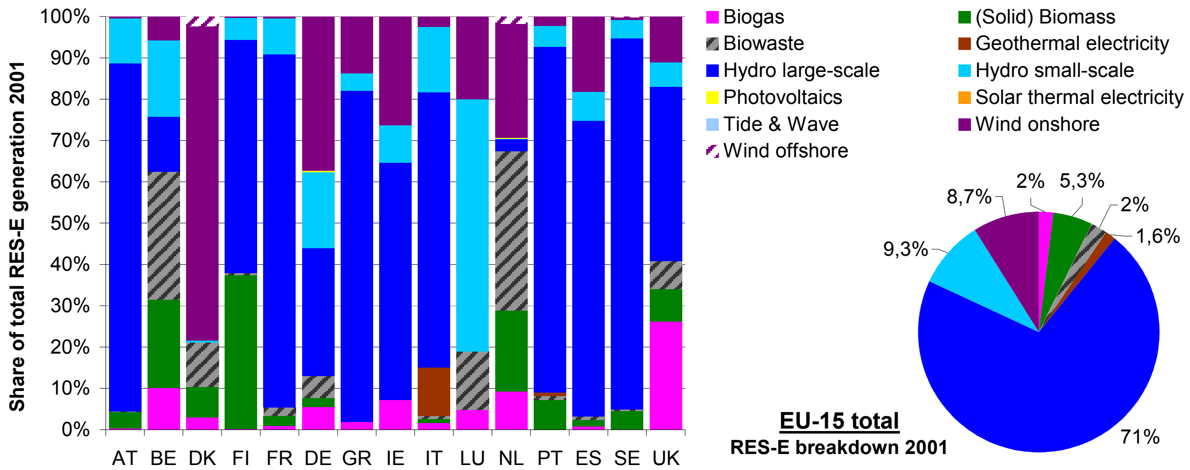


Figure 5.2 *RES-E as a share of the total achieved potential in 2001 for EU-15 countries*

[99] A brief description of the potential assessment is given in the following sub-sections for each RES-E category separately.

The country-specific situation with respect to the achieved as well as the additional realisable mid-term potential of available RES-E options is depicted in the following figures: Figure 5.2 indicates the share of the various RES-E in the *achieved* potential (as of 2001) for each EU-15 country. Again, it gets evident that (large-scale) hydropower dominates current RES-E generation in most EU-15 countries. However, for countries like Belgium, Denmark or the Netherlands – all characterised by rather poor hydro resources – wind, biomass or biowaste are in a leading position.

Figure 5.3 shows the share of different energy sources in the *additional* mid-term potential for RES-E in EU-15 countries up to 2020. On EU-15 level the largest potential is found in the sector of wind energy (44%) followed by solid biomass (24%), biogas (9%) as well as promising future options such as tidal & wave (11%) or solar thermal energy (3%). Obviously, in some countries a different ranking occurs: In a midland like Austria, where no marine resources are available, also (small-scale) hydropower represents a promising option. In contrast, for islands as United Kingdom and Ireland, tide & wave holds a huge potential. The largest wind offshore potential – in relative terms – can be found in the Netherlands, a country characterised by a high population density and accordingly little available wasteland or agricultural area suitable for energy purposes. In southern Europe solar electricity – i.e. PV and solar thermal electricity – represent a promising resource.

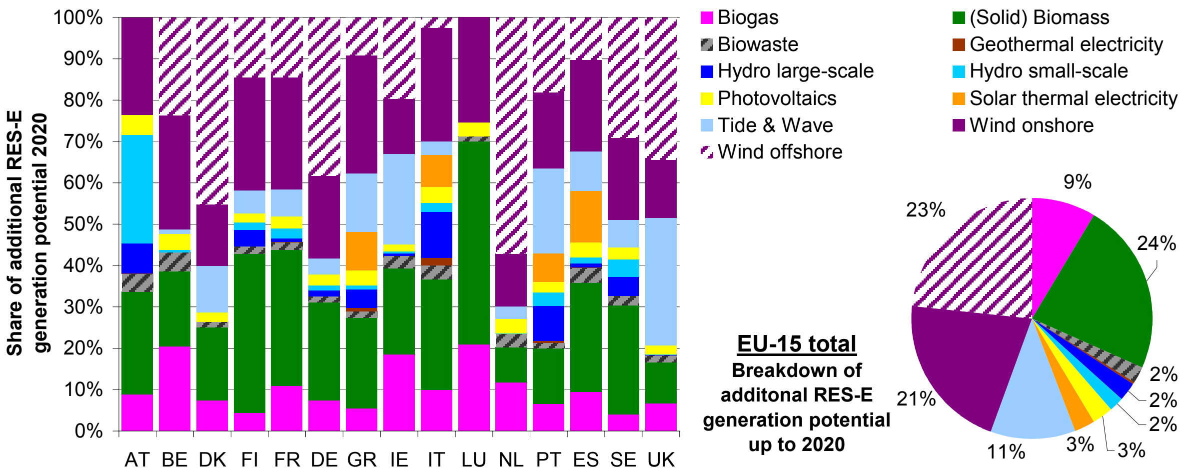


Figure 5.3 RES-E as a share of the total additional realisable potential in 2020 for EU-15 countries

Figure 5.4 relates derived potentials to gross electricity demand. More precisely, it depicts the achieved (2001) and the total realisable mid-term potentials (2020) for RES-E as share of gross electricity demand in 2001 and 2020 – for all EU-15 countries as well as the EU-15 in total. The impact of the expected demand increase[100] is crucial: If the indicated realisable mid-term potential for RES-E, covering all RES-E options, would be fully exploited up to 2020, only 42% of gross consumption could be covered, if the demand will increase as expected under 'business as usual' conditions. In contrast, if a demand stabilisation could be achieved, RES-E may contribute to meet about 55% of total demand.

Finally, Table 5.1 provides a comprehensive overview on the derived potential data – listing achieved and future potentials by country and RES-E category.

[100] Demand figures for 2020 are taken from DG TREN's BAU-forecast (Mantzos et al., 2003a).

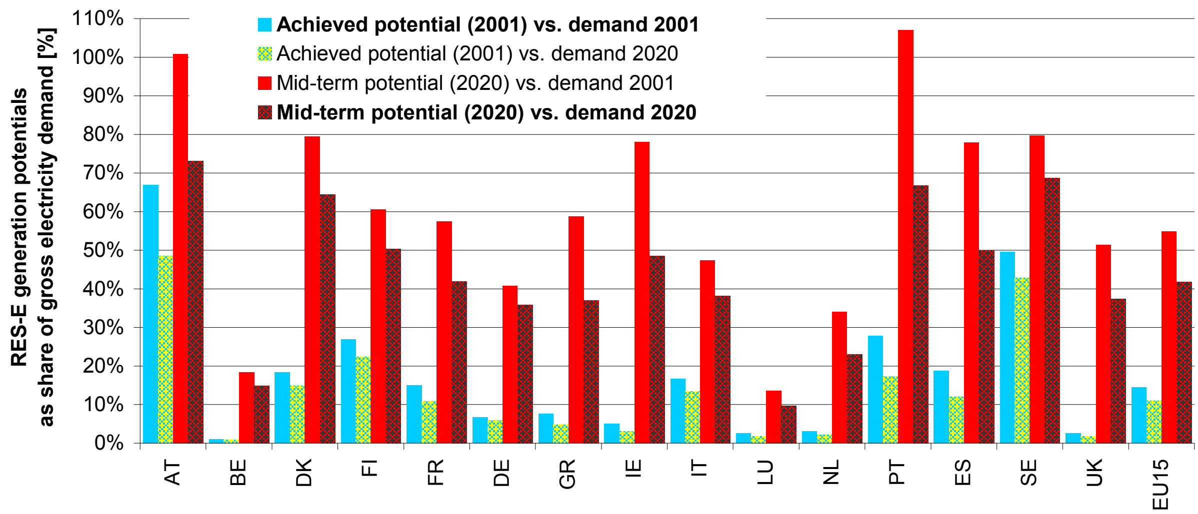


Figure 5.4 *Achieved (2001) and total realisable mid-term potentials (2020) for RES-E in EU-15 countries as share of gross electricity demand (2001 & 2020)*
Note: Demand figures taken from (Mantzos et al., 2003a)

Table 5.1 *Overview on electricity generation potentials for RES-E in the EU-15*

RES-E - Electricity generation potentials		**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)**
Gross electricity demand 2001	TWh	59.6	87.8	37.2	82.8	476.7	576.8	55.4	24.7	317.2	6.4	110.0	45.3	234.1	151.1	391.1	**2656.2**
Gross electricity demand 2020	TWh	82.2	107.6	45.8	99.4	654.2	656.7	87.9	39.7	393.0	9.1	161.8	72.6	365.3	175.2	538.0	**3488.4**
Achieved potential (2001)																	
Biogas	TWh	0.11	0.10	0.21	0.03	0.60	2.12	0.08	0.09	0.84	0.01	0.33	0.00	0.35	0.10	2.68	**7.65**
(Solid) Biomass	TWh	1.64	0.21	0.51	8.33	1.76	0.89	0.00	0.00	0.53	0.00	0.69	0.91	0.74	3.38	0.81	**20.40**
Biowaste	TWh	0.03	0.31	0.73	0.10	1.44	2.03	0.00	0.00	0.42	0.02	1.35	0.12	0.32	0.18	0.67	**7.71**
Geothermal electricity	TWh	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	6.17	0.00	0.00	0.10	0.00	0.00	0.00	**6.30**
Hydro large-scale	TWh	33.59	0.13	0.00	12.62	60.94	11.96	3.41	0.72	35.25	0.00	0.10	10.56	31.49	67.36	4.34	**272.46**
Hydro small-scale	TWh	4.34	0.18	0.03	1.18	6.22	7.13	0.18	0.11	8.43	0.10	0.00	0.65	3.09	3.37	0.59	**35.60**
Photovoltaics	TWh	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	**0.17**
Solar thermal electricity	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Tide & Wave	TWh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Wind onshore	TWh	0.17	0.06	5.20	0.07	0.30	14.44	0.58	0.33	1.29	0.03	0.97	0.28	7.99	0.51	1.14	**33.36**
Wind offshore	TWh	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.08	0.00	**0.29**
RES-E TOTAL	**TWh**	**39.88**	**1.00**	**6.82**	**22.33**	**71.28**	**38.70**	**4.25**	**1.26**	**52.94**	**0.16**	**3.50**	**12.62**	**43.97**	**74.99**	**10.24**	**383.94**
RES-E as share of gross electricity demand 2001	%	67.0%	1.1%	18.3%	27.0%	15.0%	6.7%	7.7%	5.1%	16.7%	2.6%	3.2%	27.9%	18.8%	49.6%	2.6%	**14.5%**
RES-E as share of gross electricity demand 2020	%	48.5%	0.9%	14.9%	22.5%	10.9%	5.9%	4.8%	3.2%	13.5%	1.8%	2.2%	17.4%	12.0%	42.8%	1.9%	**11.0%**
Additional realisable potential (up to 2020)																	
Biogas	TWh	1.79	3.08	1.69	1.23	22.26	14.61	1.55	3.32	9.72	0.15	3.99	2.31	12.93	1.77	12.73	**93.13**
(Solid) Biomass	TWh	5.02	2.74	4.01	10.68	66.68	46.77	6.22	3.76	26.04	0.35	2.87	4.85	36.67	12.08	19.06	**247.81**
Biowaste	TWh	0.87	0.70	0.30	0.48	3.59	2.73	0.44	0.54	3.18	0.01	1.08	0.45	5.00	1.02	3.09	**23.47**
Geothermal electricity	TWh	0.01	0.00	0.00	0.00	0.16	0.00	0.22	0.00	1.72	0.00	0.00	0.19	0.09	0.00	0.00	**2.39**
Hydro large-scale	TWh	1.46	0.00	0.00	1.11	1.83	2.83	1.28	0.10	10.83	0.00	0.00	3.07	1.27	2.11	0.13	**26.01**
Hydro small-scale	TWh	5.31	0.09	0.00	0.51	4.83	2.23	0.24	0.11	2.15	0.00	0.05	1.13	2.00	1.96	0.22	**20.82**
Photovoltaics	TWh	0.98	0.58	0.50	0.60	5.91	5.32	1.04	0.31	3.70	0.02	1.19	0.96	5.13	1.29	4.32	**31.86**
Solar thermal electricity	TWh	0.00	0.00	0.00	0.00	0.00	0.00	2.63	0.00	7.62	0.00	0.00	2.42	17.21	0.00	0.00	**29.88**
Tide & Wave	TWh	0.00	0.15	2.58	1.54	13.16	7.73	4.01	3.93	3.22	0.00	1.03	7.40	13.23	3.01	58.90	**119.88**
Wind onshore	TWh	4.75	4.17	3.38	7.61	54.99	39.26	8.09	2.41	26.73	0.18	4.32	6.61	30.63	9.07	26.81	**229.03**
Wind offshore	TWh	0.00	3.57	10.25	4.02	29.30	75.25	2.58	3.53	2.35	0.00	19.38	6.46	14.15	13.26	65.60	**249.69**
RES-E TOTAL	**TWh**	**20.19**	**15.09**	**22.71**	**27.79**	**202.70**	**196.72**	**28.30**	**18.01**	**97.27**	**0.71**	**33.91**	**35.85**	**138.32**	**45.57**	**190.86**	**1073.99**
RES-E as share of gross electricity demand 2001	%	33.9%	17.2%	61.0%	33.6%	42.5%	34.1%	51.0%	73.0%	30.7%	11.1%	30.8%	79.1%	59.1%	30.2%	48.8%	**40.4%**
RES-E as share of gross electricity demand 2020	%	24.6%	14.0%	49.6%	27.9%	31.0%	30.0%	32.2%	45.3%	24.8%	7.8%	20.9%	49.4%	37.9%	26.0%	35.5%	**30.8%**

5.1.2. Assessment of the RES-E potentials

The applied approach for the assessment of the future potentials (as presented before) is briefly described now. As in general a resource-specific methodology was developed, explanations are given for each RES-E option separately.

5.1.2.1. Biogas

► Definition and characteristics

The RES-E category biogas comprises the following subcategories:

- **Agricultural biogas:** This resource results from an anaerobic digestion process of biological deposits, covering the following primary fuels:
  - Farm slurries,
  - Agricultural residues (e.g. from sugar beet production),
  - Residues from pasture land; and
  - Separately collected biodegradable fractions of municipal waste.
- **Landfill gas:** The primary resource for this energy carrier is (the biodegradable fraction of) waste, deposited on landfill sites. Hence, recent developments regarding waste treatment regulations as e.g. given by the EU-directive on the landfill of waste (European Parliament and Council, 1999) highly influence the future potential of this energy source.
- **Sewage gas:** As primary resource waste water or sewage, respectively, processed and refined in sewage purification plant, occurs.

In general, biogas is a result of a natural decomposition process: The biodegradable decomposition of organic substances comprises the conversion of high-molecular organic bonds (fats, carbohydrates, etc.) under absence of oxygen into low-molecular compounds. This process includes the production of a mixed gas, so called biogas, consisting of:

- 55 - 70% methane (CH_4);
- 23 – 38% carbon dioxide (CO_2);
- various other trace elements.

The energetic content of biogas is directly linked to the methane content. From an ecologic point-of-view – especially due to the high percentage of methane – the energetic use of this climate damaging side-product is highly welcomed. Per molecule, CH_4 is about 6 to 10 times more damaging than CO_2.To illustrate the global relevance: 280 Mio tonnes of biogas are currently produced in paddy fields year by year, a similar amount comes from livestock farming.

In principle, three possibilities exist for utilisation as energy supply:

- Due to the often lacking demand for heat it can be used for (pure) power generation;
- Hence, if possible the combined heat and power (CHP) would be the preferable option; or
- Biogas can be refined and fed as a substitute for natural gas into the grid for gas.

With respect to electricity generation it is important to mention that there is no seasonal dependence as e.g. for hydropower, in principle, the generator can decide, when to start or stop production. Therefore, biogas represents a non-fluctuating energy source for electricity generation, if ambient seasonal temperatures are neglected (as summer production is more than winter).

► (Additional) mid-term potential

The approach for the assessment of the electricity generation potential of biogas was as follows:

1. First, an assessment of the mid-term primary energy potential[101] has been undertaken.
2. Next, country-specific achieved potentials, i.e. referring to existing plants, to be in terms of primary energy was subtracted from the overall mid-term potentials
3. Finally, electricity potentials were calculated by linking of plant-specific conversion efficiencies (about 26% on average – depending on plant size and sub-category) to the primary potentials derived above.

Based on this primary energy potential assessment, the potential for electricity from agricultural biogas is calculated by applying an average gas energy content of 21.6 and an electrical conversion efficiency of 26%. Note that biogas production should be near the source of the feed material of waste products. In general, both options as relevant for power generation have been considered – CHP vs. pure power production. Thereby, in case of landfill gas, due to the lack of heat consumers on-site, the option of CHP has been neglected in some countries.

In the following, the approach for the derivation of the *primary potential* figures is explained in more detail for each subcategory separately.

- **Agricultural biogas:** In principle, four different fuel categories are considered:
  - Farm slurries: Based on country-specific statistical agricultural data (Eurostat, 2002a), i.e. livestock of cows, swine and poultry by country, biogas production is calculated by applying typical values for the specific amount of excrements and related biogas produced. Obviously the technical potential of biogas from farm slurries depends on the number of total livestock. Therefore, to calculate the mid-term potential, country-specific shares of availability of the different slurries are applied.
  - Agricultural residues: The cultivation of a set of plants as used in agriculture (e.g. sugar beet) produces a large amount of residues for digestion. Agricultural statistics (taken from (Eurostat, 2002a)) are used to estimate the biogas potential. In this context, it is assumed that only 15% of these residues can be used for biogas production.
  - Pasture residues: A 5% availability of the total amount of pasture residues is assumed for each country. In accordance with the specific output per ha and total available area biogas potential is calculated.
  - Separated biodegradable fraction of municipal wastes: It is assumed that roughly 100 kg per capita and year can be used for agricultural biogas production. The typical gas output of this fuel fraction is in size of 100 m^3/t.
- **Landfill gas:** The future potential of landfill gas is highly influenced by recent developments regarding waste treatment regulations as e.g. given EU-wide by the EU-directive on the landfill of waste (European Parliament and Council, 1999). In

[101] If primary potentials are derived in volume units (m^3), as default an energy content of 21.6 MJ/m^3 according to (Neubarth et. al., 2000)) was assumed for the

general, the waste treatment option of landfilling is restricted in the future. In accordance with these regulations as implemented on a national level, primary potentials have been assessed. In more detail, the approach was as follows: First, the amount of waste to be generated in the year 2020 has been estimated – by applying country-specific growth rates in accordance with past observations (taken from Eurostat, 2002a). Next, in accordance with the above mentioned waste treatment regulation, a country-specific certain percentage of waste to be landfilled has been assumed. By applying figures with respect to gas rise, usability, energy content, the primary potential for landfill gas was derived on country-level.

- **Sewage gas:** Water disposal per capita and/or the amount of sewage sludge (in total per country) have been used as indicator to determine the potential of sewage gas. In this context, statistical data was taken from (Eurostat, 2002a) on a European level – hence, if newer data was available, also country-specific sources have been taken into account.

5.1.2.2. Solid Biomass

► Definition and characteristics

Following the definition of solid biomass given by the 'RES-E Directive' (European Parliament and Council, 2001) four sub-categories was defined:

- Forestry products,
- Forestry residues,
- Agricultural products,
- Agricultural residues.

Moreover, within each sub-category, a further distinction between pure power production and CHP was applied. Based on this categorization, for each sub-category a separate assessment of the available potential has been undertaken. With respect to the applied conversion technologies, differences between the sub-categories are small. Therefore, the cost-assessment is based, on the one hand, on a definition of a set of conversion technologies, and, on the other hand, on an assessment of fuel prices, where finally for each sub-category country-specific fuel prices are derived.

Electricity generation from biomass is characterised by:

- *Non-volatility of the power output:* Biomass represents – similar to fossil fuels – a fuel source for thermal power plant. Thereby, the 'stop' or 'start' power production only depends on the operation strategy or plant-type (peak load plant vs. base load plant).
- *High variable costs*: As a hindrance compared to other RES-E for almost all kind of biomass fuel costs appear.
- *Various energy conversion concepts:* Today apart from 'simple' combustion various technological concepts exist for power production from biomass. In general, a distinction between biomass-fired CHP plant, biomass-fired power plant and co-firing in conventional thermal plant has to be made.
- *Biomass represents a 'competitive resource':* In general, the energetic use of biomass is in competition to the material use. Furthermore, competition occurs

within the energetic fraction: Biomass represents a traditional resource for heating, especially in rural areas.

- *Various fuel fractions occur:* The generic-term is used to describe a broad set of different fuels, definitions in literature are often not-harmonised between the various countries.
- *Long distance transportation of biomass resources should be avoided*, since besides ecological concerns the economics are very sensitive to such costs.

► <u>(Additional) mid-term potential</u>

In general, solid biomass represents an energy source with a more or less strong limited potential – depending on country-specific conditions. Thereby, not only the primary energy potential is restricted. Moreover, the energetic use of biomass stands in competition to the material use and, in addition, competition occurs within the energetic fraction: Solid biomass like wood represents a traditional resource for heating, especially in rural areas.

The approach for the assessment of its electricity generation potential was as follows:

1. First, an assessment of the primary energy potential – more precisely, the additional realisable primary mid-term potential – was undertaken. Thereby, for each pre-defined fuel-based sub-category country-specific potentials were derived.
2. Finally, within each sub-category electricity potentials were calculated by linking of plant-specific conversion efficiencies to the primary potentials derived above. In this context, the conversion efficiency for electricity highly depends on the technological concept applied. In general, for small units and CHP-plant the electrical efficiency is lower than for pure power production.

The assessment is mainly based on processing of statistical data taken from (Eurostat, 2002a) and (FAOSTAT, 2002), cross-checked and extended where applicable by national experts or studies. In order to provide more insights into the process of potential assessment, the derivation of the primary energy potential (i.e. the additional primary energy mid-term potential) is described in the following for each sub-category:

- **Forestry products:** This sub-category covers all forms of wood (e.g. wood chips) directly harvested from forests. The additional potential is derived from the unused net annual increment of forests which are marked as available for wood supply. The unused net increment represents the difference between the net annual increment and the amount of felling harvested.[102] Hence, by applying a usability factor (about 50-70%) and density as well as specific heat value, the primary energy potential is calculated.
- **Forestry residues:** The sub-category by itself includes the following fuel sources:
  - <u>Forestry wastes:</u> Only a certain percentage of wood residues which occur in the forests in the process of harvesting should be removed (considering seriously environmental impacts). It is assumed that this amounts 5% of total annual felling.

[102] In general, the growing stock of forests increases in Europe year by year. Of course, differences occur between countries – but the methodology applied takes into consideration of country-specifics and moreover, aims to derive potentials which meet the objective of sustainability.

- Solid industrial by-products: (incl. bark, waste from sawmill- , wood- and paper industry production) Almost none of these by-products are currently additional available – due to their cheap price. By considering an average growth rate (1% per year) a small amount of this fraction will be available in 2020.
- Wood waste: The annual potential of matured timber stands in statistical correlation to population. Hence, according to statistics it is assumed that an amount of 85kg occurs on average per capita. Combining this figure with a usability of 50% the potential can be assumed.

- **Agricultural products:** The primary energy potential of energy crops is in strong interdependence with agricultural policy. Hence, as default figure it is assumed that 10% of the current arable land would be available for cultivation of energy crops in 2020. Crop yields differ by country due to different climatic conditions (in a range from 11-15 dry tonnes/ha/year).
- **Agricultural residues:** The most prominent representative of this category is straw, an EU-wide common agricultural residue which can be used for combustion. The potential assessment is based on current production of cereals, yields differ by country in accordance with actual production data (3–6.7 t/ha). Country-specific other agricultural residues, considered in the database, are e.g. solid residues in the extraction process of olive oil as typical for Spain and Greece.

5.1.2.3. Biowaste

► Definition and characteristics

In accordance with the definition of RES-E presented in the 'RES-E directive' (EC, 2001) the biodegradable part of waste is accounted as a renewable energy source.

Electricity generation from biowaste is characterised by:

- *Non-volatility of the power output:* Biowaste represents – similar to fossil fuels – a fuel source for thermal power plant. Thereby, the 'stop' or 'start' power production only depends on the operation strategy. Nevertheless, peal-load production is currently unusual.
- *Low variable costs – high investment costs*: In contrast to other biomass resource, the fuel, i.e. waste, represents in most cases an additional revenue for the plant owner. Thus, investment costs for a waste treatment plant are extraordinary high compared to other thermal plant types, caused by high efforts for cleaning and purification.
- *Long distance transportation of biomass resources should be avoided*, since besides ecological concerns the economics are very sensitive to such costs.

► (Additional) mid-term potential

Hence, so far only the potential of municipal waste is represented in the database. In order to derive the additional mid-term potential the amount of waste to be generated in the year 2020 has been assumed – by applying country-specific growth rates in accordance with past trends (taken from (Eurostat, 2002a)). Next, country-specific current waste treatment (incineration vs. recovery operations vs. landfilling) as well as implemented policy regulations (e.g. the EU-directive on the landfill of waste (European Parliament and Council, 1999)) was taken into account in order to provide stable forecasts of the future waste treatment. Finally, the potential for waste incineration occurs as residuum from other options. The biodegradable fraction has been estimated in accordance with the FORRES-study (Ragwitz et al., 2004).

5.1.2.4. Geothermal electricity

► Definition and characteristics

Electricity generation from geothermal energy is characterised by:

- *Low volatility of the power output:* Geothermal power represents an almost non-fluctuating source of energy.
- *High initial investment costs:* A huge hindrance for geothermal plant represent the high investment costs combined with a high level of uncertainty in the planning stage of a project (i.e. the assessment of drilling costs).
- *Lack of high-temperature resources:* High-temperature geothermal resources as needed for the state-of-the-art of geothermal power generation are quite rare in Europe and concentrated mainly on those countries where geothermal plants are already installed (e.g. Italy and Portugal). Of course, promising new technological options exist (e.g. hot-dry-rock) for future exploitation of low- to medium-temperature resources.

► (Additional) mid-term potential

The potential assessment is mainly based on (ESD/DGXVII, 1996). Thereby, corrections have been undertaken after consultation with national experts and own investigations. In this context, please note new options for the exploitation of low-temperature geothermal resources are on the way and for instance already discussed and investigated in certain countries (e.g. Germany) – but hence, as far as no common set of data necessary to assess the potential for the whole EU-15, it has been decided to leave this new options aside.

5.1.2.5. Hydro power – Large-scale plant

► Definition and characteristics

Electricity generation from large hydro power is characterised by:

- *High exploitation / proven technology:* Among all RES-E, hydro power represents the most explored sources, especially in EU countries like Austria or France. The various conversion technologies applied are common and well proven.
- *Low volatility of the power output:* Hydro power represents a fluctuating source of energy. In contrary to wind and PV the volatility appears in the medium- to long-term. It is characterised by a seasonal dependence, but also high annual differences occur.
- *Low social acceptance:* Public resistance has been raised in most parts of Europe since the 80's if new large-scale hydro power projects have been discussed.
- *High initial investment costs:* A huge hindrance for large-scale hydro plants represent the high investment costs.

- *Run-of-river vs. storage plant:* In general, a standard classification of hydro power plant distinguishes between run-of-river- and storage power plant. In mountainous regions (large-scale) storage plant are applied to meet peak load demand, and at proper river sites run-over-river plant deliver base load electricity.
- *Pump-storage plant:* Hence, a further sub-category of storage plant is a pump-storage plant – in order to be able to store excessive base-load energy. Such plants are commonly used all over Europe to account for peak-load supply. Hence, the energy produced from such plant is not accounted as renewable – see Article 2 of the 'RES-E Directive' (European Commission, 2001). Accordingly, electricity generation as a result of pumping[103] in existing pump-storage hydropower is not taken into account from the achieved potential and not considered in the potential assessment for new hydro plant!

► (Additional) mid-term potential

An additional realisable mid-term potential for large-scale hydro power is for most European countries hard to predict – due to above mentioned constraints, i.e. the missing public acceptance. Although hydro power is well exploited in Europe, the technical as well as the economic potential is in some countries still quite high – compared to other RES-E options.

The approach to assess the future potential was as follows: Default potential data was based on (ESD/DGXVII, 1996). Further corrections have been undertaken after consultation with national experts and own investigations. Especially, for those countries which have proposed future targets for large hydro, these figures have been taken into account – in order to derive a proper set of data. Note that, besides erecting a new plant, upgrading or refurbishment of existing plant represents in most countries a from an economic point-of-view promising option.

5.1.2.6. Hydro power – Small-scale plant

► Definition and characteristics

Electricity generation from small hydropower plant is characterised by:

- *High exploitation / proven technology:* Among all RES-E, hydro power represents the most explored sources, especially in EU countries like Italy or Austria. The various conversion technologies applied are common and well proven.
- *Low volatility of the power output:* Hydro power represents a fluctuating source of energy. In contrary to wind and PV the volatility appears in the medium- to long-term. It is characterised by a seasonal dependence, but also high annual differences occur.
- *Low social acceptance:* Public resistance has been raised in most parts of Europe since the 80's if new hydropower projects have been discussed. Hence, for small-scale plant acceptance barriers are in general not as dramatic compared to large one.

[103] More precisely, according to statistics the amount of energy used for pumping, divided by an average conversion efficiency of 75% is subtracted from the generation output of such a plant type.

- *High initial investment costs*: A huge hindrance for small-scale hydro plant represent the high investment costs.
- *Run-of-river vs. storage plant:* In general, a standard classification of hydro power plant distinguishes between run-of-river- and storage power plant.
- *Pump-storage plant:* Similar to large-scale hydropower, electricity generation as a result of pumping in existing pump-storage hydropower is not taken into account

► (Additional) mid-term potential

In contrast to large hydro, data with respect to realisable potentials – considering also environmental constraints – have been well-assessed in the past. A homogenous approach was undertaken within the project 'BlueAge' – where national experts derived in accordance with the applied approach of potential definitions reliable set of data representing country-specific potentials under consideration of economic and environmental constraints.[104] Hence, these figures are used and, of course, corrected according to recent developments, to derive the mid-term potentials. Note that, besides erecting a new plant, upgrading or refurbishment of existing plant represents in most countries a from an economic point-of-view promising option.

5.1.2.7. Photovoltaics

► Definition and characteristics

Photovoltaic power cells use a specific spectrum of the sun light to produce electricity. In principle, there are four primary applications for PV power systems:

- *Off-grid domestic systems* provide power in isolated remote areas.
- *Grid-connected distributed PV systems* are installed to supply power to a building or other load (dwellings, commercial and industrial buildings) that is also connected to the utility grid. These systems are increasingly integrated into the built environment and are likely in the future to become commonplace. Typically, for building integrated systems two different categories occur: A PV plant can either be installed on the roof ('PV on roof') - characterised by a higher load-factor, or on the facade ('PV on facade').
- *Off-grid non-domestic systems* provide power for a wide range of applications, such as telecommunications, water pumps, vaccine refrigeration, navigation aids, aeronautical warning lights and meteorological recording equipment. Energy storage is not required, a factor that also improves system efficiency and decreases the environmental impact.
- *Grid-connected centralized PV systems* have been installed for two main purposes: as an alternative to centralized power generation from fossil fuels or nuclear energy, or for strengthening of the utility distribution grid.

Of course, for purposes of the ***Green-X*** model, only grid-connected PV systems are of relevance.

[104] For details see (Lorenzoni et al., 2001) – especially, section 3.3 of the report.

Most important characteristics with respect to grid-connected PV systems are:

- *High volatility of the power output:* Due to the strong dependence of the power output on the available sun light short as well as a medium to long-term fluctuations appear;
- *High initial investment costs*.

► (Additional) mid-term potential

In general, PV represents an energy source characterised by a large potential which can be realised from a technical point-of-view. The approach for the assessment of the (additional) realisable mid-term potential is based on the following categorisation of PV plant:

- PV on roofs (building integrated),
- PV on facades (building integration),
- PV on fields (no building integration).

In principle, for *building integrated PV* (PV on roofs, PV on facades) the electricity generation potential can be calculated by linking the average figures of solar-architecturally suitable area per capita to country-specific features (mainly population size and annual solar irradiation).

In more detail, the chosen approach for the potential assessment was as follows:

1. Assessment of the *capacity potential*:

   For *building integrated PV* the methodology for the assessment of the capacity potential, based on (Gutschner et al., 2001), is illustrated in Figure 5.5 (upper part). Thereby, as a first step, a country-specific (per capita) ground floor area was aggregated.[105] Applying the corresponding overall utilisation factor of 0.4 for roofs and 0.15 for facades (for the building stock), the solar-architecturally suitable building roof and facade areas per capita are calculated. Multiplied with population, solar irradiance (i.e. 1kW/m^2) and conversion efficiency the capacity potential was derived.

   For *non-building integrated PV* (PV on 'free field') the capacity potential was derived by assuming that a maximum of 0.05% of agricultural area are available for PV installations. Again, by applying solar irradiance, conversion efficiency, potential for PV is defined.

2. Total *potential for electricity from PV* is calculated by applying country- as well as category-specific full-load hours. In this context, the achievable full-load hours of a PV plant represent the site-specific solar conditions as well as the location where the solar modules are installed, i.e. on roof, on facade or on free-field. In more detail, the calculation was as follows: The annual solar irradiation (country-specific!) multiplied with a factor representing the solar yield by category (i.e. 0.46 for facade, 0.73 for roof-systems and 0.78 for 'free field'-systems) results in achievable full-load hours. They appear on average in a range between 460 (PV on facades) and 760 h/a (PV on 'free fields') for Northern European countries (e.g.

---

[105] Compare (Gutschner et al., 2001): *"A typical statistical building for a person living in Central Western Europe has about 45 m^2 of ground floor area. Half of it is used for residential purposes, 7 m^2 for the primary sector, 6 m^2 each for the secondary sector and for the tertiary sector and the rest for other purposes."*

United Kingdom, Sweden) and in a range between 730 (PV on facades) and 1330 h/a (PV on 'free fields') for Southern European countries (e.g. Spain)

3. A further restriction is applied in order to consider aspects of grid integration. Assuming no radical changes with respect to the existing grid, as (a rather high) constraint the in maximum achievable potential of electricity from PV is limited to 8% of expected gross electricity consumption in 2020 (Mantzos et al., 2003a).

4. Finally, the additional mid-term potential is calculated by subtraction of the already achieved potential (i.e. the electricity generation potential of existing plant) – which, in general, is rather small compared to the overall mid-term potential.

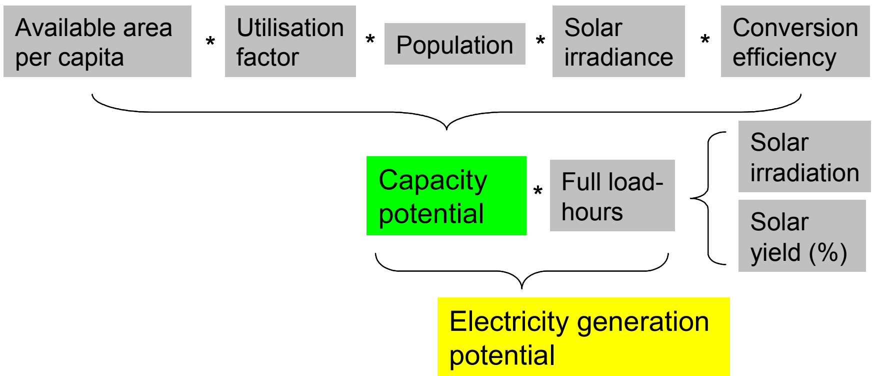


Figure 5.5 Methodology for the assessment of the building-integrated PV potential

5.1.2.8. Solar thermal electricity

► <u>Definition and characteristics</u>

Solar thermal power plant has been considered as promising new option for power generation – since several years. Hence, up to now – beside from demonstration facilities – no solar power plant has gone 'online' within Europe – of course, worldwide several (hybrid) solar thermal plant are operating well. In principle, several technological concepts appear:

- *Parabolic through plant:* Large cylindrical parabolic mirrors concentrate the sunlight on a line of focus. Several of these collectors in a row form a solar field. Hence, molten salt is used to transport the heat to a (conventional) gas or steam turbine.
- *Solar power tower plant:* The solar field of a central receiver system (i.e. the power tower) is made up of several hundred mirrors which concentrate the sun light to the central receiver. Similar to above, air or molten salt is used to transport the heat to a (conventional) gas or steam turbine.
- *Dish/Stirling Technology:* Parabolic dish concentrators are in contrary to above rather small units – in the range of kilowatts.

Through and power tower plant are usually equipped either with a thermal storage block or a hybrid fossil burner in order to guarantee a non-fluctuating power supply.

In general, solar thermal plant can use only direct irradiance – hence, as in middle and northern Europe there is only a small proportion of direct irradiance, it does not make sense to install solar thermal power units based on current technology there.

► (Additional) mid-term potential

The approach for the assessment refers to non-hybrid power station. Hence, thermal storage units are taken into calculation in order to guarantee a more constant supply. The size of the storage units determines beside plant-size, plant-concept the overall costs.

The assessment was undertaken as follows: Based on assumptions with respect to land use (0.5% of agricultural area, area factor) and country-specific data with respect to solar irradiation (direct irradiance) primary energy potentials have been assessed for Southern European countries (i.e. Greece, Spain, Portugal and Italy). Next, electricity generation potentials are derived by applying plant-specific conversion efficiencies.

5.1.2.9. Tidal & wave energy

► Definition and characteristics

- **Tidal energy:** Besides France's activities in the field of tidal barrage[106], tidal stream & tidal current power has been recognized especially within the UK and Ireland as a promising new option for power generation. In principle, a distinction between tidal barrage, near-shore and off-shore-devices occurs.
- **Wave energy:** Wave energy represents a promising future RES-E option. In principle, a distinction can be undertaken with respect to its appliance, i.e. shoreline, near-shore and off-shore-devices. Hence, off-shore wave power is yet still in a R&D-stage[107].

► (Additional) mid-term potential

- **Tidal energy:** Research activities with respect to tidal energy concentrated on tidal barrage in the earlier decades of the last century. In contrast, the assessment of the future potential of tidal stream & tidal current is accompanied by a set of difficulties. As the technological development is focused on UK, for other parts of Europe no overall in-depth resource assessment has been conducted so far.
- **Wave energy:** The future potential of wave energy is indicated in many studies as huge, depending on 'roughness' of sea etc.. Nevertheless, the technology is still not recognized by many countries, therefore EU-wide future projections of realisable potentials up to 2020 are difficult to provide. Recent assessments as provided e.g. by Thorpe (1999) have concentrated only on the UK.

---

[106] In 1966 the first and so far only large-scale tidal barrage power plant was built in La Rance, France. The installed capacity amounts 240 MW. Note, in the database it is comprised in the category large-scale hydropower.

[107] See Michael P. (2002).

For both RES-E technologies representing novel and promising future options, technological experts have been contacted – in cooperation with the project partner IT Power Ltd. - to provide a 'best guess' of the resource potential. In addition, an overall methodology based on processing of geographical data and local resource conditions was derived and finally applied to provide a first EU-wide harmonised assessment of their potential.

5.1.2.10. Wind on-shore

► Definition and characteristics

Among the currently available and commercially viable renewable resources, wind is one of the cheapest possible sources of renewable energy. When considering the total capital investment costs of locating-, and building new electric generation facilities, it is even competitive with conventional electric generation sources. Furthermore, also in several European countries wind power is characterised by a rather high additional potential still waiting to be exploited. This explains the keen interest power companies and private investors have taken in wind energy in recent years.

In general, modern wind turbines use the energy content of the wind to produce electricity. Thereby, electricity generation from wind power is characterised by:

- *High volatility of the power output:* Due to the strong dependence of the power output (P) on the wind speed (v) – P ≈ const. * v3 – short as well as a medium to long-term fluctuations appear. In this context, wind power prediction methods are developed to overcome the lack of planning awareness. The quality of a possible wind plant site can be determined by deriving the local wind climate, i.e. average annual wind speed and wind speed distribution.
- *Standardised and proven power conversion technology:* The stable growing demand for wind power starting in Europe within the early 90's led especially Denmark and Germany become the leading countries with respect to the wind turbine manufacturing industry. Technological solutions differ in detail by manufacturer, but in general, the overall concepts are proven and well established. The various components are standardised and manufacturing is characterised by major competition. Nevertheless, the typical plant size increased rapidly within the Nineties, mainly driven by the growing demand for offshore-developments. Currently, the size of typical on-shore turbines is in a range between 1 to 2 MW.

► (Additional) mid-term potential

The technical potential for on-shore wind energy is high in various EU countries, namely France, UK – but several barriers have to be overcome, e.g. public acceptance, power grid constraints.

Realisable potentials are assumed 'step-by-step' – after consultation within several research projects and discussion with other experts, keeping in mind important 'constrain indicators' like e.g. 'percentage of wind power on total electricity consumption', 'wind power (capacity) potential per capita', 'wind power (capacity) potential per land area'.

First, in accordance with data regarding land use, overall area-potentials have been assessed by country. Next, wind maps (mainly taken from (RISOE, 1998)) have been applied to the define areas characterised by certain 'wind characteristics' (i.e. mean wind speed, roughness class). Finally electricity potentials have been derived. Note, these calculations are based by appliance of a power curve for a – at present and in near future – common on-site turbine in size of 2 MW.

In this context, a set of bands – characterised by same wind conditions (i.e. described by full load-hours) – have been derived for each country – describing the overall mid-term generation potential from on-shore wind. Thereby, in order to meet the model requirements[108] and hence, to produce a set of reliable data, discrete values for full load-hours have been defined. Finally, the already achieved potential (i.e. existing plant) has been taken into account. Therefore, the additional realisable mid-term potential represents the residuum of the overall mid-term potential and the achieved potential.

For a better illustration of the final approach, Figure 5.6 illustrates the mid-term potential for on-shore wind in Germany related to discrete full load-hours.

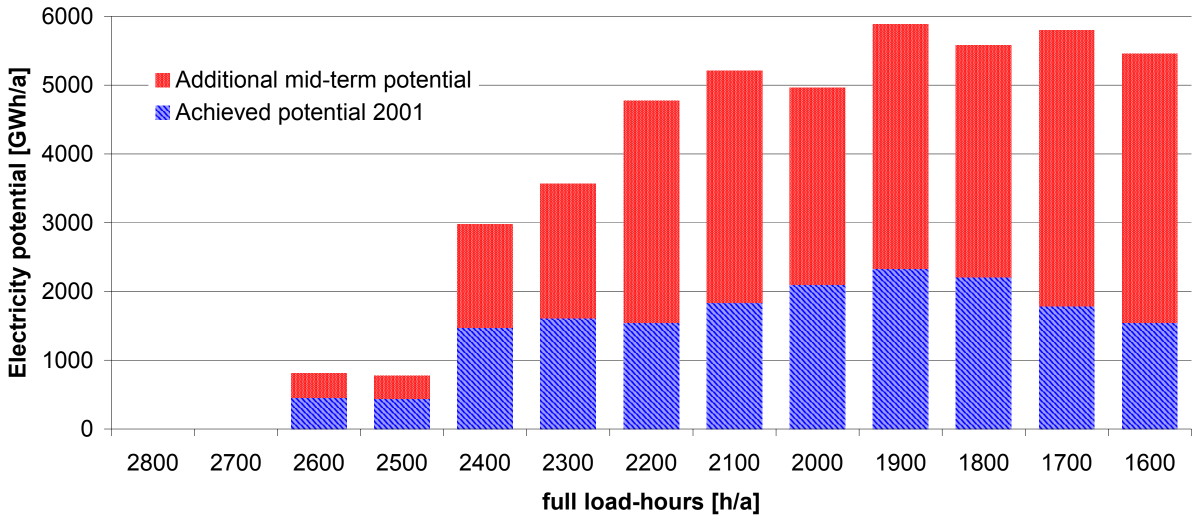


Figure 5.6 Mid-term potential of electricity from wind on-shore in Germany related to full load-hours

5.1.2.11. Wind energy – wind off-shore

► <u>Definition and characteristics</u>

As already mentioned for wind on-shore, electricity generation from wind power is characterised by:

- *High volatility of the power output:* Due to the strong dependence of the power output (P) on the wind speed (v) – P ≈ const. * v3 – short as well as a medium to

[108] To be able to model policy instruments like 'stepped feed-in tariffs' in a proper way, a discrete set of full load-hours was required.

long-term fluctuations appear. In this context, wind power prediction methods are developed to overcome the lack of planning awareness. The quality of a possible wind plant site can be determined by deriving the local wind climate, i.e. average annual wind speed and wind speed distribution. Compared to on-shore wind energy, wind conditions are more stable for off-shore plants. Therefore, higher full load-hours can be achieved and, hence, associated fluctuations of the power output appear in a smaller range.

- *Standardised and proven power conversion technology:* The stable growing demand for wind power starting in Europe within the early 90's led especially Denmark and Germany become the leading countries with respect to the wind turbine manufacturing industry. Technological solutions differ in detail by manufacturer, but in general, the overall concepts are proven and well established. The various components are standardised and manufacturing is characterised by major competition. Nevertheless, the typical plant size increased rapidly within the Nineties, mainly driven by the growing demand for offshore-developments. Nowadays, largest available turbines appear in almost the 5 MW class.

► (Additional) mid-term potential

The overall technical potential for off-shore wind energy seems to be huge in parts of Europe, especially in the North Sea – compare e.g. (Greenpeace, 2001) –, but several barriers have to be overcome, e.g. public acceptance, power grid constraints.

Realisable potentials are assumed 'step-by-step' – after consultation within the project and discussion with other experts, keeping in mind important 'constrain indicators' like e.g. 'percentage of wind power on total electricity consumption', 'wind power (capacity) potential per capita'.

First, in accordance with geographical data, overall area-potentials have been assessed by country. Next, wind maps or wind data-sources, respectively (mainly taken from (Greenpeace, 2001) and (RISOE, 1998)) have been applied to the define areas characterised by certain 'wind characteristics' (i.e. mean wind speed, roughness class). This finally enabled the derivation electricity potentials. Note, these calculations are based by appliance of an assumed power curve (based on data for a 4.5 MW turbine) for a – in near future – common off-site turbine in size of 5 MW.

A further distinction has been undertaken which helped to conduct the correct economic data: Area-classes have been defined with respect to the distance from the coastline: near shore (Zone 0), 5..30 km from coast (Zone 1), 30..50 km from coast (Zone 2) and more than 50 km (Zone 4).

For each area-class a set of bands – characterised by same wind conditions (i.e. described by full load-hours) – have been derived for each country – describing the overall mid-term generation potential from off-shore wind. Thereby, in order to meet the model requirements[109] and hence, to produce a set of reliable data, discrete values for full load-hours have been defined. Finally, the already achieved potential (i.e. existing plant) has been taken into account. Hence, the additional realisable mid-term potential represents the residuum of the overall mid-term potential and the achieved potential.

[109] To be able to model policy instruments like 'stepped feed-in tariffs' in a proper way, a discrete set of full load-hours was required.

5.2. Economic data for RES-E

The economic performance of a specific energy source determines its future market penetration. The relevant data for a brief description of the several RES-E technologies considered – suitable for the model ***Green-X*** – is described in the following. Thereby, first an overview on the derived data is given, followed by a concise description of its assessment.

5.2.1. Overview on derived economic data for RES-E

Table 5.2 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$_{el}$*year)]	[1]	[1]	[years]	[MW$_{el}$]
Biogas	Agricultural biogas plant	2500 - 4200	115 - 135	0.28 - 0.34	-	25	0.1 - 0.5
	Agricultural biogas plant - CHP	2700 - 4400	120 - 140	0.27 - 0.33	0,55 - 0,59	25	0.1 - 0.5
	Landfill gas plant	1250 - 1800	50 - 80	0.32 - 0.36	-	25	0.75 - 8
	Landfill gas plant - CHP	1400 - 1950	55 - 85	0.31 - 0.35	0,5 - 0,54	25	0.75 - 8
	Sewage gas plant	2250 - 3350	115 - 165	0.28 - 0.32	-	25	0.1 - 0.6
	Sewage gas plant - CHP	2400 - 3500	125 - 175	0.26 - 0.3	0,54 - 0,58	25	0.1 - 0.6
Biomass	Biomass plant	2200 - 2500	75 - 135	0.26 - 0.3	-	30	1 - 25
	Co-firing	550	60	0.37	-	30	-
	Biomass plant - CHP	2550 - 4200	80 - 165	0.22 - 0.27	0,63 - 0,66	30	1 - 25
	Co-firing - CHP	550	60	0.2	0,6	30	-
Biowaste	Waste incineration plant	4250 - 5750	90 - 165	0.18 - 0.22	-	30	2 - 50
	Waste incineration plant - CHP	4500 - 6000	100 - 180	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	5400 - 6300	40 - 50	-	-	25	0.005 - 0.05
Solar thermal electricity	Solar thermal power plant	2900 - 4500	165 - 230	0.33 - 0.38	-	30	2 - 50
Tidal energy	Tidal (stream) power plant - shoreline	3000	50	-	-	25	0.5
	Tidal (stream) power plant – near shore	3200	55	-	-	25	1
	Tidal (stream) power plant - offshore	3400	60	-	-	25	2
Wave energy	Wave power plant - shoreline	2400	50	-	-	25	0.5
	Wave power plant – near shore	2600	55	-	-	25	1
	Wave power plant - offshore	3200	60	-	-	25	2
Wind onshore*	Wind power plant	945 - 1050	36 - 40	-	-	25	2
Wind offshore	Wind power plant – near shore	1750	65	-	-	25	5
	Wind power plant - offshore: 5…30km	1950	70	-	-	25	5
	Wind power plant - offshore: 30…50km	2150	75	-	-	25	5
	Wind power plant - offshore: 50km…	2400	80	-	-	25	5

Table 5.2 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[110] differentiation of investment- and where suitable also O&M-costs is undertaken, whilst for all other RES-E 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. 2002, and are expressed in $€_{2002}$.

Default values for fuel costs with respect to the various fractions of biomass are illustrated in Figure 5.7. These country-specific prices are mainly based on (EUBIONET, 2003). 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. 2002. Their future development is internalised in the overall model – linked to fossil fuel prices as well as the available additional potentials.

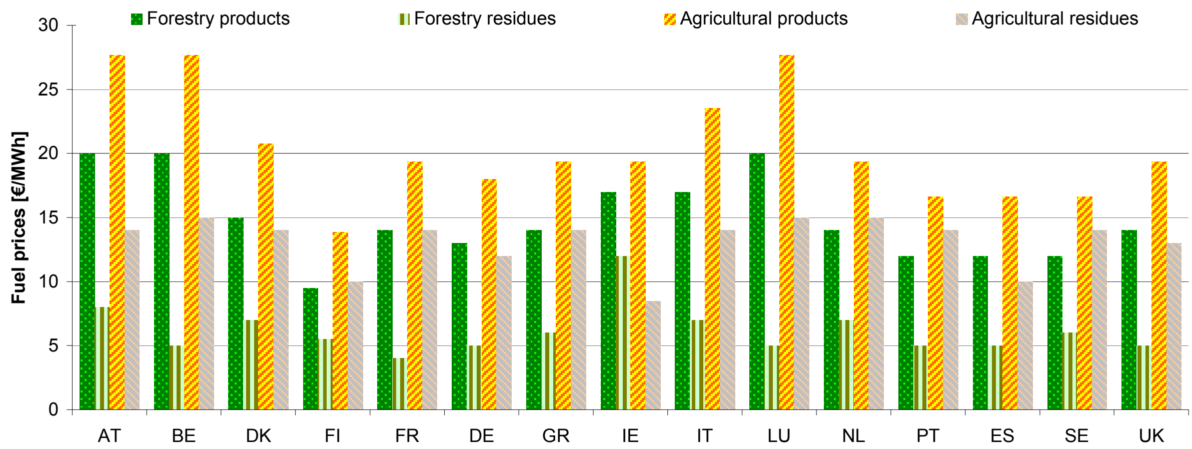


Figure 5.7 Fuel prices for various fractions of solid biomass in EU-15 countries

In order to give a better illustration of the current[111] economic conditions of the various RES-E options, electricity generation costs[112] are depicted in the following figures. Their calculation is based on the economic and technical specifications as depicted in Table 5.2, extended by missing parameter 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.

---

[110] 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).

[111] As usual, costs refer to the starting year for model simulations, i.e. 2002 and, hence, are expressed in $€_{2002}$.

[112] Note that in the model ***Green-X*** the calculation of electricity generation costs for the various generation options is done by a rather complex mechanism as described in the sections 4.2.3 and 4.3, 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.

First, Figure 5.8 depicts *long-run marginal generation costs*[113] by RES-E category. Thereby, for the calculation of the capital recovery factor two different settings are applied with respect to the payback time:[114] On the one hand, a default setting, i.e. a payback time of 15 years, is used for all RES-E options – see Figure 5.8 (left), and on the other hand, the payback is set equal to the technology-specific life time – see Figure 5.8 (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.

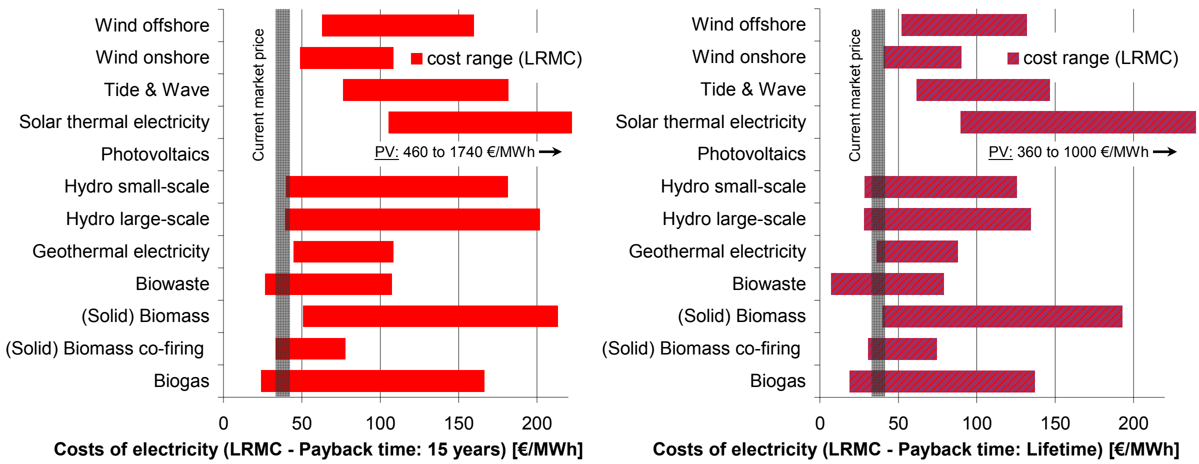


Figure 5.8 Long-run marginal generation costs (for the year 2002) for various RES-E options in EU-15 countries – based on a default payback time of 15 years (left) and by setting payback time equal to lifetime (right).

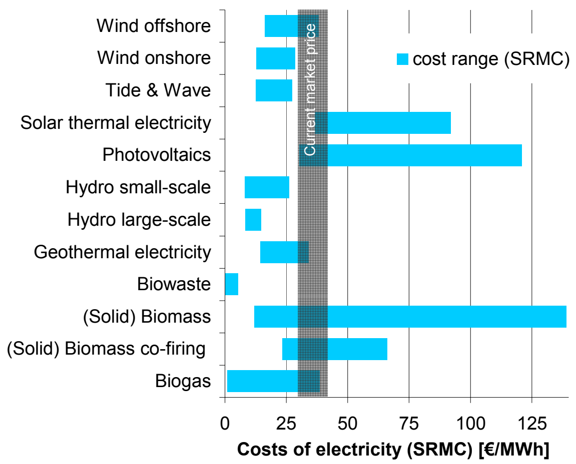


Figure 5.9 Short-run marginal generation costs (for the year 2002) for various RES-E options in EU-15 countries

113 Long-run marginal costs are relevant for the economic decision whether to build a new plant or not.
114 For both cases a default weighted average cost of capital (WACC) in size of 6.5% is used.

Figure 5.9 illustrates *short-run marginal generation costs*[115] by RES-E category. It gets 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.

5.2.2. Assessment of the economic data for RES-E

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 taking into account. References of major relevance are discussed below.

A set of studies can be 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 electricity: (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)

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

5.3. Resulting static cost-resource curve for RES-E

The combination of the data on potentials and the economic and technical data results in the static cost-resource curves. A separate curve is developed for each available RES-E category on country-level, subdivided into existing, representing the achieved potential at the end of 2001, and new plant, referring to the additional realisable potential up to 2020. Such a stepped cost-resource curves consists of several bands, characterised by similar economic conditions. Thereby, as briefly described in the formal framework of the model ***Green-X*** (see section 4.2.5), the applied approach for the fragmentation, i.e. the definition of band-specific characteristics, differs by RES-E category, see Table 5.3.

Table 5.3 Summary of the band characteristics of different technologies

Technology	**Band characteristic**
Biogas	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
(Solid) Biomass	Fuel input (fuel price), plant size/type (efficiency, investment-, O&M costs), full-load hours
Biowaste	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Geothermal electricity	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Small scale hydropower (<10 MW)	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Large scale hydropower (>10 MW)	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Photovoltaics	Plant size (inv.-, O&M costs), Application (full-load hours)
Solar thermal electricity	Plant size/type (efficiency, inv.-, O&M costs), full-load hours
Tide & Wave energy	Plant type (investment-, O&M costs), full-load hours
Wind on-shore	Full-load hours
Wind off-shore	Plant type (investment-, O&M costs), full-load hours

The development of static cost-resource curves is exemplarily described for wind onshore in the following. For a better illustration an aggregated curve, summarising all RES-E options on country-level, is depicted later on.

5.3.1. Example: Static cost resource curves for wind onshore

Table 5.4 Band-specific database for new on-shore wind power plant in Austria (status: end of 2001)

Band name	Constr. year	Base(B)/ Peak(P) load	Potential [GWh]	Load hours ele [h/a]	Load hours heat [h/a]	Efficiency ele [1]	Efficiency heat [1]	O+M costs [€/kWinst.]	Fuel category	Investment costs [€/kWinst.]
AT-E-RES-N-WI-ON-1	0	B	247.86	2400	0	1	0	40		1050
AT-E-RES-N-WI-ON-2	0	B	485.93	2300	0	1	0	40		1050
AT-E-RES-N-WI-ON-3	0	B	464.81	2200	0	1	0	40		1050
AT-E-RES-N-WI-ON-4	0	B	433.76	2100	0	1	0	40		1050
AT-E-RES-N-WI-ON-5	0	B	413.10	2000	0	1	0	40		1050
AT-E-RES-N-WI-ON-6	0	B	383.47	1900	0	1	0	40		1050
AT-E-RES-N-WI-ON-7	0	B	460.49	1800	0	1	0	40		1050
AT-E-RES-N-WI-ON-8	0	B	434.90	1700	0	1	0	40		1050
AT-E-RES-N-WI-ON-9	0	B	488.16	1600	0	1	0	40		1050
AT-E-RES-N-WI-ON-10	0	B	486.00	1500	0	1	0	40		1050
AT-E-RES-N-WI-ON-11	0	B	453.60	1400	0	1	0	40		1050

By linking the economic-data with the potential assessment (i.e. the potentials assessed for each discrete full load-hour level), static cost-resource curves are derived. For illustration Table 5.4 depicts the band-specific database for new on-shore wind power plant in Austria, i.e. data with respect to the additional realisable mid-term potential up to 2020 (as available at the end of 2001).

The following figures summarise the derived data on potentials and economics, represented by the resulting generation costs[116] for wind onshore, allowing a cross-country comparison: An overview on the achieved and the additional mid-term potential is given in Figure 5.10. Costs of electricity for new plant are depicted in Figure 5.11 (long-run marginal costs - LRMC) and Figure 5.12 (short-run marginal costs – SRMC).

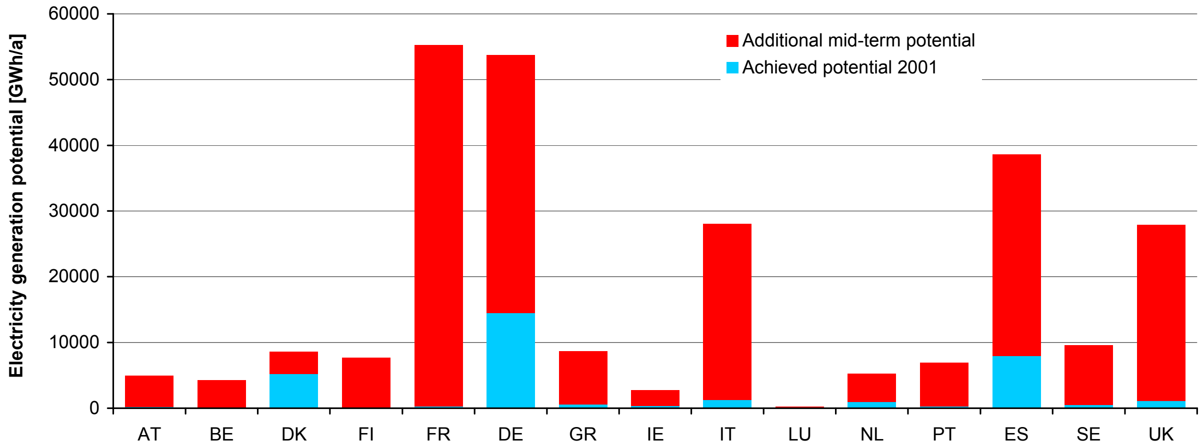


Figure 5.10 Achieved potential (2001) & additional mid-term potential (up to 2020) for electricity from wind on-shore in EU-15 countries

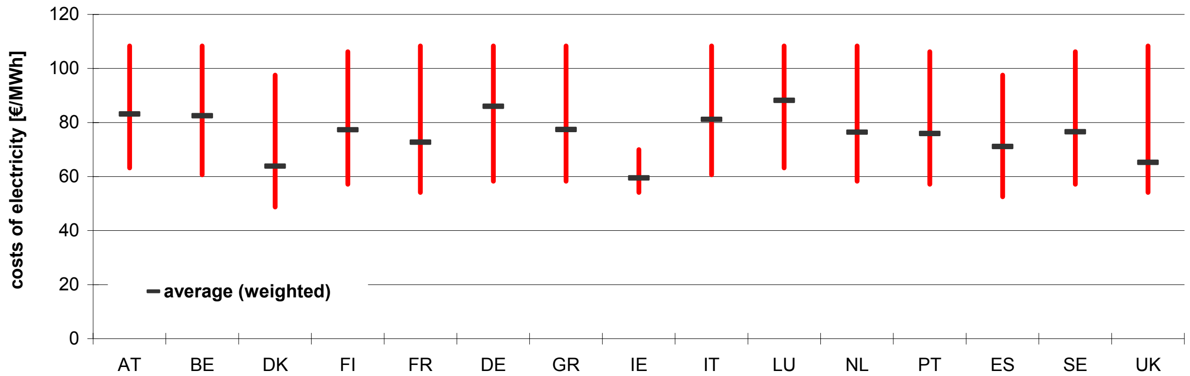


Figure 5.11 Long-run marginal generation costs for wind onshore in EU-15 countries (for new plant)

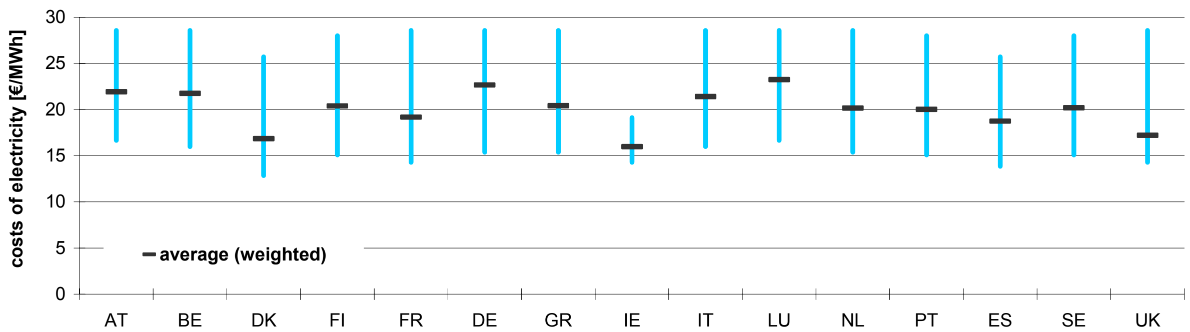


Figure 5.12 Short-run marginal generation costs for wind onshore in EU-15 countries (for new plant)

[116] Please note, these generation costs are calculated by applying a default interest rate of 6.5% and a depreciation time of 15 years to investment and O&M-costs as implemented in the database for new plant. Thereby, costs refer to the start year of the simulation (i.e. 2002).

Finally, for a better illustration of the set of data in Figure 5.13 static cost-resource curves for the additional mid-term potential of electricity from wind onshore are illustrated for Austria and Ireland. The influence of proper wind conditions is clearly indicated, explaining the apparent cost difference between these two countries. However, grid integration occurs as a huge deficit for wind power in Ireland, which results in a comparatively low realisable future potential up to 2020.

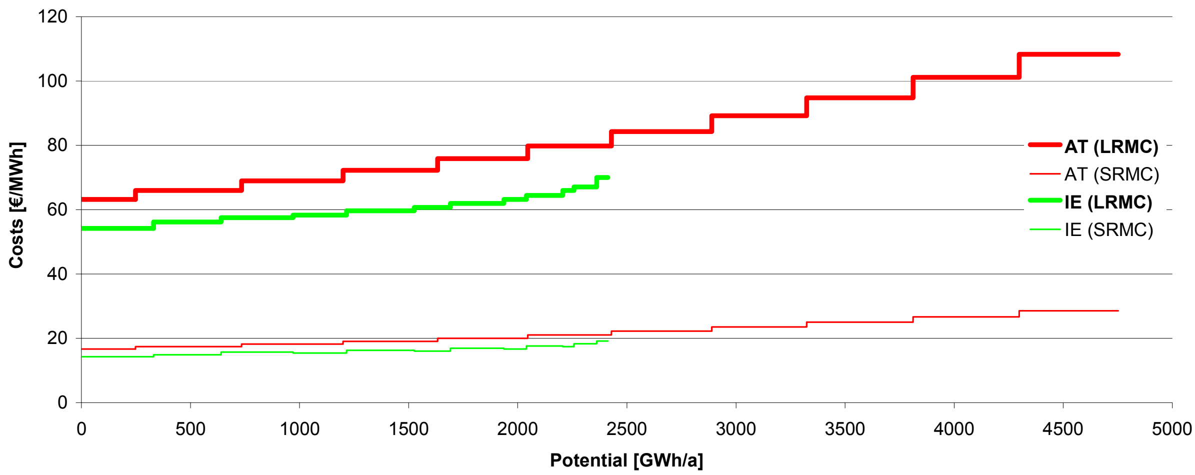


Figure 5.13 Static cost-resource curve for the additional mid-term potential of electricity from wind onshore in Austria and Ireland

5.3.2. Example: (Aggregated) static cost resource curve for Austria

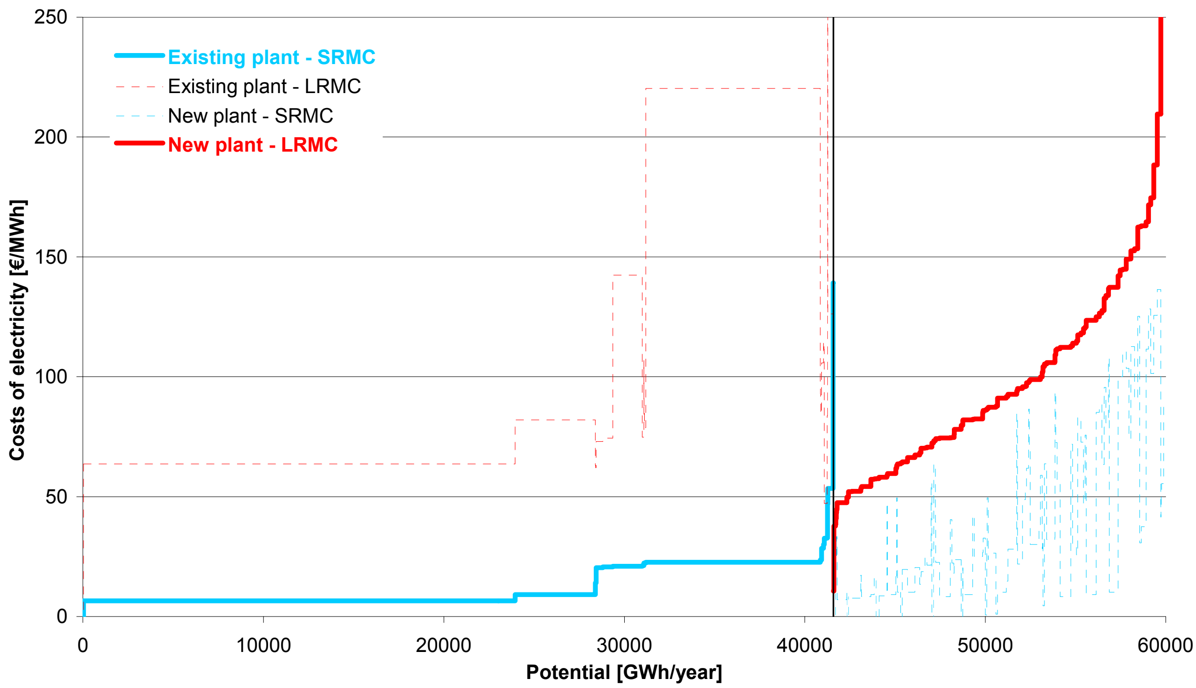


Figure 5.14 Static cost-resource curve for RES-E (incl. all RES-E options) in Austria – representing the achieved potential (i.e. existing plant) up to 2004 and the additional mid-term potential (i.e. new plant)

For illustrative purposes Figure 5.14 depicts a static cost-resource curve including all RES-E options on country level, namely for Austria. This depiction stands in accordance with the second example of the following chapter 6, i.e. the application of the model Green-X in energy policy assessment on national level. In contrast to default, the distinction between existing (i.e. achieved potential) and new plant (future options) refers to the year 2004, more precisely end of 2004.[117]

As can be seen, a fine-stepped curve emerges, where the continuous red line indicates the future potential of all RES-E options and the according long-run marginal generation costs. It represents the 'static point-of-view' – obviously, this additional potential can not be utilized within one or two years, but up to the mid-term if appropriate financial incentives are set to overcome the gap between the dynamically changing costs and the market price for (conventional) electricity, and, moreover, also non-economic barriers are removed.

5.4. Dynamic aspects

As described in section 3.2.2, 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.

5.4.1. 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*, see Table 5.5. 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 15 Member States is endogenously determined, i.e. is derived within the model.[118]

---

[117] In order to provide a reference to actuality, simulations runs start in this application example in the year 2005. Therefore an update of the database was undertaken. For details see section 6.2.

[118] For the case that only a single country is investigated, a default forecast – i.e. the 'BAU-scenario (B1)' as presented in section 6.1.6 – is taken as reference for the RES-E deployment on EU-15 level.

- For the new EU Member States (EU-10+) forecasts of the future development by RES-E categories are taken from the project 'FORRES 2020'; for details see (Ragwitz et al., 2004).
- Expected developments in the 'Rest of the world' are based on forecasts as presented in the IEA World Energy Outlook 2004 (IEA, 2004).

Table 5.5 Default settings with respect to the dynamic assessment of investment costs for RES-E technologies

RES-E category	Applied approach	Assumptions
Biogas	Experience curve (global)	LR (learning rate) = 5%
Biomass	Experience curve (global)	LR = 5%
Geothermal electricity	Experience curve (global)	LR = 5%
Hydropower	Expert forecast	No cost decrease in considered period
Photovoltaics	Experience curve (global)	LR = 15% up to 2010, 10% after 2010
Solar thermal electricity	Experience curve (global)	LR = 15% up to 2010, 10% after 2010
Tidal & Wave	Expert forecast	Cost decrease 5%/year up to 2010, 1%/year after 2010
Wind on- & offshore	Experience curve (global)	LR = 9%

Default assumptions with respect to technological learning or the cost decrease, respectively, as depicted in Table 5.5 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.[119]

One might argue that default settings are too conservative, but in this respect it has to be noted that besides the future development of investment costs also other cost and performance parameter are well considered in a dynamic context, leading – e.g. in case of biomass - to a uneven higher cost reduction in terms of resulting generation costs.

The **future development of fuel prices** as relevant for biomass and biowaste is – as default – based on the following settings: For the period up to 2010 it is assumed that they remain constant. Latter on, in the period 2010-2015 a slight rise of 0.5% per year and after 2015 a price increase of on average 1% is projected.

[119] 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).

5.4.2. 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-E. 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-E. Thereby, as in detail described in section 4.2.7, 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 as described in section 3.2.1 – of course, only if financial incentives are set appropriate.

The required data in this respect is described below. For a detailed explanation of the model implementation see previous section 4.2.7. Thereby, in accordance with equation (4-8) 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-E technologies in the past in European countries[120].

► 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 5.15, which indicates the ranges on country-level – occurring from differing bM settings for the available RES-E categories, and Figure 5.16, which complementary depicts the ranges on technology-level, a result of the differing settings by country. 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)).

[120] A detailed description of the econometric assessment as undertaken within this analysis will follow in (Ragwitz et al., 2005).

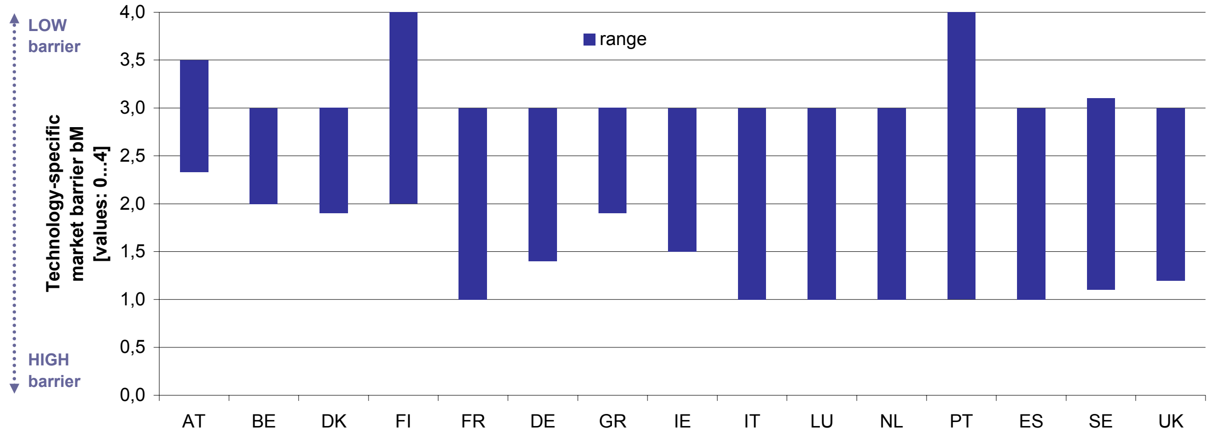


*Figure 5.15 Model-settings of dynamic parameters: Technology-specific ranges of applied **market barrier level (bM)** by country*

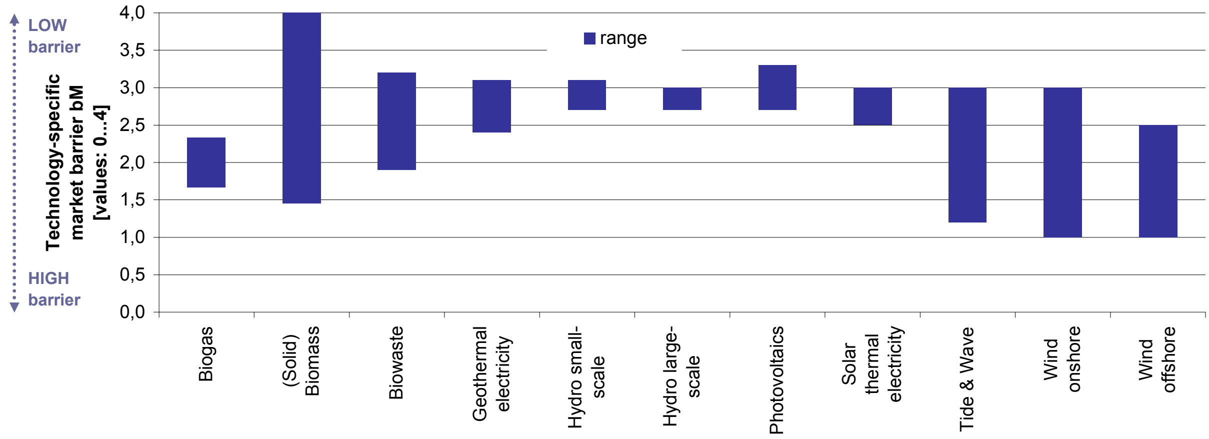


*Figure 5.16 Model-settings of dynamic parameters: Country-specific ranges of applied **market barrier level (bM)** by RES-E technology*

► 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 5.17 shows the ranges on country-level – occurring from differing parameter settings for the available RES-E categories, and Figure 5.18 complementary indicates ranges on technology-level, resulting from differing settings by country. Again, default take into account the current conditions for the various RES-E options in each country.

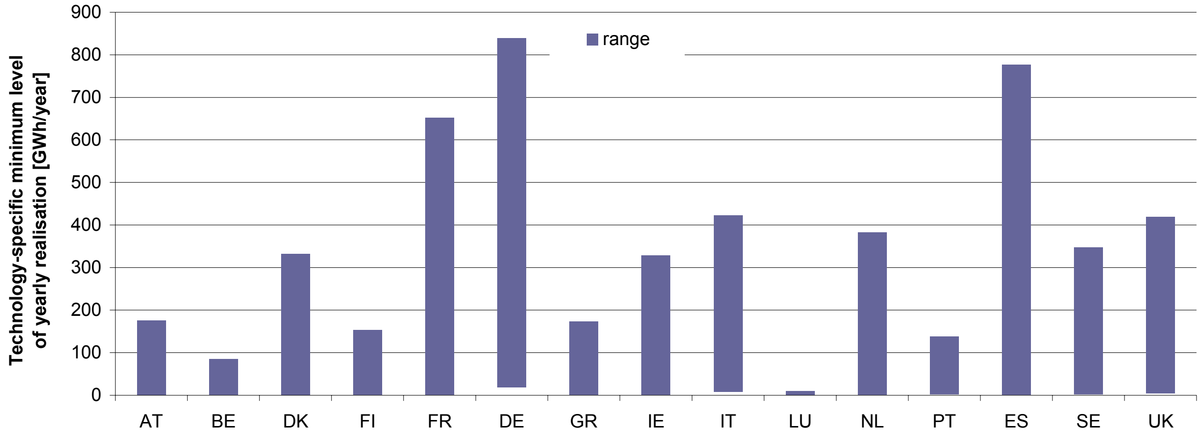


Figure 5.17 *Model-settings of dynamic parameters: Technology-specific ranges of applied* ***minimum market potentials ($\Delta P_{M\ min}$)*** *by country*

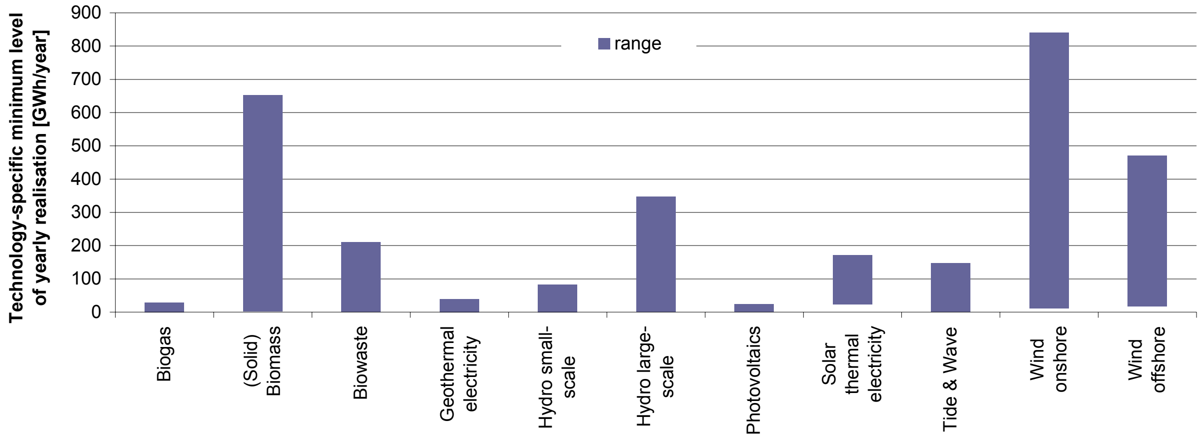


Figure 5.18 *Model-settings of dynamic parameters: Country-specific ranges of applied* ***minimum market potentials ($\Delta P_{M\ min}$)*** *by RES-E technology*

6. Results: Examples on the application of the dynamic cost-resource curves concept in the assessment of the future development and the evaluation of energy policy instruments

In the following two examples aim to illustrate the applicability of the dynamic cost-resource curve concept in combination with intensive energy policy modelling for the assessment of policy instruments. Furthermore, the practicability for forecasts of RES-E deployment based on policy inputs shall be demonstrated – of course, for a short to med time-horizon.

Glossary of important indicators in the policy assessment

To assist the interpretation of the applied indicators with respect to the assessment of energy policy strategies, a short glossary is listed below.[121] Note, as with respect to electricity generation misinterpretation is unlikely, it focuses solely on the economic assessment.

► (Average) financial support for new RES-E plant

Unit: €/MWh$_{RES}$

This indicator shows the dynamic development of necessary financial support for new RES-E installations (on average). Expressed values refer to the corresponding year. The amount represents from an investors point-of-view the average additional premium on top of the power price guaranteed (for a period of 15 years) for a new RES-E installation in a certain year, whilst from a consumer perspective it indicates the required additional expenditure per MWh$_{RES\text{-}E}$ for a new RES-E plant compared to a conventional option (characterised by the power price).

► Transfer costs for consumer (due to the promotion of RES-E)

Unit: M€/year or €/MWh$_{DEMAND}$

Transfer costs for consumer / society (sometimes also called additional / premium costs for consumer / society) are defined as direct premium financial transfer costs from the consumer to the producer due to the RES-E policy compared to the case that consumers would purchase conventional electricity from the power market. This means that these costs do not consider any indirect costs or externalities (environmental benefits, change of employment, etc.). The transfer costs for consumer are either expressed in Mio €/year or related to the total electricity consumption. In the later case the premium costs refer to each MWh of electricity consumed.

[121] These indicators are commonly applied in both examples in the following.

► <u>Total transfer costs for consumer (due to the promotion of RES-E)</u>

Units: M€ or % (in comparison to a reference case)

Total or *cumulated transfer costs for consumer in 2020* summarise both the cumulated consumer burden *within* the investigated period 2005 to 2020 as well as the residual costs for the years after 2020. Its calculation is done as follows: The required yearly consumer expenditure in the period 2005 to 2020 as well as the estimated residual expenditures for the following years after 2020 are translated into their present value in 2020.[122] More precisely, cumulated cost burden within the investigated period is calculated by summing up present values of above explained yearly transfer costs. Residual costs refer to RES-E plant installed up to 2020, and accordingly their guaranteed support.[123]

[122] Thereby, as default an inflation rate of 2.5% is applied.

[123] Assume e.g. a wind power plant is installed in 2015 and a support is guaranteed by a feed-in tariff scheme for 10 years. Accordingly, residual costs describe the required net transfer costs for the years 2021 to 2024.

6.1. Evaluation of policy instruments for RES-E at the European level with ***Green-X***

Note, in this first example also the conventional power market has been investigated, in order to consider possible trade-offs imposed by an (increased) RES-E deployment as well as due applied CO_2 constraints. Nevertheless, the core focus is put on RES-E policies, and such trade-offs are only described later on in section 6.1.8.

6.1.1. Evaluation criteria

As briefly described in section 3.3, support instruments have to be *effective* for increasing the penetration of RES-E and *efficient* with respect to minimising the resulting public costs (transfer cost for society / consumer) over time. Accordingly, this implies (i) to minimise generation costs, and (ii) to lower producer profits. In some cases both goals may not be reached together so compromise solutions must be found.

6.1.2. Definition of scenarios

The aim of the scenario runs is to analyse the effects of different support schemes – both harmonised and non-harmonised policies among the EU 15 Member States – with respect to RES-E deployment, investment needs, generation costs and transfer costs for consumers. Accordingly, they represent a contribution to the current discussion on a possible harmonisation of support instruments on EU level.[124] However, there is no prejudgment what the RES-E policy scheme should be used for in the future. Not even if a common RES-E promotion scheme should be implemented. As mentioned in section 2.4.2, if harmonisation would be proposed, a transition period of at least 7 years (thereafter) follows. Therefore, at least in the short/medium-term, national support schemes will be of crucial relevance in the promotion of RES-E. In the future – at least – some sort of combination of a community framework (harmonisation) and continuation of policies on Member State level for new and existing capacity is possible.

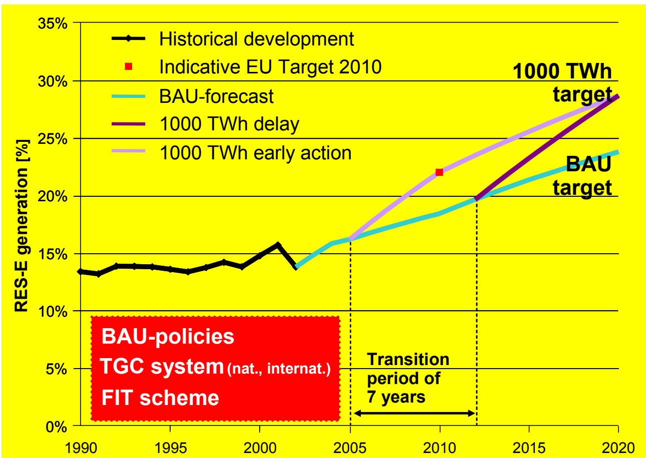


Figure 6.1 Investigated scenario paths

---

[124] By 10/27/2005 at the latest, the Commission should present a report on the experience gained with the application and coexistence of different support schemes in the Member States. The report may be accompanied by a proposal for a Community framework for RES support schemes (art.4.2).

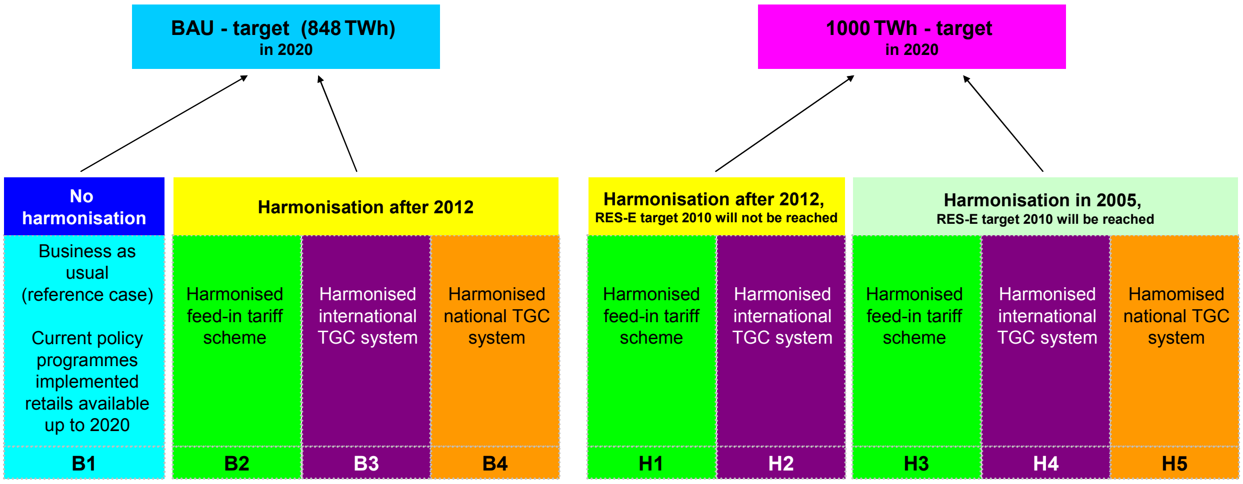


Figure 6.2 Overview on investigated cases – referring to the BAU- (left) and the 1000 TWh-target (right)

Figure 6.1 and give an overview of the investigated scenario paths and cases. Thus, the model runs try to consider the spread of possible RES-E policy deployment within the EU as follows:

- **No harmonisation**, where currently implemented policies remains available (without any adaptation) – business as usual **(BAU) forecast**
- After a **transition period of 7 years**, a **harmonisation of support schemes** takes places. To be able to analyse the effect of different (harmonised) policies compared to the status quo (BAU) it is assumed that the same RES-E target as under BAU conditions should be reached by 2020. The following currently most promising policies are investigated under harmonised conditions: Feed-in tariffs, international and national TGC systems
- To analyse the impact of the RES-E target on the efficiency of different support schemes, the achievement of a **more ambitious RES-E target for 2020** in size of **1000 TWh** is assumed for a further set of scenarios:
  - Current policy (BAU) up to 2012 - 7 year transition period - and a harmonised system thereafter. Again the goal should be reached by applying the following support mechanisms: Feed-in tariffs, international and national TGC systems
  - Harmonisation should already take place in 2005 and the indicative RES-E target in 2010 should be reached. Therefore, the effects of 'early actions' and a high interim target (2010 goal) can be shown.

6.1.3. Scenario assumptions

► <u>Gross electricity consumption</u>

The future development of country-specific electricity demands is set in accordance with the "DG TREN Outlook 2030: European Energy and Transport Trends to 2030 Outlook" (Mantzos et al., 2003a) – Baseline forecast. Therein it is projected, that electricity demand rises – on average – by 1.8% p. a. up to 2010 and by 1.5 % p. a. thereafter. Of course, on country level different demand projections are used. For example while the demand forecast for France is 2.2% p.a. up to 2010, a projection of only 1.1% p.a. is assumed for Germany.

► <u>Primary energy prices for biomass products</u>

Biomass prices are set as described in section 5.2.1, i.e. the default settings are applied. In the period 2010-2015 a slight rise of 0.5% per annum and after 2015 a price increase of on average 1% is projected.

► <u>Electricity prices</u>

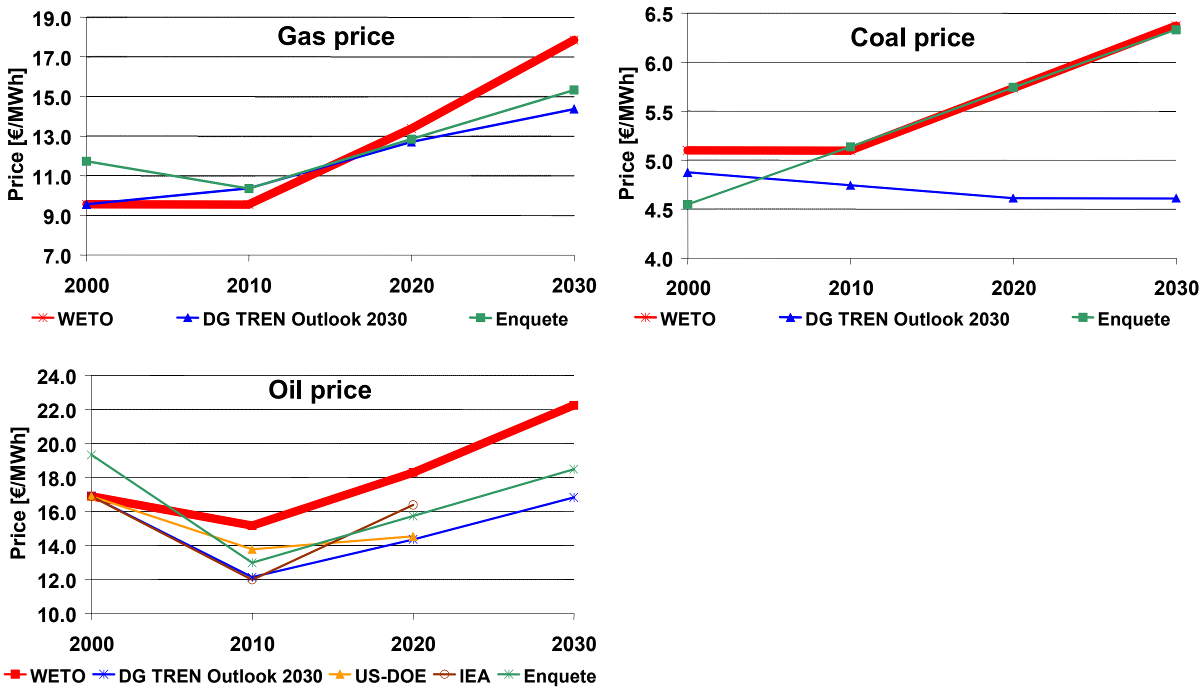


Figure 6.3 Projects of international gas, coal and oil price for Europe 2000-2030

For each EU 15 Member State the power price is derived endogenously within the ***Green-X*** model considering interconnection constraint among the countries. Calculations are based on the following settings:

- **Primary energy projections from the WETO project**. Figure 6.3 compares this cost forecast with other projections of relevance – e.g. DGTREN Energy Outlook 2030 (Mantzos et al., 2003a), Enquete commission of the German Bundestag (Enquete, 2002).
- **Different CO_2-policy assumptions**[125], namely
  - No-CO_2 constraint
  - Medium CO_2 constraint (assuming an increasing tradable emission allowance (TEA) price up to 10 €/t-CO_2)
  - High CO_2 constraint (assuming an increasing tradable emission allowance price up to 20 €/t-CO_2)
- **RES-E policies are as described in chapter 6.1.1**. Note, RES-E policy significantly influences the power market price.

[125] In the sensitivity analysis different CO_2-contraints are assumed, see section 6.1.9. The default assumption as applied in the policy assessment refers to a medium CO_2-constraint with a TEA price up to 10 €/t-CO_2.

► Interest rate / weighted average cost of capital

The determination of the necessary rate of return is based on the weighted average cost of capital (WACC) methodology.[126] Two options are considered in the analysis, namely 6.5% and 8.6%. These values are based on differing risk assessments, one standard risk level and a higher risk level characterised by a higher expected market rate of return. The 6.5% value is used as default, whilst 8.6% is used for sensitivity analysis and is applied in scenarios with lower stable planning conditions e.g. where support schemes impose a higher risk for investors (TGC system). To focus on the pure effects of the different strategies, no technology-specific risk premiums (different WACC according to their maturity and risk characteristics) are applied.[127]

► Future cost projection – technological learning

Default settings with respect to technological change are applied. For a brief description see section 5.4.1.

6.1.4. Assumptions for simulated policy instruments

The analysis focuses on the two most important support schemes within the EU, namely (i) a quota obligation based on tradable green certificates and (ii) a feed-in tariff system. A set of key input parameters are defined for each of the model runs as described below.

► General scenario conditions

Transfer costs for society hugely depend on the design of policy instruments. The design options of the instruments are chosen in a way such that transfer costs for society are low. In the model run, it is assumed that all investigated strategies – BAU as well as for reaching the 1000 TWh target by 2020 - are characterised by:

- Stable planning horizon
- Continuous RES-E policy / long term RES-E targets
- Clear and well defined tariff structure / yearly quota for RES-E technologies
- Reduced investment and O&M costs, increased energy efficiency over time.
- Reduction in barriers and high public acceptance in the long term[128].

In addition, for all investigated scenarios, with the exception of the BAU scenario (i.e. currently implemented policies remain available without adaptations up to 2020) the following design options are assumed

- Financial support is restricted to new capacity only [129]

[126] WACC is often used as an estimate of the internal discount rate of a project or the overall rate of return desired by all investors (equity and debt providers).

[127] For determining the exact setting of the support level such a technology specific WACC approach is useful. Such a procedure is - in a more detailed (country specific) analysis – feasible by applying the model ***Green-X***.

[128] In this context, it is assumed that the existing social, market and technical barriers (e.g. grid integration) can be overcome in time. The reduction depends on the assumed target, i.e. a more optimistic view is assumed for reaching the 1000 TWh target in 2020 compare to the BAU target.

[129] This means that only plants constructed in the period 2005 (or 2013, respectively) to 2020 are allowed to receive the support given by the new schemes applied on EU-15 level. Existing plant (constructed before a harmonised scheme is applied) remain in their old scheme

- Restriction of the duration in which investors can receive (additional) financial support. [130]

► <u>Scenario conditions assuming a quota obligation</u>[131]

- Tradable green certificates are standardised
- Full competition, i.e. (i) a high level of market transparency exist, (ii) an appropriate level of trading volume is available, (iii) investors are seeking the most efficient RES-E resources, leading to an idealised, fully competitive TGC market;[132]
- Additional support for less mature RES-E technologies does not exist
- Constant yearly interim targets are applied[133]
- Penalties for not fulfilling the quota obligation are set high amounts up to 200 €/MWh.

► <u>Scenario conditions assuming a feed-in tariff scheme</u>[134]

- Guaranteed tariffs are technology specific,
- Tariffs are set as low as is reasonable without causing a lower deployment rate over the RES-E portfolio.
- Guaranteed tariffs decrease over time or at least remain constant for certain RES-E technologies
- Tariffs for wind energy are designed as a stepped feed-in tariff [135]

6.1.5. Results – current situation up to the end of 2004

In order to provide an as recent as possible common base for the policy analysis, which is suitable for 'real world' policy discussions, a forecast is undertaken to deliver data for the years 2003 to 2004. This 'forecast' is based on a ***Green-X*** model run under the assumption that the currently implemented promotion scheme also remains available in 2004. Figure 6.4 illustrates the corresponding development of RES-E over time for the period 1990 to 2004, with (left) and without (right) hydropower.

An overview on the different RES-E options available in total EU-15 up to 2020 is given in Figure 6.5 – representing the perspective as common at the end of the year 2004. Accordingly, the already achieved potential for RES-E equals 448 TWh[136], whereas the

[130] In the model runs it is assumed that the time frame is restricted to 15 years

[131] With the exception of the quota obligation given in the current RES-E policies (BAU scenario)

[132] Otherwise costs rise due to strategic price setting.

[133] Interim targets are set in a way that the percentage increase between the single years is constant in the period 2013-2020 (for the case of a harmonised strategy beyond 2012) and in the period 2006-2010 and 2011-2020 (for the case that the indicative target in 2010 should be reached)

[134] With the exception of feed-in tariffs as currently implemented (BAU scenario)

[135] This means that the feed-in tariff will be reduced if actual generation is high. To set an incentive for investors to implement the most efficient technologies and locations, the reduction in the guaranteed price must be less than the total revenue that can be gained if an efficient plant and location are chosen. Profits will thus be higher at more cost effective sites. A stepped tariff e.g. is implemented in Germany

[136] The electricity generation potential represents the output potential of all plants installed up to the end of each year. Of course, figures for actual generation and generation potentials differ in

additional realisable potential up to 2020 amounts to 1078 TWh. Still hydro power dominates the RES-E market, but with limited future potential. The large (future) potential of wind energy (incl. on- and offshore), solid biomass and biogas may contribute to a large extent. In addition, new technologies like wave power and tidal stream or solar thermal electricity are yet to be developed on a large commercial scale in the EU 15.

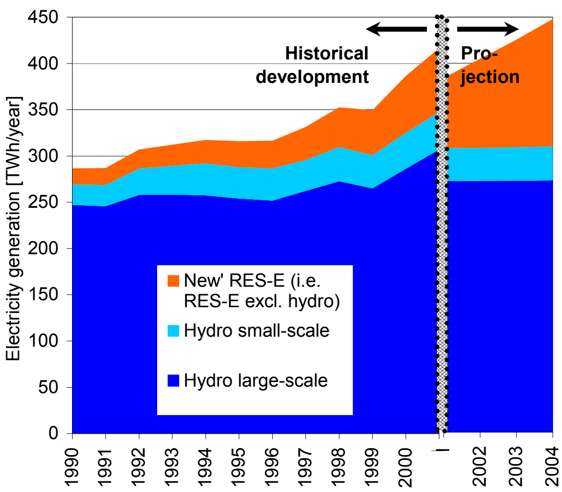


Figure 6.4 Electricity generation from RES in EU-15 countries from 1990 to 2004 – including (left hand side) & excluding (right hand side) hydro.

Source: Own investigations; Eurostat, 2003, ***Green-X*** *model run.*

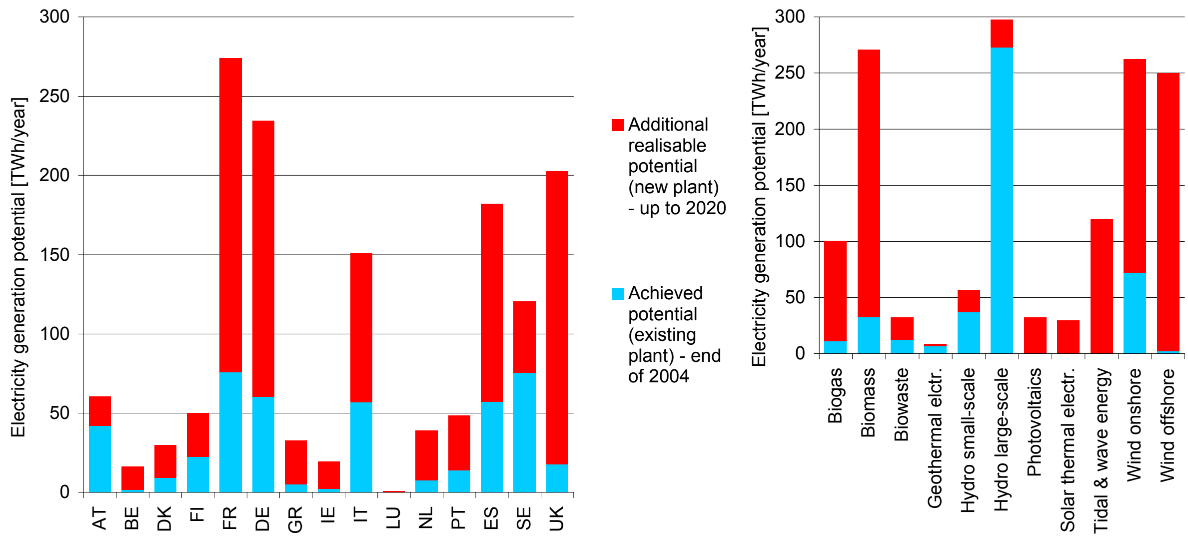


Figure 6.5 Achieved (2004) & additional mid-term RES-E potential (up to 2020) in EU-15 countries

Source: Own investigations; Eurostat, 2003, ***Green-X*** *model run.*

most cases – due to the fact that in contrast to the actual data, potential figures represent, e.g. in the case of hydropower, the normal hydrological conditions, and furthermore, not all plants are installed at the beginning of each year.

6.1.6. Results - BAU target in 2020

► RES-E deployment up to 2020 (BAU scenarios)

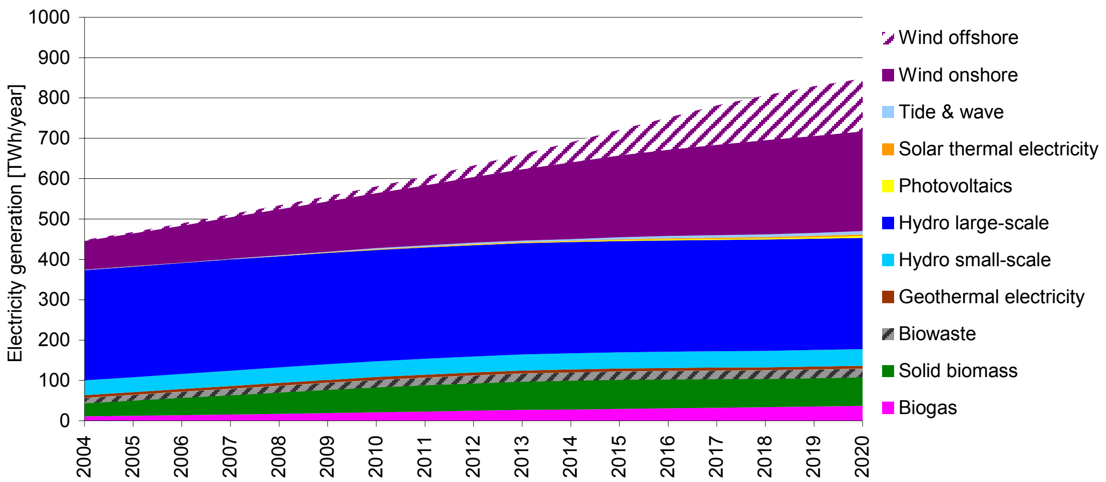


Figure 6.6 Development of RES-E generation 2004-2020 within EU 15 in the BAU scenario (B1)

Total electricity generation from renewable energy sources on EU 15 level was around 449 TWh in 2004.[137] Without any changes in support schemes it will rise to roughly 581 TWh in 2010 (equals 19.0% of gross consumption) and 848 TWh in 2020 (24.3%). This amount is – according to the BAU demand projection of (Mantzos et al., 2003a) – around 93 TWh (2% of gross demand) less than the EU target as set by the 'RES-E Directive' (2001/77/EC).[138] Remaining the current policy schemes, the EU target 2010 can be reached with a delay of around 3 years (efficiency demand according to (Mantzos et al., 2003b)) and 5 years (BAU demand according to (Mantzos et al., 2003a)), respectively.

The dynamic development of RES-E generation for the BAU case is depicted in Figure 6.6. On country level large differences in the future RES-E deployment occur. Three countries would reach the indicative RES-E targets in 2010 without any adaptation of their current strategy; namely Germany, the Netherlands and UK (assuming a binding penalty). Substantial additional RES-E penetration can be expected in most countries after 2010.

Due to less public support and acceptance, the amount of large scale hydro power plants will increase only marginally in absolute terms.[139] In relative terms the share drops significantly from around 60% in 2004 to 33% in 2020. The 'winner' among the considered technologies is wind energy, both onshore and offshore. It can be expected that around 45% (30%) of the RES-E production of plants installed after

[137] Note: RES-E generation in 2004 refers to available capacity of RES-E times normal (average) full load hours of the technologies. This means actual generation can differ from this value due to (i) variation of generation from average conditions (e.g. for hydropower or wind) and (ii) new capacity build in 2004 is not fully available for the whole period 2004.

[138] Assuming an electricity demand projected according to the efficiency scenario (Mantzos et al., 2003b), the share of RES-E amounts 20% in 2010 and 26.9% in 2020.

[139] Considering the effects of the 'Water Framework Directive' (European Parliament and Council, 2000) the total electricity generation from (large scale) hydro can even be lower in 2020 compared to the current level.

2004 in 2020 is coming from wind onshore (offshore), resulting in a share of around 30% in case of wind onshore and 15% for wind offshore on total RES-E generation in 2020, respectively. Other significant increases can be expected for solid biomass (+ 8%) and biogas (+ 6%). The portfolio of RES-E technologies indicates significant differences among the Member States as is evident from Figure 6.7.

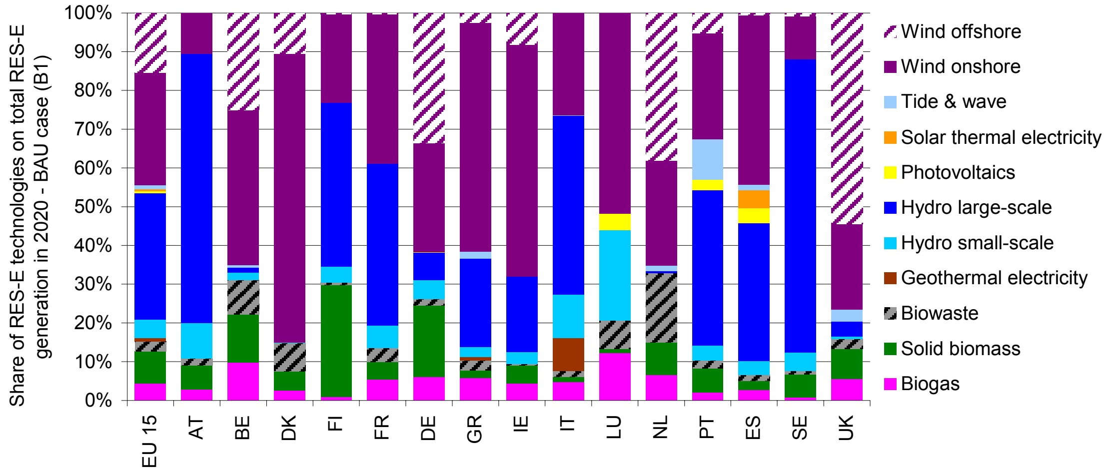


Figure 6.7 *Portfolio of RES-E technology on RES-E generation in 2020 among the Member States under BAU conditions (B1)*

The highest amount of 'new' RES-E in absolute terms is projected for the UK and Germany, followed by France, Spain and Italy. In general, actual generation depends on the applied policy and partly varies significantly among countries.

► <u>Investment needs & resulting technological learning</u> (BAU scenarios)

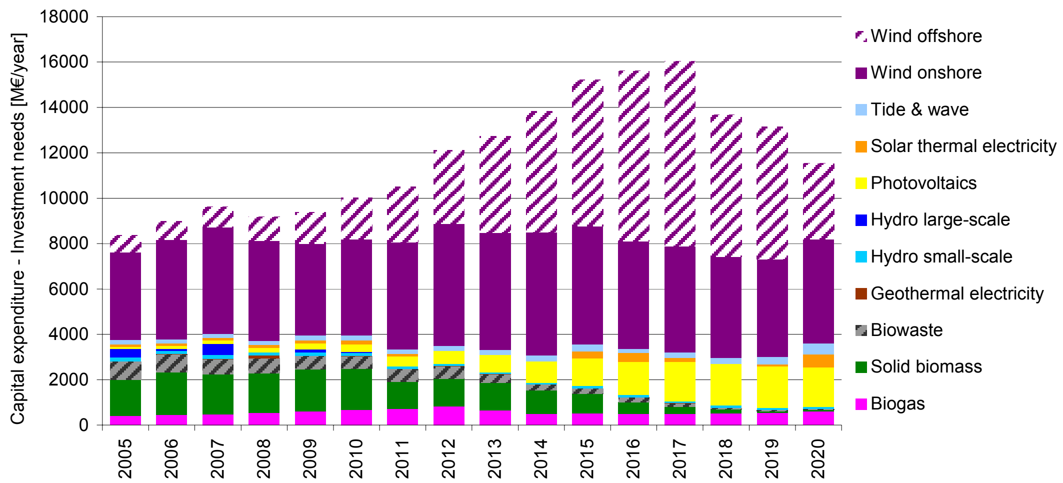


Figure 6.8 *Total investment needs in the period 2005-2020 within the EU-15 in the BAU scenario (B1)*

High investments are necessary to be able to build up the new capacity. Figure 6.8 shows the total investment needs for RES-E over time assuming BAU policy up to 2020. While necessary investments into wind onshore and biogas plants are relative stable over time, investments into solid biomass plants (including biowaste) mainly occur in the first years (2005-2015) and for wind offshore and photovoltaic mainly after 2010.

These investments in new technologies within the EU (as well as in the rest of the world) stimulate technological learning, leading to lower costs in the future. Figure 6.9 depicts the resulting cost reduction of specific investment costs for various RES-E technologies. The highest decrease is projected for tidal & wave energy and photovoltaics, leading to a cost level in 2020 in size of roughly 60% compared to 2020, followed by solar thermal electricity and wind energy.

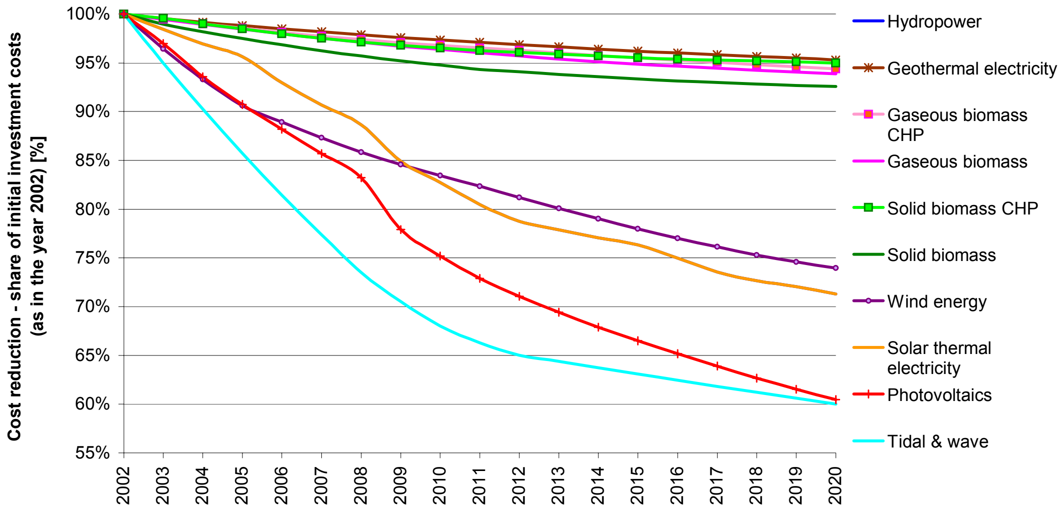


Figure 6.9 Development of the specific investment costs for various RES-E technologies according to the BAU scenario (B1)

► <u>Financial support for new RES-E</u> (BAU scenarios)

Next, financial incentives as dedicated to new RES-E plant are discussed. Figure 6.10 compares the average financial support for new RES-E capacities for the four investigated cases B1 to B4. As explained before, this item indicates from a consumer perspective necessary premium per MWh_{RES-E} for a new RES-E plant compared to a conventional option (characterised by the power price)[140]

With respect to the BAU policy (B1) it can be concluded that the average premium costs remain constant up to 2012 and decreases thereafter. The reduction, however, is lower than introducing a harmonised well designed technology specific feed-in tariff scheme (B2). Again, the necessary support nearly drops continuously over time.[141] In contrast to this scheme the entity of both a national and international TGC system is to promote currently least cost generation options (only).[142] Hence, in the first year(s)

[140] Note: At this stage a power price reduction due to the promotion of RES-E is neglected. Hence, premium costs are (slightly) overestimated.

[141] Note: The incentive compatible feed-in tariff is designed that the necessary amount drops over time. The slight increase in 2014 results from a higher exploitation of expensive options.

[142] By using technology-cluster specific quotas or granting additional support for less mature technologies a different dynamic support development can be reached

premium costs are low but increase over time as cheap production options are already used.[143]

It can be observed that premium costs for consumer are higher applying a national TGC scheme compared to an international one. In addition, considering the higher risk associated with a TGC scheme for the investors a higher support is needed in comparison with a technology specific well designed feed-in system.[144]

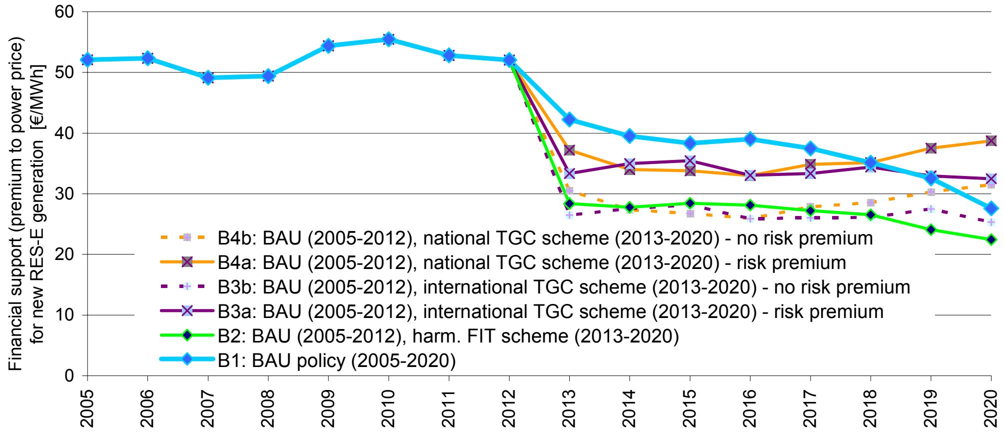


Figure 6.10 Comparison of financial support (average premium to power price) for new RES-E generation on EU 15 level in the period 2005-2020 for the cases (B1-B4)

The application of current policies leads to a high spread of the granted financial support for new RES-E among the countries as depicted in Figure 6.11a.

The necessary support per MWh new RES-E generation can be harmonised between the countries to a large extend by applying harmonised feed-in tariff schemes, see Figure 6.11b, or fully by applying an international TGC scheme, see Figure 6.11c.[145] In contrast to these two schemes national TGC systems do not (automatically) lead to similar or the same financial incentives for new RES-E production in all countries as illustrated in Figure 6.11d.[146] The premium depends on the national RES-E target setting. Assuming that the same national RES-E deployment as under the BAU policy should be reached, high distortions between the countries occur.[147]

---

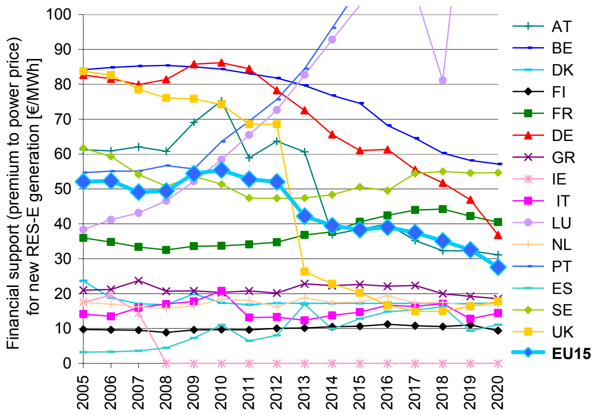
143 The development of the premium costs depends on a set of parameter – including the mid term target, the available potential and the cost reduction due to technological learning.

144 For comparison, the 'necessary' premium for the TGC-variant, where no additional risk premium is applied, is depicted in Figure 6.10, too (dotted lines).

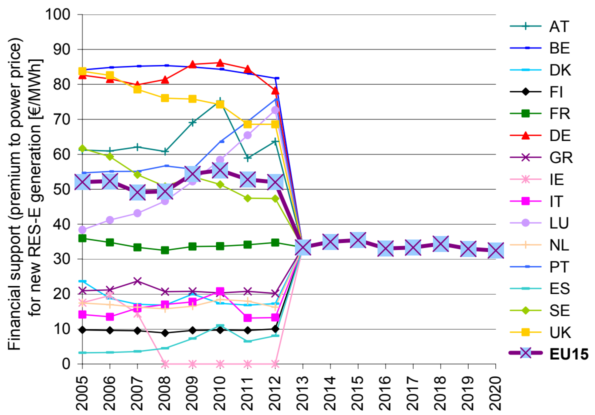
145 The remaining differences occur due to the different technology mix. In the case that for each technology the same tariff level – which of course is inefficient with respect to the consumer burden – is granted the premium support would be equal in each country, too.

146 Note: Harmonisation in the case of a feed-in scheme means that the same tariffs for the different technologies are granted. As RES-E portfolio and power price differ by country, (slight) variations in the average support occur.

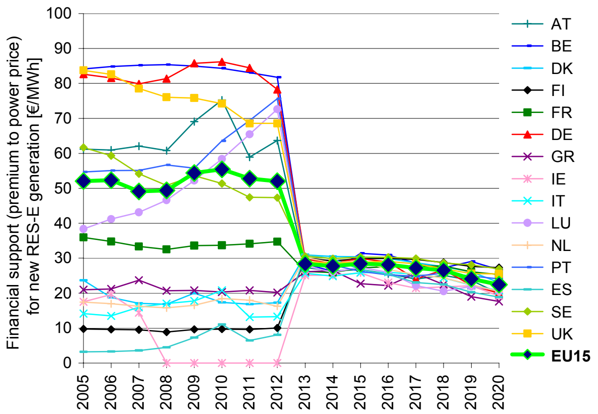
147 This fact confirms the existence of large variations in the current RES-E support.



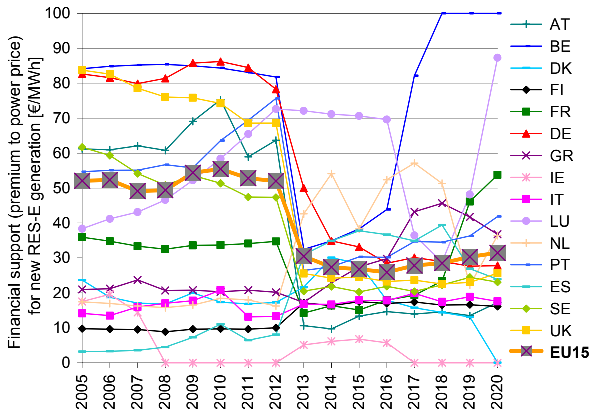
(a) **current RES-E policy schemes** (case B1)



(c) **international TGC scheme** after 2012 (case B3)



(b) internationally harmonised **feed-in tariff scheme** after 2012 (case B2)



(d) **national TGC schemes** after 2012 (case B4)

Figure 6.11 Country specific financial support (average premium to power price) for new RES-E generation in the period 2005-2020 for the cases (B1-B4):
*(a) applying **current RES-E policy schemes** (B1) … (top-left)*
*(b) applying an internationally harmonised **feed-in tariff scheme** after 2012 (B2) … (bottom-left)*
*(c) applying an **international TGC scheme** after 2012 (B3) … (top-right)*
*(d) applying **national TGC schemes** after 2012 (B4) … (bottom-right)*

Summing up, it can be concluded that the application of a harmonised approach leads to a uniform support per MWh of RES-E in the countries. This means that distortions of the technological development of each RES-E technology among the Member States can be avoided.

► Transfer costs for consumer (BAU scenarios)

The yearly necessary transfer costs for consumer on EU level reaching the BAU target over time are depicted for the four investigated cases in Figure 6.12. Thereby, transfer costs are related to gross electricity demand – expressed as required premium per MWh of demand. The yearly burden is highest remaining the current policy schemes. In this case transfer costs for society rise utmost continuously over time. For all other variants – i.e. by applying a harmonised approach – a significant reduction of the cost burden occurs after their introduction, indicating the inefficiency of (some) support schemes at present. Costs stay on a stable level applying technology specific feed-in tariffs from 2013 on, whilst for the TGC variants an increase can be observed in the last years up to 2020.

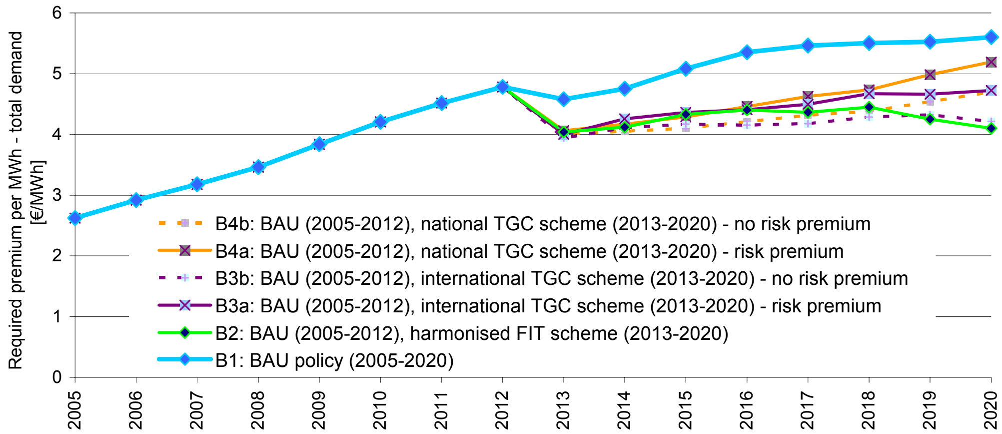


Figure 6.12 Comparison of necessary transfer costs for consumer reaching the BAU target 2020 for the cases (B1–B4)

Harmonisation reduces the distortion with respect to the required transfer costs for consumer among the countries. Nevertheless, the same promotion of one unit of new RES-E for each technology in the different Member States (harmonisation of the schemes), however, does not automatically result in a uniform burden for the consumer per MWh electricity consumption.[148]

In the case of a feed-in tariff or tender scheme the transfer costs (i.e. the required premium per MWh of demand due to the promotion of RES-E) for consumer depend on the actual national RES-E deployment. This means that the burden for the consumer is high in countries with a high RES-E deployment.[149] In the case of an international TGC scheme the burden depends on the agreed national RES-E target, i.e. costs are independent from actual national RES-E deployment; the different to the quota level can be sold at or must be purchased from the international TGC market.[150] Applying a national TGC scheme the transfer costs for consumer depend on the agreed TGC target too, however, without the opportunity to use all efficient RES-E generation options if the target setting among the countries is inappropriate.

In addition, the yearly transfer costs for consumer depend on the historical promotion of RES-E. These costs are independent from the actual RES-E policy as it is assumed that existing capacity (i.e. installed before harmonisation as of 2013) remains in their old promotion scheme – the new schemes are applied to new capacity only.

Note that the *yearly* transfer costs represent the actually yearly imposed consumer costs and are not fully comparable among each other with respect to the *total* burden for the consumer[151]. For example in the case of the BAU scenario some countries are

[148] Note, an approach how to harmonise the burden for the consumer among the countries for such a case is discussed in (Huber et al., 2004).

[149] Differing deployments are a result of the country-specific resource characteristics – i.e. a high resource-specific potential causes a high penetration.

[150] In this investigation it is assumed that each country is imposed by the same RES-E target for new plants. This means that the burden referring to the promotion of new RES-E after 2012 (by a harmonised policy, i.e. a uniform quota for new RES-E) is equal among consumer in the EU15.

[151] However, they are fully comparable regarding the *yearly burden* for the consumer.

granting investment incentives, resulting in high yearly costs for new RES-E capacity but lower costs in the years thereafter. A simple sum-up of yearly costs in the period 2005 to 2020 as expressed in Figure 6.12 does not lead to a comparable indicator, as differences among the cases with respect to the guaranteed durations[152] of support as well as 'residual costs'[153] in the period after 2020 are neglected.

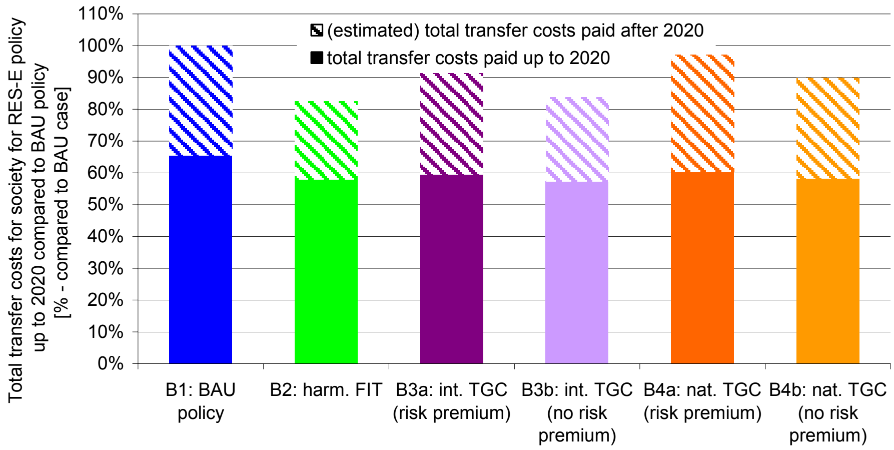


Figure 6.13 Comparison of necessary cumulated total transfer costs for consumer due to RES-E policy up to 2020 reaching the BAU target 2020 (B1 – B4).

Note: In the case of a TGC scheme total transfer costs paid after 2020 are estimated assuming that the TGC price in the year 2020 is constant up to the phase out of the support

A comparison of the *'full'* or *cumulative transfer costs for the consumer* is given in Figure 6.13. Thereby, the proportion of residual costs after 2020 (dotted area) is higher under a TGC scheme than under a feed-in system as the TGC price is high in 2020. Total transfer costs for society are lowest applying technology specific support, followed by an international TGC system. Total costs are highest retaining the current country-specific RES-E policies up to 2020, slightly above the burden in case of national TGC systems.

6.1.7. Results - 1.000 TWh target in 2020

► <u>RES-E deployment up to 2020</u> (1000 TWh scenarios)

To analyse how the RES-E target influences the RES-E portfolio and the efficiency of different support schemes, a further set of model runs are carried out fulfilling a more ambitious RES-E target. Figure 6.14 depicts the development of RES-E generation reaching 1000 TWh in 2020 on EU-15 level for the period 2004 to 2020.

---

[152] The yearly burden can be influenced by changing the guaranteed duration of the support. For example the yearly amount increases by guaranteeing a tariff for 10 years instead of 15 years. In contrast, the total burden would remain approximately constant as transfer costs have to be paid over a period of 10 years.

[153] For the harmonised cases a guaranteed duration of 15 years is assumed. This means that a capacity, which is built in 2019 will receive a public support up to 2034. In Figure 6.8, however, only the costs for the years 2019 and 2020 are depicted, neglecting the full 'residual costs' up to 2034 in the period after 2020.

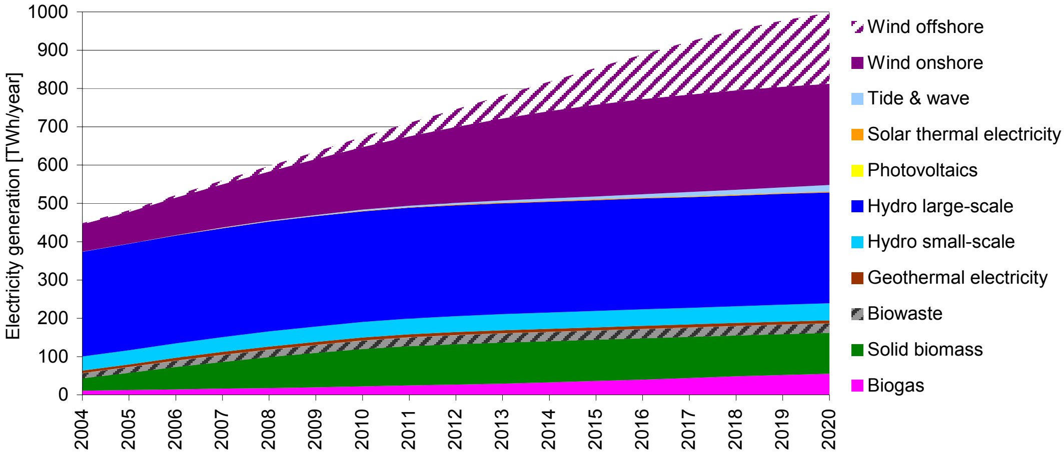


Figure 6.14 Development of RES-E generation 2004-2020 within EU-15 in the 1000 TWh scenario (case H3)

The country-specific portfolios for reaching the 1000 TWh as illustrated in Figure 6.15 (for the case of harmonised Feed-in tariffs) differ partly significantly compared to fulfilling the lower BAU target, i.e. 848 TWh by 2020. This gets evident also on EU-15 level: For example the share of wind onshore on the new RES-E generation 2005-2020 drops from around 45% to 36% as less additional potential is available contributing to a higher RES-E target. The share of wind offshore decreases too; but to a much lower extent. In contrast, electricity generation from (solid) biomass increases dramatically, from around 9% to 17%. Summing up, the portfolio is more homogenously distributed among the RES-E options, i.e. a higher spread of different RES-E technologies is necessary fulfilling the ambitious target. Thereby, the highest additional RES-E generation compared to BAU occurs for Germany, France, Spain, Italy, Sweden, Finland, Denmark und Ireland.

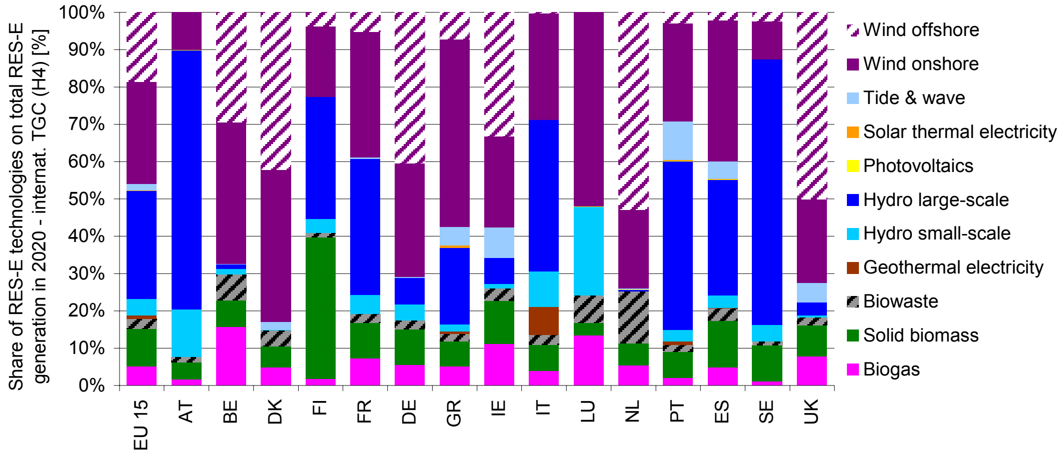


Figure 6.15 Portfolio of RES-E technology on RES-E generation in 2020 among the Member States in the 1000 TWh scenario (variant H3)

► <u>Investment needs & resulting technological learning</u> (1000 TWh scenarios)

The yearly investment needs can be estimated with around 14.000 to 16.000 M€. Similar to the BAU cases, investments for biomass mainly take place in the first decade. In the later phase investments needs increase for wind offshore, tide & wave as well as biogas, see Figure 6.16.

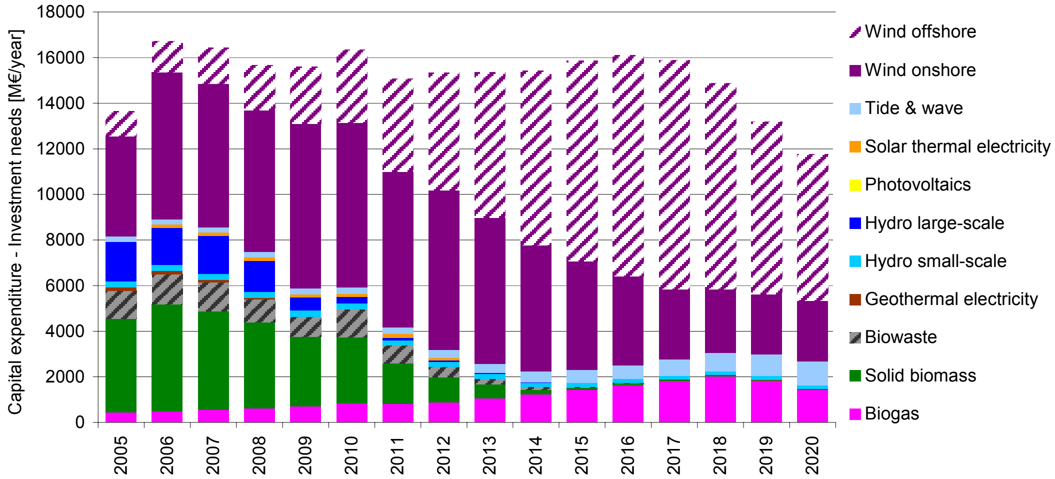


Figure 6.16 Total investment needs in the period 2005-2020 within the EU-15 in the 1000 TWh scenario (variant H3)

In general, an increased deployment induces an accelerated technological learning and, consequently, results in an increased cost reduction. A comparison with the BAU-case indicates a higher reduction especially for solid biomass and biogas (+3%[154] in 2020) and wind energy (+2% in 2020).

► <u>Financial support for new RES-E</u> (1000 TWh scenarios)

Figure 6.17 shows the granted average financial support for new RES-E installations for all investigated 1000 TWh scenarios over time. Assuming a harmonised approach after 2012 (H1 and H2) a similar picture as for the BAU cases can be observed: The necessary support in the case of a feed-in tariff scheme decreases and for a TGC scheme increases over time.[155] The effects of a harmonised strategy starting already in 2005 (H3 to H5) can be summarised as follows: Under this assumption different grant level are needed. In all cases – feed-in tariff, international and national TGC scheme – the support (slightly) drops over time. The amount, however, differs significantly. Costs within a national TGC scheme are extremely high as some countries are unable to reach their indicative target in 2010. Hence, the national TGC price corresponds with their penalty price, which is assumed to be high (200 €/MWh).[156,157]

---

[154] In the 1000 TWh scenario it is expected that the specific investment costs for the broad set of biomass and biogas technologies decrease on average to a level of 92% compared to 2002, whilst in the BAU-case a reduction to 95% occurs.

[155] Despite using efficient mechanism, costs are higher for the 1000 TWh target in 2020 compared remaining the current strategies in place and reaching 848 TWh by 2020.

[156] Assuming a low penalty the incentive to fulfil the RES-E quota is low. Under this assumption investments will be postponed, i.e. higher costs occur later.

[157] To underpin the effect of reaching a high interim target as set by the 'RES-E Directive', model runs have also been carried out assuming that this target must not be reached. It can be observed that in both cases – feed-in tariff and international TGC scheme - the necessary support is lower in the first years, however with a more moderate reduction over time.

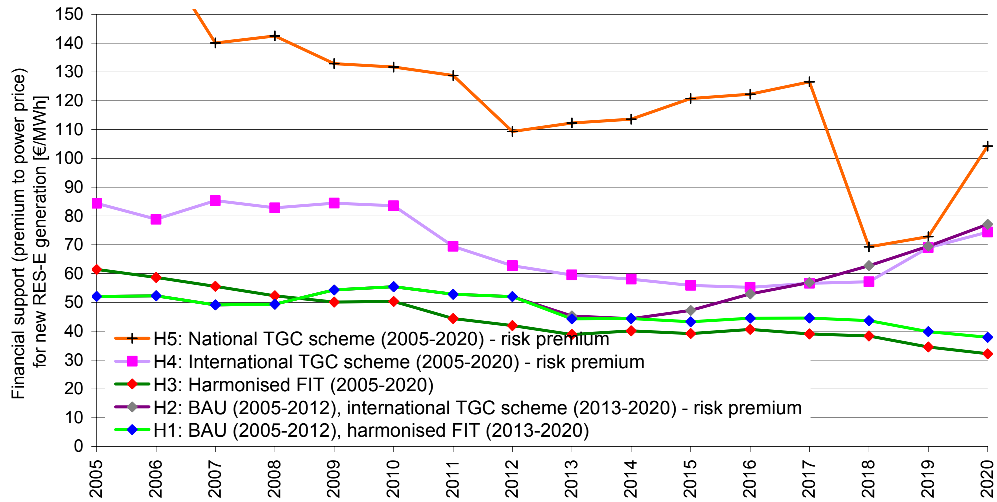


Figure 6.17 *Comparison of financial support (average premium to power price) for new RES-E generation on EU 15 level in the period 2005-2020 for the cases (H1-H5)*

► <u>Transfer costs for consumer</u> (1000 TWh scenarios)

The *yearly transfer costs for consumer* for all investigated 1000 TWh cases are depicted in Figure 6.18. The effects with respect to the yearly transfer payments for the consumer correspond well with the development of the financial support curves per MWh of new RES-E generation. For the case that harmonisation should take place after a transition period of 7 years the following main effects can be observed: Yearly transfer costs are higher in the early phase applying a feed-in tariff scheme compared to an international TGC scheme as, firstly, the tariff is designed in a way that it drops over time and, secondly, a higher deployment occur in this (early) period.

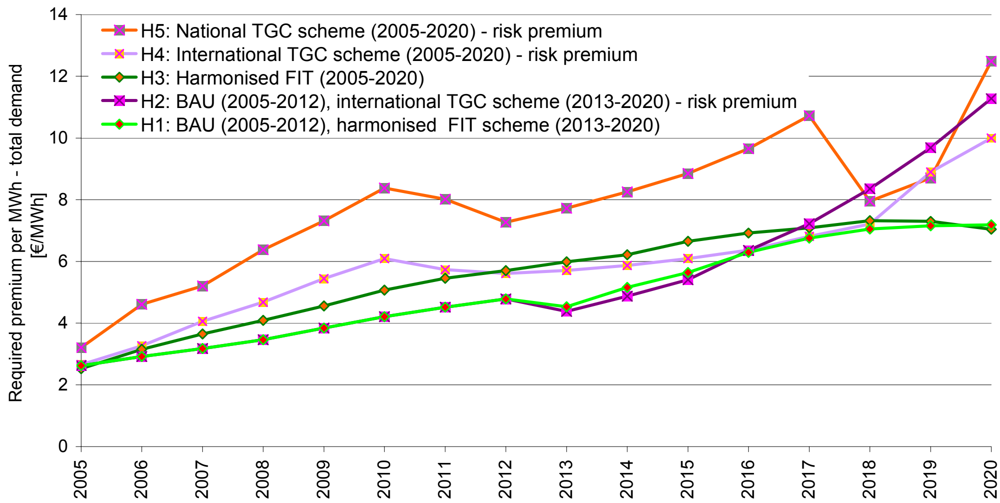


Figure 6.18 *Comparison of necessary transfer costs for consumer reaching the 1000 TWh target in 2020 starting 2005 and 2013 with a harmonised approach (H1–H5)*

Assuming a full harmonisation already in 2005, transfer costs within a TGC scheme are (much) higher if the target (quota) is very ambitious (high interim target 2010 target) and with advanced RES-E deployment, i.e. from 2018 onward.[158]

With respect to the *cumulative transfer costs* – see Figure 6.19 - it can be clearly concluded that technology specific support mechanisms are preferable to fulfil an ambitious RES-E target in the future compared to schemes, which neglect this specification. In all investigated cases transfer costs are lower applying a well designed technology specific feed-in tariff system compared to a common TGC scheme.[159]

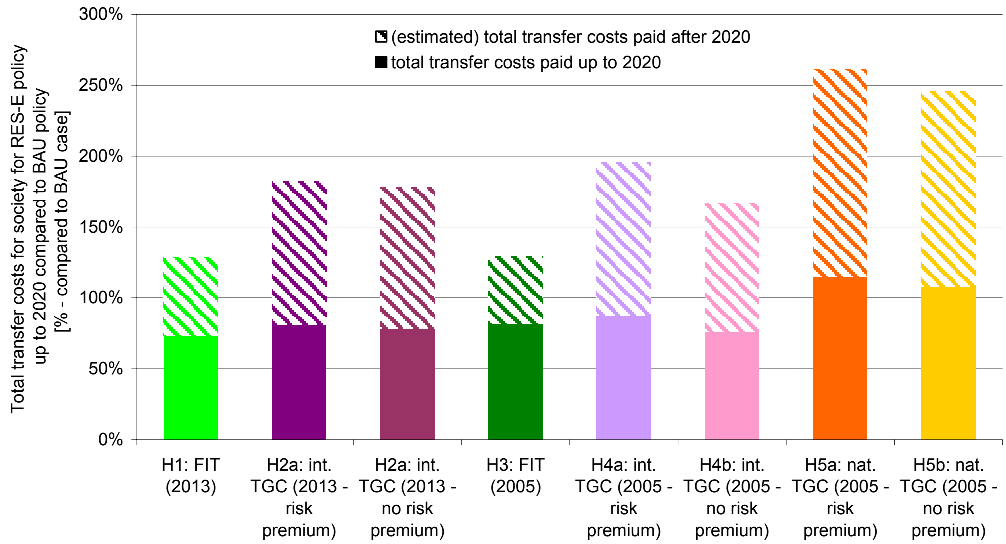


Figure 6.19 *Comparison of total transfer costs for consumer due to RES-E policy up to 2020 reaching the 1000 TWh target in 2020 (H1–H5).*
Note: In the case of a TGC scheme total transfer costs paid after 2020 are estimated assuming that the TGC price in the year 2020 is constant up to the phase out of the support

6.1.8. Impact of RES-E deployment on conventional power price and CO_2 emissions

Finally, the effects of RES-E deployment should be analysed in brief. Figure 6.20 gives an impression of the impact of RES-E deployment on the wholesale electricity price. A price reduction of 5% (BAU target) to 10% (1000 TWh target) can be observed compared to the case of no additional promotion of RES-E in the future.[160]

This means that – neglecting possible back-up costs for RES-E – deployment of RES-E leads to a price reduction on the power market of 5% to 10%. Total additional cost (burden) due to the promotion of RES-E by considering the additional transfer costs for consumer are in the magnitude of 3% (5%) for a feed-in tariff schemes and reaching the

[158] Note: Due to the high support level also less mature technologies will be stimulated.

[159] In (Resch et al., 2005b) it is shown that also technology-specific TGC systems lead to higher consumer burden compared to a well designed feed-in tariff system.

[160] More precisely, it is assumption that (i) no RES-E policy exist in the future, and (iii), a market price for tradable emissions allowances of 10 €/t-CO_2,

BAU target (1000 TWh target) up to 15% in 2020 in case of a TGC scheme for the 1000 TWh target.

Due to an additional price of 3% - 15%, however, CO_2-emissions from thermal power plants can be reduced by 20% to 25% - see Figure 6.21.

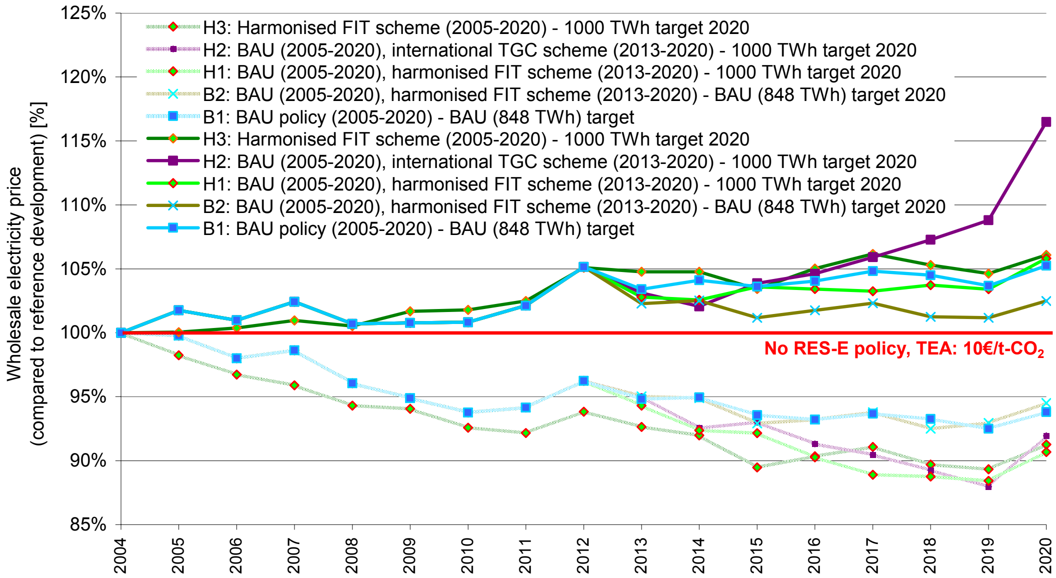


Figure 6.20 Comparison of wholesale electricity price including RES-E premium compared to reference development (no RES-E policy and TEA price of 10€/t-CO_2)

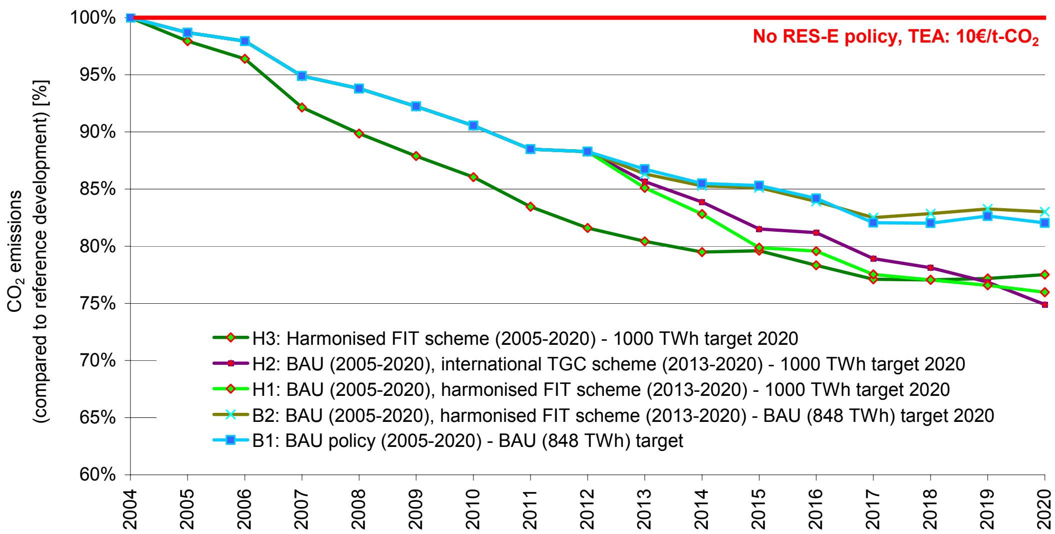


Figure 6.21 Comparison of CO_2-emissions compared to reference development (no RES-E policy and TEA price of 10€/t-CO_2)

6.1.9. Sensitivity analysis

In the following, four sensitivity cases will be outlined, accompanying the set of scenarios as described in the previous sections. In more detail, resulting electricity generation of RES-E and accompanying transfer costs for consumer will be compared to the default development of the BAU-scenario (B1) for a variation of:

- The reference price for (conventional) electricity (i.e. by imposing differing CO_2-constraints);
- Dynamic barriers (i.e., as applied to the various RES-E options to limit yearly realisations);
- Assumptions referring to technological learning (i.e. by varying learning rates as assumed on technology level);
- The Weighted Average Cost of Capital (WACC) (with impact on offer / bid prices of RES-E producer).

► <u>Impact of the reference price for (conventional) electricity</u>
(due to differing CO_2-constraints)

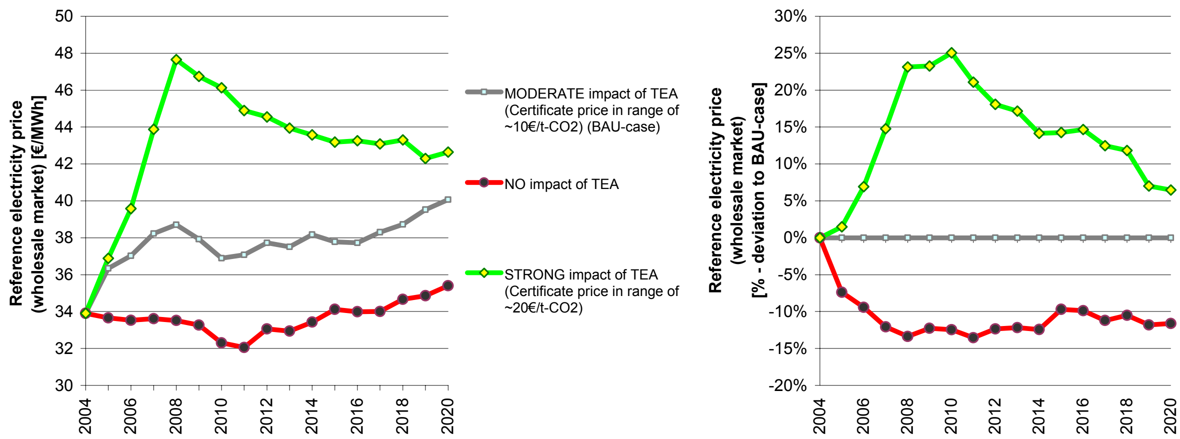


Figure 6.22 Development of the applied reference electricity price (on the wholesale market) up to 2020 for the sensitivity cases – in absolute (left) and relative terms (right – indicating the deviation to the default case (B1))

The first sensitivity case describes the impact of the reference price for (conventional) electricity on the outcomes of the analysis. Figure 6.22 depicts the development of this parameter for the investigated cases in absolute as well as the deviation to the default case in relative terms over time. Note, that these scenarios are calculated by modelling also the conventional power market in the EU15. Hence, differing reference prices are a result of applied CO_2 constraints, i.e. represented by the impact of Tradable Emission Allowances (TEA). More precisely, the following variants are investigated:

- A 'low price case' – i.e. characterized by the fact that **no impact of TEA** occurs.
- A 'moderate price case' – i.e. where a **moderate impact of TEA** can be observed (assuming an increasing tradable emission allowance price up to 10 €/t-CO_2). This variant represents the default case with respect to the conventional power market – as used for all scenarios illustrated in the previous sections.
- A 'high price case' – i.e. characterised by high reference prices as a result of a **strong impact of TEA** (assuming an increasing tradable emission allowance price up to 20 €/t-CO_2).

As can be seen in Figure 6.22, in case of a medium to high CO_2 constraint the power market requires a few years to match with the changing framework conditions. However, differences in prices will obviously remain also in the mid to long term, but they are comparatively smaller between a high and a medium CO_2 constraint in contrast to the case where no CO_2 constraint is applied.[161]

The **impact on RES-E deployment** retaining current RES-E policies (BAU-policies) on EU-15 level is depicted in Figure 6.23 (left) and Figure 6.24. Thereby, the development of total RES-E generation over time for the period 2004 to 2020 – see Figure 6.23 (left) – as well as total RES-E generation in the (final) year 2020 – see Figure 6.24 – is illustrated by expressing the deviation to the default case (B1).

On the face of it, one might argue that RES-E generation would not be influenced tremendously by a moderate variation of the reference price for (conventional) electricity on EU-15 level, as only a few countries are currently applying a promotional scheme where the financial incentive is defined as fixed premium on top of the electricity market price.[162] Hence, the results of the sensitivity cases do indeed show only small differences in terms of RES-E deployment:

- In the investigated period deviation to default is less than +/-3.5% for both variants, whilst the applied reference electricity prices vary in a range from -14% (low price variant) to + 25% (high price variant).
- Obviously, a positive correlation can be observed – i.e. a higher reference price results in a higher RES-E deployment and vice versa.
- Up to the mid-term differences are getting smaller between the variants; Although, in the year 2020 the deviation to default is utmost double for the 'high price variant' (+2.5%) compared to the 'low price case' (-1.5%).

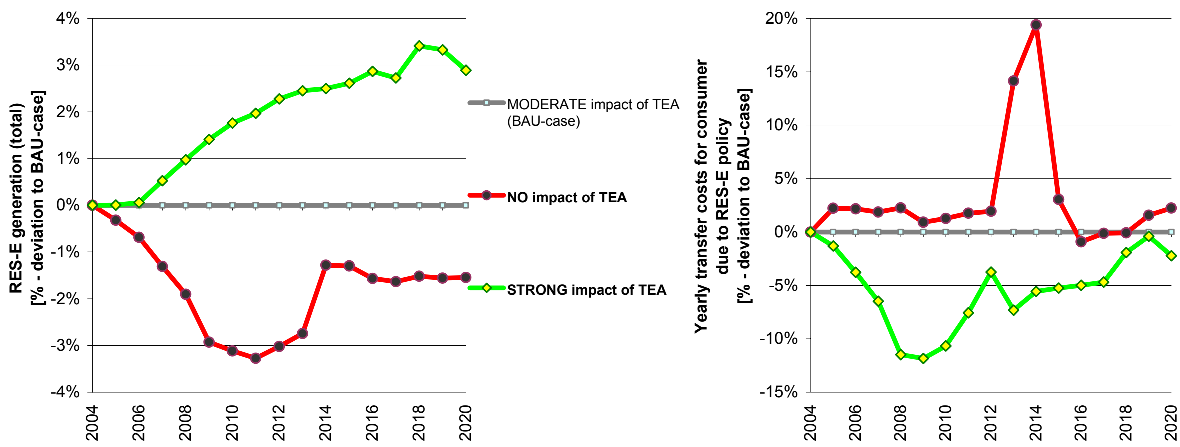


Figure 6.23 Development of RES-E generation (left) and accompanying yearly transfer costs (right) up to 2020 for all sensitivity cases (variation of reference price) – expressing the deviation to the default case (B1)

[161] Compare e.g. the deviation from the default case (med CO_2 constraint) in 2020 for the high CO_2 constraint variant (+6%) and for the variant where no CO_2 constraint is applied (-12%).

[162] Compare e.g. the Spanish RES-E policy which contains as major instrument technology specific premium feed-in tariffs. Under such a scheme the financial incentive for new RES-E is positive correlated to the electricity market price.

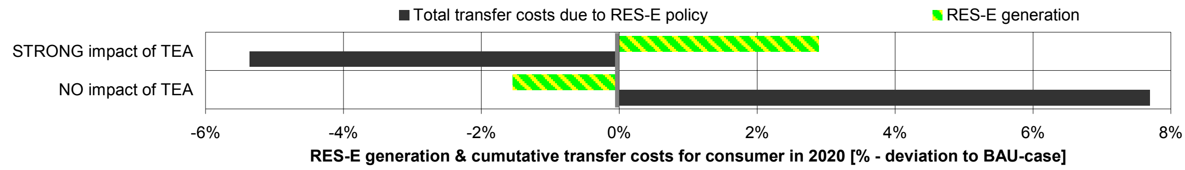


Figure 6.24 Comparison of total RES-E generation and accompanying cumulative transfer costs for consumer in 2020 for all sensitivity cases (variation of reference price) – expressing the deviation to the default case (B1)

Considering the **resulting transfer costs** for consumer due to the promotion of RES-E, a higher sensitivity can be expected and also observed – see Figure 6.23 (right) and Figure 6.24. In this context, the dynamic development of *yearly transfer costs* for consumer for the period 2004 to 2020 – see Figure 6.23 (right)– as well as *cumulative transfer costs*[163] in the year 2020 – see Figure 6.24 – is illustrated by expressing the deviation to the default case (B1). The sensitivity investigation clearly indicates:

- Transfer costs and electricity prices are negative correlated. Consequently, the consumer burden due to higher electricity prices would be – of course only partly – compensated by lower promotional costs and vice versa.
- Resulting differences in terms of RES-E deployment are recognizable in the accompanying transfer costs. More precisely, resulting deviations of the deployment reduce the 'compensational effect' of transfer costs. [164] [165]

► Impact of dynamic barriers

Next, the impact of dynamic barriers on the resulting RES-E deployment and the accompanying transfer costs for consumer is analysed. Thereby, two variants are compared with the default barrier setting as applied in the BAU-scenario (B1). Of course, policy settings are similar in all cases, i.e. assuming a continuation of current RES-E policies in the EU-15 countries. More precisely, sensitivity variants comprise:

- A **low barrier case** – i.e. characterized by low market & administrative barriers for all RES-E, consequently, allowing a faster deployment – ($\Delta P_{M\ min}$ & b_M = 120% of default);
- A **high barrier case** – i.e. characterized, in contrary to above, by high barriers and a possibly delayed deployment of RES-E technologies – ($\Delta P_{M\ min}$ & b_M = 80% of default).

[163] In this case the cumulative transfer costs refer to the promotion of all RES-E – i.e. including payments for existing plant installed before 2005 – in the period 2005 to 2020 as well as the residual of transfer costs for the period after 2020 (referring to RES-E installations up to 2020).

[164] Compare e.g. RES-E deployment and accompanying transfer costs for the 'high price case': In the short-term where RES-E deployment is utmost equal to default, transfer costs drop to a level of -12% (compared to default) in 2008. Later on, the reduction of the consumer burden is compensated by the increasing RES-E penetration or, more precisely, by their accompanying additional promotional expenditures. It can be expected that the reduction of cumulative transfer costs would be in the magnitude of -10% if no additional RES-E deployment would be induced.

[165] A further aspect – neglected in these model runs – is the impact of electricity prices on the overall demand for electricity, characterised by its price elasticity. A reduced demand in case of a higher reference price would cause a higher RES-E premium per MWh of demand for consumer.

Note, the control variable b_M, i.e. the 'market barrier level', limits the possible market penetration in a dynamic context, whilst the term $\Delta P_{M\ min}$, determining the at minimum yearly realisable potential, is of relevance in the early phase of market penetration. Both refer to a specific RES-E technology on country level, and higher values result in accelerated penetration if economic support is adequate. For a detailed description of the methodology see section 4.2.7.2.

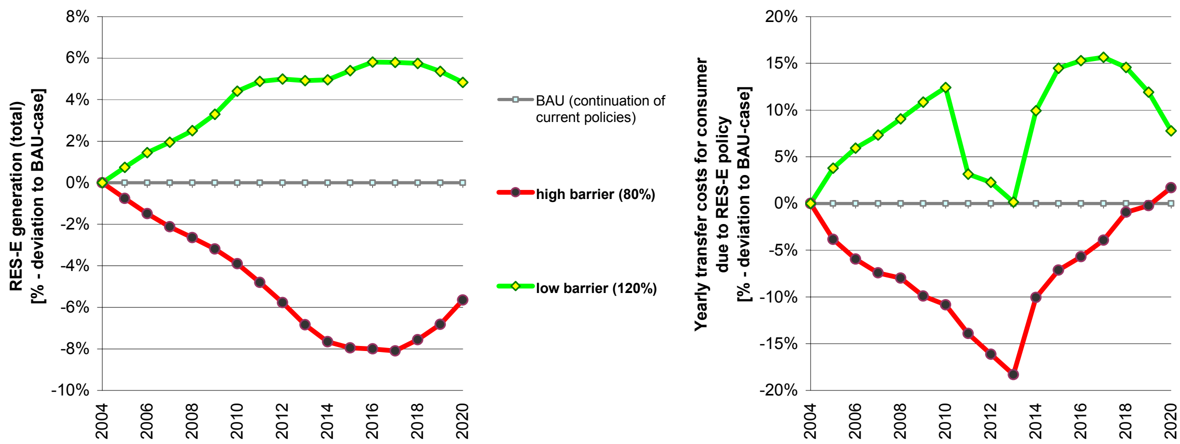


Figure 6.25 Development of RES-E generation (left) and accompanying yearly transfer costs (right) up to 2020 for all sensitivity cases (variation of dynamic barrier) – expressing the deviation to the default case (B1)

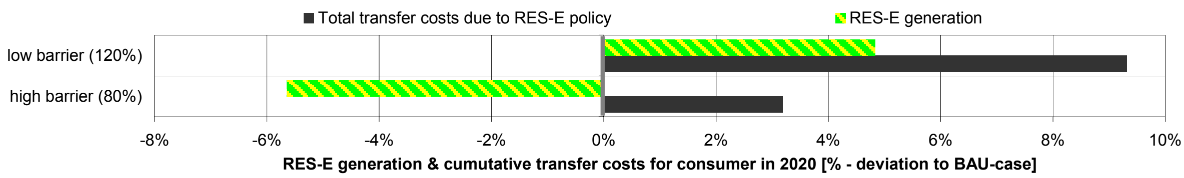


Figure 6.26 Comparison of total RES-E generation and accompanying cumulative transfer costs for consumer in 2020 for all sensitivity cases (variation of dynamic barrier) – expressing the deviation to the default case (B1)

Figure 6.25 (left) and Figure 6.26 illustrate the impact of the variation of dynamic barriers on **the development of RES-E generation** on EU-15 level up to 2020, indicating the deviation to the default case (B1). Thereby, similar to the previous sensitivity case, Figure 6.25 (left) depicts the development over time, whilst Figure 6.26 shows total RES-E generation in the (final) year 2020. Most important results are:

- As expected, in the near future up to say 2015 in case of lower dynamic barriers RES-E deployment would take place faster, and, in contrary, if barriers are set more restrictive, a delay occur compared to the default case (B1). In quantitative terms a slightly higher deviation to default occurs for the 'high barrier case' – at maximum in size of -8% compared to +6% in the 'low barrier case'.[166]

[166] The lower impact as observed for the 'low barrier' results from the fact that economic support is not sufficient enough to stimulate additional realisable deployment.

- Up to the mid-term the differences to default are getting smaller for both variants, resulting in 2020 in a deviation in size of +4.8% or -5.7%, respectively. Reason is that in case of higher barriers only a delayed, but not in total lowered RES-E deployment takes place. In a similar way, the accelerated deployment as in case of 'low barriers' may not result in the long-term to a higher penetration under the applied economic support.

The **resulting transfer costs for consumer** due to the promotion of RES-E show a rather sensitive reaction on the variation of the dynamic barrier:

- Reason for the higher deviation as in terms of total generation is that societal costs are related to a large extend to the development of new RES-E plant.
- *Yearly transfer costs* as illustrated in Figure 6.25 (right) follow the expected development in the first years – i.e. due to an accelerated (delayed) RES-E deployment costs rise (drop) compared to default. Later on, in both variants high fluctuations occur. A comparison with the according RES-E deployment helps to clarify the situation: Transfer costs act very sensitive on changing deployment – in case of a slow-down costs drop, whilst during a sudden acceleration costs rise rapidly.
- *Cumulative transfer costs in 2020* are within both variants higher compared to the default case, see Figure 6.26. Of course, reasons are different: It is obviously that an accelerated deployment – i.e. the 'low barrier case' – results in higher transfer costs (+9%) due to the increased amount of supported RES-E generation. In contrast, in the 'high barrier case' a delay in deployment occurs especially in the short term, resulting in a slightly accelerated penetration in the final period, which is accompanied by growing promotional costs. Moreover, the technology-mix is different, as cheap options contribute less compared to default (as restrictions appear on technology level). Hence, the observed deviation to default in the 'high barrier case' amounts about +3%.

► <u>Impact of technological learning</u>

Next, the impact of technological learning is investigated. Two variants are compared with the default assumptions with respect to technological learning as applied in the BAU-scenario (B1). Again, policy settings are similar in all cases, i.e. assuming a retaining of current RES-E policies on country-level. In more detail, the following variants are analysed:

- A '**low learning case**' – i.e. characterized by low learning rates for all RES-E – (LR = 80% of default);
- A '**high learning case**' – i.e. characterized, in contrast to above, by high learning rates – (LR = 120% of default).

Varied settings with respect to technological learning refer to the future development of investment-, O&M-costs as well as improvements of the conversion efficiency and related performance parameter. For those RES-E options, where it was decided to stick to expert forecasts (e.g. tidal and wave energy – see section 5.4.2), similar adaptations are undertaken.

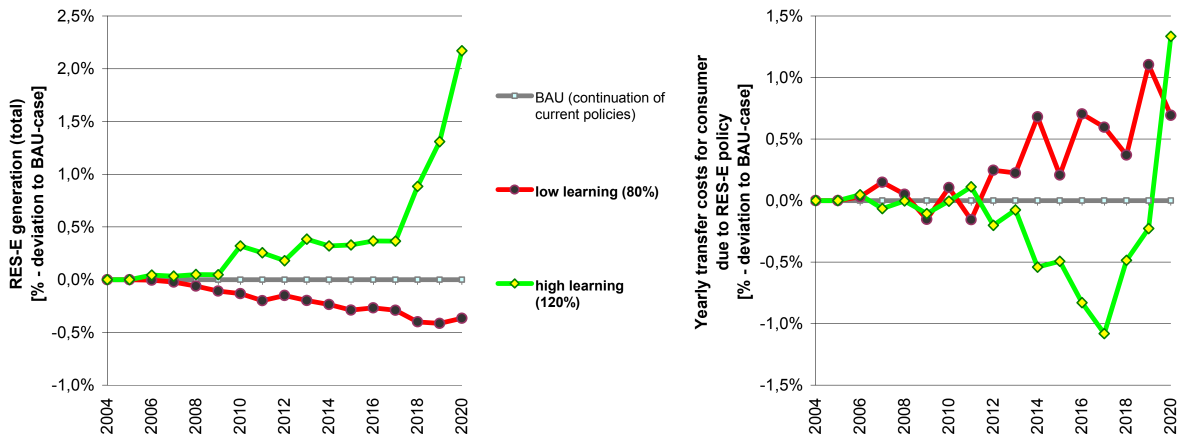


Figure 6.27 *Development of RES-E generation (left) and accompanying yearly transfer costs (right) up to 2020 for all sensitivity cases (variation of technological learning) – expressing the deviation to the default case (B1)*

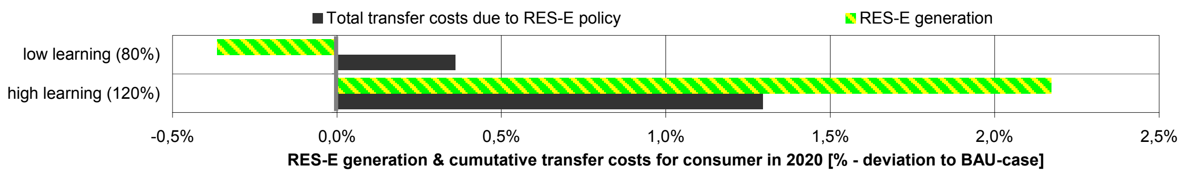


Figure 6.28 *Comparison of total RES-E generation and accompanying cumulative transfer costs for consumer in 2020 for all sensitivity cases (variation of technological learning) – expressing the deviation to the default case (B1)*

The impact of the variation of settings with respect to technological learning on **the development of RES-E generation** up to 2020 on EU-15 level is illustrated in Figure 6.27 (left) and Figure 6.28, indicating the deviation to the default case (B1). Again, similar to previous sensitivity cases, Figure 6.27 (left) shows the development over time, whilst Figure 6.28 indicates total RES-E generation in the (final) year 2020. Of interest is:

- In the 'high learning case' up to 2009 utmost no deviation occurs. Later on, in the period up to 2017 a small increase in size of about +0.3% can be observed, but in the last period from 2017 to 2020 a steep rise follows, leading to a deviation to default of about 2.3% in 2020.
- In the 'low learning case' the impact on RES-E generation is over the whole period up to 2020 very low. In the year 2020 a deviation to default of -0.4% occurs.
- Summing up, variations of technological learning as investigated in size of $^{+}/_{-}$20% to default effect RES-E deployment only in the mid-term. In case of 'low learning' the overall impact on deployment remains very small as in countries with quantity driven RES-E policies the high policy-driven demand for RES-E is not effected, whilst in countries which stick to price-driven promotion instruments financial incentives are set high enough to utmost fully absorb the impact.

With respect to the **resulting transfer costs for consumer** due to the promotion of RES-E the following observations are of relevance:

- As long as RES-E deployment shows no high deviation, *yearly transfer costs* as illustrated in Figure 6.27 (right) follow the expected development – i.e. in the 'low learning case' transfer costs are above the default level, whilst in the 'high learning case' they are below. Thereby, deviation to default is small – i.e. in size of $^{+}/_{-}$1.1%.
- The higher RES-E deployment in the period 2017 to 2020 in the 'high learning case' causes an increase of accompanying transfer costs. Accordingly, yearly transfer costs are higher compared to default in 2020.
- *Cumulative transfer costs in 2020* are within both variants higher than in the default case, see Figure 6.28. In the 'high learning case' cumulative costs are above the default level (+1.3%) due to the higher RES-E deployment – i.e. in the year 2020 a deviation of +2.3% in total RES-E generation or +4.4% in generation referring to new installations in the period 2005 to 2020 occurs. In the 'low learning case' higher transfer costs in size of +0.4% occur due to higher costs of RES-E in a dynamic context, resulting from the lower cost reductions. Hence, it is not compensated by the reduced RES-E deployment (-0.4% in total RES-E generation in 2020).

► Impact of weighted average cost of capital (WACC)

Next, the impact of the weighted average cost of capital (WACC), i.e. the assumed interest rate used for the calculation of offer / bid prices in case of new plant, is investigated. Again, resulting RES-E deployment and accompanying transfer costs for consumer are used as impact indicator. As usual, two variants are compared with the default WACC setting as applied in the BAU-scenario (B1) and, obviously, no change of policy settings is undertaken. In more detail, sensitivity variants comprise:

- A '**low WACC case**' – i.e. a low value is used for the weighted average cost of capital – (WACC = 80% of default[167]);
- A '**high WACC case**' – i.e. a high value is used for the weighted average cost of capital – (WACC = 120% of default[168]).

In general, a higher (lower) weighted average cost of capital (WACC) causes higher (lower) offer / bid prices in case of new plant and, accordingly, higher (lower) generation costs. WACC is often used as an estimate of the internal discount rate of a project or the overall rate of return desired by all investors (equity and debt providers). Default settings – as applied in the reference case (B1) – are based on differing risk assessments, one standard risk level and a higher risk level characterised by a higher expected market rate of return – including a reference value of 6.5% and a value of 8.6% applied in countries where support schemes impose a higher risk for investors (TGC system).

---

[167] A value of 5.2% is assumed for default risk, whilst in case of higher policy-related risk 6.9% are used.

[168] A value of 7.8% is assumed for default risk, whilst in case of higher policy-related risk 10.3% are used.

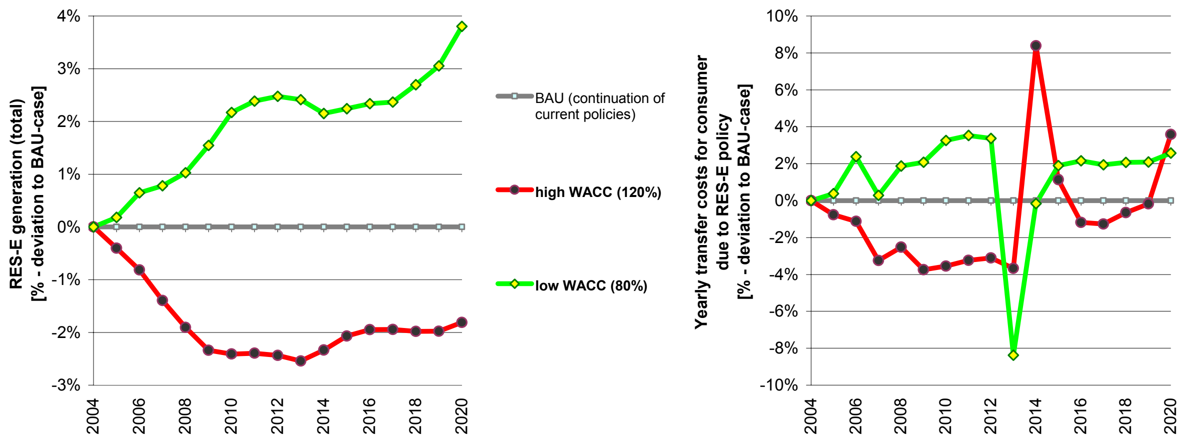


Figure 6.29 *Development of RES-E generation (left) and accompanying yearly transfer costs (right) up to 2020 for all sensitivity cases (variation of WACC) – expressing the deviation to the default case (B1)*

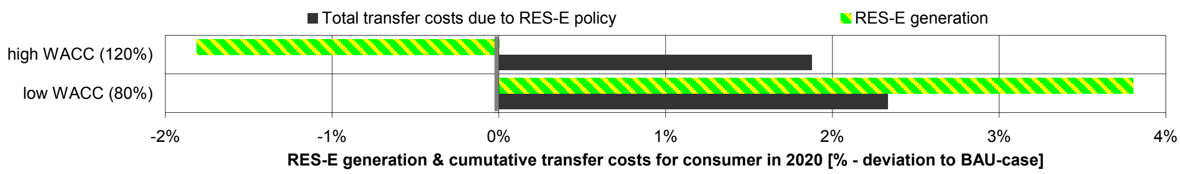


Figure 6.30 *Comparison of total RES-E generation and accompanying cumulative transfer costs for consumer in 2020 for all sensitivity cases (variation of WACC) – expressing the deviation to the default case (B1)*

An illustration of the impact of the WACC-variation on **the development of RES-E generation** on EU-15 level up to 2020 is given in Figure 6.29 (left) and Figure 6.30, indicating the deviation to the default case (B1). Thereby, similar to the previous sensitivity cases, Figure 6.29 (left) depicts the development over time, whilst Figure 6.30 shows total RES-E generation in the (final) year 2020. The following can be observed:

- As expected, in the near future up to 2012 in case of lower WACC RES-E deployment would take place faster, and, in contrary, if a higher WACC is applied, up to 2009 a slower deployment compared to the default case (B1) occurs.
- Later on, in the 'high WACC' variant deviation will stay on a rather constant level (about -2%), mainly a result of policy-driven demands for RES-E. In the 'low WACC case' the acceleration of RES-E deployment will be continued again after a small break in the period 2012 to 2016.
- Finally, in the year 2020 the deviation to default is much higher in the 'low WACC case' compared to the 'high WACC case' (+3.8% vs. -1.8%).

The **resulting transfer costs for consumer** due to the promotion of RES-E show a rather sensitive reaction on the variation of the WACC:

- *Yearly transfer costs* as illustrated in Figure 6.29 (right) follow changes of RES-E deployment in a sensitive manner– i.e. due to an accelerated (delayed) RES-E deployment costs rise (drop) compared to default.
- The higher RES-E deployment in the 'low WACC case' causes an increase of accompanying transfer costs. A 'compensational effect' due to lower generation costs can be observed especially in countries which stick to quantity driven RES-E policy instruments (i.e. TGC systems).
- In contrast, in the 'high WACC case' reduced RES-E deployment compensates only in the short term the higher specific transfer costs (due to higher generation costs).
- *Cumulative transfer costs in 2020* are within both variants higher than in the default case, see Figure 6.30. In the 'low WACC case' cumulative costs are above the default level (+2.3%) due to the higher RES-E deployment – i.e. in the year 2020 a deviation of +3.8% in total RES-E generation or +8% in generation referring to new installations in the period 2005 to 2020 occurs. In the 'high WACC case' higher transfer costs in size of +1.8% occur due to higher generation costs. Hence, reduced RES-E deployment (-1.8% in total RES-E generation in 2020) can not compensate this effect.

6.1.10. Modelling aspects: consequences of the neglect of dynamics

In the following, further model runs are depicted, which are carried out in a similar way as previous sensitivity investigations. However, aim of these scenarios is solely to illustrate modelling purposes referring to dynamic aspects – and, in contrast to above, not to discuss the sensitivity of a certain input parameter 'in touch with reality'. In more detail, resulting electricity generation of RES-E and accompanying transfer costs for consumer are compared to the default development of the BAU-scenario (B1) for the following cases:

- **No technological learning** (i.e., neglecting anticipated technological changes in total);
- **No dynamic barriers** (i.e., neglecting technology diffusion or, more precisely, limitations of yearly RES-E installations in total);
- **No dynamic barriers & no technological learning** (i.e., by neglected both above described aspects).

The impact of the applied settings on **the development of RES-E generation** up to 2020 on EU-15 level is illustrated in Figure 6.31 (left) and Figure 6.32, indicating the deviation to the default case (B1). Again, similar to previous sensitivity cases Figure 6.31 (left) shows the development over time, whilst Figure 6.32 indicates total RES-E generation in the (final) year 2020. The following observations are of relevance:

- *Neglecting technological learning*[169] leads to a slower RES-E deployment compared to default. Finally, in the year 2020 total RES-E deployment is by -11.6% lower than default.

[169] In principle, if the financial incentive as given by applied RES-E policy is set high enough to compensate increasing generation costs in the mid-term, no impact on RES-E deployment occurs.

- *Neglecting dynamic barriers* leads to a huge increase in penetration in the start year. The deviation to the default case, which is in size of 63% initially, decreases later on, leading to a deviation in size of +13% in 2020.
- *Neglecting both, dynamic barriers* and technological learning, superposes in a principal manner both effects as described above. Hence, a huge increase in penetration in the start year followed by a slower deployment later on. The deviation in size of +0.4% to default in 2020 is surprisingly low.

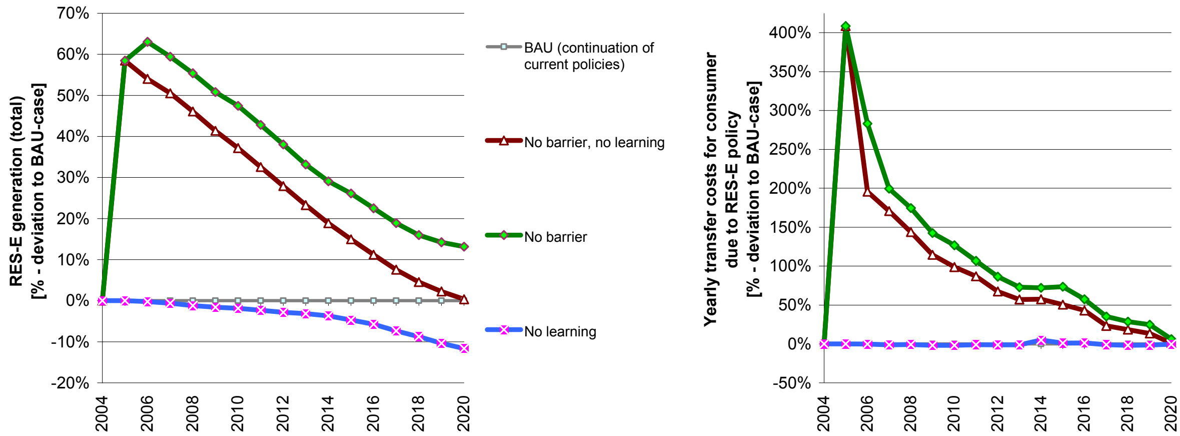


Figure 6.31 Development of RES-E generation (left) and accompanying yearly transfer costs (right) up to 2020 for all sensitivity cases (variation of WACC) – expressing the deviation to the default case (B1)

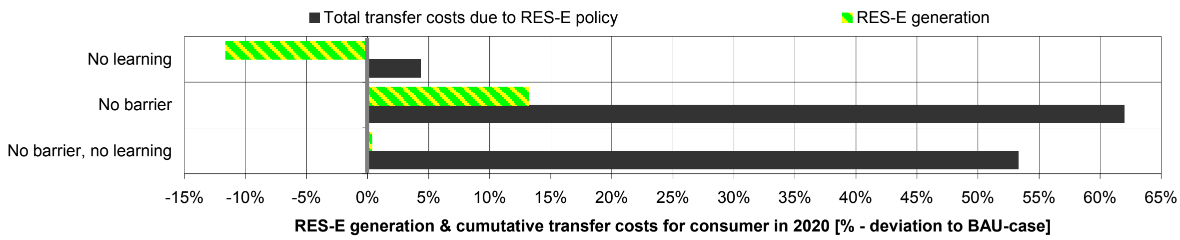


Figure 6.32 Comparison of total RES-E generation and accompanying cumulative transfer costs for consumer in 2020 for all sensitivity cases (variation of WACC) – expressing the deviation to the default case (B1)

The **resulting transfer costs for consumer** due to the promotion of RES-E are discussed in the following. In this context, the dynamic development of *yearly transfer costs* for consumer for the period 2004 to 2020 – see Figure 6.31 (right)– as well as *cumulative transfer costs*[170] in the year 2020 – see Figure 6.32 – is illustrated by expressing the deviation to the default case (B1). The following can be observed:

- In the *'no learning case'* higher cumulative transfer costs in 2020 in size of +4% occur due to higher (generation) costs of RES-E in a dynamic context, resulting from

[170] In this case the cumulative transfer costs refer to the promotion of all RES-E – i.e. including payments for existing plant installed before 2005 – in the period 2005 to 2020 as well as the residual of transfer costs for the period after 2020 (referring to RES-E installations up to 2020).

the fact that no cost reductions are considered. Hence, it is not compensated by the reduced RES-E deployment (-11.6% in total RES-E generation in 2020).

- As mentioned above, *neglecting dynamic barriers* leads to a huge increase in penetration in the start year. This causes a huge increase of accompanying transfer costs for consumer. The deviation to the default case as illustrated for yearly transfer costs in Figure 6.31 (right) is above 400% initially, but decreases later on. In terms of cumulative transfer costs a deviation of +62% is indicated.
- *Neglecting both, dynamic barriers* and technological learning, superposes in a principal manner both effects as described above - a huge increase in yearly transfer costs in the start year followed by a decreasing deviation later on. For cumulative transfer costs a deviation in size +53% can be observed.

Summing up, *neglecting technological learning* leads to a likely overestimation of transfer costs, partly compensated by the underestimation of RES-E deployment. In case of *dynamic restrictions*, respectively their negligence, the dynamic development of RES-E generation and accompanying transfer costs is, of course, not represented correctly in this model. Hence, by looking at yearly figures the deviation to default becomes smaller in the mid-term, but cumulative figures seem to be totally out of range. By neglecting both, *barriers and learning*, a 'compensational effect' can be observed.

6.2. Analysis of RES-E deployment at the national level with *Green-X*

The second example aims to demonstrate the applicability of the model for analysis carried out at the national level. As example Austria, representing a small country on the global marketplace, is chosen. In contrast to the first case, conventional power market is not subject of modelling. Thus, a reference electricity price is applied exogenously. Further explanations are given below.

6.2.1. Definition of scenarios

Aim of the scenarios is to indicate the consequences of policy decisions on resulting RES-E deployment. Current reference is given to discussions on political as well as social level with respect to the further promotion of RES-E and accompanying cost burden for consumer.

Thereby, three scenarios are taken into consideration:

- **BAU** – i.e. what can be achieved by an unchanged continuation of the feed-in tariff regulation as valid until the end of 2004.
- **Expertise** – i.e., it is assumed that new feed-in tariffs will be applied in 2005 (and later on). Tariffs and guaranteed duration are set in accordance with an expertise as conducted for the Austrian regulatory authority (E-Control) in November 2004 by (Schönbauer et al., 2004).
- **Reference case** – i.e., indicating the situation, if no further promotion activities are set for new RES-E after 2004.

6.2.2. Key assumptions[171]

In the following key assumptions representing important external model parameter for all investigated scenarios are described in detail.

► <u>Gross and final electricity consumption</u>

To be able to determine quantitative targets for RES-E it is of importance to consider the future development of Austria's electricity demand. Thereby, it has been decided to mainly stick to demand projections as published in "Energieszenarien bis 2020" (Kratena, Schleicher, 2001) – a sound analysis of the future development of energy supply and demand as well as according CO_2-emissions undertaken by the Austrian *Wirtschaftsforschungsinstitut (WIFO)*, published in April 2001. Figure 6.33 illustrates the historical development of the electricity demand as well as a forecast for its future development based on the applied BAU-scenario. Both are used in the analysis to evaluate RES-E target achievement and promotional costs in a quantitative manner.

[171] Note that various settings are based on investigations carried out within the recently finished study "Dynamic RES-E" (see Huber et al., 2004b).

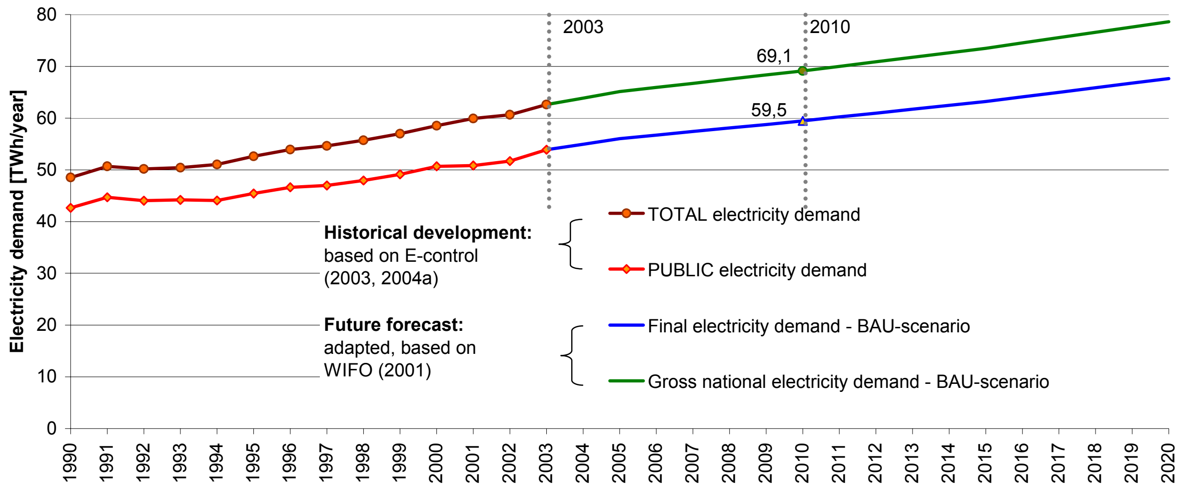


Figure 6.33 Historical and future development of the electricity demand in Austria

Source: Own investigations – based on (Kratena, Schleicher, 2001)

► <u>Primary energy prices for biomass products</u>

Fuel costs (by terms of primary energy) – differing by fuel-category – are implemented into the database as time-series. For Austria default fuel prices are assumed for each biomass sub-category in accordance with recent studies (e.g. Kranzl, 2002) and market observations – for illustration see Figure 6.34. Thereby, it is assumed that costs remain constant till 2010. In the period 2010-2015 a price increase of 0.5% per year and later on an accelerated growth is projected.

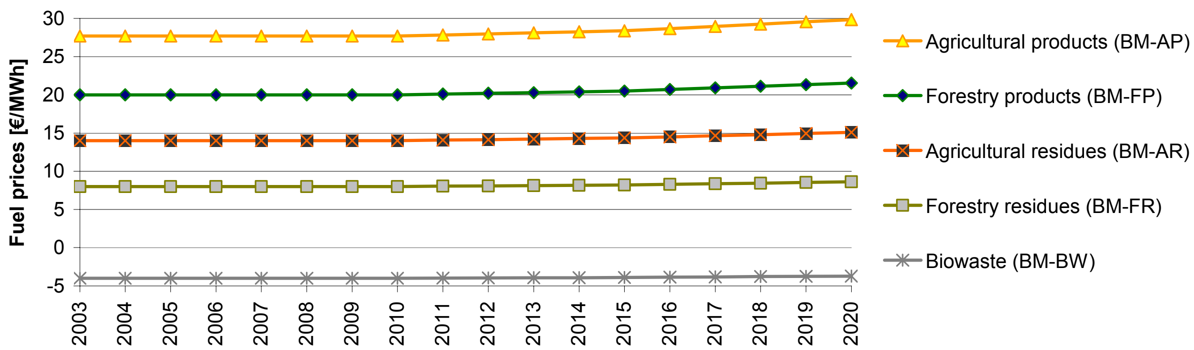


Figure 6.34 Applied fuel prices by biomass sub-category

► <u>Reference electricity price</u>

A reasonable forecast of (conventional) electricity prices is of significant importance in the evaluation of the cost efficiency of RES-E technologies and in the determination of additional transfer costs associated with the promotion of RES-E. Therefore, it has been decided to stick to projections of electricity prices as undertaken with a high level of accuracy within the project "FORRES 2020" (for details see (Ragwitz et al., 2004)).

Figure 6.35 depicts the applied price forecasts. In general, these projections indicate an increase in electricity prices for the future.[172] In more detail, in accordance with the actual recent development it is characterised by a high rise in the near future due to increasing primary energy prices (as observed for oil, gas and coal) and a moderate increase for the mid-term which fits well to the price projection for gas on the international markets. After 2005 also the impact of GHG polices – i.e. the EU Emissions Trading scheme – is taken into account: Assuming additional CO_2-costs of 10 €/t-CO_2 generation costs of fossil power stations will increase at least by 2.4 to 3.6 €/MWh.

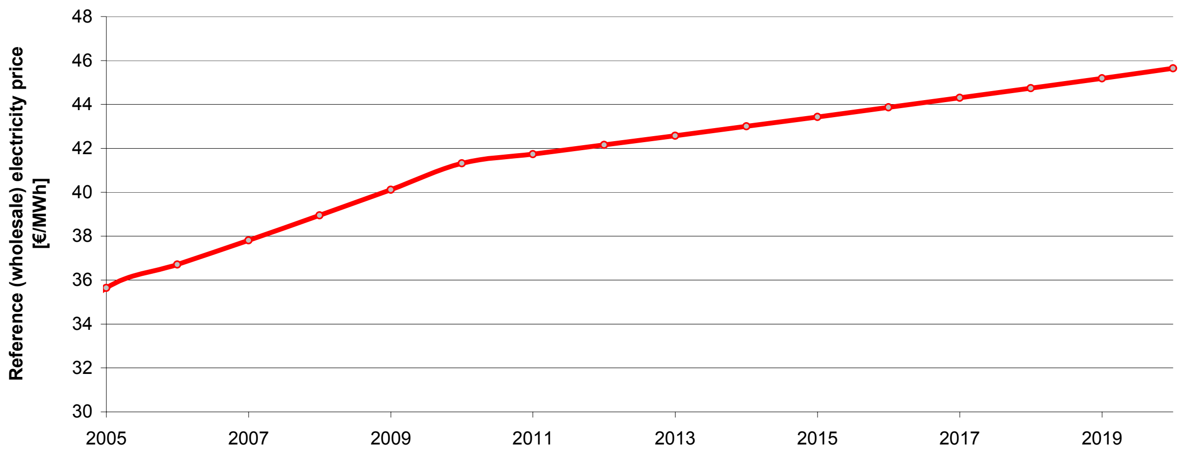


Figure 6.35 Forecast of electricity prices in Europe (up to 2025)

Source: FORRES 2020 (Ragwitz et al., 2004))

► Weighted average cost of capital

The determination of necessary rate of return is based on the weighted average cost of capital (WACC) methodology. As only feed-in tariff are subject of investigation, which due to an applied guaranteed duration of payments associate less risk, a default figure in size of 6.5% is used for all variants.

► Setting of dynamic barriers

Within the model ***Green-X*** dynamic barriers describe the impact of non-economic hindrances on the deployment of a certain RES-E. Thereby, as in detail described in section 4.2.7, the impact of three different types of barriers can be investigated with the model on country level: Technical, societal and market & administrative constraints.

For the analysis, *technical and societal constraints* have been considered only for wind energy. Thereby, the simplified percentage approach has been chosen, where the yearly realisable potential has been restricted to 50% of the total mid-term potential on band-level. In case of *market & administrative constraints*, a default setting, which refers to the current situation is applied. Hence, it thereby takes into account

[172] Besides above mentioned reasons an increase of electricity prices in the future price can also be expected due to the fact that overcapacities decrease in all European countries. Therefore, new plants have to be installed which require higher price margins.

the accelerated growth as observed the last two years and accordingly represents an – with respect to non-economic barriers – investor-friendly framework.

► Future cost projection – technological learning

Default settings with respect to technological change are applied - see section 5.4.1. Nevertheless it is important to mention, that in this case of a single and, moreover, small country the magnitude of these changes are given with respect to costs in exogenously in the model, i.e. future annual investment costs etc. in the investigated region are 'taken' from the international market[173].

► Database on potentials & costs for RES-E
– starting position at the end of 2004:

To be able to investigate comparable scenario's for the mid-term, a brief assessment of the current situation is undertaken. Thereby, information on planned and currently implemented RES-E projects (which in most cases do already have a notification on approval as 'Ökostromanlage' but, hence, are not erected yet) is taken into account in the recent update of the detailed database on RES-E potentials as conducted for Austria in several projects.[174] The set of data used within the model with respect to the state-of-the-art of RES-E in Austria – the so called 'achieved potential at the end of 2004' – is depicted in Figure 6.36.

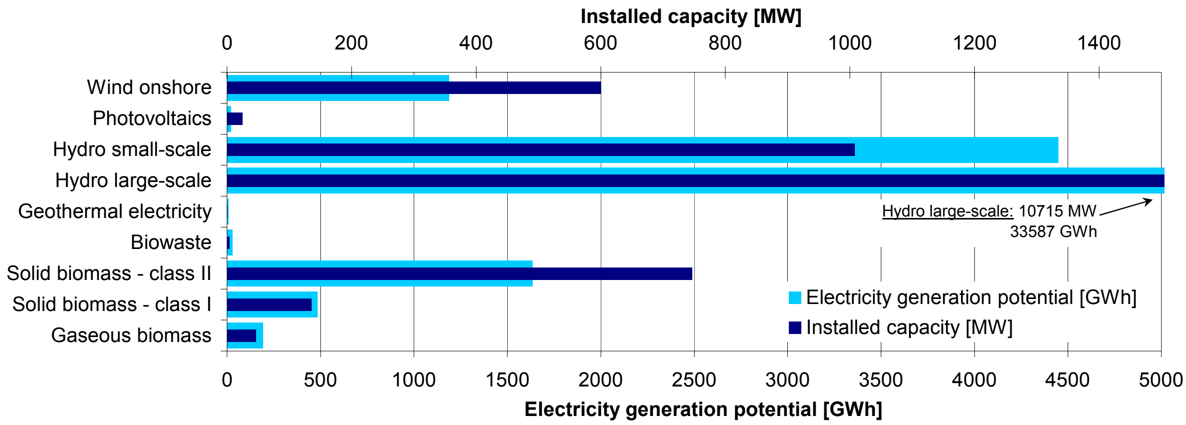


Figure 6.36 Achieved potential (2004) for RES-E in Austria (i.e installed capacity and generation potential)

Figure 6.37 provides an overview on the different future RES-E options available in Austria. Thereby, the *additional realisable mid-term potential (up to 2020)* is indicated for each RES-E separately, representing the status at the end of 2004. Hydropower represents the currently dominant but in case of large-scale plant also already most exploited renewable energy source. The largest future potential is found in the sector of wind energy and small-scale hydropower followed by the various

[173] For most RES-E technologies an experience curve approach is chosen. In this context, the existence of a global learning system is preconditioned – i.e. future annual investment and O&M-costs are 'taken' from the international market, based on an assumed global development.

[174] A comprehensive survey has been undertaken in this respect in the project "Dynamic RES-E" – as described in (Huber et al., 2004b).

fractions of solid biomass (i.e. forestry and agricultural products / residues, biowaste) – but promising future options also include biogas and photovoltaics.

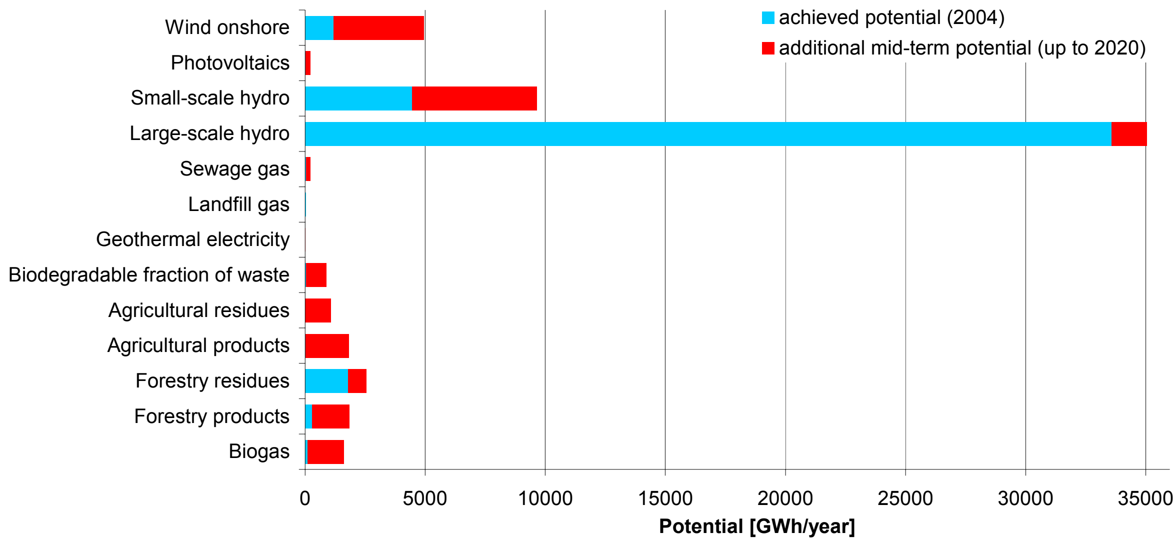


Figure 6.37 Overview electricity generation potential of RES-E in Austria

6.2.3. Model settings for promotion instruments (for the scenarios)

► Reference case

In this case no further promotion of RES-E is foreseen in the future. Hence, this case shall be seen only as a reference, in order to get aware what would happen if there will be no further promotion in the future. Therefore, expressed costs for society (due to the promotion of RES-E) refer only to existing RES-E plant (at the end of 2004) and their guaranteed feed-in tariffs!

► BAU

Under this scenario it is assumed that current feed-in tariffs – as set within the eco-electricity act by the regulation (BGBl. II – Nr. 508/2002) – will be valid also in the future. Furthermore, within this scenario guaranteed duration as well as height of tariffs is kept constant up to 2020.

Hence, the set of data according to the actual regulation (see section 3.2) had to be translated into suitable model inputs. I.e. defined ranges of tariffs (as e.g. in case of various fractions of biomass defined for different plant-sizes) had to be described by one single value for each biomass fraction. The final outcome – i.e. the applied input data for the model with respect to the height of FITs – is depicted in Figure 6.38 (violet bars). Furthermore, guaranteed duration of promotional payment has been set to 13 years (in accordance with the existing regulation)

► 'Expertise'

In this case it is assumed that new feed-in tariffs are set in accordance with an expertise as conducted for the Austrian regulatory authority (E-Control) in November 2004 by (Schönbauer et al., 2004). Note, besides the height of the tariffs as indicated in Figure 6.38 (pale-blue bars), the guaranteed duration, i.e. the period as long as a RES-E receives support, is different. Except small-scale hydropower, where duration is still kept at 13 years, support is guaranteed only for 10 years in case of new installations.

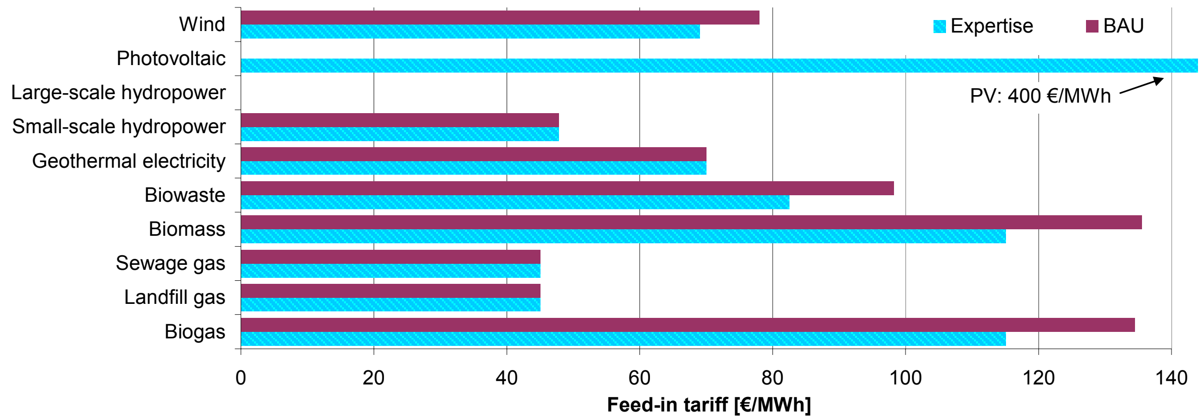


Figure 6.38 Model settings with respect to the height of feed-in tariffs by RES-E category for the BAU- & 'Expertise'-variant

6.2.4. Results of the simulation runs

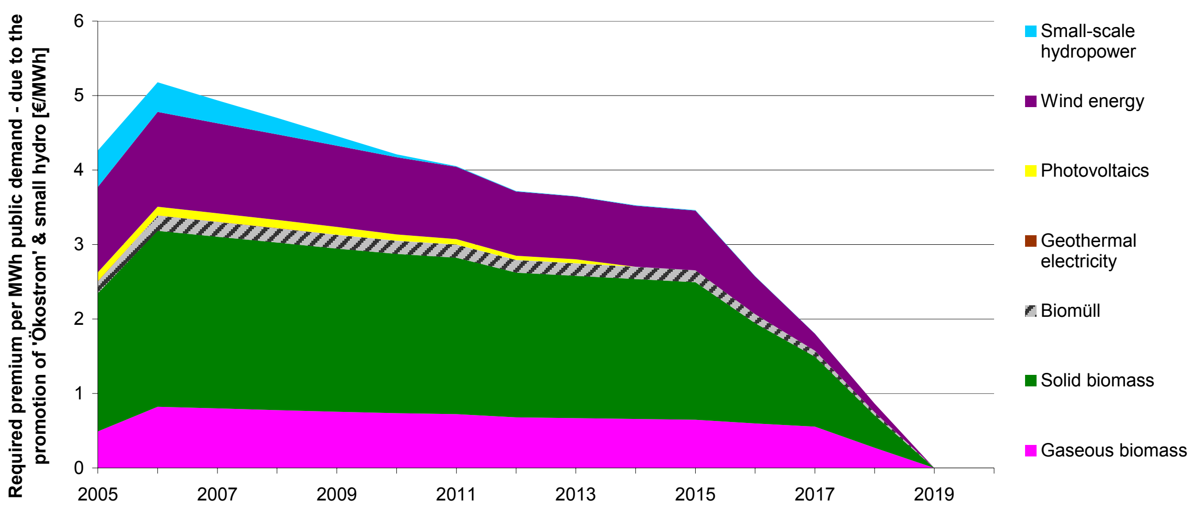


Figure 6.39 Transfer costs for consumer (by RES-E category separately) per MWh of public demand due to the promotion of RES-E (existing plant) – reference case

As starting position, the **reference case** will be analysed with respect to **the resulting cost burden for consumer**. Note, the expressed consumer cost (due to the promotion of RES-E) refer in this variant solely to existing RES-E plant and respectively those plant, which have received a permission under the conditions of the former promotion regulation (i.e. valid up to the end of 2004). Payments over time are influenced by plant-specific specifics, i.e. date of construction and guaranteed feed-in tariff due to past promotion policies. As indicated in Figure 6.39 (i.e. showing transfer costs per MWh of public demand) specific costs will increase in the near future (as new installations referring to the old scheme start operation) and decrease later on. E.g. in 2010 a similar required premium can be expected than in 2005. Finally, promotional payments for all existing RES-E will run out in 2019.

Nevertheless, the overall price cap of 2.2 €/MWh – as initially defined in the *Eco-electricity Act* for the imposable fee for public consumer – will already be exceeded taking into account the generation potential of all existing RES-E plant and their guaranteed feed-in payments.

A breakdown of the promotional costs by RES-E category is shown in Figure 6.39. As there can be seen, biomass, followed by wind energy and gaseous biomass (i.e. mainly agricultural biogas) account for roughly 90% of total costs over time.

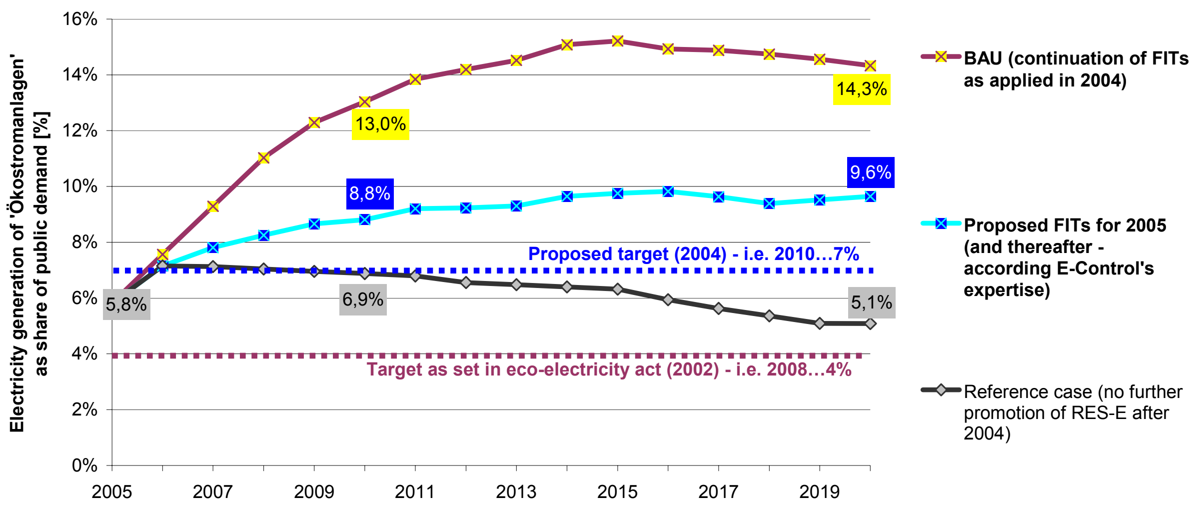


Figure 6.40 Comparison of electricity generation of 'sonstigen Ökostromanlagen' (i.e. mainly wind energy, biomass) in the period 2005 to 2020 – expressed as share of public demand

A comparison of all investigated scenarios is undertaken in the following. Comparing **electricity generation from** so called **‚sonstigen Ökostromanlagen'** (i.e. RES-E exc. waste & hydro – in other words mainly wind energy & biomass) it becomes obviously that according targets as set in the Eco-electricity Act will be met in all variants, including the reference case. As depicted in Figure 6.40, indicating the resulting share on public demand, in case of a continuation of the former feed-in tariffs (BAU-variant) a percentage of 13% may be expected for 2010, increasing steadily up to 2015 and decreasing finally to a level of 14.3% in 2020. In contrary, for the 'Expertise'-variant a rather slow growth is shown, leading to 8.8% in 2010 and 9.6% in 2020, respectively. If no further incentives are applied, obviously the percentage will decrease up to the mid-term – i.e. after say 2006, when all plant referring to the former promotion regulations would have already started operation.

The future development of **total RES-E generation** (i.e. by including all options) and corresponding gross electricity demand provides a different view. Note, both values are of relevance with respect to the targets as set on European level – i.e. the indicative target for Austria – a RES-E share of 78.1% in 2010 – as imposed by the 'RES-E

Directive'. Up to the med term a more or less dramatic decrease is indicated in Figure 6.41 for all variants. For the reference case a reduction to a level of roughly 55% occurs, whilst in the BAU-variant the RES-E share will rise from 65.9% in 2005 to 68.6% in 2010 and, later on, decrease to roughly 63% in 2020. The 'Expertise'-variant lies in between, resulting in a moderate reduction to 65% by 2010 and, later on, 58.8% by 2020.

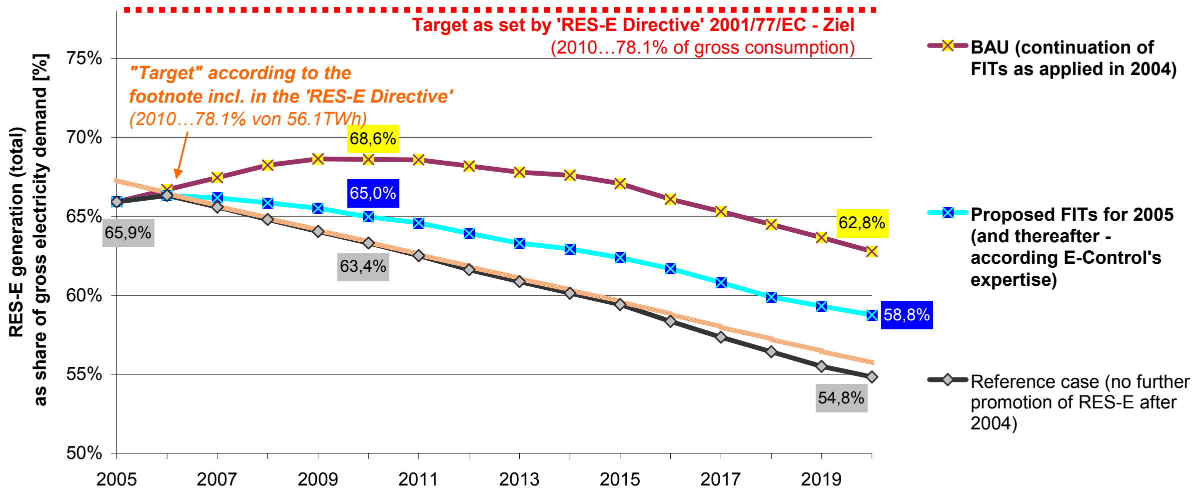


Figure 6.41 Comparison of total RES-E generation in the period 2005 to 2020 – expressed as share of total demand

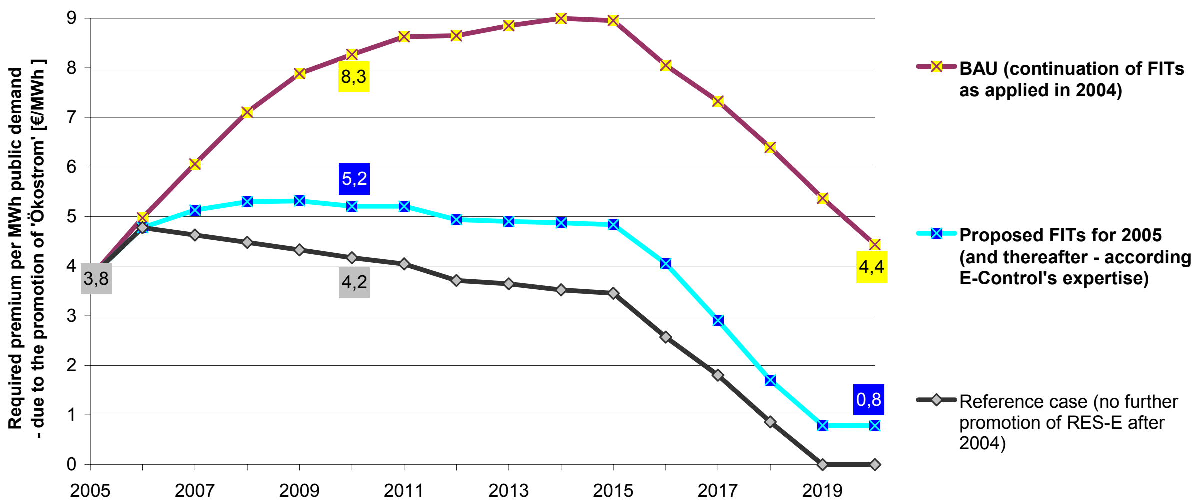


Figure 6.42 Comparison of necessary transfer costs for consumer due to the promotion of 'sonstigen Ökostrom' (i.e. mainly wind energy, biomass) – expressed as premium per MWh public demand

Transfer cost for consumer will be discussed next. Figure 6.42 illustrates the required transfer costs referring to the promotion of 'sonstiger Ökostrom' (i.e. mainly biomass and wind energy). In the BAU-case a dramatic increase can be observed in the short-term, slowing down later on, and finally, after a peak of roughly 9 €/MWh in 2015, a decrease to 4.4 €/MWh occurs. The 'Expertise'-variant will result in a rather constant burden of roughly 5 €/MWh up to say 2015, decreasing in the following to a level below 1 €/MWh in 2019. In a qualitative manner it can be stated that not much difference occurs between the reference and the 'Expertise'-variant with respect to transfer costs, whilst for the BAU-variant a huge increase is assumed.

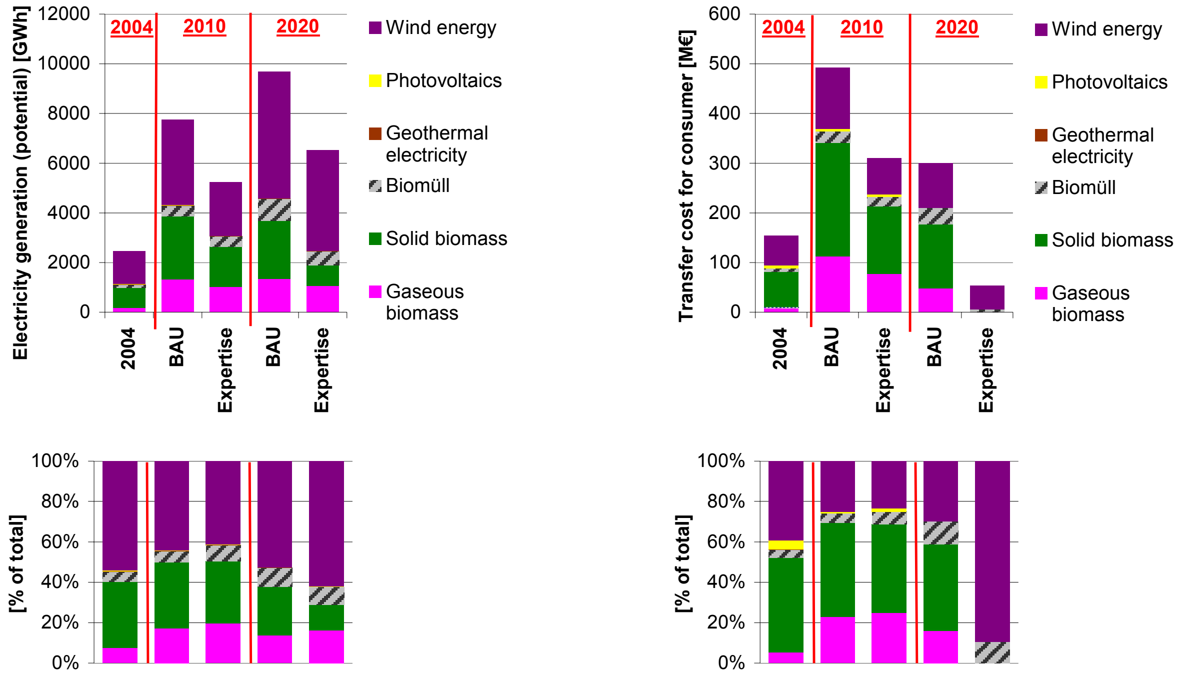


Figure 6.43 *Comparison of electricity generation (left) & resulting(yearly) transfer costs for consumer (right) for 'sonstigen Ökostrom' for covered RES-E categories for the years 2004, 2010 and 2020 – expressed in absolute (GWh or M€ - above) & relative terms(% of RES-E categories - below)*

Finally, a **comparison on technology-level** is undertaken. Thereby, Figure 6.43 provides a comprehensive illustration: A comparison of electricity generation (left) & resulting (yearly) transfer costs for consumer (right) for 'sonstigen Ökostrom' for covered RES-E categories for the years 2004, 2010 and 2020 – expressed in absolute (GWh or M€ - above) & relative terms (%-percentage by RES-E category - below) is undertaken. Looking at the absolute terms, huge differences appear between the BAU- and 'Expertise'-variant. Notably in case of biomass, the higher deployment in the BAU-case will impose substantially higher transfer cost. Accompanying relative figures to not indicate much difference between the variants e.g. in 2010, but reflect technology-specific preferences of the policy design.

7. Conclusions

The following conclusions refer to several aspects as treated in this thesis. To allow a better understanding, they are listed in a topical order.

7.1. The concept of dynamic cost-resource curves for RES-E and their model implementation as illustrated for the model ***Green-X***

The developed modelling concept of *dynamic cost-resource curves* allows the linkage between three approaches of particular importance in the field of RES-E, but also energy technologies in a general manner. It comprises the formal description of costs and potentials by means of *static cost-resource curves*, the dynamic cost assessment as e.g. arrived through the application of *experience curves*, and the implication of dynamic restrictions in accordance with *technology diffusion*.

- In the past *static cost-resource curves*[175] have faced attraction especially in the discussion of (renewable) energy sources. In particular RES-E 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. One proper tool to describe both costs and potentials represents the ***static*** *cost-resource curve.*
- The ***dynamic*** *cost-resource curve* provides the extension of above formal description of resource conditions by including aspects of technological change and technology diffusion:
  - As illustrated briefly for the model ***Green-X*** in section 4.2.6 of this thesis, costs[176] – in particular investment and operation- & maintenance costs – are dynamically adapted at technology level. Thereby, two different approaches can be applied: Standard cost forecasts or endogenous technological learning.
  - In the context of technology diffusion it is important to apply dynamic realisation restrictions. Within the model ***Green-X*** 'S-curve' patterns are applied to describe the impact of market and administrative restrictions, representing the most important in the set of dynamic non-economic barriers[177] on the deployment of a certain RES-E.

[175] For 'static cost-resource curves' as explained above in literature no common terminology is applied. Other names commonly applied to this term are 'supply curves' or 'cost curves'. Nevertheless, with respect to (renewable) energy sources the term 'static cost-resource curves' gives – at least in the opinion of the author - a clear and unambiguous wording.

[176] Note, besides the above mentioned cost parameters, dynamics are also considered with respect to other performance issues – i.e. efficiency improvements and in case of wind turbines an up-scaling of potentials (and achievable full load hours, respectively) in accordance with increasing hub-heights (due to rising turbine sizes).

[177] Note, besides market and administrative barriers also other restrictions can be considered. In the model ***Green-X*** for instance industrial, social and technical restrictions are considered additionally. Important in this respect is to apply them on the 'correct' level: E.g. technical restrictions refer to characteristics within a certain region, whilst industrial barriers, indicating the production capacity of an industry (e.g. the manufacturing of wind turbines), refer to the international level.

Dynamic aspects are of particular importance for the assessment of energy policy instruments: Consequences of the neglect of dynamics are illustrated in section 6.1.10. In case of technological change, respectively *technological learning,* an overestimation of necessary transfer costs due to the promotion of RES-E occurs, which is partly compensated by the underestimation of RES-E deployment. In case of *dynamic restrictions*, respectively their disregard, the dynamic development of RES-E deployment and accompanying transfer costs is, of course, not represented in a proper manner.

The **applicability of the dynamic cost-resource curve concept** in combination with intensive energy policy modelling, as done in the model ***Green*-X**, for the assessment of policy instruments is briefly demonstrated in chapter 6 of this thesis. Thereby, also the practicability for forecasts of RES-E deployment for a short to med time-horizon based on policy inputs is stressed. In this respect, the following conclusions are of importance in a general manner:

- *Considering dynamics is essential* for the assessment of energy policy instruments and RES-E deployment. The impact of policy instruments significantly varies from a static viewpoint. Of special importance is:
  - Technological diffusion due to changes of existing barriers over time
  - Decreasing generation costs and hence lower necessary financial incentives
  - Non-linear dynamic target /quota setting
- The dynamic cost-resource curve approach represents a tool to assist policy makers in deriving *efficient* and *effective* promotion instruments for RES-E. By its application results can be gained with respect to both costs (i.e. efficiency) and penetration (i.e. effectiveness).
- Due to the combined consideration of resource restrictions and dynamic cost developments, dynamic cost-resource curves assist in deriving *the optimal time-path for policy instruments*.
- Careful attention has to be paid *to find a suitable matching of the particular issues as combined in this concept*. I.e. the potential and cost assessment as done for considered RES-E technologies has to be suitable for implementation and match with the model implementation of technological change and technology diffusion.[178] Thereby, the overall modelling objectives have to be kept in mind.
- With respect to the *model implementation of technological learning* it is important to stress that, in general, learning is taking place on the international level. Accordingly, the deployment of a technology on the global level must be considered. Within ***Green*-X** this is done by combining endogenous[179] deployment (within the EU-15) with exogenous forecasts (taken from (IEA, 2004)).

Conclusions referring to the particular application examples of chapter 6 with respect to the energy policy assessment follow in section 7.3 and thereafter.

---

[178] For instance, if economic conditions of RES-E are described exogenously by generation costs, it makes no sense to collect data with respect to technological learning referring to investment costs.

[179] For the case that only a single country is investigated, a default forecast – i.e. the 'BAU-scenario (B1)' as presented in section 6.1.6 – is taken as reference for the RES-E deployment on EU-15 level.

7.2. The assessment of (future) potentials and costs for RES-E

The detailed survey on **(future) potentials for RES-E** as undertaken in chapter 5.1 indicates the following:

- RES-E such as hydropower or wind energy represent energy sources characterised by a natural volatility. Therefore, in order to provide accurate forecasts of the future development of RES-E, it is wise to translate also historical data for RES-E into *electricity generation potentials*[180].
- In total EU-15 the *already achieved potential* (end of 2001) for RES-E equals 386 TWh, whereas the *additional mid-term potential*[181] (up to 2020) amounts to 1078 TWh.
- Currently hydropower represents the dominant but at the same time most exploited renewable energy source within Europe. On EU-15 level the largest future potential is found in the sector of wind energy (44%) followed by solid biomass (24%), biogas (9%) as well as promising future options such as tidal & wave (11%) or solar thermal energy (3%).
- Obviously, in some countries a different ranking occurs with respect to future options: In a midland like Austria, where no marine resources are available, also (small-scale) hydropower represents a promising option. In contrast, for islands as United Kingdom and Ireland, tide & wave holds a huge potential. The largest wind offshore potential – in relative terms – can be found in the Netherlands, a country characterised by a high population density and accordingly little available wasteland or agricultural area suitable for energy purposes. In southern Europe solar electricity – i.e. PV and solar thermal electricity – represents a promising resource.
- *The impact of the expected demand increase*[182] *is crucial:* If the indicated realisable mid-term potential for RES-E, covering all RES-E options, would be fully exploited up to 2020, only 42% of gross consumption could be covered on EU-15 level, if the demand will increase as expected under 'business as usual' conditions. In contrast, if a demand stabilisation could be achieved, RES-E may contribute to meet 55% of total demand.

Besides the potential the economic performance of a specific energy source determines its future market penetration. In section 5.2 of this thesis, a brief description of the relevant economic data is given for all considered RES-E technologies. In the following, main findings - resulting from a **comparison of electricity generation costs**[183] - are listed:

---

[180] The *electricity generation potential* with respect to existing plants represents the output potential of all plants installed up to the end of 2001. Due to the fact that in contrast to the actual data, potential figures represent, e.g. in case of hydropower, the normal hydrological conditions, and, furthermore, not all plants are installed at the beginning of each year, figures for actual generation and generation potentials differ in most cases.

[181] The additional realisable mid-term potential represents the maximal achievable potential up to 2020 in addition to past installations, assuming that all existing barriers can be overcome and all driving forces are active. Thereby, only general parameters as e.g. maximal market growth rates, planning constraints are taken into account.

[182] Demand figures for 2020 are taken from DG TREN's BAU-forecast (Mantzos et al., 2003a).

[183] In the model ***Green-X*** the calculation of electricity generation costs for the various generation options is done by a rather complex mechanism as described in sections 4.2.3 and 4.3, respectively, internalized within the overall set of modelling procedures. For an exemplarily comparison of long-run marginal generation costs (as applied for new plant) a default capital

- A broad range of costs occurs for several RES-E options: On the one hand, differing resource-specific conditions, as relevant e.g. in the case of photovoltaics or wind energy, 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.
- 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 plants or co-firing of biomass are characterised by comparatively low costs and at the same time by rather limited future potentials in most countries.
  - Wind energy and in some countries also small-scale hydropower or biomass combustion (in large-scale plants) 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.

7.3. The evaluation of promotion instruments for RES-E

The following conclusions refer to the first example, i.e. the evaluation of energy policy instruments for RES-E on European level (EU-15) with the model ***Green*-X**, as briefly described in section 6.1.

► General conclusions

The following observations are made irrespective of the chosen promotion instrument.

- Independent from the type of instrument applied to support RES-E, the careful design of the strategy is as important as the question which policy tool should be implemented, e.g.
  - Within any support mechanisms existing and new plants should not be mixed.[184] Support should no longer be provided to plants that are fully depreciated or that were financially supported in an adequate way in the past;
  - The support mechanism of any instrument should be restricted to a certain time frame. The duration should depend on the policy scheme (e.g. development of the TGC price) and on the maximum yearly transfer costs that can be imposed on consumer.
  - The effects on RES-E deployment, investor stability, conventional power generation and its emission and prices are similar if the design of the instrument is similar too. Of course, as the instrument differs, the effort, the efficiency and complexity of reaching a similar impact varies among the support schemes too.

recovery factor is used – based on the following settings: weighted average cost of capital = 6.5%, pay-back time = 15 years.

[184] This means that existing plant (constructed before a harmonised scheme is applied) should remain in their old scheme, whilst new schemes refer to new plant solely.

- The effectiveness of various RES-E support schemes largely depends on the credibility of the system. A stable planning is important to create a sound investment climate and to lower social costs as a result of lower risk premium.
- *Coordination and harmonisation of the support mechanism* between the Member States leads to *lower transfer costs for consumer*. As model runs clearly indicate, a proper designed harmonised promotion of RES-E on a European level would cause lower transfer costs for consumer in total, accompanied by more levelled consumer burden among the countries. Of course, a necessary pre-condition to reach an international agreement is that *a 'fair' burden sharing concept is developed, considering both national and international benefits from RES-E generation.*
- A continuous policy – avoiding a stop and go nature – is important to build up a (national) RES-industry.
- From a societal point-of-view *the use of the full basket of available RES-E technologies is highly recommended*. The effects of neglecting some technologies – especially 'cheap' options such as hydropower – increase both generation costs and transfer costs for consumer.
- The future development of transfer costs for consumer due to the promotion of RES-E is crucially influenced by the development of electricity prices on the conventional market. Thereby, a higher consumer burden due to higher electricity prices will be compensated partly by lower transfer costs related to the promotion of RES-E.[185]
- A considerable impact of RES-E deployment on conventional power price and CO_2 emissions can be observed:
  - Without consideration of additional transfer costs for consumer due to the promotion of RES-E, a price reduction on the power market of 5% to 10% can be observed;
  - The total additional cost (burden) due to the promotion of RES-E depends on the policy target and the applied policy scheme. A wide range of +3% to +15% occurs for the set of investigated scenarios;
  - CO_2-emissions from thermal power plants can be reduced by 20% to 25%.
- Existing (non-economic) barriers for new RES-E generators should be rigorously removed and outstanding incentives should be provided:
  - Start / continue information campaigns;
  - Integration and coordination of other policies like climate change, agricultural policy or DSM issues helps to reduce administration barriers;
  - *The achievement of most policy targets for RES-E* as well as the accompanying societal costs *is closely linked to the future development of the electricity demand*. Therefore, besides setting incentives on the supply-side for RES-E, accompanying demand-side measures help to minimise the overall societal burden;
  - Due to long and complex permission procedures in many countries a long lead time for RES-E projects occurs, increasing the pressure and the costs to achieve agreed RES-E targets.

---

[185] Details in this respect are given in the sensitivity analysis described in section 6.1.9.

► Feed-in tariff

The main conclusions with respect to application of the feed-in tariff system are:

- Feed-in tariffs have been successful for triggering substantial dissemination in all countries where they have been introduced;
- In principle they are the proven and preferable national instruments for to achieve a significant RES-E deployment. A guaranteed tariff is effective, flexible, fast and easy to install and has low administration costs;
- On the one hand, a feed-in tariff does not encourage competition between investors. Hence it does not force reductions in unit electricity price. On the other hand, based on the German experiences, guaranteeing a longer duration of the tariff leads to the implementation of more efficient components compared to investments undertaken under full competition;
- An important result of the analysis is that feed-in tariffs are especially an economically effective dissemination instrument, if:
  - the feed-in tariff rates decrease over time, as experience is gained (in line with the expected learning rate);
  - a stepped feed-in tariff is applied (where appropriate).[186]

► Quota obligation based on TGCs (TGC system)

The most important perceptions with respect to a quota obligation are:

- A quota obligation system based on tradable green certificates lead to minimal total RES-E system costs, however, not to minimal costs for society. This means, a TGC system is cost efficient with respect to the installed RES-E capacity but not with respect to cost that must be born by the consumer;
- In case of a flat RES-E cost-resource curve, which appears generally spoken in case of low targets, transfer costs for consumer are relatively low as well;
- As TGC price developments are uncertain and difficult to forecast, investor risks are higher compared to a feed-in tariff. The risk premium leads to higher costs for society. Risks can be reduced by a guaranteed floor price or the allowance of banking and borrowing of TGCs, but risks remain higher compared to other support schemes;
- One main advantage of a quota obligation is that the target will be exactly reached setting enough incentives. Thus, in contrast to a feed-in tariff scheme or a tender procedure, no adjustment is necessary to fulfilling targets;
- A quota obligation encourages competition among RES-E generators if the market size is large enough (which is ensured in case of international trade) ;
- An implementation on international level can contribute to a fair international burden sharing for consumers;
- Non-compliance penalties should be significantly higher than the expected market price for TGCs, otherwise there is no incentive to fulfil the quota.

---

[186] This depends on the applicability of an 'efficiency indicator' - In case of wind energy this is easy to implement by linking tariff height to the achieved full load hours, but also for biomass (fuel input, plant size, conversion technology) or small-scale hydropower (plant size) a stepped design would be applicable.

► <u>Comparison of instruments</u>

Summing up, by focusing on resulting transfer costs for consumer as done in the analysis in section 6.1 the following findings can be drawn:

- A **quota obligation based on TGCs** is less efficient from a societal point-of-view compared to other instruments analysed, as, first, a higher risk must be born by the generator, and, second, efficiency gains are absorbed by the producer (high producer surplus) and not by the consumer;
- **Feed-in tariffs** (and also e.g. tender schemes) are useful in promoting a more homogeneous distribution among different technologies by setting technology specific guaranteed tariffs. By implementing such a policy, the long-term technology development of various RES-E options, which are currently not cost-efficient, can be supported. Reason is that due to the application of non-mature technologies a dynamic process can be started (i.e. stimulation of additional research, own industrial development, etc.) which leads, first, to a decrease in future generation costs and, second an increase of the available market potential in the future (as the market is already more matured). However, this positive effect must be compensated by economic distortions among the RES-E technologies.

7.4. Analysis of RES-E deployment at the national level – the case of Austria

Findings listed below refer to the second example as presented in section 6.2, which aims to demonstrate the applicability of the model for analysis carried out on national level. As example Austria, representing a small country on the global marketplace, is chosen.

► <u>Applicability of the modelling concept</u>

The applicableness of the ***Green*-X** model for forecasts at national level is well demonstrated in this respect. From a modelling perspective the following issues are of relevance:

- With respect to the model implementation of *technological learning*, in contrast to the application on European level, no endogenous feedback is considered. As learning is taking place at the international level, the deployment of a technology at global level must be considered. Hence, for the case that only a single country is investigated, a default forecast is taken as reference for the RES-E deployment at EU-15 level and, as usual, supplemented by an exogenous forecasts for the development in the 'rest of the world' (taken from (IEA, 2004)).
- As usual, the quality of the outcomes of an analysis highly depends on the applied data and accompanying assumptions. Therefore, a careful assessment of e.g. national/regional peculiarities for considered RES-E technologies is highly recommended.

► <u>Conclusion referring to the derived scenario outcomes:</u>

The aim of the three investigated scenarios is to indicate the consequences of policy decisions on resulting RES-E deployment. Current reference is given to discussions at political as well as at social level with respect to the further promotion of RES-E and accompanying cost burden for consumer. Thereby, three scenarios are taken into consideration, differing in applied policy assumptions - ranging from no further promotion after 2004 to a continuation of enhanced feed-in tariffs as valid until the end of 2004. Main conclusions are:

- Comparing electricity generation from so called *‚sonstigen Ökostromanlagen'* (i.e. RES-E exc. waste & hydro – in other words mainly wind energy & biomass) it becomes obviously that according targets as set in the Eco-electricity Act will be met in all variants, even without further promotion of new RES-E.
- The future development of total RES-E generation (i.e. by including all options) and corresponding gross electricity demand provides a different view. Note, both values are of relevance with respect to the targets as set at European level – i.e. the indicative target for Austria – a RES-E share of 78.1% in 2010 – as imposed by the 'RES-E Directive'. Up to the med term a more or less dramatic decrease of the share of RES-E on total demand occurs for all variants – i.e. a range of 63% to 69% can be expected in 2010, decreasing later on to 55 - 63%. In other words, in none of the scenarios a fulfilment seems likely.
- Huge differences can be observed with respect to the accompanying yearly transfer costs referring to the promotion of 'sonstiger Ökostrom': Under ambitious incentives a high peak level of 9 €/MWh (public demand) results for 2015, decreasing later on, whilst with no further promotion transfer costs drop from currently about 5 €/MWh to zero in 2019.

References

Alsema E. (2003). PV cost and development. Presentation at the PHOTEX workshop in Brussels, 4 June 2003. Utrecht University, Department of Science, Technology and Society, Netherlands.

Beurskens L., M. de Noord (2003). Offshore wind power developments. Report prepared by ECN (NL).

BMU (2002). Conference transcript of „Fachtagung Geothermische Stromerzeugung – eine Investition in die Zukunft" (in German). 20-21 June 2002, Landau/Pfalz, published by the German Ministry for Environment, Germany.

BMU (2004). Ökologisch optimierter Ausbau der Nutzung erneuerbarer Energien in Deutschland (in German). Prepared by DLR/ifeu/WI for the German Ministry for Environment, Germany.

BMWA (2002). Verordnung des Bundesministers für Wirtschaft und Arbeit, mit der Preise für die Abnahme elektrischer Energie aus Ökostromanlagen festgesetzt warden. BGBl. II Nr. 508/2002, Austrian Ministry for Economy and Labour (BMWA), Austria.

Bruntland Commission (1987). Our Common Future. World Commission on Environment and Development (Bruntland Commission), Oxford University Press, Oxford (UK).

BTM Consult ApS (1999 to 2003): International wind energy development – world market update. Yearly updated reports by BTM Consult ApS (DK).

Cleijne H, W. Ruijgrok (2004). Modelling risks of renewable energy investments. Report of work package 2 within the European research project Green-X – funded by the European Commission, DG Research; KEMA, Arnheim (NL) – available at www.green-x.at.

DLR/WI/ZSW/IWR/Forum (1999). Klimaschutz durch Nutzung erneuerbarer Energien (in German) – study for the German Ministry for Environment, Germany.

DTI/ETSU (1999). New and Renewable Energy: Prospects in the UK for the 21st century, United Kingdom.

DTI/ETSU (2001). The commercial prospects for Tidal Power. Report for DTI/ETSU by Binnie, Black and Veatch in association with IT Power, United Kingdom.

ECN (1997). Summary of Annex V: Energy Technology System Analysis Programme (ETSAP) – New directions in energy modelling. Prepared by ECN (NL), ETSAP-91—1.

Eco electricity act (2002). Ökostromgesetz sowie Änderung des Elektrizitätswirtschafts- und –organisationsgesetzes (ELWOG) und das Energieförderungsgesetz 1979 (EfG). BGBl. 149/2002, adopted by the Austrian Federal Parliament on 23-08-2002, Austria.

Enquete (2002). Analysis grid for the German Enquete Commission on Sustainable Energy Policy.

ESD/DGXVII (1996). TERES II – the European Renewable Energy Study. Report & CD-ROM by ESD et al. (1996) – on behalf of the European Commission, DG TREN.

EUBIONET (2003). Various reports (e.g. "Fuel prices in 2002/2003") on web page www.eubionet.net.

European Commission (1997). White Paper on renewable energy sources (COM(97)599).

European Commission (2003). European Energy and Transport Trends to 2030. European Commission, DG TREN; prepared by Mantzos et al., University of Athens.

European Opinion Research Group - EORG (2002). EUROBAROMETER - Energy: Issues, Options and Technologies, Science and Society. Report produced by The European Opinion Research Group (EORG) for the European Commission, DG Research.

European Parliament and Council (1999). Directive 1999/31/EC of April 26th 1999 on the landfill of waste.

European Parliament and Council (2000). Directive 2000/60/EC of October 23rd 2000 establishing a framework for Community action in the field of water policy.

European Parliament and Council (2001). Directive 2001/77/EC of September 27th 2001 on the Promotion of Electricity produced from Renewable Energy Sources in the internal electricity market.

Eurostat (2002a). Environmental statistics – Yearbook 2001 (CD-ROM).

Eurostat (2002b). Energy statistics – 2002 edition (CD-ROM).

Eurostat (2003). Personnel information.

Faber T., C. Huber, G. Resch (2004). Handbook for the toolbox Green-X. Report of work package 2 within the European research project Green-X – funded by the European Commission, DG Research; Energy Economics Group (EEG), Vienna University of Technology, Vienna (AT) – available at *www.green-x.at*.

FAOSTAT (2002). Food and Agricultural Organization of the United Nations - statistical database (on land use, forestry, etc.), available on the internet: *http:*//apps.fao.org.

Fichtner (2002). Gutachten zur Markt- und Kostenentwicklung der Stromerzeugung aus Biomasse (in German). Expertise prepared by Fichtner for Bundesinitiative Bioenergie, Stuttgart (DE).

Grübler A., N. Nakićenović, D.G. Victor (1998). Dynamics of energy technologies and global change. In: Energy Policy 27 (1999), p. 247-280.

Gutschner M. (2001). Evaluation of the technical potential of building integrated photovoltaic power systems, Report for the PVPS Task VII "Photovoltaic Power Systems in the Built Environment", Freiburg (CH).

Greenpeace (2001). North Sea Offshore Wind – A Powerhouse for Europe. Germany.

Haas R., Berger M., Kranzl L. (2001). Erneuerbare Strategien - Strategien zur weiteren Forcierung erneuerbarer Energieträger in Österreich unter besonderer Berücksichtigung des EU-Weissbuches für Erneuerbare Energien und der Campaign for Take-off (in German). Energy Economics Group, Vienna University of Technology, Vienna (AT).

Huber C. (2000). Development of Trading Rules. Report of the European research project ElGreen - funded by the European Commission, DG TREN; Energy Economics Group (EEG), Vienna University of Technology, Austria.

Huber C., T. Erge, T. Faber, J. Green, R. Haas, G. Resch, W. Ruijgrok, J. Twidell (2001). Final Report of the project ElGreen. Report of the European research project ElGreen - funded by the European Commission, DG TREN; Energy Economics Group (EEG), Vienna University of Technology, Austria.

Huber C., T. Faber, R. Haas, G. Resch, J. Green, S. Ölz, S. White, H. Cleijne, W. Ruijgrok, P.E. Morthorst, K. Skytte, M. Gual, P. Del Rio, F. Hernández, A. Tacsir, M. Ragwitz, J. Schleich, W. Orasch, M. Bokemann, C. Lins (2004a). Action plan for a dynamic RES-E policy. Report of the European research project Green-X – funded by the European Commission, DG Research; Energy Economics Group (EEG), Vienna University of Technology, Austria - available at *www.green-x.at*.

Huber, C., G. Resch, M. A. Lopez-Polo (2004b). Final report of the project Dynamic RES-E. Jubiläumsfond project no. 9408 - funded by the Österreichische Nationalbank; Energy Economics Group (EEG), Vienna University of Technology, Austria.

International Energy Agency (2003). Personnel information from Maria Agiri (IEA, Economic Analysis Division), Paris (FR).

International Energy Agency (2004). World Energy Outlook to 2030 – 2004 edition. International Energy Agency, Paris (FR).

Junginger, M., A. Faaij (2003). A global experience curve for wind energy. Paper from the "European Wind energy Conference and Exhibition 2003", Madrid, 16-19 June 2003; Department of Science, Technology and Society; Copernicus Institute, Utrecht University, The Netherlands.

Kaltschmitt M., A. Wiese, W. Streicher (2003). Erneuerbare Energien – 3rd edition (in German), ISBN 3-540-43600-6, Springer-Verlag, Germany.

Kranzl L. (2002). Die gesamtwirtschaftliche Bedeutung der energetischen Nutzung von Biomasse (in German). PhD-thesis conducted at Energy Economics Group (EEG), Vienna University of Technology.

Kratena K., Schleicher (2001). Energieprognose und -szenarien für Österreich bis 2020. WIFO, Vienna, Austria 2001.

Lorenzoni A. (2001). Blue Energy for a Green Europe – final report. EU Altener II Programme, IEFE – Universitá Commerciale L. Bocconi, Milano (IT).

Mantzos et al. (2003a). European Energy and Transport Trends to 2030. On behalf of: European Commission, DG TREN. University of Athens, Greece.

Mantzos et al. (2003b). Efficiency scenario related to the European Energy and Transport Trends to 2030. On behalf of: European Commission, DG TREN. University of Athens, Greece.

McDonald A., L. Schrattenholzer (2000). Learning rates for energy technologies. In: Energy Policy 29 (2001), p. 255-261.

Menges, R. (2003). Supporting renewable energy on liberalised markets: green electricity between additionality and consumer sovereignty. In: Energy Policy 31, No. 7 (2003), p. 583-596.

Meulbroek L. (2000). Total strategies for company-wide risk control. In: Mastering risk (vol. 3). Financial Times Mastering Series, London.

Michael P. (2002). DTI Wave Report 2002. Department of Trade and Industry, United Kingdom, 2002.

Morthorst P.E., K. Skytte, C. Huber, G. Resch, P. Del Rio; M. Gual, M. Ragwitz, J. Schleich, S. White (2003): Analysis of trade-offs between different support mechanisms. Report of work package 4 within the European research project Green-X

– funded by the European Commission, DG Research; Risoe National Laboratory, Roskilde (DK) - available at www.green-x.at.

Neij L., P. D. Andersen, M. Durstewitz, P. Helby, M. Hoppe-Kilpper, P. E. Morthorst (2003). Experience curves: A tool for Energy Policy Assessment (EXTOOL). Final report of the project EXTOOL – a European research project funded by the EC, DG RESEARCH; Coordinated by Lund University, Sweden.

Neubarth J., M. Kaltschmitt (2000). Erneuerbare Energien in Österreich (in German). ISBN 3-211-83579-2, Springer-Verlag Wien New York, Austria.

Nowak St., M. Gutschner, G. Favaro (2002). Impact of Technology Developments and Cost Reductions on Renewable Energy Market Growth. Six technology-specific reports prepared within the project REMAC2000 – in cooperation with the International Energy Agency. NET Ltd., Switzerland.

OXERA Environmental (2001). Renewable Electricity Entry Scenario. Report prepared by OXERA Environmental, United Kingdom.

Quaschning V., W. Ortmanns (2003). Specific cost development of photovoltaic and concetrated solar thermal systems depending on the global irradiation – a study performed with the simulation environment GREENIUS. Paper presented at the ISES Solar World Congress 2003, Göteborg, Sweden, 14-19 June 2003. DLR e.V., Almeria (ES).

Ragwitz M., C. Huber, G. Resch, S. White (2003). Dynamic cost-resource curves. Report of work package 1 within the European research project Green-X – funded by the European Commission, DG Research; FhG-ISI, Karlsruhe (DE) - available at www.green-x.at.

Ragwitz M., J. Schleich, C. Huber, G. Resch, T. Faber, M. Voogt, W. Ruijgrok, P. Bodo (2004). FORRES 2020 - Analysis of the renewable energy's evolution up to 2020. Draft final report of the project FORRES 2020 - on behalf of the European Commission, DG TREN; coordinated by FhG-ISI with contribution from EEG, Ecofys, Kema and REC; Karlsruhe (DE).

Ragwitz M., J. Schleich, C. Huber, G. Resch, T. Faber (2005). Estimating future market diffusion of innovative technologies applied to renewable energy sources evolution in Europe. In: Energy & Environment (2005) (forthcoming).

Resch G., M. Berger, L. Kranzl (2001): Database for the Model ElGreen. Report of the European research project ElGreen - funded by the European Commission, DG TREN; Energy Economics Group (EEG), Vienna University of Technology, Austria.

Resch G., M. A. Lopez-Polo, H. Auer, R. Haas, H. Chandler, C. Kjær, J. Twidell (2005a). Electricity from renewable energy sources in EU-15 countries – a review of promotion strategies. Report within work phase 1 of the European research project RE-XPANSION – funded by the European Commission, DG TREN; Energy Economics Group (EEG), Vienna University of Technology, Vienna (AT).

Resch G., M. T. Faber, C. Huber (2005b). Inputs to the analysis of support schemes – Scenarios on the future deployment of RES-E & accompanying consumer expenditure. Report within work phase 2 of the European research project RE-XPANSION – funded by the European Commission, DG TREN; Energy Economics Group (EEG), Vienna University of Technology, Vienna (AT).

Schaeffer et al. (2004). Learning from the sun – Final report of the Photex project. Report of the European research project Photex, supported by EC, DG TREN; coordinated by ECN, Netherlands.

Schönbauer C. (2004). Zur Neubestimmung der „Preise" (Einspeisetarife) für Kleinwasserkraft und sonstige Ökostromanlagen. Expertise for Austrian Ministry for Economy and Labour (BMWA), E-Control, Vienna (AT).

Thorpe M. (1999). Wave energy review. United Kingdom.

US-DOEn(2002). International Energy Outlook 2002, Reference Case projection

Uyterlinde M A, Daniels B W, De Noord M, De Zoeten-Dartenset C, Skytte K, Meibom P, Lescot D, Hoffman T, Stronzik M, Gual M, del Río P, Hernández P. (2003). ADMIRE-REBUS Assessment and Dissemination of Major Investment Opportunities for Renewable Electricity in Europe using the REBUS tool. Interim Report of the European research project ADMIRE-REBUS – funded by the European Commission, DG TREN; ECN, Petten (NL).

Voogt M.H., M.A. Uyterlinde, M. de Noord, K. Skytte, L.H. Nielsen, M. Leonardi, M. Whiteley, M. Chapman (2001). Effects of burden sharing and certificate trade on the renewable electricity market in Europe. Report of the European research project REBUS – funded by the European Commission, DG TREN; ECN, Netherlands.

Wene, C.-O. (2000). Experience curves for energy technology policy, International Energy Agency, Paris (FR).

WETO (2003): World Energy, Technology and Climate Policy Outlook by ENERDATA et al. on behalf of the European Commission, DG Research.