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POTENTIALS AND COSTS FOR RENEWABLE ELECTRICITY GENERATION

A data overview

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Acknowledgement
This report is the result of the data search part of a research project on future outlook and data for renewable electricity sources carried out at ECN called 'Toekomstbeelden en data DE-huishouding', registered under ECN project number 7.7476. As a practical application, most of the data were used in the EU Altener research project 'ADMIRE REBUS' in 2002 and 2003.

This report could not have been written without a structural and constructive communication and discussions between the different ECN departments and their experts. Representatives for the Wind Energy sections were Henk-Jan Kooijman and Jos Beurskens. For Solar Photovoltaic energy, key persons were Paul Wyers and Hugo de Moor. From the Biomass department, René van Ree contributed to a great extent to the Biomass section.

Abstract
This report presents the characteristic data regarding potentials and costs for technologies for renewable electricity generation. Focus is on onshore and offshore wind energy, solar photovoltaic energy and electricity from biomass and waste. Additionally, data are presented for hydropower and geothermal electricity.

The 15 EU Member States are focused upon. Data ranges are set for the Netherlands and for Europe. Estimates of renewable energy potentials are presented for individual countries. The time horizon of most figures is the year 2050.

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SUMMARY

The aim of this report is to provide an overview of key figures describing the most important technologies for renewable electricity generation. The approach has been the following: firstly, an overview is given of descriptive data as it can be found in literature. To this end, focus has been on two entities: the Netherlands on one side, and the present 15 member states of the European Union on the other (including Norway and Switzerland, 'EU+'). From this overview, for several technology parameters *data ranges* have been identified, that describe these technologies best. Finally, following a well-defined approach, the data ranges identified for the Netherlands and EU+ are used to create a country-specific data-overview.

Focus is on onshore and offshore wind energy, solar photovoltaic energy and electricity from biomass and waste. Additionally, data are presented for hydropower and geothermal electricity.

The parameters that are presented in this report can be divided into three groups: potentials, financial parameters and technical parameters.

To describe potential data, the concept is used of 'realistic potential'. Namely, the potential of renewable energy is constrained by planning issues and public acceptance. Although there might be enough space or resource technically available for renewable electricity production, it is not allways desirable to utilise all the technical potential. The realistic potential is time independent. Estimates of potentials found in literature are often based on different definitions, which sometimes can complicate their interpretation.

Specific technical data are described by parameters such as power density, load factor, and lifetime.

Financial data that have been indentified are investment costs and operation and maintenance costs (O&M).

In Tables S.1 to S.4 the data ranges for the technologies that receive most attention in the current report are indicated.

Onshore wind power

Table S.1 *Key parameters for onshore wind power and the data*

Parameter	Unit	Netherlands	EU-15	Reference year
Realistic potential	[GW]	1.5 to 3.2	60 to 315	2050
Investment costs	[€/kW]	875 to 1250	875 to 1250	2002
O&M costs	[% of investment/yr]	1.5 to 3.4	1.5 to 3.4	A
Power density	[MW/km^2]	6 to 10	6 to 10	A
Load factor	[%]	10 to 33	10 to 33	A
Lifetime	[years]	20	20	A

A In a first estimate, this parameter is considered to be time-independent.

Offshore wind power

Table S.2 *Key parameters for offshore wind power and the data*

Parameter	Unit	Netherlands	EU-15	Reference year
Realistic potential	[GW]	6 to 30	90 to 348	2050
Investment costs	[€/kW]	1546 to 2428	1546 to 2428	2002
O&M costs	[% of investment /yr]	3.2 to 6.7	3.2 to 6.7	[A]
Power density	[MW/km^2]	4 to 10	4 to 10	[A]
Load factor	[%]	14 to 39	14 to 39	[A]
Lifetime	[years]	20	20	[A]

[A] In a first estimate, this parameter is considered to be time-independent.

Solar photovoltaic energy

Table S.3 *Key parameters for solar PV and the data ranges*

Parameter	Unit	Netherlands	EU-15	Reference year
Realistic potential	[km^2]	600	16000	-
Realisable potential	[GW_p]	49 (7 to 180)	661 (98 to 4089)	2050
Investment costs	[$€/W_p$]	5 to 8	5 to 8	2002
Progress ratio	[%]	80 (75 to 90)	80 (75 to 90)	[A]
O&M costs	[% of investment /yr]	1 to 3	1 to 3	[A]
Power density	[W_p/m^2]	100 to 300	100 to 300	2000-2050
Load factor	[%]	8 to 10	12 to 16	[A]
Lifetime	[years]	25	25	[A]

[A] In a first estimate, this parameter is considered to be time-independent.

Biomass

Table S.4 *Key parameters for electricity from biomass and the data*

Parameter	Netherlands	World
Realistic potential	87-146 (PJ, 2020)	200-700 EJ (world availability, 2050)
Indicative costs of energy crops	-13 to +7 €/GJ	3 to 6 €/GJ (import to the Netherlands)

1. INTRODUCTION

This report is the result of a process of gathering, analysing and interpreting data on renewable energy technologies from various sources, seeking ranges in which the most reliable data can be found. The report has been written with a twofold purpose in mind:

1. to give an extensive overview of renewable energy data in present literature, and
2. to provide a set of data ranges for the technologies wind energy, solar PV energy and biomass. Data within these ranges is considered acceptable for ECN calculations, as long as the accompanying argumentation is defendable.

This report can be considered as an intermediate record describing data on renewable electricity generation. Firstly, because at the moment of publishing the report, it is already outdated: new literature sources are published every month, and therefore any overview cannot be exhaustive. The current report contains data that were available up to the end of the year 2002. Secondly, new or changing insights can make that the data ranges published here can always be subject to changes. Possibly, in future updates of this report, the data ranges will be narrowed over time, and new technology data and new parameters will be added. Any questions or comments on the data used in this report can be sent by e-mail to energy-data@ecn.nl.

The data that are presented mainly focus on the renewable generation technologies wind (onshore and offshore), solar photovoltaic energy and electricity generation based on biomass and waste. From literature several important parameters were grouped, so that upper and lower bounds could be determined. Discussions with ECN experts resulted in the data ranges as presented.

A first application of the collected data was the ADMIRE REBUS project, see Uyterlinde et al. (2003). In this project a model is developed that can be used to analyse the impact of renewable energy policies on (inter-)national trade. For the model analysis also data on other renewable technologies are required. Although there was not such an exhaustive literature research as on wind, solar PV and biomass, the data collected for other technologies are also given in the last chapters of this report.

It is possible that when data is cumulated within the tables, it does not precisely equal 100% of the original number. This is due to rounding errors.

The outline of the report is as follows. Chapter 2 discusses in detail the methodology used in the report, and elaborates on the parameter definitions. Chapter 3 to 7 discuss consecutively the technology parameters for onshore and offshore wind energy, solar photovoltaic energy and electricity form biomass and waste. These chapters have been set up as follows: firstly, an overview of literature sources is presented, in which for key parameters (see Section 2.3 and 2.4) data from different sources are compared. The next section then elaborates on the data ranges, and finally a country-specific part presents, based on a pre-defined assessment structure (see Section 2.5) potentials and costs for the EU-15 and Norway. Finally, Chapter 8 provides data on hydropower, and Chapter 9 on geothermal electricity generation.

Note that when EU+ is mentioned, actually the 15 EU Member States plus Norway is meant.

2. METHODOLOGY

2.1 Introduction

For this report a literature research was undertaken, from which general ranges for different parameters were selected. These were used in discussions with experts within ECN. In the discussions the ranges were, where possible, narrowed. Any value within these ranges is considered acceptable, with the restriction however that it depends on the argumentation that goes behind the value.

2.2 Literature research

The literature reviewed in this study was brought together from various sources, including databases, internet, monographs, studies, reports and scientific articles, of which a lot were supplied by ECN technology experts. Other literature was found using search engines on the internet, and using the ECN library. The search limits that were used differed per technology. The main reason for this is that on some technologies there is already much information available, and on some information not. For example for onshore wind, a technology that is in use for more than ten years now, there is not only theoretical data available, but also empirical data from different wind parks in Europe. For technologies generating electricity based on biomass, there is empirical information available on some older technologies, but technologies such as co-firing of biomass in Combined Cycle installations are not commercially available yet.

The literature search was limited to documents in Dutch, English, French and German. The time span in which the literature was made available is not more than 10 years, although the emphasis was put on the more recent work. The different sources should have comparable data (e.g. clear definitions, units etc.) but in practice this was rather laborious.

From the broad range of available titles, a selection was made of the more influential and well-regarded works. The technology experts, as well as policy and scenario experts within ECN made this selection. Some theoretical studies were not taken into account because reality already proved the conclusions wrong.

Based on this literature an overview was made per technology and per parameter (for wind, solar and biomass only). In this overview the source would be given, the value of the parameter, the range (if applicable), remarks if necessary and the reference year (if applicable). Where possible, a difference was made between data specific for The Netherlands, and data specific for the EU as a whole.

For each parameter, the range extracted from the literature was discussed with experts within ECN. Where possible the ranges were narrowed. These ranges are presented in this report.

2.2.1 Application

As an example of the practical use of the ranges, the development of the ADMIRE REBUS model is taken (Uyterlinde et al, 2003). The model provides a powerful tool for analysing the penetration of renewable electricity generation through time, in a fragmented market that is characterised by a variety of national support policies.

The Admire-Rebus methodology is founded on the construction of so-called supply curves that specify the amount of renewable electricity potential in GWh that can be achieved at certain costs (in €/kWh). For this purpose, data on costs and potentials for all relevant technologies are required, for 15 EU Member States and Norway.

The gathering of this data was combined with the development of the ECN data ranges, described in this report.

2.3 Financial and technical parameters

The technologies that are reviewed and for which data ranges have been established in this report are onshore and offshore wind energy, solar photovoltaic energy and electricity generation from biomass and waste. Other technologies were not considered for the fixing of the data ranges, but only for the country-specific part. Possibly, they will be taken into account in future updates of the current report. For each technology a set of parameters was defined. These parameters represent a set of values on which there is often discussion. In the future other parameters can be added, and present parameters can be explored in more detail.

The parameters that are presented in this report can be divided into three groups: potentials, financial parameters (costs), and technical parameters. Information on the potentials can be found in Section 2.4. The current section elaborates on Financial and technical parameters.

It must be clear that the parameter value depends on the situation in which it is used. The main reason to define a lower limit and an upper limit is that all values within the range would be acceptable, if the assumptions behind the value can be defended. It must also be clear that in the literature search, it was quite difficult to compare values and parameters from different sources. Within the different fields there are many definitions available, which are not always comparable. Where possible this was taken into account.

2.3.1 Investment costs

In this report the ranges for investment costs are based on a definition of investment costs as the total project costs, expressed in €/kW, that have to be made before the first electricity is generated. In the literature it is not always clear which costs are included in investment costs. Most of the sources include:

- costs of technology (wind turbine, solar panels etc.),
- costs of peripheric technology (power converters, generators etc.),
- costs of land,
- project management costs (including consulting and legal costs).

Costs that are not included in this definition are:

- costs for reparation after a certain period of time,
- fuel costs.

2.3.2 O&M costs

For the ranges in this report, Operation and Maintenance costs (O&M costs) are defined as the average annual costs over the technical lifetime of the installation, needed to keep the installation in operation. The O&M costs are expressed as a percentage of the total investment costs. They include:

- maintenance and repair,
- insurance,
- electricity obtained from the grid,
- management,
- tax consulting,
- ground lease,
- others like memberships, legal consultancy, etc.

2.3.3 Lifetime

When lifetime is mentioned in this document, the technical lifetime of the installation is referred to. There are two ways to calculate the lifetime of an installation: by using empirical data or by using the lifetime specified by the developer of the installation. Especially in case of new technologies the latter method is used.

2.3.4 Load factor

The load factor of an installation is the total production of an installation, related to the total number of hours in one year. The number of hours that the installation is functional is divided by the number of hours per year (normally expressed as percentage). This value depends very much on the location of the installation in the case of wind and solar PV technologies. In this report we will focus on the net production of an installation that is the electricity that is fed into the grid.

2.3.5 Growth rate

The growth rate of a technology represents the growth of a market for that technology, or, in some cases, the growth of the cumulative installed capacity of a technology. In many literature sources it is not totally clear which growth rate is referred to.

2.3.6 Progress ratio

The progress ratio is a measure that is used for expressing the decrease in investment costs of a technology as a function of cumulative capacity. For example, a progress ratio of 0.80 indicates that for every doubling in cumulative installed capacity of that technology, investment costs decrease with a factor (1-0.80 =) 0.20. The higher the value of the progress rate, the smaller the future cost decrease is expected to be.

2.3.7 Electric power

The definition of power that is used in this document differs per technology. For solar photovoltaic energy, power is expressed as power (peak) with unit W_p. This is the maximum power a solar PV installation can deliver, but generally the average output will be less. For wind energy, power is defined as the nominal power produced by the generator-rotor combination. For biomass, power is normally divided in electric power and heat power. In this report only electrical power will be taken into account.

2.3.8 Production of electricity

The production of an installation depends on various factors, including the load factor, (the averaged relative amount of time it is functioning full power) and the efficiency of an installation. The efficiency is affected by the fuel used (in the case of biomass) or the wind regime in which a turbine is operated.

2.4 Parameters for potentials

Renewable energy potentials can be obtained in two different ways: via a top-down or a bottom-up method. The top-down method starts with considering the total energy flow of a renewable source, regardless of the availability for energy production. For example wind energy or solar energy: depending on the wind speed or solar radiation, the total (theoretical) energy flow can be calculated. However only on those places where wind turbines or PV panels are built, the energy can be collected.

The bottom-up method is more laborious: every single site where energy production is possible has to be known. Hydropower and geothermal energy are good examples of this: it is only possible on suitable sites defined by nature. Potentials are defined by a combination of the two methods. The top-down method is mainly used for wind energy, solar energy and energy from biomass and wastes. The bottom-up method is used for the site-specific sources, namely hydropower and geothermal electricity.

For both methods the following potential definitions are considered:
- Theoretical potential: energy flow.
- Technical potential: technical constraints.
- Realistic potential: non-technological factors.
- Realisable potential at a certain point in time: takes into account maximum market growth rates over all countries.

Every step results in a reduction of the potential, due to various constraints. This is illustrated in the figure below.

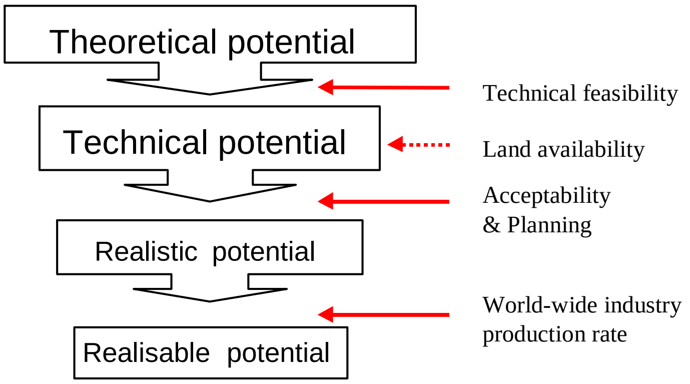

Figure 2.1 *Methodology for definition of potentials*

Theoretical potential

The theoretical potential of a renewable energy source is the total physical energy flow of that source. For example the total energy content of solar radiation on the whole land area of a Member State during one year.

Theoretical → technical potential
In this step the restrictions in technology reduce the theoretical potential. For example wind energy: it is technically not possible to convert all the energy in the wind into electricity. Another reducing factor in this matter is the availability of potential sites or primary fuel stream for biomass. Large wind turbines for example are not installed in urban areas, and not all wood residues from forestry are available for electricity production.

Technical → realistic potential
At this point planning issues and acceptability problems play a role. Although there might be enough space or resource technically available for renewable electricity production, it is not always desirable to utilise all the technical potential. This is due to a variety of factors such as:
- public or social acceptance (e.g. the Not In My Back Yard (NIMBY) syndrome),
- unacceptable environmental impacts,
- spatial planning problems,
- other market barriers.

The reduction factor is often difficult to determine, since these factors differs between countries and regions and may differ over time. For example for the Netherlands: according to several studies the potential for onshore wind power is at least 3000 MW, while the realisation in 2000 was only 430 MW. The main reduction factor in this case is the long way of complex and inefficient spatial procedures in which local and regional councils have to be brought in line with central government policy. Also the NIMBY syndrome contributes to a low realisation. Another well-known example is the strong opposition to wind power in some UK regions.

Another example of a barrier: some proposed tidal or hydro electricity schemes have provoked serious but lingering discussions about environmental impacts. Therefore these kind of projects, although they are technically feasible, are not included in the realistic potentials.

It should be noted that this methodology uses a few assumptions that are different from standard potential analysis. For instance non-competitive technologies without non-economic barriers are defined according to the ADMIRE REBUS methodology as realistic potentials. Note that on the basis of the costs price, it could very well be that these technologies would not penetrate in the market when competing with other, less expensive technologies. The other way around, competitive technologies for which there exist non-economic barriers are not included in the realistic potential.

Realistic → realisable potential
In this step the availability of technology at a certain point in time is taken into account. Although the realisable potential for the EU as a whole can be very high, it is not likely that the industry will have a sudden increase in production capacity. Therefore the realisable potential takes into account limitations related to lead times, maximum deployment growth rates and the growth rate of the capital industry.

The realistic potential is *time independent*, whereas the realisable potential is *time dependent.* The potentials for which ranges are estimated in this report are time independent, e.g. realistic potentials. The estimates of potentials found in literature are however based on different definitions, this will clearly be stated in the corresponding sections.

2.5 Assessment framework

A calculation framework has been developed to assess the influence of the different technologies and sources on the development of markets. The relationships between potentials, costs and technical aspects are fed into the ADMIRE REBUS model. The calculation framework translates these data into realistic potentials. In the calculation framework the primary data (that is the data of the starting year) is combined with the availability of different energy sources, and the potential of these sources. Since the potential that is used to calculate the shares of one technology in a multitechnology market is the realistic potential, the realistic potential for each technology in every EU country and Norway has to be determined.

2.5.1 Potential assessment framework

The potentials of each technology are assessed using a systematic approach in which the assumption is made that for each technology, one indicator can be found which to a large extent determines its potential. For example, for waste-based electricity, the starting level is the number of inhabitants in a country, in combination with a conversion factor that gives the total amount of residential waste in a country produced by those inhabitants. From this starting 'top-level' the technology is elaborated to Power and Production, using the system of levels and conversion factors. The top-level is the level in which data is entered. Other levels are always a result of calculations within the model.

Multiple bands have been defined for each technology. As a result it is possible to take differences, for example in wind regimes, into account per band.

As an example, the assessment structure of onshore wind energy is given in Table 2.1. The table shows that the toplevel (the level with the highest level number) is the area available for placing wind turbines. Depending on power density in a certain area, total installed power can be calculated. In combination with the number of hours in a year, the electricity production can be calculated.

Table 2.1 *Assessment structure for onshore wind energy*

Level	Name/unit	Factor
4	Available area [km^2]	
		× power density [MW/km^2]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

When possible, average unit sizes are used. Using the units the calculation framework can check the results of the calculations for flaws. The expected development over time can be inserted by using upper and lower bounds, or by using S-curve calculations.

2.5.2 Costs in the assessment framework

A cost parameter can be attached to each level within the framework. This parameter can be investment costs (fixed), O&M costs (fixed) or variable costs. The development curves can be inserted as well.

3. WIND ONSHORE

3.1 Introduction

In this chapter the future development of electricity generation from onshore wind, is examined, concentrating on potentials and financial and technical parameters. Section 3.2 presents an overview of literature sources that assess the future wind onshore development regarding costs and potentials. Next, Section 3.3 discusses the ranges within which the parameters are estimated to be situated: Table 3.1 lists all parameters for which a datarange will be defined, and the resulting data ranges. Finally, Section 3.4 presents a method for allocating country-specific ranges to the EU+ states.

Table 3.1 *Key parameters for onshore wind power*

Parameter	Unit	Netherlands	EU-15	Reference year
Realistic potential	[GW]	1.5 to 3.2	60 to 315	2050
Investment costs	[€/kW]	875 to 1250	875 to 1250	2002
O&M costs	[% of investment/yr]	1.5 to 3.4	1.5 to 3.4	A
Power density	[MW/km^2]	6 to 10	6 to 10	A
Load factor	[%]	10 to 33	10 to 33	A
Lifetime	[years]	20	20	A

[A] In a first estimate, this parameter is considered to be time-independent.

3.2 Literature sources and data

Wind energy is a renewable energy technology on which there is a lot of information available. Most of this information focuses on the onshore wind energy production, as this is now a well-developed technology. There is both empirical data and theoretical data available. Focus in the current chapter is mainly on potential and investment costs. Other parameters receive less attention; in some cases because less discussion occurs, in other cases because parameters simply are not mentioned in the reports.

3.2.1 Potentials

There are various sources in which the potential of onshore wind energy is expressed. What follows is a selection from a longer list, but the sources presented are considered to be the most important. Data are presented for the Netherlands, and for Europe, and have been summarised in Table 3.2 and Table 3.3. Note that technical, realistic and realisable potentials (see Section 2.4) have all been taken in the same table (see additional information in the footnotes).

The Netherlands

An overview of literature for wind onshore potential for the Netherlands is listed in Table 3.2. In the study Van Wijk, 1993 the technical potential has been assessed. This amount of 3500 MW is to be interpreted as an upper limit. As the technical potential does not change over time, the value has been mentioned in all years. In IEA (2001) the Dutch government target is mentioned, which amounts to 1500 MW in the year 2010. This target is perceived as reasonable, whether it will be achieved depends to a large extent on the future Dutch support scheme. BTM, 2001 bases its projection on market knowledge[1]. As can be seen, the number of 1109 MW is heading for the 2010 target.

[1] The numbers have been deduced from two publications: in (BTM, 2001) predictions for offshore wind are mentioned, in (BTM, 2002) the total onshore and offshore potential are mentioned.

Representing the Dutch environmental movement, the fact that SNM (2000) considers a range around 2200 MW to be realisable is a strong signal. For the 12 provinces of the Netherlands, a bottom up assessment has been made, by counting the available locations that would meet certain criteria that are judged important. These criteria have been regarding possibilities of clustering instead of stand-alone, matching infrastructural works or industrial zones, temporarily undefined area and the distance to main ecological areas. Finally, in the publication (Hamburgische Landesbank, July 2002) a total wind power of 2500 MW in the year 2011 is projected, based on an 11.6% annual increase of installed capacity beginning in 2006.

Table 3.2 *Onshore wind energy potential for the Netherlands*

[MW]	Type	2000	2006	2010	2011
Van Wijk (1993)[1]	Technical	3500	3500	3500	3500
IEA (2001)[2]	Target			1500	
BTM (2001)[3]	Realisable/Projection	454	1109		
SNM (2000)	Realisable			2110-2260	
Hamburgische Landesbank (2002)[4]	Projection	446	1443		2500

1 Technical potential (energy equivalent of 7 TWh).
2 Target Dutch government, energy equivalent of 3.5 TWh.
3 For the year 2000: realisation, for the year 2006: projection.
4 Projection (includes offshore).

Europe

When the EU potential is mentioned in the literature, it is not always clear whether the data is including or excluding offshore wind energy. In addition, it is not always clear which definition of potentials has been taken. Table 3.3 lists the results of the literature survey. Again, Van Wijk (1993) assesses the technical potential, which can be interpreted as an upper limit. BTM (2001) regards the onshore potential for the 15 EU member states[2]. Data of EWEA are target values[3]. Recent history shows that previous targets set by EWEA were rather conservative. The range presented by Matthies et al. (2003) concerns an own projection. The EU White Paper (EC, 1997) sets a target of 40 GW in the year 2010. In the datasheet of the MARKAL tool (Lako, 1997) an upper boundary of 61000 MW for the year 2050 has been defined: simulation results cannot exceed this value. In this set, also a lower boundary has been defined (7200 MW), but this has currently been exceeded by far. The values by DKW (2001) are projections. The values from EWEA/GP (2001) are based on a scenario approach, which calculates the required contribution from wind power to electricity production, which is needed to achieve 12% of the worldwide electricity production in the year 2020.

2 The values have been deduced by subtracting non EU-member states and offshore projections.
3 Note, that the target for onshore wind power recently has been updated from 55 GW to 65 GW in the year 2010, and from 100 GW to 110 GW in the year 2020 (EWEA, 2003).

Table 3.3 *Onshore wind energy potential Europe*

[MW]	Type	2000	2005	2010	2020	2030	2040	2050
Van Wijk (1993)[1]	Technical	276,500		276,500	276,500	276,500	276,500	276,500
BTM (2001)[2]	Real./ Proj.	13,487	39,926					
EWEA (2002)[3]	Target			55,000	100,000			
Matthies et al. (2003)[4]	Projection			60,000-85,000				
EC (1997)[5]	Target			40,000				
Lako (1997)[6]	Upper bound	6,450		16,000	28,600	40,900	51,700	61,000
DKW (2001)	Forecast			31,200	50,100			
EWEA/GP (2001)[7]	Scenario				16,000			

Source: EU-15

1 Technical potential (energy equivalent of 554 TWh).
2 For the year 2000: realisation, for the year 2005: projection.
3 Target; see also Footnote 8.
4 Projection, 'pessimistic' and 'optimistic' (presumably includes offshore).
5 Target (includes offshore).
6 Upper boundary.
7 Scenario to achieve 12% of worldwide electricity use from wind. Value applies to OECD Europe.

Growth rates for the Netherlands

Assuming 454 MW installed in the year 2000, it can be calculated what growth rates occur, or are required to attain a certain future penetration. For IEA (2001) this implies a 12.7% annual growth to reach the target in the year 2010. BTM Consult (2001, 2002) projects an average growth rate[4] of 16% for the period 2000-2006. If the potential according to SNM (2000) were to be realised in ten years, this would imply an annual growth rate of 17%. In (Hamburgische Landesbank, 2002) a growth rate is projected of 24% until the year 2006, and 11.6% until the year 2011, as indicated in the report.

Growth rates for Europe

For the ten-year period between the reference years, annual growth factors have been calculated. This has been done in all cases whenever possible: when two consecutive years are available. These numbers are in most cases based on growth of cumulative installed capacity; only for EWEA/Greenpeace the market growth is considered. The growth rates are rather small compared to the period 2000-2010 for the Netherlands.

Table 3.4 *Overview of calculated growth rates*

[%]	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
EWEA (2002)[1]		6.2			
Lako (1997)[2]	9.5	6.0	3.6	2.4	1.7
DKW (2001)[3]		4.8			
EWEA/GP (2001)[4]	25 → 20	20 → 10	0		

1 Refers to EU-15 Onshore.
2 Refers to EU-15 Onshore.
3 Refers to EU-15 Onshore.
4 OECD Europe, includes offshore, refers to market growth.

4 Growth rate calculated based on combination of data from publications 2001 and 2002.

3.2.2 Technology costs

Investment costs

In Table 3.5 the investment costs of onshore wind energy are given mentioned by the listed literature sources. Notice that no country-specific data are available, only general data. The costs according to Lako (2002) comprise rotor, nacelle, tower civil work, infrastructure and grid connection. In Lako (1998) a small distinction has been made for inland and shore locations. It assumes relatively larger dimensions due to a lower average wind speed. Although not explicitly stated, it can be deduced that in EWEA/GP (2001) the investment costs only refer to onshore wind.

Table 3.5 *Onshore wind investment cost*

	Investment cost	Unit	Reference year
Lako (2002)	900	[$Euro_{2000}$/kW]	2000
Lako (1998)	985 (shore location) - 1000 (onshore inland)	[ECU/kW]	2000
EWEA/GP (2001)	879	[Euro/kW]	2001

Progress ratio

In EWEA/GP (2001) a changing progress ratio (PR) over time is mentioned. The study starts with a PR of 0.85 until the year 2010. Then, a PR of 0.90 is taken until he year 2025, and beyond this year no more cost reduction is assumed (PR=1). Remarkable is the fact that for the calculation the growth in *cumulative number of manufactured turbines* is taken as a reference, whereas it is more common to use the cumulative installed capacity as a parameter. Since in the report it is also assumed that the installed turbine size increases from an average of 1 MW in 2002 to 2 MW from 2031 onwards, the resulting cumulative capacity doubles faster that the cumulative amount of turbines. This method of approach thus slows down the cost reduction over time.

In Lako (2002) the PR of wind power is not distinguished over time, but related to components. Total costs are subdivided to rotor and nacelle, tower and the sum of civil work, infrastructure and grid connection, and this all for the period 2000-2030. Most of the cost reduction is expected for rotor and nacelle: PR is supposed 0.90. For the tower, this ranges between 0.93 and 0.96. For civil work, infrastructure and grid connection together, not large cost reduction is expected, namely a range of 0.96-0.98. The highest number indicates the ‘reference’ case, and the lowest number the ‘low’ case.

3.2.3 Technical aspects

Load factors

Table 3.6 and Table 3.7 present the load factors as found in literature. Only in Lako (1998) and in EWEA/GP (2001) load factors have been explicitly mentioned. For the other reports load factors have been derived from calculation, using the projected power and electricity production. In case of a technical potential (Van Wijk, 1993), only the value for the year 2050 has been given.

Time-dependency: as can be seen, only EWEA/GP (2001) gives a changing load factor in the course of time. The reasons that are given for this increase are higher placed and larger rotors, especially for inland locations. Also, a growing share of offshore wind can contribute to this increase, but that cannot be derived from the report.

From the next tables it can be seen that all numbers are within a range of 20% to 30%.

Table 3.6 *Onshore wind energy load factors the Netherland*

[%]	Based on:	2010	2050
IEA (2001)[1]	Target	26.6	
Van Wijk (1993)[2]	Technical potential		22.8

[1]Based on target for the Netherlands.

[2]Based on technical potential for the Netherlands.

Table 3.7 *Onshore wind energy load factors Europe*

[%]	Based on:	2000	2010	2020	2030	2040	2050
Lako (1998)	Inland location	24.0	24.0	24.0	24.0	24.0	24.0
Lako (1998)	Shore location	27.4	27.4	27.4	27.4	27.4	27.4
EWEA/GP (2001)[1]	Onshore/offshore	25.0	25.0	28.0	28.0	30.0	
Van Wijk (1993)	Technical potential						22.9

[1]Probably refers to a mix of both onshore and offshore.

Lifetime

The lifetimes that are assumed in the reports are mostly not explicitly indicated. In reports where lifetime *is* mentioned, a span of 20 years is common.

3.3 Data ranges

The literature overview as given in the previous sections introduces a variety of values for different parameters. It is necessary to distinguish the various definitions and methods that are used in the different sources to make the data comparable. For example, comparing a technical potential (that has been calculated without taking into account political, legal and economic aspects) to a realisable potential in a certain area only makes sense if the assumptions behind both values are known. Of course there are also restrictions, for example that the realisable potential can, by definition, not exceed the technical potential.

In order to assess the data ranges, the available literature sources were taken into account supplemented by expert judgement. In some cases, additional assumptions were necessary to fix data ranges. The data ranges presented in the current document are rather broad, because the aim was to incorporate also specific situations, for which the circumstances have been explained in more detail (Kooijman, 2002). For future updates of the current document, the ranges should be narrowed, and additional information should be added on the assumptions that influence the ranges.

3.3.1 Potential

For wind energy the lower limit of the data range for potentials is the targets that are set by the EWEA for the Netherlands and for the EU. The reason to do so is that at present these targets seem realistic, sometimes even on the conservative side. The realistic potential will be higher than the targets given in the EWEA studies. The upper limit of the range is set by the technical potential, even though the technical potential will probably never be reached. This way, there still is room for different assumptions that affect the potential that can be used in calculations.

For wind onshore in the Netherlands, the realistic potential data range is defined between 1.5 and 3.2 GW. For the Netherlands, 1.5 GW is a policy target.

For wind onshore in the EU, similarly, the technical potential of 315 GW (Van Wijk, 1993) is used as an upper bound, although considered conservative by some experts (this depends on the definition of available land area). As a lower boundary, 60 GW (target EWEA[5]) was used. Summarising, the data range for the realistic potential of wind onshore for EU-15 is set between 60 GW and 315 GW.

3.3.2 Technology costs

Investment costs

The investments costs of wind energy depend mainly on the wind regime (annual average wind speed) in which the wind park is built, the type of generator, the tower and the rotor that are used and the distance between different turbines. The ECN Wind Energy Department has made a computer model in which some calculations were done to find the lower and the higher bounds, see Kooijman (2002). Using these calculations, and after internal discussions, a range could be found for the investment costs between 875 €/kW and 1250 €/kW. These costs represent all the costs per kW that have to be made before the first electricity can be generated.

Within different countries the investment costs will differ this much. In the future the updating of this range will probably not mean that the range will be smaller, but that the circumstances in which the values can be found will be described in more detail. For example, the range can be split in sub-ranges for different wind regimes.

Operation and Maintenance

The Operational and Maintenance costs of a wind turbine can be expressed by a percentage of the investment costs of the installation. The O&M costs will change over time, since in the first five or six years there will be still warranty on the rotor and the generator. After the warranty period the O&M costs will increase. For this range, the total O&M costs over the lifetime of an installation are considered, which means that the annual O&M costs are cumulated and divided by the technical lifetime of the installation. However, this method is a bit rough.

Experts from the ECN Wind Energy Department stated a range between 2% per year and 4.5% per year including a warranty period of six years. Recalculation to total technical lifetime excluding warranty[6] yields a range of 1.4% to 3.2%, which could reasonably be a little higher. As an estimate, the final range is assumed to be between 1.5% and 3.4% of total investment costs per year.

3.3.3 Technical aspects

Power density

In order to estimate the amount of capacity that can be allocated to a certain area, the power density is a relevant parameter. Estimates from experts at the ECN Wind Energy Department have yielded a range for the power density for onshore wind in Europe of 6 to 10 MW/km^2.

Load factors

Load factors can be given in a very broad range. The reason for this is that the production of an installation depends on the wind speed, and the power density in an area. Investors in wind energy will always calculate the combination of wind power, wind speed, load factors, energy production per m^2 rotor surface and distance between turbines in order to find the economically most optimal combination. Also political decisions such as permits can affect the most economic solution. It is not very useful to elaborate all the different situations in which these calculations are made. The previously mentioned computer model developed by the ECN experts (Kooijman, 2002) does precisely these calculations, but based on their own set of assumptions.

5 Note that the target for onshore wind power recently has been updated from 55 GW to 65 GW in the year 2010, and from 100 GW to 110 GW in the year 2020 (EWEA, 2003).

6 A technical lifetime of twenty years minus a warranty period of six years yields 14 years, meaning that the initial range of 2% to 4.5% should be multiplied by a factor (14 / 20 = 0.7).

Every wind energy project will have a separate and more case-specific set of assumptions, which will determine the technological choices and with that the load factors that can be reached. However, it is possible to define a range in which the outcome of the calculations (and the empirical load factors) is found. The lower bound is determined by an economic motivation: turbines that have a load factor less than the lower bound will probably never be built since it will not be possible to pay back the investment costs. The upper bound is limited by technical constraints: the maximum size of a turbine in combination with a maximum wind regime will lead to a specific load factor. These considerations have led to a range for wind onshore load factors between 10% and 37%.

Lifetime
For onshore wind turbines in a first estimate a technical lifetime of 20 years is assumed.

3.4 Specific data for the European Union+

This section describes how the estimates of costs and potentials for onshore wind energy in the ADMIRE REBUS project (Uyterlinde et al., 2003) were derived.

3.4.1 Assessment structure

In the table below, the assessment structure is shown to assess the realistic potential of onshore wind energy in capacity and energy production. Starting from the available area, the power capacity is estimated, which yields, in combination with the wind onshore load factor, a certain amount of average annual electricity production.

Table 3.8 *Assessment structure for onshore wind energy*

Level	Name/unit	Factor
4	Available area [km^2]	
		× power density [MW/km^2]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

3.4.2 Potential

The first step in assessing the potential is to determine the available land area. The potential of onshore wind energy is more or less site independent, contrary to hydro or geothermal power for example. Conditions are however the availability of open space with a windy climate and access to a power grid somewhere, preferably nearby. Question is how to determine this available area.

In theory, agricultural area can be suitable, being mostly open areas and accessible for vehicles. The same can be said about some non-agricultural areas, for example industrial sites. A wind turbine itself does not take much space on the ground, only the tower occupies several square meters. With around 10-20 turbines per square kilometre, this can be neglected (less than one per thousand). In practice the available area for wind energy is limited by non-technical factors, such as public resistance. Another limiting factor is the length of the permission procedures, often caused by this public resistance.
The determination of available area will not be based here on theoretical, technical potential estimates, nor on national targets. Theoretical estimates do not take into account technical restrictions, whereas technical potential estimates do not take into account the effect of social acceptance for example. National targets are mostly the result of a political process, in most cases it is

not known what exactly the relation is with available area. Besides this, history shows that targets often are increased in the past ten years, while the geographical and demographic situation have not been changed. Since it is no use within this study to make a thorough assessment of the available area per country, taking into account all mentioned technical and social effects, a bottom-up approach will be used based on land use statistics. The assumption will be made that only certain part of the agricultural area and non-agricultural area is available for the development of wind energy. The factors describing the area availability are based on expert judgement, in which several known issues about (realistic) potential of onshore wind energy are reflected. One of them is the Dutch potential as determined by SNM (2000), others are listed in the literature section of this chapter.

Band definitions

Subdivision in bands of equal circumstances (banding) will be based on wind regimes, i.e. a distinction will be made between areas having different annual average wind speeds. A description of these regimes can be found in the European Wind Atlas (Troen, 1989). The division of the wind regimes into bands is based on the average annual wind speed at a hub height of 50 m (the height of the rotor axis of the wind turbine). In Table 3.9 the band definition is shown. In Tabel 3.10 the split-up of the total country area is shown, based on the European Wind Atlas and according to the band definition.

Table 3.9 *Band definitions representing wind regimes*

Band	Average wind speed [m/s]
1	> 7
2	6-7
3	5-6
4	< 5

Available area

The realistic potential will show no time dependency, since there are no technology restrictions related to the available area: it is not expected that technical development of wind turbines will result in the application in other areas than mentioned above. Although small wind turbines are being developed for placement on roofs or aside highways, this development will not be taken into account here. In the future the potential assessment should probably be reconsidered, depending on the success of this development.

It is assumed that if more than 25% of the available area is used as agricultural area, all wind turbines will be placed in the agricultural area. For Band 1, in which the best wind sites are located, the assumption is made that 4% of the area will be available for wind turbines. For the other bands, other uses of the agricultural area are more competitive, and only 2% will be available for wind energy. For the countries with less than 25% agricultural area of the total available area, the assumption is made that wind turbines will also be placed on non-agricultural sites. Again, Band 1 locations are more favourable than the other locations. In the case of agricultural area, assumed is that 2% of the agricultural area is available for Band 1 area, and only 1% for the other bands. For band 1 on non-agricultural sites an availability of 1% is assumed, against a 0.2% availability for other bands. Using the band splits of the total land area from Table 3.10 the total area per band per country can be calculated. It is furthermore assumed that the agricultural/other area is equally distributed across the total country area. In Table 3.11 the resulting net available area is given.

Table 3.10 *Split up of the total land area into bands, based on the European Wind Atlas. The bands correspond to regions with an average wind speed*

[%]	Band 1	Band 2	Band 3	Band 4
Austria	2	15	38	45
Belgium	10	50	35	5
Denmark	30	40	30	0
Finland	10	35	40	15
France	15	20	25	40
Germany	15	40	30	15
Greece	15	20	25	40
Ireland	30	55	15	0
Italy	0	20	30	50
Luxembourg	0	10	50	40
Netherlands	33	50	17	0
Norway	55	20	23	2
Portugal	0	10	30	60
Spain	5	10	30	55
Sweden	20	30	25	25
United Kingdom	60	15	15	10

Table 3.11 *Assumed available land area per country per band, based on the assumption that per country a certain share of the agricultural area and non-agricultural area is available for wind energy*

[km^2]	Band 1	Band 2	Band 3	Band 4
Austria	18	31	80	94
Belgium	34	54	38	5
Denmark	161	138	103	0
Finland	315	114	130	49
France	946	551	689	1.102
Germany	620	709	532	266
Greece	197	83	104	166
Ireland	223	89	24	0
Italy	0	256	385	641
Luxembourg	0	1	5	4
Netherlands	126	69	23	0
Norway	1.712	26	30	3
Portugal	0	30	89	177
Spain	260	205	616	1.129
Sweden	851	124	103	103
United Kingdom	0	0	6	56

Power potential

Using the available areas from Table 3.11 the realistic potential can be determined. This will be done using the power density of wind energy onshore. A density of 10 MW/km^2 for all bands has been taken. The resulting realistic power potential is given in Table 3.12.

Table 3.12 *Onshore wind power realistic potential, based on a power density of 10 MW/km² for all bands and the available areas*

[MW]	Band 1	Band 2	Band 3	Band 4	Total
Austria	192	362	918	1,087	2,560
Belgium	372	533	373	53	1,331
Denmark	2,752	1,835	1,376	0	5,963
Finland	3,263	2,246	2,567	962	9,038
France	11,013	7,344	9,181	14,689	42,226
Germany	7,090	9,457	7,093	3,546	27,186
Greece	2,182	823	1,029	1,646	5,679
Ireland	2,389	1,071	292	0	3,752
Italy	0	3,418	5,127	8,545	17,090
Luxembourg	0	9	46	37	91
Netherlands	1,206	914	311	0	2,431
Norway	17,358	1,070	1,230	107	19,765
Portugal	0	293	880	1,761	2,935
Spain	2,735	2,736	8,208	15,048	28,727
Sweden	8,782	2,553	2,127	2,127	15,589
United Kingdom	17,972	1,295	1,295	864	21,426
Total	77,304	35,960	42,052	50,472	205,789

Uyterlinde et al, 2003, Wind onshore potentials used in are slightly different due to more optimistic assumptions regarding land availability in the EU. The overall impact of this difference is very limited.

Energy potential

The average wind speed is linked to the average annual electricity production. It is assumed that every band has the same load factor in every country and that these factors will not change towards 2030, i.e. they are time independent. The band dependent load factors are given in the table below (Kooijman, 2002). Using these load factors the average annual electricity production per band can be calculated. The results are shown in Table 3.14.

Table 3.13 *Load factors*

	Load factor [%]
Band 1	34
Band 2	24
Band 3	16
Band 4	10

Table 3.14 *Onshore wind energy realistic potential*

[GWh/a]	Band 1	Band 2	Band 3	Band 4	Total
Austria	571	762	1,287	952	3,572
Belgium	1,107	1,120	523	47	2,797
Denmark	8,196	3,858	1,929	0	13,983
Finland	9,719	4,721	3,597	843	18,880
France	32,800	15,441	12,867	12,867	73,975
Germany	21,117	19,882	9,941	3,107	54,046
Greece	6,498	1,730	1,442	1,442	11,112
Ireland	7,114	2,252	409	0	9,776
Italy	0	7,186	7,186	7,485	21,857
Luxembourg	0	19	64	32	115
Netherlands	3,592	1,922	436	0	5,949
Norway	51,699	2,249	1,724	94	55,765
Portugal	0	617	1,234	1,543	3,394
Spain	8,146	5,752	11,504	13,182	38,584
Sweden	26,156	5,367	2,982	1,864	36,368
United Kingdom	53,529	2,723	1,815	756	58,824
Total	230,243	75,602	58,941	44,214	408,999

3.4.3 Technology costs

Investment costs

In Lako (2002) the expected worldwide development of future costs for onshore and offshore wind energy have been investigated. In this study a cost split of the total investment with respect to expenditures for the turbine, grid connection, civil works etc. has been made. The development in time of the different cost factors has been made using different progress ratios for these components. It is expected that the development of the turbine costs will have the largest effect on the total costs. In Table 3.15 the development of the investment cost for onshore wind energy with cost breakdown is shown.

Table 3.15 *Development of average investment costs per component worldwide*

[€/kW]	Turbine	Tower	Other *	Total
2000	603	113	185	900
2005	516	106	180	801
2010	451	101	175	726
2015	406	97	172	674
2020	375	94	169	637
2025	351	91	167	609
2030	335	90	165	589
Decrease 2000-2030	44%	20%	11%	35%

Source: Lako, 2002.

* Civil works, infrastructure, grid connection etc.

Since no specific information is available on the country and wind regime dependent investment costs for onshore wind energy these costs will be derived using Lako (2002) and specific information for the Netherlands (Kooijman, 2002).

In Table 3.16 the country dependent cost split of the investments in 2000 is shown, based on information from IEA (2002) and Kooijman (2002) for several countries. In some specific situations country-specific assumptions were required, in case no specific information was available. In general the turbine costs including tower are around 75%-85% of the total investment costs in 2000.

The share of turbine plus tower costs in the total investment costs in 2030 (Lako, 2002) is 72%. It is assumed that this will be the case for every country, i.e. that the investment costs are totally harmonised within the EU+ in 2030.

Table 3.16 *Cost split of the investments in the year 2000*

[%]	Turbine including tower	Other
Austria	77	23
Belgium	78	22
Denmark	83	17
Finland	77	23
France	76	24
Germany	83	17
Greece	75	25
Ireland	76	24
Italy	76	24
Luxembourg	76	24
Netherlands	76	24
Norway	77	23
Portugal	75	25
Spain	75	25
Sweden	77	23
United Kingdom	76	24

It is assumed that the costs mentioned by (Lako, 2002) do concern the most favourable sites, thus having a wind regime as defined for Band 1. In (Kooijman, 2002) a method is given to assess the investment costs for less favourable sites, for Band 2 to 4. Depending on the average wind speed the optimum turbine configuration is different and likewise the total investment costs. In practice wind turbines with a larger rotor diameter and hub height are preferred for locations situated in a weak wind climate, to increase the electricity output compared to a situation in a strong wind regime. But larger diameters and heights involve higher costs. Therefore the wind regime dependent investment costs are the result of an optimisation with respect to the total production costs per kWh. The results of this analytical approach for the Dutch situation are given in Table 3.17. Decommissioning costs are not included in the total investment costs. These costs are typically in the range of 12 to 100 €/kW (Diamantaris, 2002).

Table 3.17 *Estimated costs per band in the Netherlands in 2000*

	Total investment [€/kW]
Band 1	941
Band 2	1018
Band 3	1110
Band 4	1220

Source: Kooijman, 2002

To be able to calculate the country and band dependent investment costs the information in Table 3.16 and Table 3.17 is combined, assuming that the ratio of the band dependent investment costs in the Netherlands is the same for the other countries. Results are shown in the table below.

Table 3.18 *Investment costs in the year 2000, differentiated between bands of a common wind regime*

[€/kW]	Band 1	Band 2	Band 3	Band 4
Austria	929	1005	1096	1204
Belgium	917	992	1082	1189
Denmark	861	932	1016	1117
Finland	929	1005	1096	1204
France	941	1018	1110	1220
Germany	861	932	1016	1117
Greece	953	1032	1125	1236
Ireland	941	1018	1110	1220
Italy	941	1018	1110	1220
Luxembourg	941	1018	1110	1220
Netherlands	941	1018	1110	1220
Norway	929	1005	1096	1204
Portugal	953	1032	1125	1236
Spain	861	932	1125	1236
Sweden	929	1005	1096	1204
United Kingdom	941	1018	1110	1220

In Table 3.19 the expected investment costs for 2030 are shown for every band, here the band ratio's from Table 3.17 are used as well. It is assumed that these costs are harmonised for within the EU+ by that time.

Table 3.19 *Harmonised investment costs in the year 2030, differentiated between bands of a common wind regime*

[€/kW]	Band 1	Band 2	Band 3	Band 4
All countries	589	638	695	764

O&M costs

Annual O&M costs can be divided (Neumann, 2002) into maintenance and repair (~26%), insurance (~13%), electricity consumption from the grid (~5%), management and tax consulting (~21%), ground lease (~18%) and others, such as memberships and legal consultancy etc. (~17%). The annual, band dependent O&M costs are elaborated in Kooijman (2002). It concerns averages during the lifetime of the turbine. The results are shown in Table 3.20.

Table 3.20 *Average annual O&M costs in 2030*

	Annual O&M [%]*	Annual O&M [€/kW]
Band 1	4.00	23.60
Band 2	3.50	22.30
Band 3	2.75	19.10
Band 4	2.00	15.30

* As percentage of the total investment costs.

It is assumed that these band dependent O&M costs, as percentage of the total investment costs, will have no time dependency, i.e. the shares in Table 3.20 remain the same in the period 2000-2030.

3.5 References

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4. WIND OFFSHORE

4.1 Introduction

Whereas for wind onshore a lot of experience has been gained over the past decades, the offshore placement of wind turbines has only recently become important. Several offshore wind parks have been commissioned, but most plans still only exist on paper. This implies that there is not much empirical data available yet. Theoretical data is also scarce and expert opinions still differ a lot, which results in broad ranges. Within a short period, the offshore business is expected to increase significantly. In the literature overview, data on potentials have received most attention.

Table 4.1 *Key parameters for offshore wind power and the resulting data ranges*

Parameter	Unit	Netherlands	EU-15	Reference year
Realistic potential	[GW]	6 to 30	90 to 348	2050
Investment costs	[€/kW]	1546 to 2428	1546 to 2428	2002
O&M costs	[% of investment/yr]	3.2 to 6.7	3.2 to 6.7	A
Power density	[MW/km^2]	4 to 10	4 to 10	A
Load factor	[%]	14 to 39	14 to 39	A
Lifetime	[years]	20	20	A

[A] For a first estimate this parameter is considered to be time-independent.

4.2 Literature sources and data

4.2.1 Potential

The Netherlands

Table 4.2 lists the most important publications that mention Dutch numbers. In IEA (2001) the Dutch government target of 6000 MW is mentioned, which is aimed for in the year 2020. In SNM (2002), a significant group of environmental organisations take position in favour of large offshore wind power parks confirming the government target. Finally, the numbers presented in CA (2001) should indeed be regarded as a realistic potential.

Table 4.2 *Offshore wind energy potential the Netherlands*

[MW]	Based on:	2000	2006	2020
IEA (2001)[1]	National target			6000
SNM (2002)[2]	Realisable potential			6,000
CA (2001)[3]	Estimate	10,000	10,000	10,000

[1]Dutch government target.
[2]Confirmation of the Dutch government target, indicated as a realisable potential.
[3]Resource estimate (energy equivalent of 33 TWh).

Europe

An important literature source with respect to European wind energy comes from the EWEA[7], in which targets for the years 2010 and 2020 have been set (EWEA, 2002). It often has occurred that onshore wind energy targets have been realised before the targeted year, the actual development of the realisation increased much faster than expected. However there are not so many experiences gained yet with the offshore wind power market, therefore the offshore wind energy target should be interpreted with more care. The number from EWEA/GP (2001) is higher than the EWEA target and is based on a calculation in which the aim was to achieve a future penetration of wind power of 12%.

Table 4.3 *Offshore wind energy potential EU*

[%]	Based on:	2000	2010	2020	2030	2040	2050
EWEA (2002)[1]	Targets		5,000	50,000			
CA (2001)	Estimates	138,600	138,600	138,600	138,600	138,600	138,600
Lako (1997)[2]	Upper bound	215	5,750	20,450	43,150	68,500	95,500
DKW (2001)	Forecast		1,300	2,300			
EWEA/GP (2001)[3]	Scenario			70,000			

1 Target values. See also Footnote 7.
2 Upper bound for modelling.
3 Scenario to achieve 12% of worldwide electricity use from wind. Value applies to OECD Europe.

Growth rates

In Table 3.4 an overview is given of calculated growth rates, based on capacity data as found in the respective studies.

Table 4.4 *Overview of calculated growth rates, based on cumulative capacities, all referring to EU-15*

[%]	2000-2010	2010-2020	2020-2030	2030-2040	2040-2050
EWEA (2002)		25.9			
Lako (1997)	38.9	13.5	7.8	4.7	3.4
DKW (2001)		5.9			

4.2.2 Technology costs

Investment costs

In Table 4.5 two studies in which investment costs for offshore wind energy are mentioned. Data derived in (Kooijman, 2002) are considered as leading concerning investment costs of offshore wind energy, while data as presented by (Lako 2002) are considered rather low.

Table 4.5 *Offshore wind energy investment cost*

Reference	Location	Unit	Investment Costs	Reference year
Lako (2002)	Nearshore	[$Euro_{2000}$/kW]	1375	2000
Lako (2002)	Offshore	[$Euro_{2000}$/kW]	1700	2002
Kooijman (2002)	Nearshore	[$Euro_{2002}$/kW]	1930	2000
Kooijman (2002)	Offshore	[$Euro_{2002}$/kW]	1800	2010

7 Note that the target for offshore wind power recently has been updated from 5 GW to 10 GW in the year 2010, and from 50 GW to 70 GW in the year 2020 (EWEA, 2003).

Progress ratios
As for onshore wind, Lako (2002) splits the progress ratio (PR) of wind power into components. For rotor and nacelle, the same value has been supposed as for onshore wind: the PR equals 0.90. For the tower the cost reduction is supposed to be slightly less: a range between 0.925 and 0.95 is given. For civil works, infrastructure and grid connection together, not much cost reduction is expected, but still a little more than for onshore: a range of 0.95-0.975 is given. The highest number indicates the 'reference' case.

4.2.3 Technical aspects

Power density
No literature information is available yet on this parameter.

Load factors
In Table 4.6 load factors for offshore wind energy mentioned in Lako (1998) and CA (2001) are listed. Data from the computer model Markal from Lako (1998) have been directly taken from the report, whereas the data from CA (2001) have been recalculated.

Table 4.6 *Offshore wind energy load factors for Europe*

[%]	Based on:	2000	2010	2050
Lako (1998)	Nearshore location	33.8	33.8	33.8
Lako (1998)	Offshore location		36.5	36.5
CA (2001)	Estimate			37.9

Lifetime
No literature information is available yet on this parameter.

4.3 Data ranges

In order to find the data ranges, the literature sources available were taken into account including expert judgement from Kooijman (2002). The data ranges presented in the current document are rather broad. In future updates of the current document the ranges should be narrowed.

4.3.1 Potential

For offshore wind energy the same method has been applied for determining the data range as has been done for onshore wind power. This resulted in a realistic offshore wind energy potential range for the Netherlands between 6 and 30 GW (note: 6 GW is the national target). For Europe, a lower bound of 90 GW and an upper bound of 348 GW have been determined (Kooijman, 2002).

4.3.2 Technology costs

Investment costs
Not much information is available on the investment costs of offshore wind energy. Depending on water depth, distance to shore and turbine size, offshore wind power investment costs are estimated in a range between 1500 €/kW and 2500 €/kW (Kooijman, 2002).

Operation and Maintenance
Obviously, the costs for servicing an offshore wind park are higher than for an onshore park, since it is more difficult to access. The data range estimated for annual wind offshore O&M costs is between 3.2% en 6.7% of the total investment costs.

4.3.3 Technical aspects

Power density

The power density for offshore wind in Europe is supposed to range from 4 to 10 MW/km^2.

Load factors

For offshore wind it was possible to give an indication of the load factor depending on the wind speed, see Kooijman (2002). The load factor depends on the wind power density, which differs with the distance to the shore (*d*). In Table 4.7 these combinations are presented.

Table 4.7 *Load factor offshore wind energy*

Wind speed [m/s]	*d* = 100 km Improved design [%]	*d* = 20 km highly improved design [%]	Representative Value [%]
10.0	33.5	43.8	39
8.5	25.9	33.9	30
7.5	20.2	26.5	23
6.0	11.7	15.3	14

Source: Kooijman, 2002

The data range is set with the lower and upper values of the representative case, resulting in a range between 14% and 39% (wind regime dependent).

Lifetime

For offshore wind turbines in a first estimate a technical lifetime of 20 years is assumed.

4.4 Specific data for the European Union+

4.4.1 Assessment structure

The assessment of the country-dependent power and energy potential is basically the same as for onshore wind power. The parameters are discussed in this section.

Table 4.8 *Assessment structure for offshore wind energy*

Level	Name/unit	Factor
4	Available area [km^2]	
		× power density [MW/km^2]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

4.4.2 Potential

Starting point for the determination of the realistic potential for offshore wind energy is the study by Germanisher Lloyd and Garrad Hassan (Germanisher Lloyd, 1995) about the available sea area for offshore wind energy in the EU. The available area has been researched up to a water depth of 40 m and a maximum distance offshore of 30 km. Furthermore the available area was identified within different wind speed bands. Finland, Norway and Sweden were not included in the study. For the purpose of the current report, the countries are split up into three categories, depending on the amount of available sea area with water depths less than 50 m.

A. Category A countries have an area outside the 12 miles zone with water depths less than 50 m, but no possibilities for wind offshore within the 12 miles zone, besides demonstration projects:
   - Netherlands (one demonstration project of 100 MW has been planned, the Near Shore Wind park, but Dutch policy tends towards defining the whole 12 miles zone as an exclusion area).

B. Category B countries have an area outside the 12 miles zone with water depths less than 50 m:
   - Belgium
   - Denmark
   - Germany
   - United Kingdom

C. Category C countries do not have enough area outside the 12 miles zone with water depths less than 50 m:
   - Norway
   - Finland
   - France
   - Portugal
   - Greece
   - Sweden
   - Ireland
   - Spain
   - Italy

In the table below the division from Germanisher Lloyd (1995) is shown, together with the assumed availability of sea area. The total area identified is regarded here as technical potential, hence these availability factors reflect the step from *technical* potential to *realistic* potential. Due to restrictions regarding visibility of turbines it is assumed that for the countries in Category A and B the potential closer than 10 km distance from shore is zero. Because of the sparse area outside the 12 miles zone for countries in Category C an availability of 5% is assumed.

Table 4.9 *Assumed availability of sea area*

Depth [m]	Distance [km]	Category A Availability [%]	Category B Availability [%]	Category C Availability [%]
0-10	0-10	0	0	5
0-10	10-20	0	5	10
0-10	20-30	50	25	25
10-20	0-10	0	0	5
10-20	10-20	0	5	10
10-20	20-30	50	25	25
20-30	0-10	0	0	5
20-30	10-20	0	5	10
20-30	20-30	50	25	25
30-40	0-10	0	0	5
30-40	10-20	0	5	10
30-40	20-30	50	25	25

For the North Sea countries (Category A and B except Belgium) there is extra available area above a distance of 30 km offshore with water depths less than 50 m. This is not the case for the countries in Category C.

Wind speed band splits

The average wind speed is linked to the average annual electricity production. It is assumed that every band has the same load factor in every country. These load factors are given in Table 4.10 (Kooijman, 2002).

The extra available area for the North Sea countries[8] has been identified with an extra Band 5. This applies to the countries of Categories A and B except Belgium. For Denmark the extra area above a distance of 30 km offshore will be enough for at least 5 GW, and for the other countries in Categories A and B this is assumed to be 25 GW. These numbers are based on assumptions made with OWECOP-R15 (Kooijman, 2001 & 2002), together with information about sea depths in Europe (TU Delft contribution to CEO network: http://www.deos.tudelft.nl/altim/ceo, 1995).

Average conditions for this band are taken as follows: load factor of 39%, water depth of 40 m and a distance offshore of 50 km.

Table 4.10 *Band definitions wind offshore and load factors*

Band	Wind speed [m/s]	Load factor[1] [%]
1	> 9	39
2	8-9	30
3	7-8	23
4	< 7	14
5	> 9	39

[1] Load factors are results from model calculations (Kooijman, 2002). Actually the load factor is a design parameter, higher load factors require higher investment costs with lower wind speed regimes. However, for modelling purposes a lower load factor have been used instead, the cost price in €/kWh will not be affected.

The power density of wind offshore has been taken 6 MW/km^2. Combining the country categories and the available area identified in Germanisher Lloyd (1995) provides the potentials as listed in Table 4.11. The Nordic countries Sweden, Norway and Finland were not identified in Germanisher Lloyd (1995). For Sweden and Norway the potentials from Voogt (2001) are used. For Finland information about potentials is available in the Finnish NEMO-2 research program (NEMO-2, 1998). Although the total available area is huge (equivalent to a potential of 17 GW according to the program), it is expected due to heavy icing that the potential remains modest, around 3 TWh/a with wind speeds of 7.5-8 m/s. This equals around 1489 MW in Band 3.

Table 4.11 *Potential for offshore wind*

[MW]	Band 1	Band 2	Band 3	Band 4	Band 5	Total
Belgium		1,194	64			1,258
Denmark	2,534	12,772	261		5,000	20,567
Finland [1]			1,489			1,489
France	419	12,520	6,506	1,162		20,607
Germany		6,566	221		25,000	31,787
Greece			1,403	1,796		3,199
Ireland	1,594	2,023	767	61		4,445
Italy			27	11,456		11,483
Netherlands	306	2,115			25,000	27,421
Norway[2]	95	95	63	63		316
Portugal		74	911	628		1,613
Spain		492	1,989	2,797		5,278
Sweden[2]		674	674	577		1,925
United Kingdom	719	14,956	44		25,000	40,719
Total	5,667	53,481	14,419	18,540	80,000	172,107

[1] (NEMO-2, 1998)
[2] (Voogt, 2001)

[8] This refers to the area with water depths less than 50 m but a distance to coast above 30 km.

The energy potential can be calculated using the load factors mentioned in Table 4.10, the results are listed in the table below.

Table 4.12 *Potential for offshore wind*

[GWh/a]	Band 1	Band 2	Band 3	Band 4	Band 5	Total
Belgium		3,138	129			3,267
Denmark	8,657	33,565	526		17,082	59,830
Finland			3,000			3,000
France	1,431	32,903	13,108	1,425		48,867
Germany	0	17,255	445		85,410	103,111
Greece	0		2,827	2,203		5,029
Ireland	5,446	5,316	1,545	75		12,382
Italy			54	14,050		14,104
Netherlands	1,045	5,558			85,410	92,014
Norway	325	250	127	77		778
Portugal		194	1,835	770		2,800
Spain		1,293	4,007	3,430		8,731
Sweden		1,771	1,358	708		3,837
United Kingdom	2,456	39,304	89		85,410	127,259
Total	19,360	140,547	29,050	22,738	273,312	485,007

4.4.3 Technology costs

Costs for fixed bottom mounted offshore wind energy converters have been extracted from the ECN computer model OWECOP-R15, see Kooijman (2002). The main characteristics used to this purpose are:

- 50 × 2.5 MW turbines, ‘improved turbine design’ (year 2004/2005),
- water depth: less than 20 m, 20 m to 30 m, and 30 to 40 m respectively,
- distance to shore: less than 12 miles (~22 km), 12 miles to 40 km, 40 km to 100 km, further than 100 km,
- power density: 6 MW per km^2 sea area.

A summary of the investment costs for 2005 is shown in Table 4.13, O&M costs for 2005 are shown in Table 4.14. Both are listed as a function of the sea depth and the distance offshore.

O&M costs are here limited to expenditures for operation and maintenance of the wind farm and ground lease. The annual O&M costs per kilowatt may increase by as much as 1.6% when including periodic costs for electricity use from the grid, management, accountancy, public relations and most importantly insurance. Note that decommissioning costs are not addressed here.

Table 4.13 *Investment costs in [€/kW] as function of sea depth and distance to shore*

Distance to shore [km]	0-20 m depth [€/kW]	20-30 m depth [€/kW]	30-40 m depth [€/kW]
< 22	1546	1689	1777
22-40	1609	1752	1840
40-100	1704	1847	1935
100-200	2197	2340	2428

Source: Kooijman, 2002

Table 4.14 *O&M costs as percentage of investment costs as function of sea depth and distance to shore*

Distance to shore [km]	0-20 m depth [%]	20-30 m depth [%]	30-40 m depth [%]

< 22	4.14	3.81	3.55
22-40	4.08	3.77	3.53
40-100	4.06	3.77	3.54
100-200	3.57	3.38	3.22

Source: Kooijman, 2002

Combining all available information results in the investment costs listed in Table 4.15 below.

Table 4.15 *Investment costs wind offshore in 2005*

[€/kW]	Band 1	Band 2	Band 3	Band 4	Band 5
Belgium		1711	1656		
Denmark	1767	1697	1619		1935
Finland*			1687		
France	1729	1702	1681	1592	
Germany		1671	1632		1935
Greece			1755	1721	
Ireland	1704	1635	1577	1550	
Italy			1669	1682	
Netherlands	1745	1699			1935
Norway*	1717	1704	1687	1622	
Portugal		1775	1700	1629	
Spain		1703	1706	1646	
Sweden*		1704	1687	1622	
United Kingdom	1751	1727	1681		1935

* Band-averages are used here, since no information is available about the relationship between available area, distances offshore and costs.

Further analysis using O&M data from Table 4.14 shows that the O&M costs in 2005 for countries in Categories A and B will be around 66-70 €/kW/a. An average value of 68 €/kW/a will be taken for these countries. For the countries in Category C the analysis show that the O&M costs will be around 65 €/kW/a.

Future development of investment costs

For the future development of the investment costs is referred to Lako (2002), in which assumptions on a future growth and a progress ratio led to a decrease in investment costs as indicated in Table 4.16. This development is supposed to apply to the investment costs presented in Tabel 4.15.

Table 4.16 *Development of average investment and O&M costs wind offshore*

Year	Investment [€/kW]	O&M [€kW/a]
2000	-	-
2005	1515	50
2010	1379	47
2015	1291	45
2020	1229	43
2025	1180	41
2030	1143	40

Source: Lako, 2002

Table 4.17 *Projected investment costs wind offshore for 2030*

[€/kW]	Band 1	Band 2	Band 3	Band 4	Band 5
Belgium		1154	1024		
Denmark	1208	1156	1089		1336
Finland*			1111		
France	1197	1174	1143	1073	
Germany		1156	1099		1336
Greece			1161	1121	
Ireland	1180	1134	1072	1018	
Italy			1149	1159	
Netherlands	1156	1110			1336
Norway *	1187	1163	1111	1081	
Portugal		1233	1177	1119	
Spain		1180	1175	1131	
Sweden *		1163	1111	1081	
United Kingdom	1196	1171	1096		1336
Average	1187	1163	1111	1081	1336

* Band averages.

4.5 References

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5. SOLAR PHOTOVOLTAIC ENERGY

5.1 Introduction

In the last decade a first step to a large-scale mature PV business was set. It became a multibillion-dollar business attracting attention from other sectors like the building installation sector. A prosperous growth rate of over 20% has been achieved, mainly by introduction of grid-connected PV in the built environment (IEA 2002). A typical grid connected system, especially in Japan, Germany and the Netherlands, has a size of 3 kW_p and is installed on the roof of a family house.

In the present and coming decade the dominant market will remain to be roof top systems. There is an increasing interest in larger PV plants (MW_p size) as expressed by the European Commission (FP6 Work Programme, 2002). Though the value of the generated electricity will be lower (competition from other large-scale renewable sources) it can be attractive, as the cost can be considerably lower (30-50%) than BIPV (Building Integrated PV).

The current chapter focuses on the long-term future of PV, concentrating on potentials, costs and other parameters. Section 5.2 presents an overview of literature sources that assess the future PV development regarding costs and potentials. Next, Section 5.3 discusses the range within which the parameters are estimated to be situated; these are summarized in Table 5.1. Finally, Section 5.4 presents a method for allocating country-specific ranges to the EU-15 member states.

Table 5.1 *Key parameters for solar PV and the resulting data ranges*

Parameter	Unit	Netherlands	EU-15	Reference year
Realistic potential	[km^2]	600	16000	-
Realisable potential	[GW_p]	49 (7 to 180)	661 (98 to 4089)	2050
Investment costs	[€/W_p]	5 to 8	5 to 8	2002
Progress ratio	[%]	80 (75 to 90)	80 (75 to 90)	A
O&M costs	[% of investment/a]	1 to 3	1 to 3	A
Power density	[W_p/m^2]	100 to 300	100 to 300	2000-2050
Load factor	[%]	8 to 10	12 to 16	A
Lifetime	[years]	25	25	A

A In a first estimate, this parameter is considered to be time-independent.

5.2 Literature sources and data

This section presents the potential for PV, according to the definitions in the Methodology chapter. To resume, the overview below lists the four types of potentials:

- Technical potential: technical constraints.
- Realistic potential: non-technological constraints.
- Realisable potential: maximum market growth rates.

The other types of potential will be discussed in the sections below. Note, that most data have been found for the Netherlands only. It appeared difficult to find reports that assess the 15 European Member States as an aggregate. Only the section discussing the *realisable* potential refers to separate geographical regions.

5.2.1 Potential

Technical potential

Typically, the technical potential is assessed by an inventory of the maximum amount of surface that is estimated to be available. The only report by that did so is Corten, Bergsma (1995), in which the technical potential for area that is suitable for BIPV in the Netherlands has been assessed, without limiting this potential for reasons of orientation. The estimate is based on a very detailed inventory of roof and facade area, based on existing buildings and refers to the year 2010. The results of this inventory are the following: technical potential of BIPV on roof area: 667 km^2 (117 GW_p), of BIPV on facades: 230 km^2 (41 GW_p)[9]. In (DEIO, 1997), also a technical BIPV potential for the Netherlands is mentioned, namely 'at least 110 GW_p', set equal to 800 km^2. For ground based PV (GBPV) no information has been found, but technically it is possible to cover large parts of the land surface available. Also, no other reports have been found that assess the technical potential for the European Union.

Realistic potential

The realistic potential can be independent of time in case the available surface (in km^2) is supposed to be constant. The realistic potential expressed in power unit (GW_p) however is related to the achieved power density, which is supposed to range from 200 to 300 W_p/m^2 (see Section 5.3.3). Below, the literature sources have been discussed; Table 5.2 lists the overview.

Most studies assessing the realistic PV potential limit themselves to building integrated PV (BIPV); for ground based PV (GBPV) only Alsema (1992) estimates the potential. The authors assume that approximately by the year 2040 an area of 336 km^2 is available for PV, with 220 km^2 coming from agricultural areas. Optimal inclined placement of modules increases the effective area by 15%, yielding a total realistic potential of 70 GW_p.

A source which is referred to in different reports is Okken (1993), which estimates the *realistic* BIPV potential in the Netherlands as 12.5 GW_p, and the Central PV power generation as 20 GW_p, both for the year 2030. These numbers can be considered as expert judgements. Although the conversion efficiency has not been stated explicitly, this potential can be converted to an area using a future power density of 200 W_p/m^2, which results in 62.5 km^2 and 100 km^2 respectively.

In Krekel (1987) the total realistic roof area has been estimated as 120 km^2, resulting in a total peak power of 24 GW_p assuming a power density of 200 W_p/m^2.

The publication EnergieNed (1997) mentions a technical PV potential of 88 GW_p, but it does not explain how the potential has been determined, nor what efficiency has been assumed. Based on a value of 200 W_p/m^2, this would mean a total surface requirement of 440 km^2.

9 This equals a peak power density of 175 W/m^2 of a PV system in the year 2010.

Table 5.2 *Overview from literature of areas and realistic potentials for PV in the Netherlands*

	BIPV [km^2]	GBPV [km^2]	[GW$_p$]
Alsema (1992)[1]	116	220	70
DACES (2050, 2001)	-	-	47.1
EnergieNed (1997)[2]	-	-	88
IEA (2001)	357	-	107
Krekel (1987)[3]	120	-	24
De Lange (2000)[4]	195	-	34
Okken (1993)	38%	62%	32.5

1 In (Alsema, 1992) it is assumed that 336 km^2 is available for PV (including 220 km^2 from agricultural areas), approximately by the year 2040. Optimal placement of modules increases the effective area by 15%. The value of 70 GW is mentioned in the report. In addition, the report assumes a capacity to be installed annually of 1.4 GW, based on 2% of the total potential, of which two-third should come from agricultural areas.

2 (EnergieNed, 1997) does not explain how the potential has been determined.

3 (IEA, 2001) determined, based on a comparison of countries, a *rule of thumb* for assessing the BIPV potential. For Europe, a value of 24.5 m^2 roof and facade area per capita has been found. For the Netherlands, this approach yields 357 km^2 of area available. The GW$_p$ entries in the table have been calculated using the long-term yield of 300 W$_p$/m^2.

4 In (De Lange, 2000) a technical potential is assessed by considering building integrated PV and PV combined with noise barriers (assumed BIPV), as projected for the year 2020. Power yield is assumed 175 W$_p$ per m^2.

In a recent publication by IEA (2001) a rule of thumb has been formulated to assess the realistic BIPV potential. Based on an analysis of the European countries, for the Netherlands the realistic potential amounts to 357 km^2. Assuming a long-term yield of 300 W$_p$/m^2 the total potential is 107 GW$_p$. This scheme can also be applied to Europe, resulting in a realistic potential of 8100 km^2, which yields at 300 W$_p$/m^2 a capacity of 2430 GW$_p$ (GBPV is not included).

Realisable potential

Not all potential that is available can actually be implemented, or realised. The technical potential for the use of PV may be large, but the insufficient capacity of the present production facilities, the high cost of PV systems and the lack of infrastructure prevent to really achieve the installation of so much PV power on a short term. The growth rate of the PV industry, time to allow price reduction as well as gaining consumer and supplier interest are restricting factors.

This section presents an overview of realisable potentials that have been found in literature, for the Netherlands, for Europe and for the world. As an overview Table 5.3 presents the realisations of installed capacity for the year 2001 for the three regions.

Table 5.3 *Installed PV capacity in the year 2001 for the Netherlands, EU-15 (with and without Norway and Switzerland), and the IEA-countries*

	Capacity [MW$_p$]
The Netherlands	20.5
Europe (EU-15)	276
EU-15 including Norway and Switzerland	300
IEA-countries	982

Source: IEA-PVPS, 2002

The Netherlands

An illustration of the historic trend can help interpreting the range of future growth rates. From Figure 5.1 it can be seen that the average annual growth rate steadily increases. The fluctuations that can be observed possibly indicate shifts in commissioning dates; for instance, many projects planned for the year 1997 only came into service by 1998.

Extrapolating this growth to the future could indicate growth rates of 50% or higher for the coming years. To maintain such a high growth rate for the coming decade is very demanding for all parties involved and requires among others a stable policy support. In the paragraphs below, sources are discussed that estimate a realisable growth rate and the accompanying realisable potential.

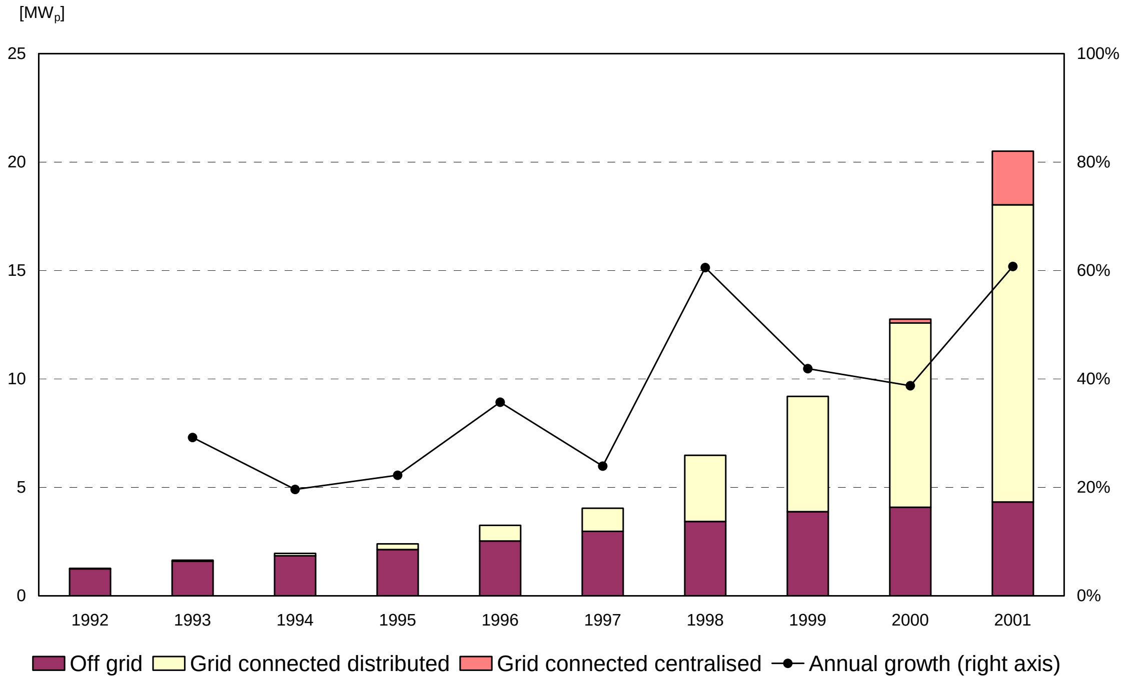

Figure 5.1 *Historic cumulative capacity for PV power in the Netherlands. The line indicates the annual growth (installed capacity) (IEA-PVPS, 2002)*

The numbers for the realisable potentials can be characterised by interest class; for example PV industry and research (stakeholders in favour of PV deployment), Non-PV industry (establishment reluctant to change), and policy targets.

It can be seen from the figures in Table 5.4 that each source accordingly should be interpreted with regard of its respective background: the range in estimated data is very wide.

Table 5.4 *Realisable potential for the Netherlands*

[MW_p]	2005	2007	2010	2020
Alsema (1992)				200-8000
DEIO (1997)		119		1450
Ekomation (2000)		73-155		
Rotterdam (2002)				1000-3000
Ybema (1999)				1990
PV Convenant (1997)		100	250	1400
PV Stuurgroep (2000)[1]	50	100	250	1650
PV Stuurgroep (2000)[2]	120-230	255-500	555-1100	3240-6425
Eurelectric (2000)				35

1 Refers to the ‘Baseline’ scenario.
2 Refers to the ‘Deltaplan’ scenario

In order to achieve the realistic potential as stated in Alsema (1992), a capacity of 1.4 GW_p to be installed annually is required. However, when discussing whether this is realisable, the expected potential is significantly less in the year 2020: 200 MW_p to 8 GW_p.

In DEIO (1997) ‘expected PV development’ is mentioned, based on the programme NOZ-pv 1996-2000.

Ekomation (2000) expects for the year 2007 an installed capacity of 73 to 155 MW_p.

In order to push forward the developments of solar energy use in the built environment, the *Declaration of Rotterdam* (Rotterdam, 2002) sets a realisable goal for the year 2020 at 1 to 3 GW_p.

Ybema (1999) estimates the realisable potential for the year 2020 by assuming a maximum annual amount of power to be installed, related to the PV world market. This results in an amount of 11 km^2 for the year 2020, equal to 2 GW_p. Using the same arguments, the *realistic* equivalent (which also refers to the year 2020) of this potential is estimated as 46 km^2, equal to 8 GW_p[10].

In PV Convenant (1997), the PV sector and the Dutch government representatives agreed on targets for the coming decades. In PV Stuurgroep (2000) two scenarios have been developed, of which one adhered to the previously mentioned targets (*baseline*-scenario), and a second one is more ambitious (*deltaplan*-scenario). The document does not have an official status; the discussion about the targets is still ongoing.

Finally, from Eurelectric (2000) a growth rate of 5.5% can be deduced, calculated from 12 MW_p in 2000 to 35 MW_p in 2020 (Tennet estimate). This is proven to be conservative, considering the enormous increase of installed PV capacity in recent years.

Europe
The installed power in the European Union amounted to approximately 276 MW_p in the year 2001 (300 MW_p including Switzerland and Norway), whereas for the year 2000 the EU-15 capacity was 199 MW_p; an increase thus of 50% (IEA-PVPS, 2002). Of this increase, 85% has been installed in Germany. The second player on the European PV market is the Netherlands, with 8% of the capacity installed during the year 2001. Table 5.5 presents the overview of the realisable potentials for Europe.

Table 5.5 *Realisable potential for the Europe in GW_p installed PV power*

[GW_p]	2003	2010	2020	2030	2050
Baromètre (2002)	0.485	1.738			
EPIA/Greenpeace (2001)			41		
Lako (1998)				107.5	277.5
EC (1997) and EPIA (2002)		3			

Critical remarks concerning the short-term growth of PV power come from Baromètre (2002), which reminds that the recent growth is too much focused on only Germany, which makes predictions quite uncertain. Baromètre (2002) does not expect that the EU target of 3 GW_p PV power in 2010 can be achieved. Projected are 485 MW_p in 2003 and 1738 MW_p in 2010. This equals a growth rate of 20% per year.

According to EPIA/GP (2001) an installed capacity of 41 GW_p is realisable for Europe in the year 2020. Until the year 2020, an overall growth rate is expected of 27.3% until the year 2010, followed by a growth rate of 34.4% until the year 2020. For the period 2020-2040, the projected growth rate is 15% per year. Regarding the share of grid-connected versus off-grid appliance the initial growth is expected to be fastest in the grid-connected sector, whereas by 2010 this will be replaced by the emerging worldwide off-grid sector.

[10] The study assumes an increasing efficiency over time, starting from 147 W/m^2 in the year 2001, and 183 W/m^2 in the year 2020.

In the EC White Paper on renewable energy the EU target for PV in the year 2010 has been defined as 3 GW_p. This value has also been aimed at by EPIA (EPIA, 2002).

World

In order to illustrate current PV shipment growth rates, Figure 5.2 presents a historical overview of growth rates as they have been achieved (Maycock, 2002). On a world level, the annual growth rate for PV module shipments approaches 30%. According to IEA (2002), the total capacity installed in the IEA countries in the world amounts to 982 MW_p. For those countries, the annual rate of growth of total installed capacity between 1992 and 2001 varied from year to year between 20% in 1994 and 40% in 2000. Between 2000 and 2001 the rate of increase was 35%.

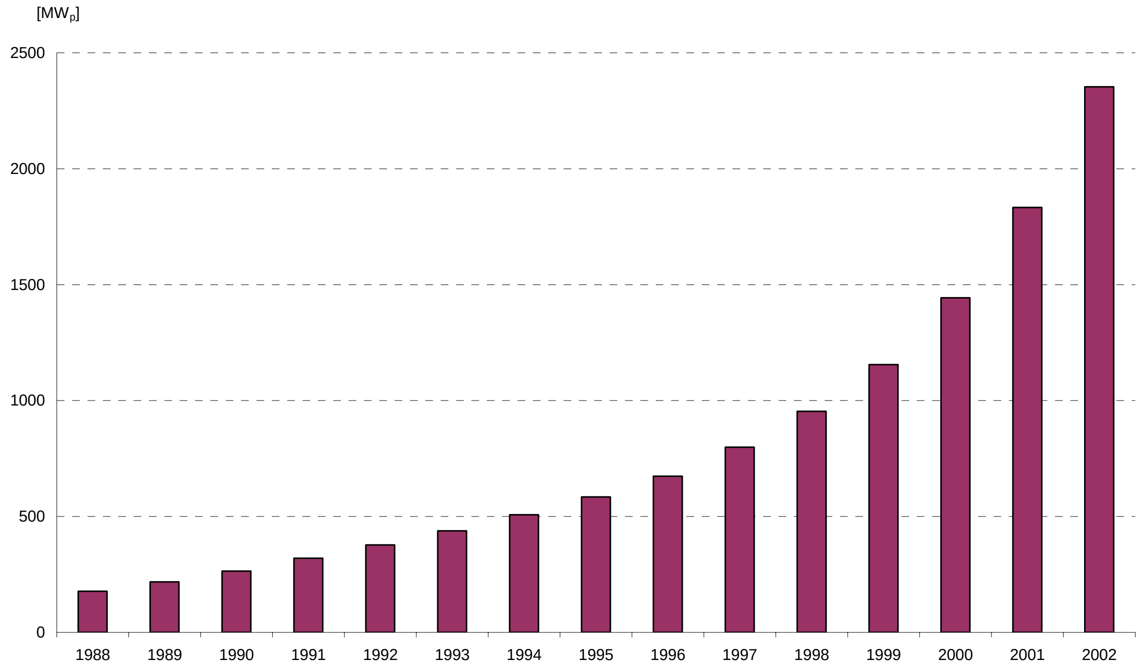

Figure 5.2 *World shipment data for PV modules (not capacity of systems) (Maycock, 2003)*

Regarding future estimates on the world level, only EPIA/GP (2001) assesses the realisable potential, based on installed capacity. Other sources, such as Strategies Unlimited (2000), present the medium term module shipment expectations. As a reference, the resulting numbers have been displayed in

According to EPIA/GP (2001), similar growth rates apply to the world as to Europe. An installed capacity of 207 GW_p for the world is expected realisable for the year 2020. Again, the share of grid-connected appliances initially is expected to grow faster than off-grid sector, which is expected to change by the year 2010. A third source, (EPIA, 2002) foresees 23% growth per year on a world level, in which the share of Europe in the world market will grow at an additional rate of 1% per year over the coming decade. Also Alsema (1992) refers to the world growth rate, and assumes 18% annual growth until 2002, followed by 30% until 2020, whereas 30% is judged ‘really high’.

Table 5.6 Realisable potential for the world in GW_p installed PV power

[GW_p]	2000	2005	2010	2020	2040
EPIA/GP (2001)[1]				207	6075
Strategies Unlimited (2002)[2]	1.2	2.9-3.6	6.5-10.5		

[1] For the year 2040, a global solar electricity output is projected of 9113 TWh. Assuming an average amount of full load hours of 1500 per year (1500 kWh/kW, load factor 17%), the calculated cumulative capacity is 6075 GW_p.
[2] (Strategies Unlimited, 2002) assesses the development of cumulative PV module shipments.

5.2.2 Costs

Investment costs

This section gives an overview of investment costs as found in literature. An overview is presented in Table 5.7. For the Netherlands, the only reference that splits up costs shares is Neele (2001), based on Novem data for the period 1992-1999. Dunlop (2001) presents results for Florida, and Lako (2002) for the world. Two additional sources have been regarded in order to show the investment costs shares attributed to the system components. The data have been presented in equal currencies in Table 5.8.

Table 5.7 *Overview of investment costs for PV. Data are in original currencies*

Source	Unit	Investment	Year	Applies to
Smekens (2003)[1]	[$98/$kW_p$]	4500-4860	2000	System
DACES (2050, 2001)	[€/W_p]	6.67	2000	System, world
EnergieNed (1997)	[NLG/kW_p]	11800	2000	System, NL
Lako (2002)[2]	[€ 2000/kW_p]	5400		System
de Lange (2000)	[NLG/kW_p]	10000		For the year 2000
EUREC (2002)	[€/kW_p]	4.0-5.0	System	Achieved 2000
Lako (1998)[3]	[ECU/kW_p]	5000 to 5750	2000	
van Sambeek (2002)	[€/kW_p]	4190	2000	MEP data
Ikki (2002)[4]	[kYen/kW_p]	863-1040	2000; 1999	
Harmon (2000)	[$/$W_p$]	3.50	1998	Average price of PV modules
WEA (2000)	[1998$/$W_p$]	5-10	1998	Example

[1] Lowest value refers to Eastern Europe, highest value refers to Western Europe.
[2] Assumes module price: 4000 $€_{2000}$/kW, inverter & cabling 750 $€_{2000}$/kW and installation 650 $€_{2000}$/kW.
[3] Range due to different EU regions.
[4] First value refers to residential PV systems, second value refers to PV for industrial or public facilities.

Table 5.8 *The results from the above table using efficiency PV system of 100 W_p/m^2*

	Cost [€/kW_p] excl. VAT (Neele, 2001)	[€/kW_p], status of the year 2000 (Dunlop, 2001)	[$€_{2000}$/kW_p] (Lako, 2002)
Module	3.9	3.8-8.7	4.0
Inverter & Cabling & Additional	1.1	1.0-5.7	0.8
Installation	0.2	0.5-2.2	0.7
Total	5.2	5.4-16.6	5.4

1 NLG = 0.45 € and 1 USD_{2000} = 1.08 €

Operation and Maintenance costs
The studies in which O&M costs have explicitly been presented are listed in Table 5.9.

Table 5.9 *O&M costs for PV systems*

Source	Unit	O&M cost fix	Reference year	Applies to	[%] of investment
Smekens (2003)[1]	[$98/kW$_p$]	18-45	2000	Europe	0.37-1
DACES (2050, 2001)[2]	[€/W$_p$/yr]	0.2-0.01			3
Lako (1998)[3]	[ECU/kW$_{pe}$]	20.5-8.1		Europe	

1 Lowest value refers to Western Europe, highest value refers to Eastern Europe.
2 First value refers to the year 2000, second value refers to the year 2050.
3 Value 20.5 refers to the year 2000, 8.1 refers to the year 2030 (22 and 9.2 respectively for South Spain). This corresponds to 0.4% in 2000 and 0.75% in 2010, 2020 and 2030 (0.38-0.63 for South Spain).

Progress ratio
An overview of progress ratios from literature is given in Table 5.10.

Table 5.10 *Progress ratios for PV*

Source	Primary Source	Progress Ratio	Refers to
Alsema (1992)[1]		0.80-0.90	
DACES (2050, 2001)[2]	Neij 1999, EPRI 1997, Dignard-Bailey	0.78-0.95	
Lako (2002)[3]		0.8-0.95	
de Lange (2000)	(Ybema, 1999)	0.8	
Seebregts (1999)[4]	MARKAL Europe/Global	0.81	System
Seebregts (1999)[5]	Reduced MESSAGE global	0.72	System
Seebregts (1999)[6]	ERIS global	0.85	System
Harmon (2000)[7]	Various	0.798	Module ’68-’98
Snik (2002)[8]	Various	0.78 and 0.84	Mostly module

1 Refers to the long term. Further assumes a minimal production of 500 MWp/year before learning will occur.
2 For multi-crystalline (default/optimistic/pessimistic): 82%/80%/95%, for thin film 82%/78%/90% respectively.
3 0.8 for module, 0.85-0.87 for inverter, cabling, and 0.90-0.95 for installation.
4 Period 1990-2050 (max. amount of doublings 11 resp 13).
5 Period 1990-2050 (max. amount of doublings 5).
6 Period 1990-2050 (max. amount of doublings 16).
7 Only historical rates ‘BOS cost reduction equal to or greater than module cost reduction’.
8 Only historical rates.

5.3 Data ranges

In this section, ECN will formulate an own viewpoint on potential and price data. For every parameter as mentioned in Section 5.2, a paragraph elaborates on the data-range that ECN judges plausible.

5.3.1 Potential

Technical potential
The available surface area in the built environment that has been found for the Netherlands by Corten, Bergsma (1995) seems correct. No information is available on the GBPV. For Europe, no data are available at all. In addition, the practical use of this parameter is not apparent, because in any case, limitations of practical and social origin decrease the technical potential.

The technical potential of solar photovoltaic energy in the Netherlands is considered to be very large (>1000 km^2, 200-300 GW$_p$), as also for Europe (>80·10^3 km^2, 16·10^3-24·10^3 GW$_p$). However, ECN prefers not to fix a data range because of the fact that the technical potential is not of much use for modelling purposes or other studies.

Realistic potential
Some limiting factors exist in the large-scale implementation of PV. For instance, it is not realistic to qualify the total roof area in a country to be available for solar panels: at least European roofs facing north as well as shaded parts are not well suited. In IEA (2002) a rule of thumb is described which assesses the surface area that is available for solar PV, for each country. This comprises area available in the building sector[11], both of roofs and on facades. The report assesses the total area that is available, taking all sorts of limiting factors into account, among which the acceptance by the public. The resulting value for the Netherlands is quite in accordance with values found in other reports, at least when taking into account the different assumptions regarding the conversion of surface available (in km^2) to the realistic power potential. For Europe, no other realistic potential assessments have been found, and therefore the ECN estimate of the realistic potential will be based on the just mentioned report.

Considering the goal of the study, and the analysis performed[12], ECN assumes the resulting numbers to be a realistic BIPV potential. For EU-15, this amounts to 8100 km^2, and for the Netherlands to 357 km^2. For GBPV, an estimate for the Netherlands and for Europe is presented. Also, the surface estimated as a *technical* potential in Corten, Bergsma (2003), namely 900 km^2 in total, is considered for estimating the value for the realistic potential.

The above considerations lead to the following. The realistic potential of solar photovoltaic energy in the Netherlands is estimated to be 400 km^2 (80-120 GW_p) for BIPV and 200 km^2 (40-60 GW_p) for GBPV. For Europe, the BIPV area is estimated as 8000 km^2 (1600-2400 GW_p) and the GBPV as another 8000 km^2 (1600-2400 GW_p).

Realisable potential
The Netherlands is one of the European countries in which installed capacity increased more than the worldwide average. The realisable potential estimates the limits to the development of PV in the Netherlands and in Europe. In order to do so, the limitation of the growth in worldwide PV production capacity and the market can be useful.

The world PV market has increased from 3.3 MW_p per year in 1980 to more than 500 MW_p per year in 2002 (Maycock, 2003). The average growth rate, though fluctuating, was over 20% in the period 1988-2002. Future estimates of the world PV market range from 15% to 25% per year. As an example, such a development has been displayed in Table 5.11, and graphically in Figure 5.3. For the year 2002, the cumulative world production according to Maycock (2003) is used: 2353 MW_p.

Table 5.11 *Example of a development of the worldwide cumulative PV producton until the year 2050, starting from the realisation in the year 2002*

[GW_p]	2002	2030	2050
Realisation in 2002 (Maycock 2003)	2		
Cumulative PV producton at growth rate of 15% per jaar		118	1928
Cumulative PV producton at growth rate of 25% per jaar		1217	105528

[11] The total building sector has been assessed: residential, agricultural and industrial for example.
[12] Actually, the report bases on current construction works, whereas in the time period to 2050 it can be foreseen that the available BIPV area has increased considerably.

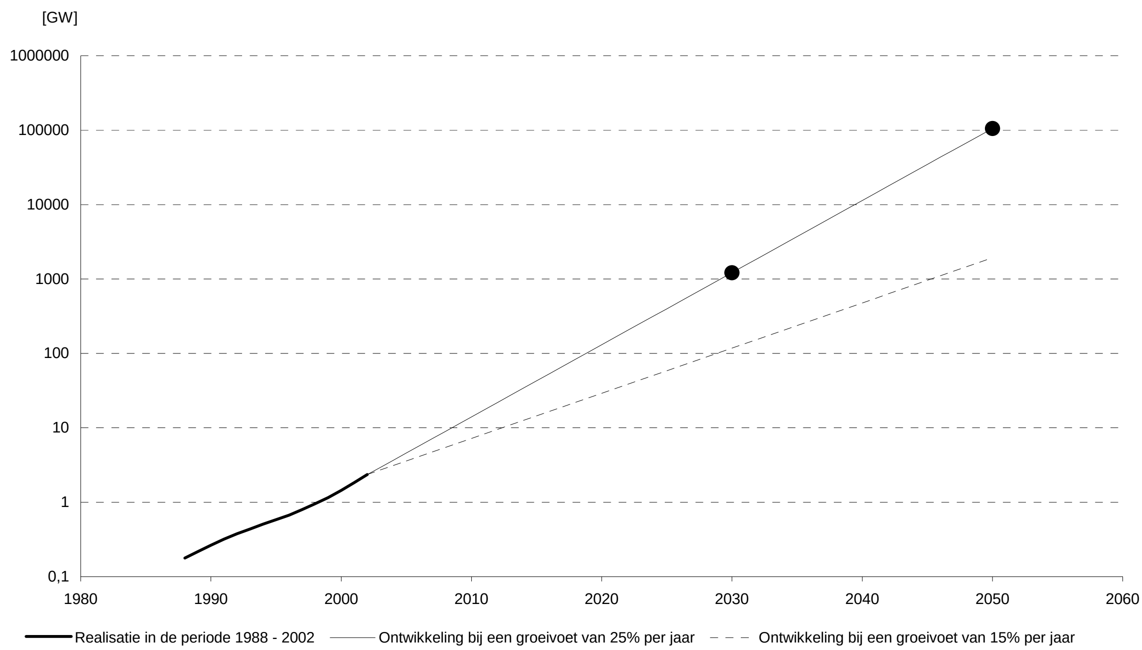

Figure 5.3 *Example of development of the worldwide cumulative PV production until the year 2050. Realisations until the year 2002 have been based on (Maycock 2003)*

For the Netherlands, it is supposed that the penetration of solar PV keeps pace with Europe. Certainly the solar irradiation is less than in Spain or Italy, but on the other hand the demand for renewable energy and notably solar PV is relatively high.

The installed capacity for the Netherlands (40-60% growth per year) and the cumulative worldwide module shipments (20-30% growth per year) has increased considerably over the past few years. Currently, several countries in Europe demonstrate very high growth rates in solar PV. For the case of the Netherlands, from 2000 to 2001 the total capacity installed increased at a rate of 60%. In Germany, even 70% growth has been reached during this period. However, to maintain such a high growth rate during a decade is a challenge.

It is expected that the future growth for the worldwide annual PV module production growth will decrease in the course of time. As an estimate, the annual growth rates until the year 2050 are estimed as displayed in Table 5.12.

Table 5.12 *Estimate of a possible development of annual growth rates for the worldwide annual PV module production growth (based on power)*

[%]	Low estimate	Average estimate	High estimate
2002-2010	20	25.0	30
2011-2020	15	22.5	30
2021-2030	15	17.5	20
2031-2040	10	12.5	15
2041-2050	5	10.0	15

This annual growth can also be expressed in an amount of produced capacity doublings. These have been displayed in Table 5.13.

Table 5.13 *Amount of capacity doublings*

	Doublings low relative to 2001	Doublings average relative to 2001	Doublings high relative to 2001
2010	2.4	2.9	3.4
2020	4.4	5.8	7.2
2030	6.4	8.2	9.8
2040	7.8	9.9	11.8
2050	8.5	11.2	13.9

As an estimate, ECN assumes the above PV production growth rates to apply to determine the realisable potential for both the Netherlands and for Europe. Here, no differentiation between the Netherlands and Europe is applied; the ranges are thus indicative, and are depicted in Table 5.14 for the Netherlands and in Table 5.15 for Europe.

Table 5.14 *Estimate of the range in realisable potential for the Netherlands, in which no decommissioning has been taken into account*

[GW_p]	Low estimate	Average	High estimate
2001	0.021[1]	0.021[1]	0.021[1]
2010	0.1	0.2	0.2
2020	0.4	1.2	3.0
2030	1.7	5.8	18.6
2040	4.5	18.9	75.1
2050	7.3	49.1	180[2]

1 In the year 2001 the PV capacity in the Netherlands mounted to 20.51 MW_p (Novem, 2002).

2 The upper boundary in the year 2050 is based on a realistic potential of solar photovoltaic energy in the Netherlands mounting to 600 km^2 available surface, with a power density mounting to 300 W_p/m^2.

Table 5.15 *Estimate of the range in realisable potential for Europe, in which no decommissioning has been taken into account*

[GW_p]	Low estimate	Average	High estimate
2001	0.276[1]	0.276[1]	0.276[1]
2010	1	2	3
2020	6	16	40
2030	23	78	250
2040	60	255	1011
2050	98	661	4089

1 In the year 2001 the PV capacity in Europe mounted to 276 MW_p (IEA 2002).

Storage of electricity is an important condition for such a high penetration rates[13]. The growth scenario has a significant impact on the future cost of PV power. High growth and high deployment indicate expansion of the PV production industry, and offer opportunities for cost reduction. Also, R&D has impact on these costs.

[13] When the relative share of PV power in a national electricity mix becomes important, electricity storage is necessary. For the Netherlands for example, today an additional amount of 10% of the installed conventional capacity can be fed into the grid without additional measures. Based on the capacity of today in the Netherlands, the maximum power could be 2 GW_p of PV power. When exceeding this amount, additional measures, such as electricity storage, demand-side and supply-side management are required (Menkveld, 2003).

Costs

Investment costs

Costs of PV systems depend on system layout. For the investment cost of the most important systems, roof top systems on family houses, large-scale power plants and small solar home systems, the module cost is more than 70%. The cost of the balance of system (BOS) components differs across countries, as it has a dependence on locally determined effects. Also, financial incentives can have an impact on price development in a region.

The prices mentioned under Section 5.2.2 appear to be representing the cost of the cheapest systems available on the market. The PV system investment costs are assumed to be situated in a range of 5 to 8 €/W_p for the year 2001. This includes module, balance of system and labour for installation.

Operation and Maintenance costs

Ranges from literature make 0.4% to 3% of investment costs. An important issue regarding the O&M costs is the difference in lifetime of system components. Typically the inverter component has a shorter lifetime than the PV module. In case this component should be replaced two times in the total lifetime of the PV system, a large burden arises for the annual O&M costs. This can account up to 20% of the initial system costs.

As PV-integration becomes more common, specialised contracts are offered that take care of O&M. Presently in the Netherlands such contracts range from annually 30 € to 120 € per dwelling, an average of annually 40 € for 30 m^2 is assumed (Neele, 2001). This would be below 1% of the investment costs.

Further, it can be assumed that, thanks to technical progress, the O&M costs of future systems will decrease. According to Alsema (1992) long-term O&M costs decrease to 1 to 1.5 € per m^2.

Annual O&M costs, comprising also insurance and spare-parts are assumed to be in a range of 1% to 3% of the total initial investment costs in the year 2000. For future systems, this share can decrease somewhat.

Progress ratio

The investment costs of solar PV per kW_p have been steadily decreasing over time. A first distinction that must be made when discussing PV progress ratios is the difference between learning effects on PV modules on one side and on BOS, the inverter and installation costs on the other. Thereby, most studies that are available calculate a progress rate out of *historical* data, whereas the aim of the current exercise is to estimate *future* progress rates. Nevertheless, these historical data can be valuable for determining a range. From Snik (2002) it can be found that historically, progress ratios of 0.78 to 0.90 have occurred, based on several sources.

Reports that assess future progress ratios that are proposed vary from low (0.78) to moderate (0.85) and high (0.95). Alsema (1992) on the long term assumes a progress ratio of 0.80 to 0.90.

In a best case, new technology and better processes accelerate the cost decrease of PV, which yield a high learning effect, resulting in a PR of 0.75. On the other side, problems due to feedstock, equipment and power yield can provoke that the critical mass for important cost reduction possibly cannot be reached, which aggravates learning and results in a PR of 0.90. Thus, the future progress ratio of PV system investment costs are estimated to be in a range between 0.75 and 0.9, with 0.8 as the most probable value for the present decade.

5.3.2 Technical aspects

Firstly, the *power density* measures the efficiency of incident solar radiation conversion to electrical output, measured in Watt-peak (W_p). Secondly, the concept of *full load hours* indicates the amount of imaginary hours during which a PV system would deliver at peak power to yield the annual production. Finally, the *lifetime* of a system is important when considering the costs of a PV system. The following sections discuss the parameters mentioned above.

Power density

To express the PV potential, the most useful unit is the available area (expressed in km^2), as it is not restricted by technology assumptions. In order to convert this area to an electrical power output, assumptions on the power density are required. For the year 2000, the power density amounts to approximately 100 $W_p/m^{2.}$ This value is supposed to increases to maximally 200 W_p/m^2 in the year 2030 and 300 W_p/m^2 in the year 2050. As a lower range, the 200 W_p/m^2 will be reached in the year 2050. Using the power density, conversion from surface (m^2) to power (W_p) can be performed. Figure 5.4 presents the assumed changes in power density graphically.

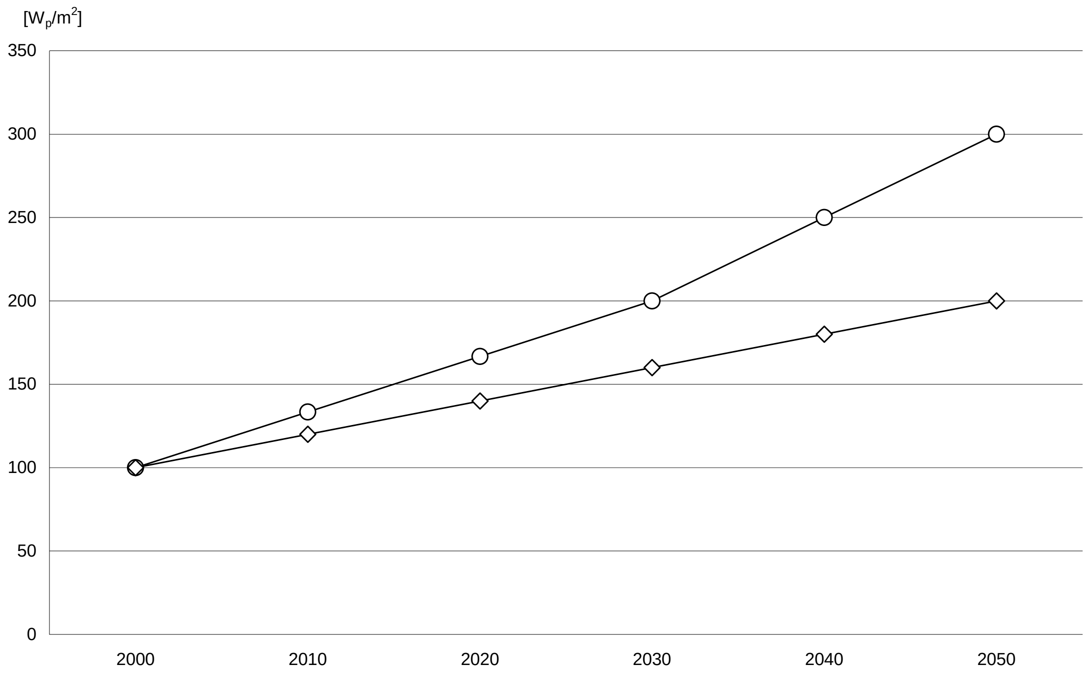

Figure 5.4 *The assumed development of PV power density*

Full load hours

The average solar intensity varies accross the European countries. For the conversion of power to energy, a country-specific analysis yields an estimate of 965 $kWh/m^2/y$ for the Netherlands. For Europe, the solar intensity ranges from 950 (for Finland) to 1738 $kWh/m^2/y$ (for Greece) (see also Section 5.4.2). Based on these figures, a load factor (or capacity factor) can be calculated: the ratio of full load hours to the total hours in a year (namely 8760).

In addition to the dependence on geographical location, irradiance losses[14] and system losses[15] occur in a PV system, which influence the energy yield and thus the load factor. Taking both losses together, the PV system *performance ratio* is estimated to be in a range between 0.8 and 0.9, in which the higher values rather apply to future and large systems.

Combining values for solar intensity and performance ratio, the *average load factor* can be calculated for the Netherlands and for Europe. As the average solar intensity varies accross Europe, the annual amount of solar irradiation and thus the load factor depends on the geographical location. These have been displayed below.

Table 5.16 *Overview of ranges in PV-system load factors*

Performance ratio	0.8	0.9	1.0
		Resulting load factor [%]	
Netherlands	8.8	9.9	11.0
Europe	11.3	12.7	14.1
GR, IT, PT and ES only	15.2	17.1	19.0

In (Novem, 2002), the average annual energy production for grid-connected PV systems is calculated using an amount of full load hours equal to 700, resulting in a load factor[16] of 8.0%. This value is considered to be a lower bound.

For the Netherlands, the average load factor ranges from 8% to 10% (assuming an overall system efficiency of 0.8 to 0.9). For Europe, the additional assumption is that most PV power installations will be constructed in the South of Europe, also taking into account that GBPV potentially has a higher system efficiency. This results in a range of 12% to 16% average load factor for Europe.

Lifetime

The current lifetime of PV modules is approximately 25 years, or less in case of thin film technology. The current technical lifetime of the inverter is less, approximately 10 to 15 years; the additional investments due to inverter replacement is compensated for in annual operation and maintenance costs (see Section 5.2.2). The aim is to increase the technical lifetime of PV modules and inverters to 30 years.

5.4 Specific data for the European Union+

5.4.1 Assessment structure

The assessment in the current section will take place according to the scheme below: based on the available area and the power density, a power is calculated, which is converted to an amount of annual energy production by using a certain load factor.

[14] Irradiance losses are the energy losses that account for the difference between global horizontal irradiance as measured with a pyranometer and the global plane irradiance as measured with a reference cell, and includes the orientation effect, shading loss, soiling loss, reflection loss and the spectral effect (Baltus 1998).

[15] System losses are the energy losses that account for the difference between the nominal array energy and the AC energy output, and includes the fundamental loss at standard test conditions, low irradiance loss, temperature effect, DC-cabling loss, blocking diode loss, mismatch loss, static and dynamic maximum power point loss and inverter losses (Baltus 1998).

[16] Full load hours (700) divided by the amount of hours in a year (8760) yields 0.080.

Table 5.17 *Potential assessment structure for solar PV*

Level	Name/unit	Factor
4	Available Area per band [m^2]	
		× Power density
3	Power [MW_p]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

5.4.2 Potential

Band definitions

Using a map of the solar radiation for the EU does banding. This map (Novem, 1995) contains an overview of the average annual solar radiation, ranging from smaller than 1000 kWh/m^2 to higher than 1800 kWh/m^2. The band splits are listed in the table below.

Table 5.18 *Band splits solar radiation*

[kWh/m^2/y]	Range
Band 1	> 1800
Band 2	1600-1800
Band 3	1400-1600
Band 4	1200-1400
Band 5	1000-1200
Band 6	< 1000

Per country an estimate of the share of land area per band is made using this map, these shares are listed in Table 5.19. Assumed is that the relation between geographic location and future solar radiation will not change.

Table 5.19 *Shares of the country area per band*

[%]	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Austria			5	85	10	
Belgium					100	
Denmark					95	5
Finland						100
France			30	40	40	
Germany					70	30
Greece	25	75				
Ireland					70	30
Italy	15	60	15	10		
Luxembourg					100	
Netherlands					10	90
Norway						100
Portugal		67	33			
Spain	15	50	35			
Sweden						100
Switserland		85	15			
United Kingdom					25	75

Potential assessment
PV modules can be installed on every surface with free access to sunlight, on roofs, facades of buildings or even on special land areas, PV fields. In this study the assessment has focused on the available area on buildings. To be able to assess the available area on roofs and facades, information from the Photovoltaic Power Systems Programme from the IEA has been used (IEA, 2001). In this study the available area for Building Integrated PV (BIPV) is derived. The results of the IEA assessment for selected IEA countries is listed in table Table 5.20 and Table 5.21, for the non-listed EU countries (Belgium, France, Greece, Ireland, Luxembourg, Portugal) and Norway and Switserland, several rules of thumb mentioned in (IEA, 2001) have been applied, see Table 5.22. Information about population can be found in appendix B. The population in 2000 has been used to determine the available area on buildings.

Table 5.20 *Available area for BIPV on roofs of different types of buildings*[*]

[km^2]	Residential	Agricultural	Industrial	Commercial	Other	Total
Austria	85.7	17.1	15.2	17.5	4.2	139.6
Belgium	92.2	30.7	25.6	25.6	15.4	189.6
Denmark	50.9	14.8	10.6	10.6	1.1	88.0
Finland	78.3	21.0	19.2	8.5	0.4	127.3
France	533.1	177.7	148.1	148.1	88.9	1095.9
Germany	721.8	164.0	229.7	164.0	16.4	1295.9
Greece	95.5	31.8	26.5	26.5	15.9	196.3
Ireland	34.2	11.4	9.5	9.5	5.7	70.4
Italy	410.3	114.0	136.8	91.2	11.4	763.5
Luxembourg	3.9	1.3	1.1	1.1	0.7	8.1
Netherlands	127.5	42.7	52.8	35.8	0.6	259.4
Norway	40.2	13.4	11.2	11.2	6.7	82.7
Portugal	90.1	30.0	25.0	25.0	15.0	185.3
Spain	252.0	78.7	55.1	55.1	7.9	448.8
Sweden	134.5	36.1	32.9	14.5	0.7	218.8
Switserland	67.1	21.9	21.1	12.8	15.4	138.2
United Kingdom	601.9	71.1	61.6	168.2	11.9	914.7

Source: IEA, 2001
[*] Estimates for Belgium, France, Greece, Ireland, Luxembourg, Norway, Portugal and Switserland using rules of thumb.

Table 5.21 *Available area for BIPV on facades of different types of buildings*[*]

[km^2]	Residential	Agricultural	Industrial	Commercial	Other	Total
Austria	32.1	2.1	5.7	8.7	1.6	50.3
Belgium	35.9	5.1	10.2	10.2	5.1	66.6
Denmark	19.1	1.9	4.0	5.3	0.4	30.6
Finland	19.1	1.9	4.0	5.3	0.4	30.6
France	207.3	29.6	59.2	59.2	29.6	385.0
Germany	270.7	20.5	86.1	82.0	6.2	465.5
Greece	37.1	5.3	10.6	10.6	5.3	69.0
Ireland	13.3	1.9	3.8	3.8	1.9	24.7
Italy	153.9	14.3	51.3	45.6	4.3	269.2
Luxembourg	1.5	0.2	0.4	0.4	0.2	2.8
Netherlands	47.8	5.3	19.8	17.9	0.2	91.1
Norway	15.6	2.2	4.5	4.5	2.2	29.0
Portugal	35.1	5.0	10.0	10.0	5.0	65.1
Spain	94.5	9.8	10.7	27.6	3.0	145.5
Sweden	50.5	4.5	12.4	7.3	0.3	74.8
Switserland	25.2	2.7	7.9	6.4	5.8	48.0
United Kingdom	225.7	8.9	23.1	84.1	4.4	346.3

Source: IEA, 2001
[*] Estimates for Belgium, France, Greece, Ireland, Luxembourg, Norway, Portugal and Switserland using rules of thumb.

Table 5.22 *Available area per capita for BIPV on roof and facade areas, rules of thumb*[*]

[m^2/capita]	Roofs	Facades
Residential	9.0	3.5
Agricultural	3.0	0.5
Industrial	2.5	1.0
Commercial	2.5	1.0
Other	1.5	0.5
All	18.5	6.5

Source: IEA, 2001

[*] Applied to Belgium, France, Greece, Ireland, Luxembourg, Norway, Portugal and Switserland

The total BIPV area for the EU countries plus Norway and Switzerland is around 8400 km^2. If the effect of change in population towards 2030 is taken into account (see Appendix B), the total BIPV area would decrease to approximately 8250 km^2, provided that the amount of area available per capita (see Table 5.22) will not change. As however a decrease in the number of persons per household is foreseen, it is assumed here that the long-term area potential will stay around 8400 km^2.

To calculate the power potential a power density of 100 W_p/m^2 has been taken for the year 2000, for 2030 a power density of 200 W_p/m^2 has been assumed (increase in efficiency, see also below: *Energy production*). Together with these power densities and the available BIPV area the total PV power potential can be calculated for the year 2000, see Table 5.23. In 2030 the power potential will be twice as high. It is furthermore assumed that the types of buildings mentioned in Table 5.22 are proportionally spread across every band.

Table 5.23 *BIPV power potential per band for each country in the year 2000*

[GW_p]	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Total
Austria			0.9	16.1	1.9		19.0
Belgium					25.6		25.6
Denmark					11.3	0.6	11.9
Finland						15.8	15.8
France			37.0	51.8	59.2		148.1
Germany					123.3	52.8	176.1
Greece	6.6	19.9					26.5
Ireland					6.7	2.9	9.5
Italy	15.5	62.0	15.5	10.3			103.3
Luxembourg					1.1		1.1
Netherlands					3.5	31.5	35.0
Norway						11.2	11.2
Portugal		16.8	8.3				25.0
Spain	8.9	29.7	20.8				59.4
Sweden						29.4	29.4
Switzerland		15.8	2.8				18.6
United Kingdom					31.5	94.6	126.1
Total	31.0	144.2	85.3	78.3	264.1	238.7	841.7

Potential energy production

In 2000 the average efficiency of PV modules is around 10%. With a solar radiation density of 1000 W_p/m^2 this equals 100 W_p/m^2. It can be expected that the average efficiency in the future will increase due to technology development. It will be assumed that in 2030 this efficiency has increased to 20%. Therefore the power density of PV system will increase to 200 W_p/m^2. The performance ratio of PV cells is around 85%[17]. Together with these numbers the average electricity production and load factors per band can be calculated. The results are shown in Table 5.24.

Table 5.24 *Average electricity production per band in 2000 and in 2030 and load factors*

[kWh/m²/y]	2000	2030	Load factor [%]
Band 1	157	315	18.0
Band 2	145	289	16.5
Band 3	128	255	14.6
Band 4	111	221	12.6
Band 5	94	187	10.7
Band 6	81	162	9.2

Using the average electricity production from the table above the total energy potential per band can be calculated. The results are shown in Table 5.25. Since the power density will increase from 100 W_p/m^2 to 200 W_p/m^2 the energy potential for 2030 is twice as high (not depicted).

Table 5.25 *BIPV energy potential per band for each country in the year 2000*

[TWh/a]	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Total
Austria			1.2	17.8	1.8		20.8
Belgium					24.0		24.0
Denmark					10.5	0.5	11.0
Finland						12.8	12.8
France			47.2	57.3	55.4		159.9
Germany					115.3	42.7	158.0
Greece	10.4	28.7					39.2
Ireland					6.2	2.3	8.5
Italy	24.4	89.5	19.8	11.4			145.1
Luxembourg					1.0		1.0
Netherlands					3.3	25.5	28.7
Norway						9.0	9.0
Portugal	0.0	24.2	10.5				34.8
Spain	14.0	42.9	26.5				83.5
Sweden						23.7	23.7
Switzerland		22.9	3.6				26.4
United Kingdom					29.5	76.4	105.8
Total	48.8	208.3	108.8	86.5	246.9	192.8	892.2

5.4.3 Technology costs

5.4.4 Technical aspects

Technology costs will be similar for all countries and based on available data. No technology breakthrough is assumed. Lako (2002) is used as input source. Costs per band as well as per country are assumed to be equal, O&M costs are estimated 1% of the investment costs.

[17] It is expected that the performance ratio will increase in future to 0.9 (see Section 5.3.2).

Table 5.26 *Solar PV technology costs*

[€/kW$_p$]	2000	2030
Investment costs	5400	1100
Annual O&M costs	54	11

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6. BIOMASS AND WASTE

6.1 Introduction

Biomass and waste not only serve the energy sector, but also provide for food and raw material. This makes the characterisation of the biomass option very complicated. Not only are there many different sources to be considered, but energy from these sources also needs its specific conversion technology to produce electricity. The result is a very complex mix of energy sources (that is, biomass-based fuels) and conversion technologies, of which the combination is not only determined by technological limits, but also very much by economical factors. In this chapter biomass sources and conversion technologies will be considered. As a result of the complexity of biomass, the structure of this chapter will differ from the structure of wind and solar PV.

The structure of this chapter is as follows. The first section of this chapter deals with a literature overview on biomass potential. Then, costs are discussed, and finally the resource assessment structure for EU specific data is presented. The aim of the exercise is not to present an exhaustive set of data but rather to simplify the enormous amount of data that is available, and to present a general overview of the complex situation that exists for biomass in relation to the energy supply. Table 6.1 present a brief overview of key data regarding potential and costs.

In the recent EU Directive on renewable electricity (EC, 2001) a definition of biomass is given. This definition was discussed extensively in different commissions and in the European Parliament and is likely to be adopted by most European countries. The definition of biomass is given as: *'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.* In this report biomass will be considered all materials complying the EU definition of biomass.

Table 6.1 *Key parameters for electricity from biomass and the data*

Parameter	Netherlands	World
Realistic potential	87-146 ($PJ_{th,}$ 2020)	200-700 EJ (world availability, 2050)
Indicative costs of energy crops	-13 to +7 €/GJ	3 to 6 €/GJ (import to the Netherlands)

6.2 Biomass and waste potential

6.2.1 Biomass and waste potential in the Netherlands

In order to draw a picture of the biomass and waste availability and use, firstly data for the year 1999 are presented. The data presented in Table 6.2 focuses on the availability and deployment in the Netherlands (Koppejan, 2000; Weterings, 1999). Here, the availability of biomass for energy purposes has been modest. Besides the biomass that actually is used, additional potential has been attributed to biomass of which properties are well-suited for energy generation, for which a conversion technology is available, for which no alternative and more profitable applications exist and for which initiatives for energy generation have been undertaken at present. It can be deduced from the table that 7% of the mass availability (717 out of 10310 kton wet basis, w.b.) and 12% of the biomass-related energy content (8.8 out of 76 PJ_{th}) has been deployed in the year 1999. This shows that the resources with the higher energy content have been deployed first. Alternative applications existed for the remaining biomass potential. This illustrates the competition issue as elaborated upon in 6.1.

In the Netherlands, it also is a viable option to import biomass from abroad. The market decides whether it is an attractive option; price of biomass, transport costs and economic value in the

Netherlands determine the extent to which foreign biomass will be imported. An assessment has been performed by (Koppejan 2000) and (Weterings 1999), which yields the numbers presented inTable 6.3. As estimated from the assessment, 0,1% of the biomass production in Europe can become available for the Dutch energy sector. Annually 1918 kton w.b. would equal 28.8 PJ_{th} per year (indicative number due to large uncertainty). For the biomass share becoming available for the Netherlands from the rest of the world no data were available, the input has been set to zero.

Adding the indigenous and imported biomass availability for energy supply in the Netherlands results in a total availability of 12,228 kton w.b., corresponding to 104.8 PJ_{th} per year (Koppejan, 2000; Weterings, 1999).

Table 6.2 *Biomass production, availability and use in 1999 in the Netherlands*

Type of biomass	Total biomass production	Biomass availability for energy purposes		Actual use for energy generation in the year 1999	
	[kton w.b.]	[kton w.b.]	[PJ_{th}]	[kton w.b.]	[PJ_{th}]
Energy crops	6,900	3	0	0	0
Biomass residues*	80,600	2,025	18.4	251	3
Biomass waste*	22,400	8,282	57.6	466	5.8
Total	109,900	10,310	76	717	8.8

Source: Koppejan 2000, Weterings 1999

* Biomass residues refer to rest products from agriculture and forestry (like forestry residues, manure and straw) and mono-streams as a result of typical activities; waste refers to residues of production processes (like roadside hay, wood, sludge and industrial waste). All data refer to the year 1999.

Table 6.3 *Estimates of import potential of biomass for the Dutch energy supply, based on production estimates for Europe and the World*

Type of biomass	Europe			Rest of world		
	Production	Available for Netherlands		Production	Available for the Netherlands	
	[kton w.b.]	[kton w.b.]	[PJ_{th}]	[kton w.b.]	[kton w.b.]	[PJ_{th}]
Energy crops	234	0	0	906	n/a	0
Biomass residues	1,173,000	1674	25.2	32,920,000	n/a	0
Biomass waste	459	244	3.6	3,490,000	n/a	0
Total	1,866,000	1918	28.8	37,316,000	n/a	0

Source: Koppejan 2000, Weterings 1999

The biomass availability as presented in Table 6.2 and Table 6.3 is based on the current situation. The total production is much larger than the share that can become available to energy supply. Especially when regarding future developments, the influence of policy on the biomass availability may increase. As indicated in 6.1, in order to assess the future potential of biomass and waste streams, assumptions need to be made for the future society. In (Koppejan, 2000; Weterings, 1999) three scenarios have been defined, based on which statements regarding the expected availability for electricity generation have been made. The report has a global scope, that is, not only inland production has been assessed, but also the possibilities for import from other EU countries and from the world. Detailed results have been listed in Table 6.4. The scenario for which the results have been listed is Scenario 2, which supposes among others a free market and an energy price that mounts to 1.5 times the energy price in 1999. This scenario appeared to yield the best opportunities for biomass; factors that could heavily influence the outcome concern price of fossil fuels, energy policy as well as agricultural and waste policy, and social acceptance. In the column that lists the 1999 availability, the results from Table 6.2 and Table 6.3 have been summed. Comparing the results for 1999 to the (scenario-based) results for the year 2020, it becomes clear that a 15% increase is estimated (from 105 PJ_{th} to 121 PJ_{th}). It is not considered reasonable that, under the assumed scenario conditions, much more biomass than currently available will come on the market. This is a result of assumptions regarding use of biomass in other sectors.

Table 6.4 *Availability of biomass for energy supply for the Netherlands in 1999 and 2020 (scenario based)*

Type of biomass	1999		2020
	[kton w.b.]	[PJ_{th}]	[PJ_{th}]
Indigenous energy crops	3	0	6
Biomass residues	2025	18.4	43
Biomass waste	8282	57.6	72
Import from EU	1918	28.8	Included above
Import from rest of world	-	-	-
Total	12228	104.8	121

Source: Koppejan 2000 and Weterings 1999

As a continuation of (Koppejan 2000), another study (Zeevalking, 2000) extends the biomass options taken into account, and analyses in more detail the availability and the energy content. This, among other changes, leads to different numbers in comparison with the previous table. Scenario assumptions are similar, but the results change. This can be seen in Table 6.5.

Table 6.5 *The updated 1999 and 2020 (scenario based) availability for the energy supply of biomass for the Netherlands*

Type of biomass	1999 [PJ_{th}]	2020 [PJ_{th}]
Indigenous energy crops	0	5-5
Biomass residues	15	25-41
Biomass waste	19	57-100
Import from EU	-	Included above
Import from rest of world	-	Included above
Total	34	87-146

Source: Zeevalking, 2000

6.2.2 Biomass and waste potential in Europe and the world

For the case of Europe, no data are available for the long term. In the previous section, data for Europe have been presented that refer to 1999 (Table 6.3). But then again, this number does not indicate to what extent this potential in future can become available to the energy supply.

In (Faaij 2001) and (Lysen 2000) assessments have been performed for the long-term (reference year 2050) global biomass availability. The approach that has been used estimates the area for agriculture, pastures and grassland, forests and unproductive area. Next, estimating the tons grain equivalent that will be necessary to feed the expected 9.4 billion people in 2050, the global food consumption is estimated. To do so, it is important to make assumptions on the average diet. It appears to be important to what extent this diet is of animal origin; nourishment based on vegetable products is less land-intensive. Also, the average yield of biomass, related to the available land quality and production method, is an important parameter. The results of this assessment are presented in Table 6.6.

Table 6.6 *Long-term (2050) worldwide biomass availability*

Biomass options	Estimated yield [EJ/year]
Agricultural land for non-food purposes	140-430
Biomass production on marginal land	0 or 60-150
Agricultural residues food production	15
Forestry residues	0 or 14-110
Manure	0 or 5-55
Organic waste	5-50

Source: Faaij 2001 and Lysen 2000

The total maximum available global biomass potential in the year 2050 is estimated 100-1250 EJ/year (average about: 200-800 EJ/year). With an expected increase in the demand for biomass materials of 0-150 EJ/year, the maximum net available potential for other purposes is 100-1100 EJ/year (average about: 200-700 EJ/year). Apart from critical success factors determining the biomass availability, such as population growth and economic development, efficiency and productivity food production systems, feasibility of using marginal and degraded lands, forest production and sustainable harvest levels, and the increased use of biomaterials, an allocation problem can occur. The important issue is, to what extent the Netherlands can participate in this potential. On the short term, this share can be considerable, being not so many players on the market yet. On the longer term however, local use of this biomass potential and increased demand from other countries can limit the possibilities for the Netherlands.

As indicated in Section 6.1, biomass might be available in large quantities, but due to competition on the market of raw materials, it is possible that in due time (in some studies the year 2020 is mentioned) the available resource for electricity generation decreases considerably.

6.3 Costs of biomass

In order to assess the costs for biomass and waste, two subdivisions of fuel type have been made:

1. Costs of indigenous sources.
2. Costs of imported sources from other EU-countries and from outside the EU.

All of these costs heavily depend on market developments. Especially for future price development, it is very difficult to estimate the levels. In Van Ree (2002) a proposition for key numbers has been made. To this report is referred here.

6.3.1 Costs of indigenous sources for the Netherlands

Table 6.7 *Overview of price ranges for biomass resources in the Netherlands for the year 2000*

Biomass source	Price in the year 2000 [€/GJ]
Indigenous energy crops	5.5-7.0
Forestry residues [1]	-0.7-0.7
Roadside hay	-1
Crop residues[2]	5.5-5.6
Chicken manure	-1.6
Liquid Manure	-11.5
Sewage-sludge	-3.6
VGI-residues[3]	0.2
MSW (GFT)[4]	-2.0
Industrial Waste	-12.6

Source: Koppejan 2000 and Van Ree 2000

1 Based on several categories (fresh wood including bark, forestry residues and wood from fruit sector and tree cultivation).

2 Based on straw (from rapeseed).

3 Food industry residues.

4 Biomass waste from households.

6.3.2 Costs of imported sources from inside and outside the EU

Literature yields a range from 3 to 6 €/GJ for import of energy crops, for prepared biomass, delivered at a Dutch harbour. This is potentially lower than indigenous biomass growing. Several effects cause the range that is indicated for the price. For instance, extensive forestry is cheaper than intensive forestry. Other aspects that are important concern the overall sustainability of the delivery, including transport and fertiliser use. Optimisation parameters can be found in the physical form in which biomass will be transported: as a raw material only versus the feasibility to convert it to fuels of higher energy content.

6.4 Technology data

Many different technologies are available for biomass processing. Some of these can cover a wide spectrum of fuels, others are very limited in the type of biomass they can cope with. For electricity production, mainly thermo chemical and biochemical processes are at stake. Other processes are also available, like Hydro Thermal Upgrading or liquid biofuels technologies, but these are not discussed in this report.

Table 6.8 *Biomass conversion technologies*

Type of process	Technology	Market availability	Indicative Plant size	Output
Thermo chemical conversion	Direct co-firing coal plant	Available	60-240 MW_e	Electricity
	Indirect co-firing coal plant	Available	120 MW_e/20 MW_e for steam-sided integration	Electricity
	Indirect co-firing gas-fired plant	For heat only[1]	30 MW_e for CC	Electricity and heat
	Combustion	Available	< 1 MW_{th} or 25-40 MW_e	Electricity and heat
	Pyrolysis	Available	8 MW_e	Electricity
	Gasification	Available[2]	1-10 to 30-150 MW_e	Electricity
Biochemical conversion	Digestion	Available	30 kW_e (liquid manure) 40000 t/yr (dry matter)	Electricity

1 Combined Cycle (CC) expected for 2007.

2 Improved technologies will penetrate in period 2005-2015.

For the thermo chemical processes, conditions have been defined that limit the potential. For instance, co-firing of biomass in coal plants depends heavily on the expected future deployment of coal plants. Within this perspective, decisions have been made regarding the technologies taken into account. In the following section a discussion will be presented about all future technologies, explaining whether or not they currently are considered of importance; see Table 6.8 for an overview. For all of the technologies presented detailed data exist, subdividing each group in subsets. However, in order to limit the number of technologies to be assessed, a cross-section of these technologies has been defined, which will be used in the current report. This cross-section is presented in Table 6.9.

Co-firing in coal plants
This process can be subdivided in *direct co-firing*: no pre-treatment of the biomass, and *indirect co-firing*: pre-treatment of the biomass is required for technical reasons, co-firing can rate up to 20%, while this is 3.5% for steam-sided integration. Examples of both the direct and indirect process exist in the Netherlands today. Because the direct version requires only little investment, this option is used more frequently. On the other hand, in the case of direct co-firing, fuel properties are stricter to be considered, and therefore possibly more expensive due to higher fuel costs. A limiting factor to this technology on the long term is the future deployment of coal plants. Depending on the policy regarding refurbishing existing plants and the construction of new coal plants, fewer opportunities could remain in the future.

Gas co-firing
Because of the solid character of biomass, the fuel first needs to be converted to a gaseous energy carrier, in order to be burnt in a gas turbine. The ECN Biomass department expects that this technology will not see a breakthrough (de Vries, 2002). The reason is that the percentage of biomass that can be co-fired in a gas installation is very limited. To raise this co-firing percentage special technologies are required for pre-treating the biomass, specificly for gas turbines. These adaptations are not expected to be economic profitable. It is considered that it will be more viable to develop separate, stand-alone biomass plants (Biomass Integrated Gasification with a Combined Cycle (BIG/CC)). For this reason, gas co-firing will not be taken into account in the further assessment. However, small-scale (<15 MW_{th}) CFB technology used for co-firing biomass in a gas-fired boiler is already available and used.

Combustion
Standalone combustion processes remain relatively small. Very small systems (below 1 MW_{th}) are assumed only to yield heat, and therefore don't count for electricity production. Fuels that can be combusted are pure biomass and also waste, whereas for the latter only the biodegradable part counts as renewable. Investments for waste-incineration are relatively high, due to flue gas cleaning equipment. Both types of combustion plants are evaluated in the further assessment, but due to their different features as independent technologies.

Pyrolysis
Although pyrolysis is interesting for the utilisation of MSW and already is in use in Germany, it will not be taken into account in this report.

Gasification
Expectations of this technology are high. At present, only the fluidised bed (FB) technology combined with a gas-engine is available on the market. A circulating FB with a gas-engine is expected available on the market in the year 2005, which is also expected to be the case for the bubbling FB. On the medium term (2010-2015) a large scale circulating FB with a combined cycle (CC) is expected.

Digestion
In this process a combustible gas is extracted from a biomass stream by means of anaerobic fermentation. This process matches well with biomass of a high moisture content or even liquid biomass, such as manure. Also, the use of landfill gas is comprised.

Technology lifetimes
The lifetimes of the technologies described above are all supposed to be 20 years.

Table 6.9 *Costs and efficiency assumptions for electricity production. In case no entry exists for the years 2010 and 2020, the value for 2000 applies*

Technology[1]			2000	2010	2020
Direct co-firing	Investment	[€/kW]	75-220[2]		
	O&M	[% of investment]	6[3]		
	Efficiency	[%LHV[4]]	39.5		
Co-firing in Coal plants	Investment	[€/kW]	1050-2400		
	O&M	[% of investment]	4-6		
	Efficiency	[%LHV]	35-38.5		
Co-firing in Gas plants	Investment	[€/kW]	550-2250		
	O&M	[% of investment]	5-6		
	Efficiency	[%LHV]	42.5-83		
Combustion	Investment	[€/kW]	1375	1306	1241
	O&M	[% of investment]	4		
	Efficiency	[%LHV]	30		
Combustion, CHP	Investment	[€/kW]	2500		
	O&M	[% of investment]	4[5]		
	T-Efficiency	[%LHV]	56.5		
	E-Efficiency	[%LHV]	23.5		
Waste incineration	Investment	[€/kW]	6478-7712[6]		Increase 20% for higher eff.
	O&M	[€/kWh]	0.017-0.022		
	Efficiency	[%LHV]	20-30		
Gasification	Investment	[€/kW]	10,200	11,000-12,600[7]	4535-7165[8]
	O&M	[% of investment]	6.5		
	Efficiency	[%LHV]	20	21-28	23-43
Digestion	Investment	[€/kW]	5000	4750	4513
	O&M	[% of investment]	6		
	Efficiency	[kWhe/ton]	8-22-100[9]		

Source: Zeevalking 2000, Van Ree 2002

1 O&M: annual costs as percentage of the investment costs, unless otherwise specified.
2 High value based on (Sambeek, 2003).
3 See (Sambeek, 2003), based on 0.3 €ct/kWh.
4 Lower Heating Value.
5 In addition to the fix O&M, a variable O&M of 0.011 €/kWh is expected.
6 See (Sambeek, 2003).
7 Refers to CFB, starting from the year 2005.
8 Refers to CFB CC, expected in the period 2010-2015, lowest value for 150 MW_e, highest for 30MW_e.
9 8 kWh_e/ton for landfill site, 22 kWh_e/ton for liquid biomass, 100 kWh_e/ton for dry biomass.

As explained before, not all biomass streams are compatible with every technology. Table 6.10 presents the matching technology/biomass combinations, as they will be used in the further assessment. The table indicates which combinations render the most profitable use of a biomass stream. Other combinations are technically possible, but these are regarded less profitable.

Table 6.10 *Overview of preferential combinations of energy carriers-technology*

	Direct co-firing	Combustion (incl. CHP)	Waste incineration	Gasification	Digestion
Energy Crops, Forestry residues, Solid Manure, Sewage Sludge	×	×		×	
Liquid Manure, Landfill gas					×
Agricultural residues	×	×		×	
Industrial waste and Biodegradable part of MSW				×	×
MSW			×	×	

6.5 Specific data for the European Union+

6.5.1 Resource assessment

Potentials for electricity production from biomass depend highly on the availability of biomass sources or fuels. In general some biomass sources do have other usage, such as agricultural waste (straw) or manure. Therefore the potential assessment will focus on the determination of the amount of different biomass sources available for electricity production. The type of biomass fuels or residues will be included in the band definition. Therefore all conversion technologies have the same banding; the total biomass resource (in PJ) from the bands can be converted into electricity with the different technologies. This implies that the sum of the fuel input of one band for all technologies will equal the total resource of that band. Some combinations of biomass-conversion technology are not likely to be possible, these combinations can be excluded beforehand. The biomass-technology combinations together with the band definitions are listed in table Table 6.11.

Table 6.11 *Biomass-technology combinations and the band definitions*

Band[1]	Source	Co-firing	Combustion	Gasification	Degestion	CHP
1	Energy crops	×	×	×		×
2	Foresty	×	×	×		×
3	Solid manure	×	×	×		
4	Liquid manure				×	
5	MSW		×			
6	Barley residues	×	×	×		×
7	Maize residues	×	×	×		×
8	oil crops residues	×	×	×		×
10	Rapeseed residues	×	×	×		×
12	Wheat residues	×	×	×		×
13	Landfill gas				×	
14	Sewage sludge				×	
15	Industrial waste		×			

[1]Band 9 and 11 are not included in the final version of this study. For consistency reasons the numbering will remain unchanged.

Explanation of biomass sources listed in Table 6.11:

- Band 1: biomass production from special energy crops, the total annual yield is supposed to be available for energy production.
- Band 2: residues from forestry, only roundwood and fuelwood production has been taken into account.
- Band 3: manure from chickens only.
- Band 4: manure from cattle, pigs and sheep.
- Band 5: municipal solid waste, only the biodegradable fraction.
- Band 6-12: residues from agricultural production, total annual residues are supposed to be partially available for energy production.
- Band 13: gas production from digestion of landfilled waste on special landfill sites.
- Band 14: gas production from digestion of sewage sludge.
- Band 15: waste from industrial production according to the Eurostat definition, only the biodegradable fraction.

Explanation of technologies in Table 6.11:

- Co-firing: co-firing of solid biomass in coal fired power plants, requires modifications to those plants for preprocessing of the biofuel.
- Combustion: power plants fired with biomass only.
- Gasification: biogas fired power plants, the gas originates exclusively from gasification of biomass.
- Digestion: mostly small scale biogas fired power plants, from digestion gas of wet biomass sources.
- CHP: combined heat power plants, combustion of solid biomass only for electricity and heat production; although CHP can be fired with biogas originating from digestion, however only combustion plants will be regarded.

Energy crops

The availability of agricultural area for energy crops depends highly on the competition between other purposes for these areas. If more profit can be made from other crops, the potential for energy crops will be rather small. The same can be said about the costs of the agricultural ground; if these costs are relatively low, it can be expected that changing to energy crops is more likely to occur than in countries having high ground costs.

Competition between different types of crops is too complex to elaborate here and will be outside the scope of this study. Nevertheless, to be able to show differences between countries the effect of different costs for agricultural ground will be regarded, see Section 6.5.2.

Competition between different applications of energy crops, such as fuel input for electricity production or biofuels for example, will also not be regarded. It is assumed that the total production from energy crops will be available for electricity production. The amount of available energy crops can however be analysed in separate scenario's concerning different future use of these crops.

In Gielen (1998) it is mentioned that scenario studies for Western Europe suggest a land availability for energy crops of 200-250 thousand km^2. Projections for land use in a sustainable scenario (Lehmann, 1996) show that 167 thousand km^2 of unused agricultural area will be available for the planting of energy crops. It will be assumed here that on the long term the land availability in the EU-15 including Norway and Switzerland will be approximately 10% of the total agricultural area of 1.44 million km^2. Furthermore it will be assumed that 75% of the unused area is available in the Southern countries Portugal, Spain, Italy and Greece.

For the assessment no distinction has been made with respect to the type of energy crops. An average energy content of 16.5 GJ/ton is therefore assumed. Furthermore a EU wide harvest index of 0.6 is assumed. The yields per harvest as listed in Table 6.12 are based on information in Gerlagh (1998) and expert judgement.

In the table below the energy potential from energy crops is listed. It concerns the potential for the national production of energy crops for every country, import and export are not considered. The area that is regarded is the agricultural area according to the definition of FAO (2002), the averages from 1994-1999 have been taken. The overall growth rate of the agricultural area for the listed countries is around 0.6 ‰, therefore it is assumed here that there will be no major changes in future area availability.

Table 6.12 *Potential of energy crops*

	Agricultural area[1] [1000 ha]	Available area [1000 ha]	Yield/harvest [ton ODM/ha][2]	Potential [PJ/a]
Austria	3,470	160	7.0	31
Belgium	1,360	63	8.2	14
Denmark	2,689	124	6.7	23
Finland	2,259	104	5.3	15
France	29,972	1,380	7.3	278
Germany	17,279	796	8.5	185
Greece	9,038	1,703	3.9	182
Ireland	4,399	203	6.8	38
Italy	15,556	2,930	5.2	423
Luxembourg	117	5	8.2	1
Netherlands	1,970	12[3]	8.1	3
Norway	1,074	49	5.4	7
Portugal	3,830	721	2.9	58
Spain	29,971	5,646	3.1	482
Sweden	3,272	151	7.4	30
Switzerland	1,581	73	7.4	15
United Kingdom	17,439	803	7.0	154
Total	145,276	14,921		1,939

[1] Source: FAO, 2002.
[2] Oven Dry Matter.
[3] Zeevalking, 2000.

Table 6.13 *Assessment structure for energy crops*

Level	Name/unit	Factor
10	Available area [ha]	
		× yield [ton/ha]
9	Yield per harvest [ton]	
		× 1/harvest index
8	Ton biomass [ton]	
		× specific energy production [GJ/ton]
7	Fuel input [GJ]	
		× conversion efficiency
6	GJ output [GJ]	
		× 1/3600
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8.760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Forestry residues

There is a certain amount of residues remaining from roundwood production. Part of this amount is used for energy supply within the wood production industry, the other part can be available for renewable energy production. Besides the residues from roundwood, there is the actual production of fuelwood, for households, CHP etc. To assess the potential for renewable electricity production from forestry residues it must be known what share of the annual production is available for renewable electricity purposes. It is estimated that on average around 35% of the total EU wide annual production of roundwood will be available as residue (IEA Bioenergy, 2002). The maximum EU wide availability of fuelwood for electricity production is also estimated at 35%. In Table 6.14 the amount of wood available for energy production is based on the average production from 1997 until 2001 (FAO, 2002). It is assumed that there is a sustainable exploitation of production forests in the EU, therefore the total availability in 2030 will be assumed to be equal to the availability listed in table Table 6.14. In this table the production of fuel wood and roundwood are combined.

Table 6.14 *Production of round- and fuel wood and potential in PJ*

	Annual production [mln m^3]	Potential [PJ]
Austria	17.7	48.4
Belgium	2.0	5.5
Denmark	2.7	7.3
Finland	56.0	152.8
France	50.7	138.4
Germany	42.8	116.8
Greece	3.3	8.9
Ireland	2.5	6.7
Italy	15.3	41.6
Luxembourg	0.1	0.3
Netherlands	1.2	3.2
Norway	8.8	24.1
Portugal	9.6	26.1
Spain	17.4	47.6
Sweden	64.6	176.3
Switzerland	6.7	18.4
United Kingdom	7.6	20.7
TOTAL	309.0	843.3

The available amount of energy in PJ can be calculated using:
specific mass: 0.52 ton ODM/m^3
specific energy: 15 GJ/ton ODM.

Table 6.15 *Assessment structure of forestry residues*

Level	Name/unit	Factor
10	Total Wood production [m^3]	
		× availability factor
9	Wood residue available [m^3]	
		× specific mass
8	Ton biomass [ton]	
		× specific energy
7	Fuel input [GJ]	
		× fuel efficiency
6	GJ output [GJ]	
		× reciprocal seconds per hour [=1/3600]
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8.760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Manure

A distinction is made between liquid manure and solid manure. Liquid manure consists of cattle, pigs and sheep manure, while for solid manure only chicken manure has been taken here. Via the number of animals and the specific manure production per (type of) animal the potential energy can be calculated.

The availability factor of manure is not always 100% since manure can be used for other purposes (fertiliser etc.). Besides this, the collection of manure is not always possible. Therefore it can be assumed that this factor can be very low, but may rise in the future.

In Table 6.16 are the used availability and production rates per type of animal listed.

Table 6.16 *Assumed availability and average annual production rates*

Source	Availability [%]	Average production [kg/head/a]
Cattle	20	13,285
Chickens	61	27
Pigs	20	1,123
Sheep	5	561

The conversion process (technology) for manure of chicken will mainly be combustion, for the other types this will be only anaerobic digestion. With an efficiency of 30% and energy content of 6.6 GJ/ton the electricity production from solid manure is around 550 kWh/ton. The net electricity production from digestion is around 22 kWh/ton (Halen, 2000).

Table 6.17 *Potential of manure from cattle and chickens*

	Cattle			Chickens		
	Average 1997-2001 [mln. heads]	Manure available [kton/a]	Realistic potential [GWh]	Average 1997-2001 [mln. heads]	Manure available [kton/a]	Realistic potential [GWh]
Austria	2.2	5,829	128	13	213	117
Belgium	3.1	8,275	182	44	729	401
Denmark	1.9	5,116	113	20	325	179
Finland	1.1	2,918	64	6	101	56
France	20.4	54,192	1,192	235	3,865	2,126
Germany	15.0	39,937	879	106	1,749	962
Greece	0.6	1,551	34	28	465	255
Ireland	6.8	18,072	398	11	187	103
Italy	7.2	19,040	419	107	1,759	967
Luxembourg	0.2	436	10	2	38	21
Netherlands	4.2	11,184	246	102	1,677	922
Norway	1.0	2,710	60	3	53	29
Portugal	1.3	3,379	74	35	573	315
Spain	6.0	16,056	353	127	2,095	1,152
Sweden	1.7	4,553	100	8	124	68
Switserland	1.6	4,316	95	7	109	60
United Kingdom	11.3	29,922	658	152	2,507	1,379
Total	85.6	227,486	5,005	1,006	16,569	9,112

Table 6.18 *Potential of manure from pigs and sheep*

	Pigs			Sheep		
	Average 1997-2001 [mln. heads]	Manure available [kton/a]	Realistic potential [GWh]	Average 1997-2001 heads [×1000]	Manure available [kton/a]	Realistic potential [GWh]
Austria	3.6	809	18	367	10	0.2
Belgium	7.0	1,580	35	149	4	0.1
Denmark	11.8	2,657	58	146	4	0.1
Finland	1.4	306	7	117	3	0.1
France	14.7	3,298	73	10,205	286	6.3
Germany	25.4	5,711	126	2,239	63	1.4
Greece	0.9	212	5	8,950	251	5.5
Ireland	1.7	390	9	5,434	152	3.4
Italy	8.3	1,865	41	10,967	308	6.8
Luxembourg	0.4	83	2	8	0	0.0
Netherlands	13.4	3,020	66	1,394	39	0.9
Norway	0.5	118	3	2,375	67	1.5
Portugal	2.4	530	12	5,950	167	3.7
Spain	20.9	4,692	103	24,279	681	15.0
Sweden	2.1	474	10	437	12	0.3
Switserland	1.5	1,991	44	429	12	0.3
United Kingdom	7.2	1,609	35	42,182	1,183	26.0
Total	123.2	29,345	647	115,628	3,242	71.6

The assessment structure is as follows:

Table 6.19 *Assessment structure manure (solid & liquid)*

Level	Name/unit	Factor
6	Ton manure [ton]	
		× specific energy production [kWh/ton]
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8,760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Agricultural residues

In Diamantidis (2000) and Koukios (1998) the residue yield of different crops are estimated. These availabilities will be used here, with some additions and modifications. Since residues do have multiple purposes, such as fodder, fertilizer and/or soil conditioner, only a fraction of the available residues will be taken here for energy purposes. This fraction is in general 50% but 25% is taken in the case of maize. Furthermore a distinction is made between Northern/Middle European countries and Southern European countries. The southern European countries are Portugal, Spain, Italy and Greece. The availabilities of agricultural residues are listed in Table 6.20, the assessment structure is given in Table 6.21.

Table 6.20 *Availabilities of agricultural residues for different crops [ton/km^2]*

Avaliability	North/Middle Europe	South Europe
Barley	150	100
Maize	240	100
Oilcrops	200	100
Rapeseed	150	80
Wheat	200	100

The specific energy content of the crops is estimated at an average value of 15 GJ/ton.

Table 6.21 *Assessment structure for agricultural residues*

Level	Name/unit	Factor
9	Crop area [ha]	
		× specific mass [ton/ha]
8	Ton biomass [ton]	
		× specific energy [15 GJ/ton]
7	Fuel input [GJ]	
		× fuel efficiency [%] (see below)
6	GJ output [GJ]	
		× reciprocal seconds per hour [=1/3600]
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Table 6.22 *Potential of barley and maize residues and potential of oilcrops and rapeseed residues and wheat residues*

	Barley		Maize		Oilcrops		Rapeseed		Wheat residues	
	Average area 1997-2001 [km^2]	Potential [PJ]	Average area 1997-2001 [km^2]	Potential [PJ]	Average area 1997-2001 [km^2]	Potential [PJ]	Average area 1997-2001 [km^2]	Potential [PJ]	Average area 1997-2001 [km^2]	Potential [PJ]
Austria	2,423	5.5	1,082	3.2	2,733	8.2	566	1.3	1,839	6.6
Belgium	582	1.3	199	0.6	1,983	6.0	97	0.2	277	1.0
Denmark	7,250	16.3	1,188	3.6	6,549	19.6	1,165	2.6	0	0.0
Finland	5,696	12.8	627	1.9	1,348	4.0	627	1.4	0	0.0
France	16,123	36.3	21,195	63.6	50,976	152.9	11,515	25.9	18,112	65.2
Germany	21,742	48.9	12,281	36.8	28,005	84.0	10,674	24.0	3,678	13.2
Greece	1,272	1.9	11,969	18.0	8,526	12.8	0	0.0	2,089	3.8
Ireland	1,870	4.2	37	0.1	828	2.5	37	0.1	0	0.0
Italy	3,523	5.3	16,811	25.2	23,432	35.1	496	0.6	10,568	19.0
Luxembourg	31	0.1	10	0.0	104	0.3	5	0.0	15	0.1
Netherlands	508	1.1	57	0.2	1,281	3.8	10	0.0	156	0.6
Norway	1,708	3.8	65	0.2	624	1.9	65	0.1	0	0.0
Portugal	241	0.4	3,886	5.8	2,134	3.2	0	0.0	1,712	3.1
Spain	33,249	49.9	33,275	49.9	21,969	33.0	435	0.5	4,544	8.2
Sweden	4,421	9.9	718	2.2	3,640	10.9	572	1.3	0	0.0
Switzerland	471	1.1	185	0.6	951	2.9	143	0.3	218	0.8
United Kingdom	12,332	27.7	5,784	17.4	19,298	57.9	4,794	10.8	0	0.0

Municipal solid waste and landfill gas

Total availability of waste

The availability of municipal solid waste (MSW) depends on the domestic waste production in a country. It has a strong correlation with the number of inhabitants. Hence the available amount of MSW depends on the development of the population in time. In the appendix an overview is given about the expected population development.

The average annual waste production per capita can be calculated using (Smith, 2001), this equals approximately 450 kg in 1999. The energy content of waste is around 10 GJ/ton. The future waste production per capita and the specific energy content can be considered as a scenario parameter.

Only electricity production from the biodegradable fraction of waste is regarded as renewable in the EU Renewables Directive. This fraction equals approximately 50%. A recent study (Harmelink, 2002) has been used to differentiate this biodegradable share between countries. It is assumed that the biodegradable fraction remains the same towards 2030, it is however also a scenario parameter.

The total average waste arisings per person in 2030 is assumed to increase 20% towards 2030, from 450 kg/p/a in 1999 to 540 kg/p/a (Gerlagh, 2002). On average 25% of the total MSW arisings in 1999 are recycled or used for composting (Smith, 2001). It is assumed that this will increase to 50% in 2030 (Gerlagh, 2002).

Using the information above it is now possible to assess the country and time dependent waste arisings and recycling/composting percentages. The results are shown in the table below, the arisings concern the total amount of waste (including non-biodegradable fraction). The assessment structure for the total amount of waste available for energy production (combustion of MSW and production of landfill gas) is given in Table 6.24.

Table 6.23 *Waste arisings, recycling/composting and availability*

	Arisings		Recycling/composting		Total available MSW	
Year	[kg/p/a] 2000[1]	[kg/p/a] 2030	[%] 2000[1]	[%] 2030	[Mton/a] 2000	[Mton/a] 2030
Austria	509	540	44	50	2.3	2.0
Belgium	473	540	18	50	4.0	2.7
Denmark	487	540	26	50	1.9	1.4
Finland	406	540	23	50	1.6	1.4
France	486	540	24	50	22.0	17.0
Germany	451	540	49	50	19.0	21.0
Greece	368	540	7	50	3.6	2.7
Ireland	534	540	7	50	1.9	1.3
Italy	462	540	21	50	21.0	13.7
Luxembourg	442	540	16	50	0.2	0.2
Netherlands	549	540	44	50	4.9	4.5
Norway	452	540	25	50	1.5	1.3
Portugal	379	540	16	50	3.2	2.6
Spain	384	540	30	50	10.7	9.8
Sweden	362	540	45	50	1.7	2.3
Switzerland	452	540	25	50	2.4	1.8
United Kingdom	486	540	17	50	24.2	16.6
Total					126.3	102.3

Source: Smith, 2001

Table 6.24 *Structure for assessing the total available amount of waste*

Level	Name/unit	Factor
12	Number of inhabitants [1000]	
		× annual waste production [ton/inhabitant]
11	Annual waste production [kton]	
		× (1-% recycling/composting)
10	Available waste [kton]	

Direct energy production from MSW

On average 70% of the net amount of available MSW is landfilled in 2000 (Smith, 2001). It is assumed that towards 2030 this will decrease to 15%, hence the future availability of waste is 85% of the net amount of MSW (Gerlagh, 2002). This amount of waste is supposed to be available for electric energy production via incineration in special designed power plants. Using the biodegradable shares from (Harmelink, 2002) and an average energy content of 10 GJ/ton waste the total energy potential of the biodegradable share can be calculated. The results are shown in Table 6.25.

Table 6.25 *Energy potential for incineration of Municipal Solid Waste*

	Share available for energy recovery [%][1]		Share bio degradable [%][5]	Potential biodegradable share [PJ]	
	2000[2]	2030		2000	2030
Austria	18.7	85	41	1.8	7,0
Belgium	17.9	85	38	2.7	8,8
Denmark	83.8	85	49	7.8	6,0
Finland	3.1	85	46	0.2	5,4
France	47.1	100[3]	45	46.6	76,5
Germany	44.4	100[3]	84	70.9	176,2
Greece	0.1	85	49	0.0	11,2
Ireland	0.0	85	51	0.0	5,7
Italy	6.7	85	50	7.0	58,3
Luxembourg	60.5	85	46	0.5	0,6
Netherlands	55.0	100[4]	55	14.8	24,6
Norway	28.6[3]	85	51[3]	2.2	5,6
Portugal	0.0	85	41	0.0	9,1
Spain	6.6	85	48	3.4	40,1
Sweden	74.5	85	69	9.0	13,3
Switzerland	28.6[3]	85	51[3]	3.5	7,6
United Kingdom	11.2	85	47	12.7	66,4
TOTAL				183.1	522,5

1 Of net amount (excl. recycling and composting).
2 Smith, 2001.
3 Data not available, number based on EU average.
4 Zero landfill policy (Gerlagh, 2002).
5 Harmelink, 2002.

The assessment structure for MSW is shown in the table below. It can be seen as a continuation of the structure shown in Table 6.24.

Table 6.26 *The assessment structure for MSW*

Level	Name/unit	Factor
10	Available waste [kton]	
		× % available for energy production
9	Net amount of available waste [kton]	
		× % biodegradable fraction
8	Biodegradable waste available [kton]	
		× specific energy content [GJ/ton]
7	Fuel input [GJ]	
		× efficiency
6	GJ output [GJ]	
		× 1/3600
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Energy production from landfill gas

The remaining fraction of the total available amount of MSW (Table 6.23) is assumed to be landfilled. In landfill sites digestion of waste takes place, producing landfill gas with a methane content of on average 55%. Since methane is a greenhouse gas with a greenhouse effect of more than 20 times the effect of CO_2, it is assumed here that in the EU collection of gas produced by landfill sites will be obligatory in the future. In that case it can either be incinerated directly (flared) or used in a gas turbine or CHP installation for electricity and heat production. Using the total amount of landfilled waste the energy content of the country depending production has now to be calculated. This will be done for a situation with energy recovery, thus no direct flaring of the gas.

From http://www.geocities.com/RainForest/Canopy/6251/Landfillcalc.htm (2002) it can be learned that on average a landfill site produces 4 m^3 of landfill gas per ton waste annually. However during the lifetime of a landfill site (approx 15 years) the production is not constant, but it will be assumed here that the assessment can be done using this average production rate. The methane content of 55% results in an average energy content of 17.4 GJ per m^3 landfill gas (for 100% methane this is 31.6 MJ/m^3). The total annual gas production per annually ton landfilled waste can now be calculated and is on average 60 m^3 (15 x 4).

It is furthermore assumed that the values elaborated above can be taken for every country (EU plus Norway and Switserland). However the Netherlands, Germany and France do have a zero landfill policy in the future, therefore the amount of waste for landfill decreases to zero for these countries towards 2030. For the other countries specific information about national policies is not available yet.

In the table below the energy potential of landfill gas is shown for 2000 and 2030, using the method described above.

Table 6.27 *Landfill gas potential*

	Share available for energy recovery [%][1]		Potential [PJ]	
	2000[2]	2030	2000	2030
Austria	38	15	0.9	0.3
Belgium	23	15	1.0	0.4
Denmark	18	15	0.4	0.2
Finland	92	15	1.6	0.2
France	44	0[3]	10.0	0.0
Germany	100	0[3]	19.8	0.0
Greece	98	15	3.7	0.4
Ireland	76	15	1.5	0.2
Italy	100	15	22.0	2.1
Luxembourg	58	15	0.1	0.0
Netherlands	36	0[3]	1.8	0.0
Norway	70	15	1.1	0.2
Portugal	100	15	3.3	0.4
Spain	100	15	11.2	1.5
Sweden	69	15	1.3	0.4
Switzerland	70	15	1.8	0.3
United Kingdom	99	15	25.1	2.6
TOTAL			106.5	9.4

1 Of net amount (excl. recycling and composting).
2 (Smith, 2001).
3 Zero landfill policy (Gerlagh, 2002).

It must be noted that the shares of MSW and landfill gas available for energy recovery in 2000 in Table 6.25 and Table 6.28 do not always add up to 100% for every country in Smith (2001). This can be caused by import and export of waste. The effect of import/export has not been included in the potential data towards 2030, i.e. in these data only the domestic potential is reflected.

In Table 6.28 the assessment structure for landfill gas is shown, it can be seen as a continuation of the structure shown in Table 6.24.

Table 6.28 *The assessment structure for landfill gas*

Level	Name/unit	Factor
10	Available waste [kton]	
		× % available for landfill
9	Net amount of available waste [kton]	
		× average landfill gas production [m^3/ton/a]
8	Organic waste available [kton]	
		× specific energy content [GJ/m^3]
7	Fuel input [GJ]	
		× efficiency
6	GJ output [GJ]	
		× 1/3600
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Industrial waste

Since little information is known about the availability of industrial waste an extrapolation of IEA statistics until 1998 (average realisations) has been done here. This extrapolation has been conducted using correlations with figures about past and future GDP and population development (FAO, 2002). It is assumed that the average realisations from IEA (2001) do concern the total amount of waste, hence a correction for the biodegradable share should be made. The results of this quick scan are shown in the table below. For some countries the statistics about industrial waste production are not available. It is however not assumable that there is no actual industrial waste production in those countries.

Table 6.29 *Potential of industrial waste*

[PJ]	2000	2005	2010	2015	2020	2025	2030
Austria	0.7	0.8	1.0	1.1	1.2	1.4	1.6
Belgium	2.1	2.4	2.7	3.1	3.5	4.0	4.4
Denmark	-	-	-	-	-	-	-
Finland	3.0	3.7	4.2	4.8	5.3	5.9	6.4
France	19.1	22.4	25.6	29.0	32.7	36.5	40.6
Germany	32.1	37.1	42.2	47.7	53.4	59.5	66.1
Greece	1.1	1.4	1.6	1.9	2.2	2.6	3.0
Ireland	-	-	-	-	-	-	-
Italy	2.3	2.7	2.9	3.3	3.6	4.0	4.3
Luxembourg	-	-	-	-	-	-	-
Netherlands	6.5	7.8	8.9	10.1	11.5	13.0	14.6
Norway	0.2	0.3	0.3	0.4	0.4	0.5	0.5
Portugal	-	-	-	-	-	-	-
Spain	2.7	3.3	3.8	4.3	4.9	5.5	6.1
Sweden	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Switzerland	4.7	5.2	5.8	6.5	7.2	7.9	8.5
United Kingdom	1.8	2.0	2.3	2.6	2.9	3.2	3.6

Sewage sludge
No information is available about the production of electricity from sewage sludge in the EU, besides numbers mentioned in (Voogt, 2001). Therefore these numbers will be presented here as long term potential of electricity production from sewage sludge. In the table below these numers are shown.

Table 6.30 *Potentials of sewage sludge for the year 2010*

	Potential [GWh]	Power potential [MW][1]
Austria	354	51
Belgium	156	22
Denmark	208	30
Finland	73	10
France	2481	354
Germany	1500	296
Greece	63	9
Ireland	102	15
Italy	4178	597
Luxembourg	20	3
Netherlands	144	21
Norway	96	14
Portugal	144	21
Spain	1298	185
Sweden	1708	244
Switzerland	n/a	n/a
United Kingdom	1042	149

Source: Voogt, 2001
1 Recalculated using 7000 average annual production hours

Co-firing
For the assessment of the future capacity of co-firing biomass in coal plants the projected future capacity of coal-fired plants in different countries is considered using (IEA, 2001). These capacities are listed in Table 6.31.

Table 6.31 *Projected capacities of coal fired plants*

[GW]	Coal and Coal Products			
	2000	2001-2005	2006-2010	2011-2020
Austria	1.90	1.54	1.54	1.45
Belgium	2.08	1.21	1.21	1.01
Denmark	5.38	3.47	3.04	3.04
Finland	5.11	5.11	4.24	2.32
France	12.50	11.92	7.22	7.22
Germany	48.78	58.05	58.65	58.65
Greece	4.53	4.75	4.75	4.75
Ireland	1.26	1.76	1.76	1.76
Italy	6.68	10.30	18.90	21.00
Luxembourg	0.00	0.00	0.00	0.00
Netherlands	3.28	3.28	3.28	3.99
Norway	0.08	0.08	0.08	0.08
Portugal	1.78	1.78	1.78	1.20
Spain	11.45	11.45	11.41	9.94
Sweden	1.00	0.97	0.97	0.94
Switzerland	0.00	0.00	0.00	0.00
United Kingdom	33.43	59.41	52.58	44.81
Total	139.24	175.08	171.41	162.16

Source: IEA, 2001

The maximum energy input from biomass for the capacities in Table 6.31 is listed in the table below. This maximum input is calculated using the shares as listed in the table and for 7500 production hours per year.

Table 6.32 *Projected maximum biomass fuel input for co-firing*

[PJ]	2000	2001-2005	2006-2010	2011-2020
Co-firing share	10%	10%	15%	20%
Austria	13.5	10.9	16.4	20.6
Belgium	14.8	8.6	12.9	14.4
Denmark	38.2	24.7	32.4	43.2
Finland	36.3	36.3	45.2	33.0
France	88.8	84.7	77.0	102.6
Germany	346.6	412.5	625.1	833.4
Greece	32.2	33.8	50.6	67.5
Ireland	9.0	12.5	18.8	25.0
Italy	47.5	73.2	201.4	298.4
Luxembourg	0.0	0.0	0.0	0.0
Netherlands	23.3	23.3	35.0	56.7
Norway	0.6	0.6	0.9	1.1
Portugal	12.6	12.6	19.0	17.1
Spain	81.4	81.4	121.6	141.3
Sweden	7.1	6.9	10.3	13.4
Switzerland	0.0	0.0	0.0	0.0
United Kingdom	237.5	422.1	560.4	636.8
Total	989.3	1244.0	1826.9	2304.4

6.5.2 Biomass costs

Fuel costs

The fuel costs for wood, energy crops and agricultural residues are taken from (Vesterinen, 2001). Costs of manure as well as costs of waste are set to zero. These costs are listed in Table 6.33.

Table 6.33 *Fuel costs energy crops and agricultural residues and wood*

[€/GJ]	Energy crops and agricultural	Wood
Austria	4.0	5.0
Belgium	3.7*	6.3
Denmark	4.0	4.0
Finland	2.1	2.2
France	3.7*	4.0
Germany	3.3	3.5
Greece	3.7*	4.0
Ireland	6.4	2.5
Italy	4.1	5.0
Luxembourg	3.7*	6.3[1]
Netherlands	3.7*	2.5
Norway	3.7*	2.6[2]
Portugal	3.7*	1.7
Spain	1.8	3.0
Sweden	3.7*	3.0
Switzerland	3.7*	5.0[3]
United Kingdom	3.7	4.3

* No specific information available, averages are used instead.
1 Assumption: same as Belgium.
2 Assumption: average of Finland and Sweden.
3 Assumption: same as Austria.

Discussion about costs of waste

Future EU waste policy will tend towards less landfilled waste and more incineration of waste. Therefore, in order to be profitable, the costs of waste should be adjusted to achieve a minimal positive return on investment. Since investment costs are high for adequate incineration plants this means that the waste processing plant in most cases will get or should be paid for the waste removal, thus having negative fuel costs. This is actually already the case in several countries, such as the Netherlands and Denmark.

The premium of waste for waste incineration plants however depends on total income from electricity sales and the green value of generated electricity. If the green value increases, the premium for waste can decrease and vice versa. Since nothing can be said about future green values of renewable electricity, the waste premium will be calculated internally within the ADMIRE REBUS model to obtain a minimal positive return on investment for waste incineration.

Other costs

For energy crops the following costs for land area are used:

Table 6.34 *Agricultural land prices in 2001*

Country	Average prices in 1998 [€/ha]
Austria, France, Finland, Sweden	4000-5000
Netherlands	27500-35000 (in 2000)
Luxembourg	50000
Other EU countries	10000-15000

Source: CBS, 2001

It is assumed that future prices of agricultural land will stay around the values as listed in the Table. Annual costs for agricultural land use can be derived by annuity factors using the interest rate and a period of 30 years.

6.5.3 Technology parameters

Investment and O&M costs

The costs per technology are listed in the table below. When applicable the expected future costs are given. The investment costs as well as the O&M percentages are calculated using (averaged) data from Van Ree (2002). Information about the costs for combustion of waste is obtained from Sambeek (2003) and extrapolated towards 2020 using Van Ree (2002).

Table 6.35 *Investment and O&M costs biomass technologies*

Technolgy	Unit size	Investment [€/kW$_e$]			Annual O&M
	[MW$_e$]	2000	2010	2020	[% of investment]
Co-firing[1]	60-240	190	190	190	6
Combustion	25	1590	1510	1430	4
Waste combustion	40	7500	9000	1100	5
Gasification	1-150[2]	3400	2575	1750	5-6.5
Digestion	0.03	5000	4750	4510	6

[1] Share of co-firing 10%-40%
[2] Increase in unit size from 1 MWe in 2000 to 30-150 MWe in 2010-2015

Fuel conversion efficiencies and load factors

The energy conversion efficiencies of the different technologies for the conversion from biomass into electricity and their expected future development are shown in the table below. Load factors are also shown in this table.

Table 6.36 *Fuel efficiencies and load factors*

		2000	2010	2020+	Load factors
Co-firing	[%]	38	38	38	80
Combustion	[%]	30	30	30	70
Waste combustion	[%]	22	25	30	90
Gasification	[%]	20	28	40	63
Digestion of liquid manure	[kWh$_e$/ton]	22	22	22	

Source: Van Ree, 2002

Combined Heat & Power

Only CHP in combination with combustion of solid biomass is taken into consideration. This concerns wood waste, solid agricultural residues and chicken manure. Technology parameters and investment and O&M costs are shown in the table below; only values for 2002 are listed.

Table 6.37 *Technology parameters CHP*

Parameter	Unit	
Investment	[€/kW]	2500
O&M fix	[€/kW/a]	100
O&M var	[€/kWh_e]	0.011
Electric efficiency	[%]	23.5
Heat efficiency	[%]	47
Load factor	[%]	74 (6500 h/a)
Technical lifetime	[a]	20

Source: Van Dril, 1999

In Table 6.38 the assessment structure for electricity production from CHP plants is shown.

Table 6.38 *Assessment structure for CHP*

Level	Name/unit	Factor
8	Fuel input [GJ]	
		× heat efficiency
7	GJ thermal output [GJ_{th}]	
		× electric efficiency/heat efficiency
6	GJ output [GJ_e]	
		× 1/3600
5	Production [GWh]	
		× reciprocal LF [=1/LF]
4	Production [GWh] with load factor = 1	
		× reciprocal yearly hours [=1/8760]
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

Heat value for CHP

In Table 6.39 current and expected future values for heat production from CHP are given. These are derived using the current and expected future gas prices, with an efficiency of 85% from a reference technology (gas fired boiler).

Table 6.39 *Heat values for CHP*

[€/GJ]	2001	2005	2010
Austria	7.47	8.29	8.29
Belgium	5.42	5.49	5.49
Denmark	6.41	5.87	5.87
Finland	6.00	6.05	6.05
France	6.11	5.82	6.18
Germany	7.48	9.50	8.40
Greece	11.70	13.32	13.32
Ireland	5.64	6.46	6.46
Italy	7.64	7.27	6.54
Luxembourg	8.67	8.73	8.73
Netherlands	6.75	5.98	5.98
Norway	5.38	5.61	5.85
Portugal	9.23	8.47	8.47
Spain	5.96	5.20	5.20
Sweden	10.16	9.28	9.28
United Kingdom	6.56	5.29	6.02

Source: Oostvoorn, 2003

6.6 References

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7. HYDRO

7.1 Introduction

In this chapter the data used in the ADMIRE REBUS project is presented. The chapter does not include any ECN data ranges comparable to the ranges for wind, solar PV and biomass.

In this chapter only *non-pumped-storage* hydro plants are regarded as a renewable electricity source. The distinction between small and large hydro is defined here at 10 MW plant size.

Literature research has revealed large differences between realisations according to EIA/DOE, Eurostat, IEA, the *World Atlas and Industry Guide of the International Journal on Hydropower and Dams* and the UDI World Electric Power Plants database for example. It is often not clear whether pumped storage is included or not, nor if net production from pumped storage is included in the total hydro electricity production. Another problem is the definition of small hydro: it is often not clear what upper limit plant size is meant when small hydro is mentioned. And if this limit is mentioned explicitly it ranges from 1 to 15 MW across several reports and statistical databases. This makes a consistent intercomparison of literature sources a very laborious and sometimes impossible task.

In this report mainly information from the BlueAge report of the European Small Hydro Association, ESHA (ESHA, 2000) is used for the assessment of small hydro potential. For large hydro mainly information is used from the World Atlas and Industry Guide 2002 of the International Journal on Hydro & Dams (World Hydro Atlas, 2002).

Note, that recently a publication on hydropower developments has become available (Lako, 2003). In this report, additional information can be found, and more detailed information is available.

7.2 Small hydro

7.2.1 Potential of small hydro

Small hydro is defined as hydroelectric plants, with a total power of less than 10 MW per plant. The BlueAge report of the ESHA (ESHA, 2000) is used as input for the assessment of the total potential of small hydro. The band shares of low investments-high investments are taken from Voogt (2001). The load factors are taken from Eurostat statistics (Eurostat, 1999) and represent the average of the period 1995-1999.

Table 7.1 *Existing capacities and additional potentials of small hydro by band*

[MW]	Load factor Avg. '95-'99	Total potential	Existing capacities[2]	Low investment Band 1	Medium investment Band 2	High investment Band 3
Austria	56.8%	1942	837	252	609	244
Belgium	35.1%	126	60	24	24	18
Denmark	28.0%	11	11	0	0	0
Finland	40.9%	452	304	123	25	0
France	42.4%	3277	2016	1184	48	29
Germany	56.2%	1952	1402	0	275	275
Greece	35.9%	150	49	0	58	43
Ireland	30.4%	73	34	0	25	19
Italy	43.3%	2849	2201	254	227	168
Luxembourg	29.7%	39	39	0	0	0
Netherlands	39.6%[1]	19	2	17	0	0
Norway	50.0%	1851	889	962	0	0
Portugal	26.9%	770	257	0	292	221
Spain	37.0%	2648	1530	68	449	601
Sweden	46.6%	1500	943	0	121	436
United Kingdom	35.0%	250	177	0	0	73

1 Based on EU average.
2 Eurostat 1999 statistics.

7.2.2 Costs of small hydro

Costs are based on recalculation from Voogt (2001) and represent the total investment costs. It must be noted that these costs represent the costs of *new* hydro plants. Since most economically favourable sites are already developed, investment costs for these new sites will be higher than existing hydro plants.

Table 7.2 *Investment costs for new small hydro plants per band*

[€/kW]	Band 1	Band 2	Band 3
Austria	2311	3366	5627
Belgium	1904	3224	6050
Denmark	2311	3366	5627
Finland	2311	3366	5627
France	1904	3224	6050
Germany	2311	3366	5627
Greece	1409	2233	3998
Ireland	2311	3366	5627
Italy	1904	3224	6050
Luxembourg	2311	3366	5627
Netherlands	2311	3366	5627
Norway	2311	3366	5627
Portugal	1409	2233	3998
Spain	1409	2233	3998
Sweden	2311	3366	5627
United Kingdom	2311	3366	5627

Source: Voogt, 2001

O&M costs are recalculated using Voogt (2001) and are given in Table 7.3.

Table 7.3 *Annual O&M costs for new small plants as percentage of the investment*

[%]	1	2	3
Austria	6.3	6.4	5.3
Belgium	4.7	4.1	3.1
Denmark	3.1	3.1	2.6
Finland	4.6	4.6	3.8
France	5.6	4.9	3.7
Germany	6.3	6.3	5.3
Greece	6.3	5.9	4.6
Ireland	3.4	3.4	2.9
Italy	5.7	5.0	3.8
Luxembourg	3.3	3.3	2.8
Netherlands	4.4	4.4	3.7
Norway	5.6	5.6	4.7
Portugal	4.7	4.4	3.4
Spain	6.5	6.0	4.7
Sweden	5.2	5.2	4.4
UK	3.9	3.9	3.3

Source: Voogt, 2001

Costs for existing plants are calculated using Chapter 8 (economic analysis) of the Layman's handbook (Penche, 1998). The costs of specific plants in Germany, France, Ireland, Portugal and Spain are given. For the other countries the average costs are calculated.

Table 7.4 *Costs of existing small hydro*

	Investment cost [€/kW]	O&M[1] [%]	O&M [€/kW/a]	Investment cost [€/kW]	O&M [€/kW/a]
Austria				1640	63
Belgium				1640	63
Denmark				1640	63
Finland				1640	63
France	683	4.01	27		
Germany	4424	4.08	180		
Greece				1640	63
Ireland	1259	4.65	59		
Italy				1640	63
Luxembourg				1640	63
Netherlands				1640	63
Norway				1640	63
Portugal	704	2.00	14		
Spain	1132	3.00	34		
Sweden				1640	63
United Kingdom				1640	63
Average	1640	3.55	63		

[1] Annual O&M as percentage of total investment.

7.3 Large hydro

7.3.1 Potential of large hydro

Large hydro is defined as hydroelectric plants with a total power of more than 10 MW per plant. The assessment of potentials for large hydro is based on the World Atlas and Industry Guide 2002 of the International Journal on Hydro & Dams (World Hydro Atlas, 2002). In this Atlas the total hydro power potential is mentioned (pumped up storage is not regarded in this report). The potential for large hydro is calculated by subtracting the small hydro potential from ESHA BlueAge (ESHA, 2000). The results are evaluated for possibilities of future development per country using the Country Notes in the World Hydro Atlas 2002.

The band shares of low investments-high investments are taken from Voogt (2001). The load factors are taken from Eurostat statistics (Eurostat, 1999) and represent the average of the period 1995-1999.

Table 7.5 *Existing capacities and additional potentials of large hydro by band*

[MW]	Load factors Avg. '95-'99 [%]	Total potential	Existing capacities[1]	Low investment Band 1	Medium investment Band 2	High investment Band 3
Austria	36.1	10,959	10,835	0	0	124
Belgium	37.5	43	43	0	0	0
Denmark	n/a	0	0	0	0	0
Finland	53.5	3,217	2,577	640	0	0
France	34.9	22,916	22,916	0	0	0
Germany	69.2	1,980	1,980	0	0	0
Greece	16.1	3,523	3,052	0	0	471
Ireland	41.3	199	199	0	0	0
Italy	27.1	17,468	14,370	494	0	2,604
Luxembourg	n/a	0	0	0	0	0
Netherlands	29.5	35	35	0	0	0
Norway	47.2	28,696	26,652	0	872	1,172
Portugal	34.7	4,244	3,507	0	172	565
Spain	24.0	11,341	11,193	0	0	148
Sweden	46.5	15,489	15,489	0	0	0
United Kingdom	36.0	1,392	1,299	0	0	93

[1] Eurostat 1999 statistics.

7.3.2 Costs of large hydro

Costs are again based on recalculation from Voogt (2001) and represent the total investment costs. It must be noted that these costs represent the costs of *new* hydro plants. Since most economically favourable sites are already developed, investment costs for these new sites will be higher than existing hydro plants.

Table 7.6 *Investment costs for new large hydro plants per band*

[€/kW]	Band 1	Band 2	Band 3
Austria	2587	4171	7337
Belgium	2338	4316	8271
Denmark	2587	4171	7337
Finland	2587	4171	7337
France	2338	4316	8271
Germany	2587	4171	7337
Greece	1663	2901	5377
Ireland	2587	4171	7337
Italy	2338	4316	8271
Luxembourg	2587	4171	7337
Netherlands	2587	4171	7337
Norway	2587	4171	7337
Portugal	1663	2901	5377
Spain	1663	2901	5377
Sweden	2587	4171	7337
UK	2587	4171	7337

Source: Voogt, 2001

O&M costs are recalculated using Voogt (2001) and are given in Table 7.7.

Table 7.7 *Annual O&M costs for new plants as percentage of the investment*

[%]	Band 1	Band 2	Band 3
Austria	2.9	2.4	2.0
Belgium	3.3	2.4	1.9
Denmark	n/a	n/a	n/a
Finland	4.3	3.5	3.0
France	3.1	2.2	1.8
Germany	5.6	4.6	3.8
Greece	1.9	1.4	1.1
Ireland	3.3	2.7	2.3
Italy	2.4	1.7	1.4
Luxembourg	n/a	n/a	n/a
Netherlands	2.4	1.9	1.6
Norway	3.8	3.1	2.6
Portugal	4.1	3.1	2.5
Spain	2.9	2.1	1.7
Sweden	3.8	3.1	2.6
UK	2.9	2.4	2.0

No information on investment and O&M costs of existing large hydro plants is available yet.

Table 7.8 *Assessment structure for small and large hydro*

Level	Name/unit	Factor
3	Power [MW]	
		× 8.760 [yearly hours/1000]
2	Production [GWh] with load factor = 1	
		× LF
1	Production [GWh]	

7.4 References

ESHA (2000): *BlueAge, Strategic study for the development of Small Hydro Power in the European Union*. European Small Hydropower Association ESHA, 2000.

World Hydro Atlas (2002): *World Atlas and Industry Guide 2002.* The International Journal on Hydropower and Dams, 2002.

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DOE/EIA: Department of Energy, *Energy Information Administration*, http://www.eia.doe.gov.

Penche, C. (1998): *Layman's handbook on how to develop a small hydro site.* Prepared under contract for the European Commission, DG Energy, by the European Small Hydro Association (ESHA), Second Edition, June 1998.

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8. GEOTHERMAL ELECTRICITY

8.1 Introduction

In this chapter the data used in the ADMIRE REBUS project is presented. The chapter does not include any ECN data ranges comparable to the ranges for wind, solar PV and biomass.

There are two ways of producing energy from geothermal plants: direct use (thermal energy) and electricity. In many countries there is a considerable potential for direct use of the geothermal resource (low temperatures), especially in countries with volcanic activity, but in this section only geothermal electricity production will be regarded. This will be done on a country-by-country basis: countries having no potential for geothermal electricity generation according to the available literature and references will be omitted.

Ferrara Declaration

On April 29-30, 1999, the European Geothermal Energy Council (EGEC) invited the geothermal business community from all European countries to a seminar in Ferrara in Italy, a city with a thriving geothermal heating system embedded in rich cultural heritage. The goal of the meeting was to discuss the current situation of geothermal energy in R&D, implementation and market deployment, to hear about examples of successful applications, to define the future market possibilities and to set targets for a geothermal energy future. These targets are shown in Table 8.1.

Table 8.1 *Geothermal electricity targets according to the Ferrara Declaration*

	1998	2010	2020
Power [MW_e]	940	2000	3000[1]/8000[2]
Electricity generation [GWh_e/y]	4300	16000	24000[1]/64000[2]

1 Without support.
2 Ecologically driven.

8.1.1 Potential

Austria

There is 1 MW_e brought into operation in January 2001 (WEC, 2001) with an expected annual output of 3.8 GWh. It is not clear whether this output is electricity only.

France

There are only low-enthalpy geothermal resources in metropolitan France, thus not suitable for power plants (WEC, 2001). On the overseas department Guadelope was 4.2 MW_e installed in 2000 (IGA, 2002). Annual production is around 24 GWh_e (Geothermie I, 2002), resulting in a load factor of 65%.

Objective of ADEME (French Agency for Environment and Energy Management) is to increase the capacity on Guadeloupe to 20 MW_e (WEC, 2001). Development of the geothermal electricity potential is also expected in the overseas departments of Martinique and La Réunion (Laplaige et al., 2000), studies will be conducted in the next years.

Greece
Currently there is no electricity generation from geothermal power plants in Greece. However, there are two high temperature fields being explored and drilled on Milos and Nysiros Islands. As a result of these explorations it is expected that the potential at least on Milos is around 200 MW_e (Geothermie II, 2002). For 2005 a capacity of 2-3 MW_e is expected, producing 0-2 Gwh_e/a (Fytikas et al., 2000).

Between 1986 and 1988 actually a small 2 MW_e plant was operational on Milos, but due to strong opposition from local inhabitants the electricity production has been stopped.

Italy
In Italy there is around 785 MW_e installed capacity in 1999/2000 (IGA, 2002) at four fields with total capacities ranging from 40 MW_e to 547 MW_e. The total annual production has reached 4403 GWh_e in 1999, this means a load factor of 64%. According to WEC (2001) the same electricity production was reached by 621 MW_e, thus meaning a load factor of 81%.

It is planned to bring an additional 390 MW_e into operation in the period to 2005, of which 245 MW_e will replace units to be decommissioned (229 MW_e) and 145 MW_e will be related to new field development (WEC, 2001). Thus total increase to be expected until 2005 is 161 MW_e, resulting in 946 MW_e installed.

Table 8.2 *Development of power capacity and production since 1985*

Year	Capacity [MW_e]	Production [GWh_e]	Load factor [%]
1985	459	2840	71
1989	545	3150	66
1995	682	n/a	--
1996	742	3762	58

Source: Geothermie, 2002

The total resource is estimated at 970 MW_e according to Geothermie II (2002).

Portugal
Currently 16 MW_e installed power on the Azores at two areas having 11 MW_e and 5 MW_e, an extra potential of 235 MW on 12 areas have been identified (IGA, 2002). The limited geothermal resources on the mainland of Portugal have been developed for direct use.
In 1997 Portugal produced 46 GWh_e electricity with 8 MW_e power installed, resulting in a load factor of 66% (Geothermie I, 2002).

8.1.2 Costs

Production costs in the USA are in the range of \$0.015 tot \$0.035 per kWh_e, for new power plants this is probably about \$0.05/kWh_e (DOE, 2002).

Investment
According to (DOE, 2002) in the USA the initial investment costs for the geothermal field and power plant is around \$2000/kW_e, ranging from \$3000-\$5000 per kW_e for a small plant (<1 MW_e) and \$1500-\$2500 per kW_e for larger plants, depending on the resource temperature and chemistry.

O&M
Operation and Maintenance costs in the USA range from \$0.015 tot \$0.045 per kWh_e (DOE, 2002).

8.1.3 Load factor

Most geothermal plants in the USA can run at greater than 90% availability, producing more than 90% of the time (DOE, 2002). According to the Ferrara Declaration an increase of the average load factor from 52% in 1998 to 91% (8000 h/a) in 2020 can be expected in Europe.

A summary of Section 8.1.3 concerning load factors is given below.

- France 65%
- Italy 58%-81%
- Portugal 66%

It will be assumed that load factors for all countries having potential for geothermal electricity production will increase to 90% towards 2030.

8.2 References

DOE (2002) http://www.eren.doe.gov/goethermal/geofaq.html, November 2002.

Fytikas, et al. (2000): *Geothermal exploration and development activities in Greece during 1995-1999*, proceedings World Geothermal Congres, May-June 2000, Japan.

Geothermie I (2002): http://www.geothermie.de/egec-geothernet/geothermal_resources.htm, November 2002.

Geothermie II (2002): http://www.geothermie.de/egec-geothernet/ci _europe/<country>/basic_informations_2000_<country>.htm, November 2002.

International Geothermal Association (2002): http://iga.igg.cnr.it/electricitygerneration.php, November 2002.

Laplaige, et al. (2000): *The French geothermal experience; Review and Perspectives*, proceedings World Geothermal Congres, May-June 2000, Japan.

WEC (2002): World Energy Council, Survey of Energy Resources 2001.

APPENDIX A BAND DEFINITIONS

Rebus definition[1]	ADMIRE REBUS definition	Band definition
Small hydro band 1	Small hydro band 1	Existing capacities
Small hydro band 1	Small hydro band 2	Low investments
Small hydro band 2	Small hydro band 3	Medium investments
Small hydro band 3	Small hydro band 4	High investments
Large hydro band 1	Large hydro band 1	Existing capacities
Large hydro band 1	Large hydro band 2	Low investments
Large hydro band 2	Large hydro band 3	Medium investments
Large hydro band 3	Large hydro band 4	High investments
Wind onshore band 1	Wind onshore band 1	> 7 m/s
Wind onshore band 2	Wind onshore band 2	6-7 m/s
Wind onshore band 3	Wind onshore band 3	5-6 m/s
Wind onshore band 4	Wind onshore band 4	< 5 m/s
Wind offshore band 1	Wind offshore band 1	> 9 m/s
Wind offshore band 2	Wind offshore band 2	8-9 m/s
Wind offshore band 3	Wind offshore band 3	7-8 m/s
Wind offshore band 4	Wind offshore band 4	< 7 m/s
Wind offshore band 1	Wind offshore band 5	> 9 m/s[2]
Photovoltaics band 1[3]	Photovoltaics band 1	> 1800 kWh/m^2/y
Photovoltaics band 2[3]	Photovoltaics band 2	1600-1800 kWh/m^2/y
Photovoltaics band 3[3]	Photovoltaics band 3	1400-1600 kWh/m^2/y
	Photovoltaics band 4	1200-1400 kWh/m^2/y
	Photovoltaics band 5	1000-1200 kWh/m^2/y
	Photovoltaics band 5	< 1000 kWh/m^2/y
PS solid fuels band 1	Biomass co-firing band 2	Forestry
	Biomass gas co-firing band 2	Forestry
	Biomass combustion band 2	Forestry
	Biomass gasification band 2	Forestry
PS solid fuels band 2	Biomass co-firing band 1	Energy crops
	Biomass gas co-firing band 1	Energy crops
	Biomass combustion band 1	Energy crops
	Biomass gasification band 1	Energy crops

Rebus definition[1]	ADMIRE REBUS definition	Band definition
PS solid wastes band 1	Biomass co-firing band 6	Barley
	Biomass gas co-firing band 6	Barley
	Biomass combustion band 6	Barley
	Biomass gasification band 6	Barley
	Biomass co-firing band 7	Maize
	Biomass gas co-firing band 7	Maize
	Biomass combustion band 7	Maize
	Biomass gasification band 7	Maize
	Biomass co-firing band 8	Oilcrops
	Biomass gas co-firing band 8	Oilcrops
	Biomass combustion band 8	Oilcrops
	Biomass gasification band 8	Oilcrops
	Biomass co-firing band 10	Rapeseed
	Biomass gas co-firing band 10	Rapeseed
	Biomass combustion band 10	Rapeseed
	Biomass gasification band 10	Rapeseed
	Biomass co-firing band 12	Wheat
	Biomass gas co-firing band 12	Wheat
	Biomass combustion band 12	Wheat
	Biomass gasification band 12	Wheat
Farm slurries	Biomass digestion band 4	Liquid manure
Municipal Solid Waste	Biomass combustion band 5	MSW
	Biomass gasification band 5	MSW
Landfill gas	Biomass digestion band 13	Landfill
Sewage Sludge	Biomass digestion band 14	Sewage Sludge
Industrial waste	Biomass combustion band 15	Industrial waste
Geothermal electricity band 1	Geothermal electricity band 1	Low investments
Geothermal electricity band 2	Geothermal electricity band 2	Medium investments
Geothermal electricity band 3	Geothermal electricity band 3	High investments

1 Voogt, M., et al., *Renewable energy burden sharing REBUS*, Report for the European Commission, DG Research, ECN-C--01-030, May 2001.
2 40 m water depth, 50 km offshore; for selected North Sea countries.
3 Different band definition.

APPENDIX B COUNTRY INFORMATION

Table B.1 *Projected development of population per country*

[Thousands]	1995	2000	2005	2010	2015	2020	2025	2030
Austria	8,047	8,080	8,042	7,953	7,848	7,735	7,605	7,442
Belgium	10,137	10,249	10,297	10,296	10,272	10,244	10,205	10,143
Denmark	5,228	5,320	5,362	5,374	5,372	5,365	5,359	5,343
Finland	5,108	5,172	5,189	5,187	5,180	5,165	5,138	5,084
France	58,139	59,238	60,303	61,203	61,892	62,412	62,753	62,935
Germany	81,661	82,017	81,860	81,353	80,673	79,864	78,897	77,678
Greece	10,454	10,610	10,631	10,579	10,472	10,325	10,149	9,955
Ireland	3,609	3,803	3,990	4,201	4,410	4,594	4,745	4,877
Italy	57,301	57,530	57,165	56,390	55,239	53,861	52,364	50,776
Luxembourg	410	437	464	490	518	546	576	605
Netherlands	15,459	15,864	16,142	16,313	16,420	16,507	16,571	16,572
Norway	4,359	4,469	4,552	4,614	4,670	4,733	4,800	4,857
Portugal	9,916	10,016	10,080	10,082	10,030	9,940	9,831	9,716
Spain	39,737	39,910	39,874	39,569	39,018	38,272	37,395	36,428
Sweden	8,827	8,842	8,785	8,703	8,625	8,571	8,518	8,426
Switzerland	7,118	7,170	7,148	7,073	6,972	6,860	6,729	6,563
United Kingdom	58,821	59,634	60,164	60,487	60,792	61,171	61,466	61,518

Source: FAO Statistical Databases: *http://apps.fao.org/default.htm* April 2002.

Table B.2 *Land area per country in 1999*

[km²]	Total land area	Agricultural area	Other area (Non Arable & Non Permanent)
Austria	82,730	34,190	67,940
Belgium	30,230	13,604	22,673
Denmark	42,430	26,440	19,410
Finland	304,590	22,720	282,820
France	550,100	299,000	354,950
Germany	356,680	170,130	236,300
Greece	128,900	90,200	90,200
Ireland	68,890	44,180	58,100
Italy	294,110	162,680	179,890
Luxembourg	2,590	1,166	1,943
Netherlands	33,880	19,670	24,390
Norway	306,830	10,270	298,060
Portugal	91,500	41,420	64,450
Spain	499,440	299,800	314,140
Sweden	411,620	32,350	384150
Switzerland	39,550	15,800	35,160
United Kingdom	240,880	172,190	181,200

Source: FAO Statistical Databases: *http://apps.fao.org/default.htm* April 2002.

APPENDIX C EUROSTAT DIVISION OF RENEWABLE ENERGY SOURCES

Below is a table containing the new Eurostat devision for renewable energy statistics. Productions are expressed in GWh.

107001	Gross hydro-electrical production
107002	Gross production from geothermal electric energy
107005	Gross production from wind energy
107011	Gross production from conventional thermal energy, biomass
107015	Gross electricity generation from hydropower plants (Installed capacity < 1 MW)
107016	Gross electricity generation from hydro power plants (Installed capacity >= 1 MW and <= 10 MW)
107017	Gross electricity generation from hydro power plants (Installed capacity > 10 MW)
107023	Gross electricity generation from photovoltaics
107024	Gross electricity generation from solar thermal
107025	Gross electricity generation from municipal solid wastes
107026	Gross electricity generation from wood/wood wastes
107027	Gross electricity generation from biogas
107028	Gross electricity generation from industrial wastes
107100	Total net production
107101	Net production from hydroelectric energy
107102	Net production from geothermal electrical energy
107105	Net production from wind energy
107111	Net production from convential thermal energy, biomass
107301	Gross production by pumped storage hydroelectric energy
107302	Energy absorbed by storage pumping

The sum of the data from 107025 & 107026 & 107027 equals the data in 107011.

The sum of 107125 & 107126 & 107127 should equal 107111, but these three tables are not available at Eurostat.

Hydro pumped storage is not included in the tables 107015 & 107016 & 107017, but it is actually in the other hydro tables.