Resources and future availability of energy sources

A quick scan

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Acknowledgement/Preface

This report gives a quick scan and analysis of data and literature on the resources and (currently perceived) availability of energy sources, notably of the fossil fuels oil, gas and coal, the fissile energy sources uranium and thorium (a source of fissile uranium), and the renewable energy sources wind power (onshore and offshore), solar energy (photovoltaic, PV), and biomass.

This report is one of the outcomes of the ECN internal project ‘Optimal end visions for a sustainable society’ targeted on the effect of the possible constraints with regard of fossil energy sources and uranium as well as the (perceived) limitations of renewable energy sources on the possibilities for a transition towards a more sustainable energy system. The results of this quick scan, described in this report, will be used to estimate the consequences of limited availability of energy sources in a number of transition paths (forthcoming). The project is registered at ECN under project number 77629.

Abstract

This assessment is a quick scan and analysis of recent literature on the resources and availability of fossil, renewable, and fissile energy sources. The fossil energy sources are oil, gas, and coal; the renewables covered are wind, solar, and biomass; and the fissile energy sources are uranium and thorium. The results of the scan and analysis of literature data are described, and preliminary conclusions are drawn.

A peak in oil production may be deferred to, e.g., 2035, if the next conditions would be fulfilled:

- Global oil demand does not increase significantly.
- Resources of conventional oil (e.g. Middle East) prove to be relatively large.
- Unconventional oil resources turn out to be large and producible in sizeable quantities.

The oil price hinges on the balance between oil demand and supply. The oil market will tighten when ‘Peak Oil’ approaches. If this happens in the near future, the oil price could remain high. Gas production scenarios show that a peak may occur between 2020 and 2050. The peak may be deferred by a slowly increasing demand during the next decades, and by successful exploration and production of conventional gas. Unconventional gas *resources* are huge, but it is uncertain to which extent they would be producible.

Coal *reserves* are rather evenly spread around the globe, and a peak in coal production in the next 50 years is not envisioned. Also a peak in production of uranium and thorium is not envisioned in the first half of the 21st century. Current use will not lead to a quick depletion.

Renewable energy sources are by definition infinite, although their potential is bounded by geographical constraints. The global and regional availability has been estimated for wind energy, solar energy (PV), and biomass, together with a description of factors influencing this availability. Specific analyses show that in 2035, onshore wind, offshore wind, and PV could produce approximately 7, 18, and 6%, respectively, of total power generation in the EU-15. The use of biomass - energy crops, agricultural and forestry residues, and organic waste - in the EU-15 may possibly increase from 2.1 to 7 EJ/a in the period 2000-2050. Approximately one-third of this potential could be made available by energy crops. On the long term, countries with surplus biomass potential could develop into exporters of bioenergy (biofuels from biomass).

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Summary

This assessment is a quick scan of recent literature on the resources and availability of fossil, renewable, and fissile energy sources. The fossil energy sources are oil, gas, and coal; the renewables covered are wind, solar, and biomass; and the fissile energy sources are uranium and thorium. Generally, the period until 2050 (or 2035, if applicable) has been analysed. In this study, the results of the analysis of literature data are described, and preliminary conclusions are drawn.

The results with regard to availability of fossil fuels and fissile energy sources are described in terms of reserves and resources, and geographical distribution. Geographical distribution of reserves and resources is important. If resources are found in only a few world regions, limited access to those regions may adversely influence the security of supply.

The results with regard to availability of the 'renewables' wind, solar, and biomass are far more conditional. These energy sources are bounded by geographical constraints, e.g., wind and solar energy, as (long-distance) transport of electricity based on wind or solar energy is very costly.

Fossil energy sources, uranium, and thorium

Fossil energy sources - oil, gas, coal - and sources of fissile energy - uranium and thorium (a source of fissile uranium) - have in common that they are exhaustible. They are generally categorised in terms of *proved reserves* and *resources*. The definition of *proved* oil *reserves* is: 'The estimated quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing and economic operating conditions'. The term '*resources*' refers to reserves - probable, possible - with a lower probability of occurrence. A relatively simple categorisation of the *reserves* and *resources* of fossil fuels and fissile energy carriers is the following (see Table S.1):

- *Reserves* and *resources* of (conventional) oil and gas, coal, and uranium and thorium.
- *Reserves* and *resources* of unconventional oil, gas, and uranium.

The Middle East is the dominant oil province, covering 63% of the conventional oil *reserves*. Conventional oil is equivalent to approximately 60 years of current production - 40 years for the *reserves*, 22 years for the *resources*. Adding unconventional oil *reserves* results in a Reserves/Production (R/P) ratio of 80 years. Unless unconventional oil *resources* would be producible in the 21st century, oil production will decline sooner or later.

The *reserves* and *resources* of conventional gas are comparable in size to those of conventional oil, but the global gas consumption is lower than that of oil. The gas reserves are not evenly distributed around the globe: 41% are in the Middle East, and 27% in Russia. Conventional gas *reserves* and *resources* are equal to approximately 120 years of current production. Including the unconventional gas *reserves* does not significantly change this figure. The unconventional gas *resources* are huge, but it is uncertain to which extent they would be producible.

Coal *reserves* are rather evenly spread around the globe: 25% are in the USA, 16% in Russia, and 11.5% in China. The R/P ratio - approximately 185 or 260 years depending on the literature source used - far outstrips R/P ratios for oil and gas. Coal *resources* are deemed to be several times larger than the *reserves*, but some of them may be low-grade and/or hardly mineable.

The Reasonably Assured Reserves (RAR) and Estimated Additional Reserves (EAR) of uranium - together the 'known conventional resources' - represent 4.59 MtU. If the resources yet undiscovered but believed to exist based on geologic evidence are added, the resource base may be even 14.39 MtU.

This is equivalent to 210 years of current uranium demand, and inclusion of reserves and resources of thorium increases this figure to approximately 280 years. Probably, reserves and resources of thorium are underestimated.

Table S.1 summarises the results of the quick scan for fossil and fissile energy sources.

Table S.1 *A quick scan of fossil and fissile energy reserves and resources*

Energy source	Conventional Reserves & Resources					Unconventional divided by Conventional	
	Reserves (R) [EJ]	Resources (RR) [EJ]	R/P ratio (R/P) [Years]	RR/P ratio (RR/P) [Years]	Main regions[a]	Reserves ratio (UR/R)	Resources ratio (URR/RR)
Oil	6,351	3,525	40	22	Middle East, FSU	0.43	2.97
Gas	5,105	6,879	52	69	FSU, Middle East	0.01	4.77
Coal	19,620	116,108	185	1,100	USA, FSU, China	-	-
Uranium & Thorium[b]	2,745	4,915	100[c]	180[c]	Oceania, North America	-	134

a) The Former Soviet Union (FSU) is a main producer of oil, gas, and coal. Reserves and resources of uranium are rather evenly spread, with main producing centres in Oceania (Australia) and North America (Canada).
b) Reserves of uranium and thorium are reported in EJ of thermal energy (conversion ratio of 0.4 PJ/tU). Unconventional uranium resources refer to uranium extracted from seawater (long term, speculative).
c) The reserves and resources of U and Th are divided by the uranium demand for civil reactors (68,435 tU).

A possible peak in production of finite energy sources

The production of oil, natural gas, coal, and uranium and thorium may show a peak in the near or distant future, depending on the extent to which probable and possible reserves get converted into proved reserves over time and depending on the depletion. Two energy sources may peak in the first half of the 21st century, viz. oil and conventional gas. Scenario analysis shows that a peak in global oil production (the so-called ‘Peak Oil’) may occur in the next few decades. ‘Peak Oil’ may be deferred to, e.g., 2035 (Figure S.1), if the following conditions are fulfilled:

- Global oil demand does not increase significantly.
- Resources of conventional oil (e.g. Middle East) prove to be relatively large.
- Unconventional oil resources turn out to be large and producible in sizeable quantities.

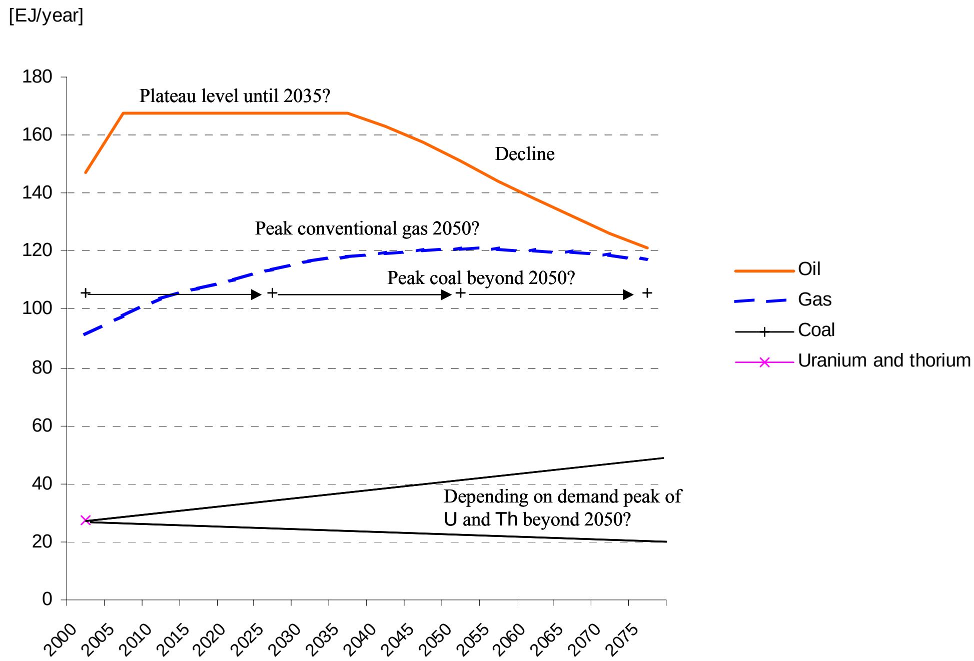

Figure S.1 *Possible peak in production of finite energy sources*
Note: The lines for uranium and thorium are meant to illustrate scenarios of continued growth or decline.

Figure S.1 shows the possible occurrence of a peak in production of finite energy sources. The oil price hinges on the balance between oil demand and supply. The oil market will tighten when 'Peak Oil' approaches. If this happens in the near future, the oil price could remain high.

Gas production scenarios show that a peak may occur between 2020 and 2050. The peak may be deferred by a slowly increasing demand during the next decades, and by successful exploration and production of conventional gas. In the period until 2050, a substantial production of unconventional gas is more difficult to imagine than a sizable production of unconventional oil, as production of unconventional oil (extra-heavy oil, tar sands) is already significant today.

Although coal is globally much more abundant than oil and gas, coalfields can be depleted on a regional scale. However, coal, uranium and thorium have relatively high R/P ratios (for uranium the demand is used as the reference instead of production). The reserves of uranium in the categories RAR and EAR would be sufficient until 2040-2050. A peak in production for coal or uranium/thorium is not envisioned in the first half of the 21st century.

Wind and solar power

Renewable energy sources are by definition infinite, although their potential is bounded by geographical constraints. The global and regional availability has been estimated for wind energy, photovoltaic energy (PV), and biomass, together with a description of factors influencing this availability. For onshore wind, two types of potentials may be regarded, viz.:

- The *realistic* potential then takes into account considerations of spatial planning, environmental impacts (e.g. bird casualties), public acceptance, etc, but not costs.
- The *realisable* potential also takes into account the extent to which a technology is constrained by lead times, maximum deployment, growth rates, etc

The *realisable* potential is really important, but it is necessary to make some expert judgement with regard to the chance that wind turbines would be built in regions with really low average wind speeds, especially in developed world regions such as the European Union (EU-15).

Literature studies with regard to the potential of offshore wind show that its *realisable* potential in Europe (EU-15) is larger than the *realisable* potential of onshore wind, including a correction for areas of sub-marginal wind speeds. All in all, it is quite possible that the onshore wind capacity in the EU-15 will increase to some 132.5 GW in 2035 - 5.6 times the capacity in 2003 - and that simultaneously offshore wind will increase to 250 GW - 900 times the installed capacity in 2003. These estimates factor in that the development of offshore wind may be faster than onshore wind, as there are less conflicting functions on sea than on land. Some expect offshore wind to reach 250 GW in 2020, but this could put serious strains on planning and logistics. Also, transmission of electricity may be a constraint, e.g. in countries like the UK and Germany: studies show that offshore wind electricity would have to be transported over relatively large distances.

Assessments of photovoltaic energy (PV) show that the available area of roofs and façades on buildings in the EU-15 could be of the order of magnitude of 7,000 to 8,000 km^2. One literature source takes into account the future need for solar thermal systems for hot water, space heating, etc. This would entail a reservation of 3 m^2/capita. If the highest area potential (8,000 km^2) is corrected for this potential demand, the remaining area - approximately 85% - would be equivalent to 710 GW of PV, based on a power density of 100 Wp/m^2 (a figure representative of current technology). Such a potential may be considered as a *realistic* potential. Not all of the *realistic* potential may be developed over time. A prerequisite appears to be a substantial reduction of the price of PV systems. Also, regions with a relatively modest yield - the 'flux' on a horizontal surface varies from e.g. 200 W/m^2 in Australia to 105 W/m^2 in the UK - will have more difficulty in developing their potential than e.g. Greece, Italy, and Spain. Also, today the PV capacity in the EU-15 is a tiny 562 MW (2003).

Taking into realistic growth rates, it is deemed possible that the installed capacity in the EU-15 would be some 262.5 GW in 2035, approximately 470 times the installed capacity in 2003. Another indicator is the roof or façade area based on 100 W/m^2, viz. 2,625 km^2 (7 m^2/capita).

Figure S.2 shows the possible development of onshore and offshore wind and photovoltaic energy in the EU-15, based on specific analyses for these energy sources.

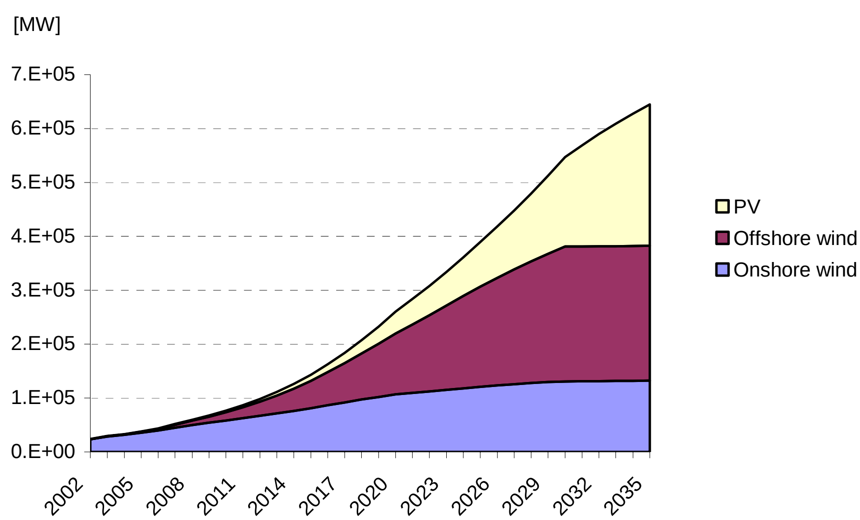

Figure S.2 *Possible development of onshore and offshore wind and PV in the EU-15*

The corresponding electricity generation based on these renewables compared to the projected electricity demand of the EU-15 is shown in Figure S.3. In the legenda of Figure S.3, mention is made of the renewables onshore wind, offshore wind, and PV. The balance of the generation mix is denoted by 'Coal, gas, nuclear, hydro'. For the year 2035, the shares of wind and PV in total power generation could be as follows:

- Onshore wind 7%
- Offshore wind 18%
- PV 6%

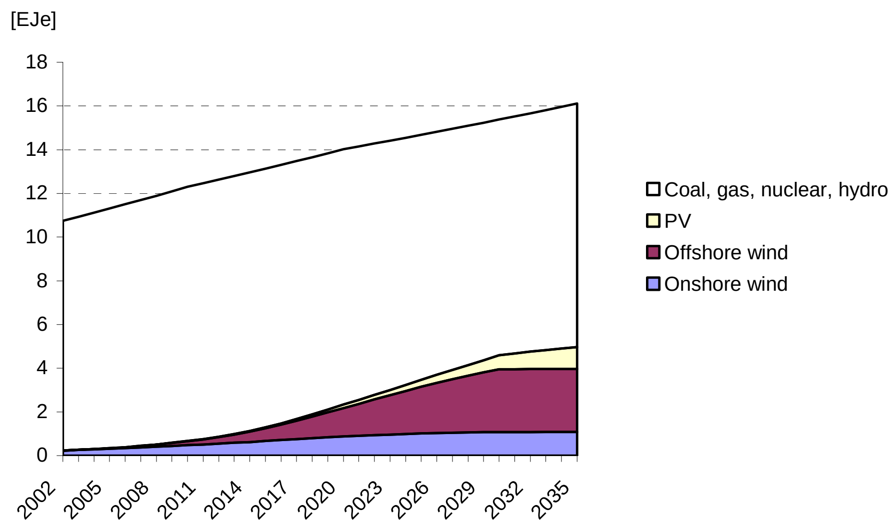

Figure S.3 *Electricity generation by wind and PV as a fraction of total EU-15 generation*

Thus, onshore and offshore wind and PV could supply 30% of the electricity (EU-15) by 2035. PV may show a steady growth after that. The share of wind and PV could possibly increase to 40-50% in 2050. This is an ambitious target, as it will also require much effort to balance demand and supply of electricity during the seasons. Technologies like (large- and small-scale) electricity storage, hydrogen, etc. will need to be developed and applied all over Europe.

Biomass

On a global scale, the following areas are used for agriculture, forestry, fibre production, etc.:

- Agricultural land 5.0 Gha
- Land for forestry and fibre production 4.0 Gha
- Remaining land (*inter alia* mountains, savannah, steppe, and grassland) 4.2 Gha

(Hoogwijk, 2004) assumes that the area available for food production will remain approximately 5 Gha. According to Hoogwijk, the *geographical potential* is the theoretical biomass potential on a certain land area. The global *geographical potential* of biomass ranges from 305 to 660 EJ/a in 2050, and from 395 to 1,165 EJ/a in 2100. The *geographical potential* of OECD Europe appears to range from 10 to 16 EJ/a in 2050, and from 15 to 21 EJ/a in 2100.

The use of biomass *in the broad sense of the term* - energy crops, agricultural and forestry residues, and organic waste - in the EU-15 may increase from 2.1 EJ/a in 2000 to 7 EJ/a in 2050 (with a compounded average growth of about 2.5%/a). About one-third of the aforementioned potential could be made available by energy crops. The figure of 7 EJ/a is underpinned by country-specific estimates for Austria, Denmark, Finland, Germany, the Netherlands, and Sweden.

Besides, Europe could import biomass from overseas and from Central and Eastern Europe. There are several world regions that could have export potential, e.g. the FSU, Oceania, and East Africa. Studies by Yamashita *et al*. and Faaij prove invariably that the energy penalty of biomass transport by ship for 'raw' biomass is not an insurmountable problem. The cost of electricity based on imported biomass could be high compared to conventional alternatives: 6.4-8 €ct/kWh and 3-5 €ct/kWh, respectively.

1. INTRODUCTION

The availability of fossil fuels (oil, gas and coal), uranium and thorium, and renewables (wind, solar, biomass) strongly affects current and future energy supply systems. Declining availability of fossil fuels may cause increases in fuel prices and declining security of energy supply in the current energy system. On a global scale, renewable energy sources seem to be ample. However, renewables may not be developed in time or may be more limited on a regional scale than desired. Generally, the period until 2050 (or 2035, if applicable) has been analysed.

Limited availability of fossil fuels and renewable energy sources on a local scale may affect the sustainability of future energy systems. A number of organisations point out the necessity of a transition towards a more sustainable energy supply system. Such a system should overcome current problems in the energy supply system, e.g. decrease dependency on imported fossil fuels and environmental problems. A transition towards a more sustainable energy supply system presumes, generally speaking, an increased use of renewable energy sources such as wind, solar energy, and biomass and the use of clean fossil technologies (more efficient conversion technologies, use of carbon sequestration). Whereas the potential of biomass, solar and wind energy is enormous on a global scale, local availability varies. Fossil fuels and fissile energy sources are finite and their depletion may become a constraint in the future, depending on the extent of the resources and the rate of depletion. These developments may lead to import dependency and possibly, when demand exceeds availability, to the impossibility to fulfil demand by means of an energy carrier or source. Future energy systems wished might therefore not fully develop in the direction desired, possibly leading to suboptimal conditions.

In order to analyse possible effects of the availability of energy sources on the chances for future transitions, an overview of the foreseen availability of energy sources is needed. This leads to the research questions:

- Which estimates of the resources of fossil and fissile energy sources are available?
  - How large are reserves or resources according to current knowledge?
  - What are the main regions in which the reserves and resources are to be found?
  - What are the estimations of the timeframe in which resources might decrease or become exhausted?
- Which estimates of the potential of renewable energy sources are available?
  - Which potential seems to be realistic for a specific region?
  - Which factors influence the potential?

To answer the research questions, a quick scan and analysis of available literature has been performed. Such literature sources, e.g., the proved reserves of fossil energy resources estimated by BP, depletion scenarios, etc. have been used to estimate the availability of oil, gas, coal, uranium, (onshore and offshore) wind power, solar power, and biomass. The next few chapters describe the outcomes of the quick scan for the different energy sources. In each chapter, relevant definitions and estimates of resources or potential are given. The report ends with conclusions.

The availability of fossil and fissile energy sources is described in terms of *proved reserves* and *resources*. For oil and gas, the definition of *proved reserves* is: ‘The estimated quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing and economic operating conditions’. The term ‘*resources*’ refers to reserves - probable, possible - with a lower probability of occurrence. Furthermore, oil, gas, and uranium are not only available in conventional reservoirs or geological deposits, but are also available as unconventional *reserves* and *resources*. The unconventional *reserves* and *resources* of oil (e.g. from tar sand and extra-heavy oil), gas (e.g. coal-based methane, methane hydrates), and uranium (uranium extracted from seawater) are considered too.

Table 1.1 gives a quick overview of the main literature sources used for the assessment of the fossil and fissile energy sources.

Table 1.1 *Main literature sources for fossil and fissile energy resources and availability*

Energy sources	Main literature sources	Additional analyses	Type of analysis
Oil	BP, 2004; BGR, 2002	√	Depletion scenarios
Gas	BP, 2004; BGR, 2002	√	Depletion scenarios
Coal	BP, 2004; BGR, 2002		
Uranium and thorium	WEC, 2004; BGR, 2002	√	Depletion scenarios

In case of oil, conventional gas, and uranium and thorium, additional analyses have been performed. These are meant to investigate a possible peak in production of these energy sources.

With regard to the renewable energy sources wind (onshore and offshore), photovoltaic energy (PV), and biomass, the following main literature sources have been used (Table 1.2).

Table 1.2 *Main literature sources for renewable energy resources and availability*

Energy sources	Main literature sources	Additional analyses	Type of analysis
Onshore wind	De Noord *et al*., 2004	√	Feasible scenarios
Offshore wind	BTM, 2004; De Noord *et al*., 2004; Greenpeace, 2004	√	Feasible scenarios
Photovoltaic energy (PV)	Lehmann *et al*., 2002; De Noord *et al*., 2004	√	Feasible scenarios
Biomass	Hoogwijk, 2004; De Noord *et al*., 2004; Frey *et al*., 2004		

Additional analyses have been performed for onshore and offshore wind and PV. It is important to factor in time lags due to implementation difficulties, viz. competing land use in case of onshore wind, planning and logistics for offshore wind, growth constraints for PV, and transmission of electricity for both onshore and offshore wind.

The study has the following contents. Chapter 2 addresses the resources and availability of oil, Chapter 3 of gas, and Chapter 4 of coal. Then, Chapter 5 covers the resources of onshore wind in Europe (transmission of electricity between continents is deemed hardly achievable in practice). Chapter 6 gives an overview of the resources of offshore wind in the EU-15, and Chapter 7 of PV. Chapter 8 gives a view of the resources of uranium and thorium. Finally, Chapter 9 presents a number of conclusions.

2. RESOURCES AND AVAILIBILITY OF OIL

2.1 Introduction

During the last four decades, oil has developed into the most important fossil fuel on earth. Its use outstrips that of other energy sources like natural gas, coal, hydro power, nuclear power, biomass, wind power, etc. Oil is mainly produced from conventional reservoirs - onshore and offshore - and to a lesser extent from unconventional oil, viz. from extra heavy oil and tar sand. §2.2 presents definitions of proved, probable, and possible oil reserves and §2.3 gives an overview of the world's proved oil reserves. §2.4 addresses the resource base of unconventional oil. Unconventional oil encompasses extra heavy oil, tar sand, and oil shale. Global oil production scenarios are presented in §2.5, and §2.6 presents some preliminary conclusions.

2.2 Proved, probable, and possible oil reserves

There is a lot of data available on reserves and resources of conventional and unconventional oil. This study mainly draws on data from (BP, 2004) and (BGR, 2002) as these literature sources are recent and readily available. Data from the United States Geological Survey (USGS), World Energy Council (WEC), and the International Energy Agency (IEA) are not used - an exception is data on uranium resources from (WEC, 2004) - as this would require too much analysis. The character of this study - a quick scan - did not enable in-depth analysis of reserves and resources. The authors have tried not to give too much weight to single estimates.

The most common distinction is that between so-called proved, probable, and possible reserves. In order to delineate the proved reserves from the probable and possible resources, a number of definitions are presented, in particular, of ultimately recoverable resources, proved, probable and possible reserves, and oil in place[1], based on (BP, 2004).

Ultimately recoverable resource (URR) is an estimate of the total amount of oil that will ever be recovered and produced. It is a subjective estimate in the face of only partial information. Whilst some consider URR to be fixed by geology and the laws of physics, in practice estimates of URR continue to be increased as knowledge grows, technology advances and economics change. The URR estimate is typically broken down into three main categories:

- Cumulative production
- Discovered reserves
- Undiscovered resources.

Cumulative production is an estimate of all of the oil produced up to a given date. Discovered reserves are an estimate of future cumulative production from known fields and are typically defined in terms of a probability distribution, viz. proved, probable and possible reserves.

Proved reserves are defined as 'The estimated quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing and economic operating conditions'. A probability cut-off of 90% is sometimes used to define proved reserves, i.e. the proved reserves of a field are defined as having a better than 90% chance of being produced over the life of the field. In this sense, proved reserves are a conservative estimate of future cumulative production from a field.

[1] Oil in place exceeds the amount of oil that will ever be recovered, as a fraction of the oil (or gas) in a reservoir is not producible in any way. With regard to coal, slightly different definitions are used. They are presented in Chapter 4.

Probable reserves are designated as 'indicated' or P50 reserves: reserves which are estimated to have a better than 50% chance of being technically and economically producible.

Possible reserves are designated as 'inferred' reserves, sometimes referred to as P10 or P20 reserves, i.e. including reserves which, at present, cannot be regarded as 'probable', but which are estimated to have a significant, but less than 50% chance of being technically and economically producible.

In general, a portion of a field's probable and possible reserves tends to get converted into proved reserves over time as operating history reduces the uncertainty around remaining recoverable reserves: an aspect of the phenomenon referred to as 'reserves growth'. Even taken together, proved, probable and possible reserves are only a proportion of oil in place since it is impossible to recover all of the oil and gas present in a given reservoir.

Figure 2.1 illustrates the relation between reserves and resources (Nakićenović, 2001).

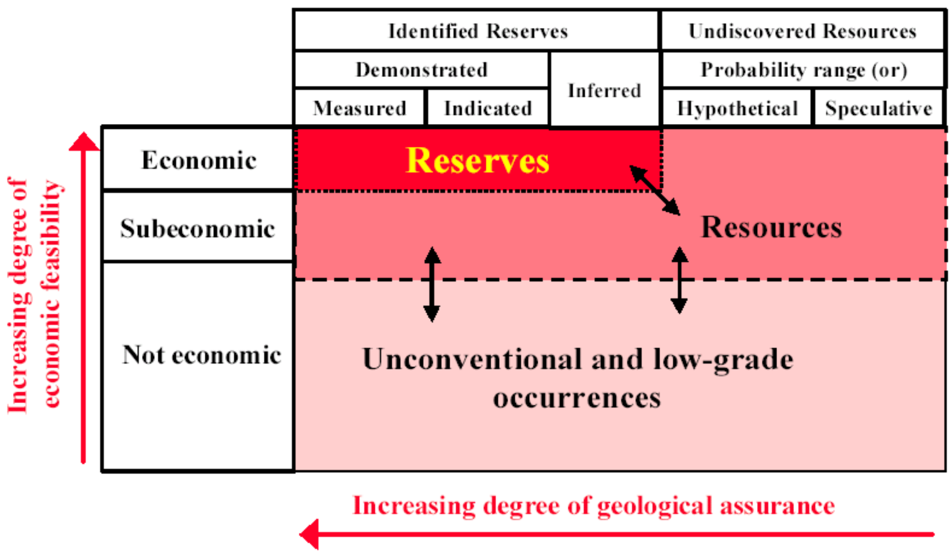

Figure 2.1 *Relation between reserves and resources*
Source: Nakićenović, 2001.

2.3 Proved conventional oil reserves

Figure 2.2 shows the development of proved conventional oil reserves according to (BP, 2004).

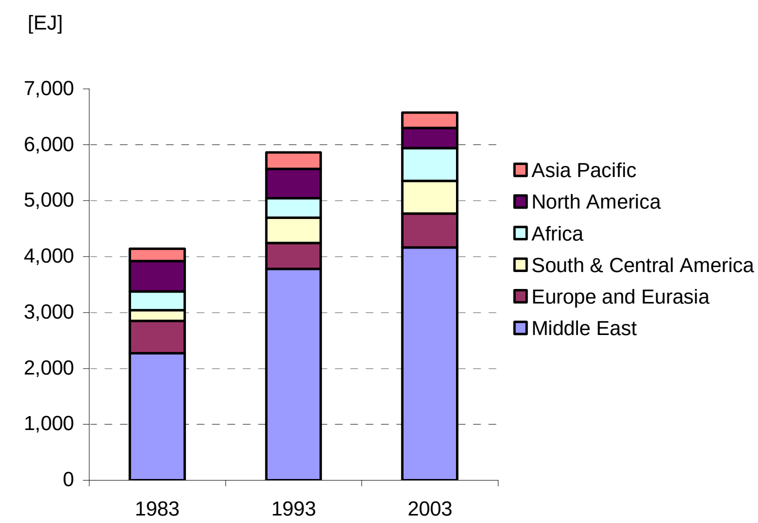

Figure 2.2 *Proved oil reserves as a function of time*
Source: BP, 2004.

The Middle East proves to be the dominant conventional oil province of the world. Also, the world's proved oil reserves seem to level off, which may be due to difficulties met in finding new oil reservoirs. Appendix A presents a more detailed picture of the oil reserves.

As the demand for oil increases (Appendix B), the Reserves/Production (R/P) ratio tends to fall (Figure 2.3). From 1983 to 1993, the effect of exploration (new oil reservoirs) and re-evaluation (existing reservoirs) was larger than that of increased oil demand, and the Reserves/Production ratio increased from 33 to 42.5 years. After 1993, the effect of exploration and re-evaluation (1.2%/a) did not exceed that of increased oil demand (1.4%/a), and the R/P ratio declined to 41 years. New oil finds prove to be insufficient to keep pace with increased demand for oil.

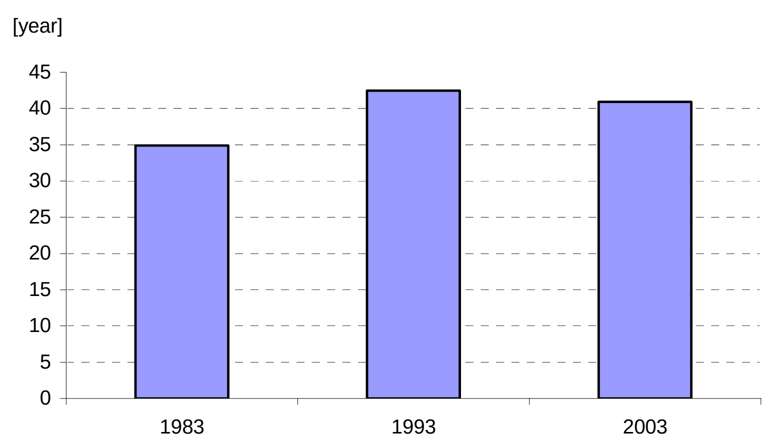

Figure 2.3 *Reserves/production ratio based on 'BP Statistical Review of World Energy'*
Source: BP, 2004.

2.4 Unconventional oil

According to the German BGR (Bundesanstalt für Geowissenschaften und Rohstoffe), the unconventional oil reserves amount to 2,760 EJ compared to 6,350 EJ for conventional oil (BGR, 2002). On top of that, the unconventional oil resources are estimated at 10,460 EJ compared to conventional oil resources of 3,525 EJ (Table 2.1).

Table 2.1 *Reserves and resources of conventional and unconventional oil*

	Conventional oil			Unconventional oil		
[EJ]	Reserves	Resources	Total	Reserves	Resources	Total
North America	354	573	927	1,297	5,523	6,820
S & C America	546	304	850	460	1,883	2,343
Europe	139	152	291	42	84	126
Eurasia	629	890	1,519	397	1,255	1,652
Middle East	3,961	904	4,865	418	502	920
Africa	470	434	904	21	251	272
Asia Pacific	252	268	520	126	962	1,088
World	6,351	3,525	9,876	2,761	10,460	13,221

Source: BGR, 2002.

The sum of conventional oil reserves and resources is estimated at 9,880 EJ or 1,725 Gb (billion barrel), 50% more than BP's proved reserves (Appendix A). Conventional reserves and resources are equal to approximately 60 years of current production (reserves 40 years, and resources 20 years). As the proved unconventional oil reserves are approximately 2,760 EJ or 475 Gb, the sum of conventional oil and unconventional oil reserves is equal to 80 years of current production. Oil demand during this century in excess of this amount (~12,640 EJ, ~2,220 Gb - can only be met from unconventional resources (~10,460 EJ, ~1,825 Gb). It is, however, doubtful whether more than the unconventional reserves could be produced before 2100.

2.5 Oil production scenarios 2000-2075

Several organisations or authors have developed global oil production scenarios. An important aspect of these scenarios is the possible occurrence of 'Peak Oil', a peak in worldwide oil production due to decreasing oil resources and increasing cost of oil production. The Association for the Study of Peak Oil & Gas (ASPO), an organisation of oil experts, expects a peak in global oil production within a decade, which may have severe consequences for economic development. This viewpoint is endorsed by *inter alia* (Salameh, 2003). Others contend that a peak in global oil production is imminent (Lynch, 2004). Appendix C presents a few oil production scenarios and corresponding estimates of global oil resources.

Four oil production scenarios are used to determine the timescale of occurrence of 'Peak Oil':

- The so-called '2004 scenario' of consultant geologist Campbell. He is the founder of the aforementioned ASPO. Campbell is of the opinion that the current high oil prices are due to an anticipated peak in global oil production, called 'Peak Oil'. Such a peak will be followed by continuous decline (Campbell, 2002; Internet sources 1-2). Campbell warns for such a peak for more than a decade (Campbell, 1991). The '2004 scenario' is based on conservative estimates of oil production from known and yet unknown fields.
- The 'ASPO 2002 scenario' based on (Aleklett *et al.*, 2002; ASPO, 2004). This scenario from ASPO shows much resemblance with Campbell's '2004 scenario', but it assumes a somewhat larger resource base for conventional oil.

- Scenario 'Medium', which has been developed in the framework of this study. Scenario 'Medium' has a larger resource base for conventional oil than the second scenario ('ASPO 2002 scenario'). It is used to analyse the effect on the timescale of 'Peak Oil'.
- Scenario 'High' based on conventional oil resources in (Lako, 2002). This study draws on data of global oil reserves and resources from the USGS that are optimistic but not unrealistic. Scenario 'High', the scenario with the most abundant resources - an Estimated Ultimate Recovery (EUR)[2] of 20,000 EJ (3,500 Gb) - presumes a levelling off of global oil production in the period 2003-2035, and a steady decline after that date.

The scenarios suggest that global oil production might peak in the next 30 years (Figure 2.4).

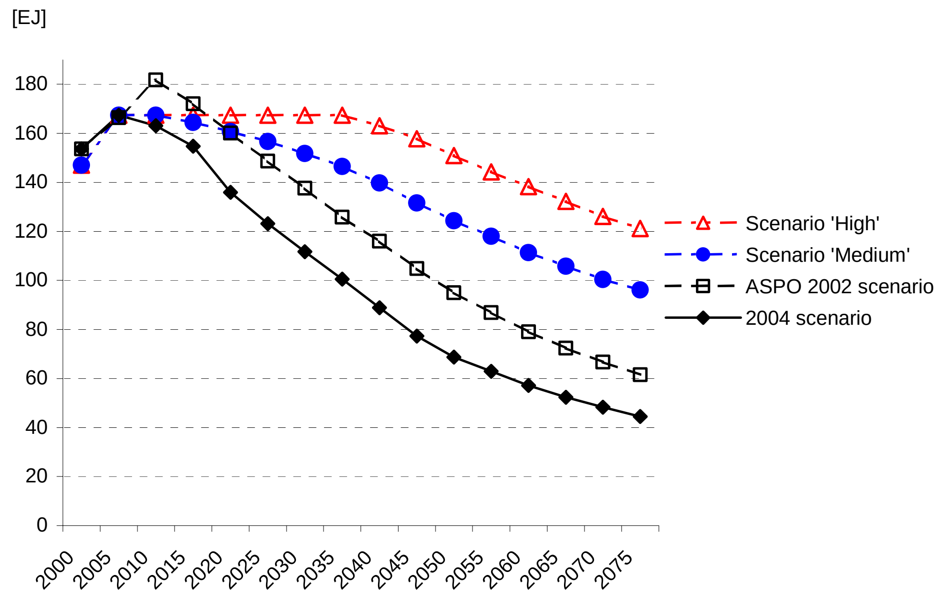

Figure 2.4 *Global oil production scenarios based on Appendix C*

Table 2.2 shows the main characteristics of the four scenarios. More information on scenarios and corresponding resource estimates may be found in Appendix C.

Table 2.2 *Main characteristics and results of '2004 scenario' and alternative scenarios*

Scenario		2004 scenario	ASPO 2002	Medium	High
EUR	[Gb]	2,500	2,800	3,175	3,500
	[EJ]	14,320	16,050	18,190	20,065
Compared to '2004 scenario'	[%]	100	112	127	140
Share of Middle East					
Year 2010	[%]	24	28	17	14
Year 2050	[%]	31	51	42	38
Year 2075	[%]	N/A	N/A	49	43
Peak characteristics					
Peak (period)	[Year]	2006	2010	~ 2010	2010-2035
Decline after peak	[%/a]	-2.0	-1.65	-0.85	-0.80

Sources: Campbell, 2002; Internet sources 1-2; Aleklett *et al.*, 2002; ASPO, 2004; Lako, 2002.

The scenarios 'Medium' and 'High' demonstrate that a larger resource base may defer 'Peak Oil' and that oil production may decline more gradually after 'Peak Oil'. They also show a comparable dependence on oil from the Middle East, viz. a share of 'regular oil' from the Mid-

2 Estimated Ultimate Recovery (EUR) = oil producible until 2100, inclusive of cumulative production.

dle East of 38-42% in 2050, and a share of 43-49% in 2075. Therefore, the Middle East will remain a vital swing supplier of oil in the future, indicating the strategic importance of oil.

‘Peak Oil’ may be deferred, if the following conditions are fulfilled:
- Global oil demand remains flat; a sharp increase in oil demand may trigger ‘Peak Oil’.
- Resources of conventional oil (e.g. Middle East) prove to be relatively large.
- Unconventional oil resources turn out to be large and producible in sizeable quantities.

The oil price hinges on the balance between oil demand and supply. The oil market will tighten when ‘Peak Oil’ approaches. If this happens in the near future, the oil price could remain high. A yardstick for the future oil price level could be $40/barrel or more (Al-Husseini, 2004).

2.6 Preliminary conclusions

Oil is the fossil fuel that is most in danger to become short in supply. New oil finds prove to be insufficient to keep pace with increased demand for oil. The levelling off of the proved conventional reserves may be due to difficulties met in finding new oil reservoirs. The Middle East is the dominant oil province of the world, covering 63% of the proved conventional reserves. Conventional oil is equivalent to approximately 60 years of current production (40 years for the reserves, and another 20 years for the resources). The conventional oil reserves and resources combined with the unconventional oil reserves would be sufficient for 80 years of current production. Unless unconventional oil resources would be producible in the 21st century, which is doubtful, oil production is set to decline (probably between 2010 and 2035).

Global oil production scenarios show that a larger resource base may defer ‘Peak Oil’. A sharp increase in oil demand may trigger ‘Peak Oil’. Also, oil production may decline more gradually after ‘Peak Oil’ if the resource base is large. In the scenario with the most ample oil resources (scenario ‘High’) ‘Peak Oil’ may be deferred to, e.g., 2035. However, ‘Peak oil’ not only depends on the ultimately available oil resources, but also on the future pattern of global oil demand. If the demand for oil continues to rise, ‘Peak Oil’ might not be deferred to, e.g., 2035.

Therefore, ‘Peak Oil’ may be deferred considerably, if the next conditions would be fulfilled:
- Global oil demand does not increase significantly.
- Resources of conventional oil (e.g. Middle East) prove to be relatively large.
- Unconventional oil resources turn out to be large and producible in sizeable quantities.

The oil price hinges on the balance between oil demand and supply. The oil market will tighten when ‘Peak Oil’ approaches. If this happens in the near future, the oil price could remain high.

3. RESOURCES AND AVAILIBILITY OF GAS

3.1 Introduction

Presently, natural gas and coal have almost equal shares in global energy production and consumption (second only to oil). Natural gas is generally produced from conventional gas occurrences onshore and offshore, and to a small extent from unconventional resources (e.g., coal bed methane). Unconventional gas resources may be quite substantial or even huge, if 'gas hydrates' (also denoted as 'clathrates') in Arctic regions or on the ocean floor might be producible.

§3.2 gives an overview of the world's proved gas reserves. §3.3 addresses the resource base of unconventional gas[3]. Gas production scenarios are presented in §3.4, and §3.5 presents some preliminary conclusions.

3.2 Proved conventional gas reserves

The definitions of proved, probable, and possible oil reserves in Chapter 2 equally apply to natural gas. Figure 3.1 shows the development of the proved conventional gas reserves (BP, 2004).

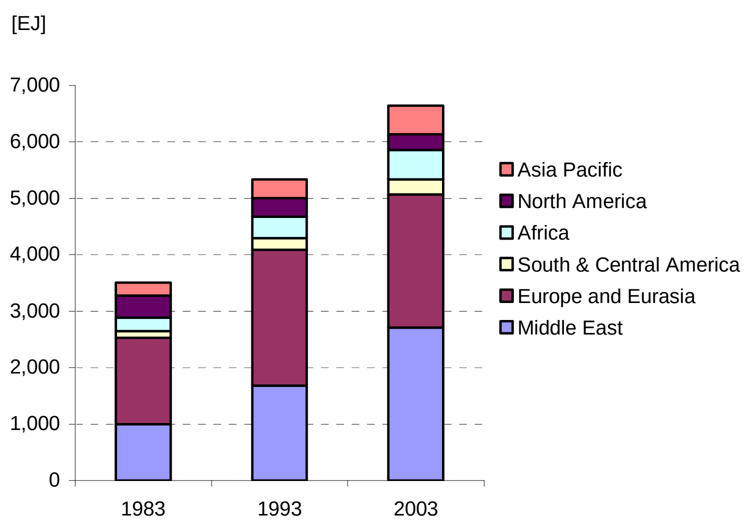

Figure 3.1 *Proved gas reserves as a function of time*
Source: BP, 2004.

The main provinces for natural gas are situated in the Middle East and Russia. Appendix A gives a more detailed picture of the proved gas reserves. The increase of the proved gas reserves after 1993 was just sufficient to keep pace with increased gas production (Appendix B). Consequently, the Reserves/Production ratio for conventional gas stabilised after 1993 (Figure 3.2).

[3] Unconventional gas encompasses gas from 'tight sands' and aquifers, coal bed methane, and gas hydrates in Arctic regions and on the ocean floor.

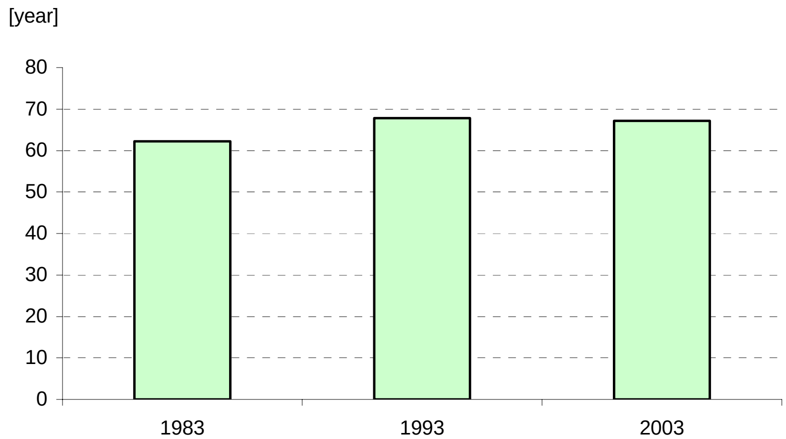

Figure 3.2 *Reserves/production ratio based on 'BP Statistical Review of World Energy'*
Source: BP, 2004.

In the period 1983-1993, the effect of exploration (new reservoirs) and re-evaluation (existing reservoirs) was larger than that of increased gas demand, and the Reserves/Production ratio increased from 60 to 67 years. After 1993, both effects were roughly equal and the R/P ratio remained 67 years: exploration and re-evaluation keep pace with increased gas demand.

3.3 Unconventional gas

Unconventional gas encompasses gas from 'tight sands' and aquifers, coal bed methane, and gas hydrates in Arctic regions and on the ocean floor. The unconventional gas reserves amount to 60 EJ compared to 5,100 EJ for conventional gas (Table 3.1). On top of that, the unconventional gas resources are estimated at 32,780 EJ compared to conventional gas resources of 6,880 EJ.

Table 3.1 *Reserves and resources of conventional and unconventional gas*

	Conventional gas			Unconventional gas		
[EJ]	Reserves	Resources	Total	Reserves	Resources	Total
North America	240	866	1,106	48	5,851	5,899
S & C America	224	313	537	-	4,560	4,560
Europe	213	226	439	6	1,869	1,875
Eurasia	1,787	3,048	4,835	3	6,073	6,076
Middle East	1,869	1,350	3,219	-	3,649	3,649
Africa	375	355	730	-	2,764	2,764
Asia Pacific	395	720	1,115	3	8,012	8,015
World	5,105	6,879	11,984	60	32,779	32,839

Source: BGR, 2002.

According to (BGR, 2002), the combined conventional gas reserves and resources amount to approximately 12,000 EJ (80% more than BP's proved gas reserves). Conventional gas reserves and resources are equivalent to approximately 120 years of current production (reserves 53 years, and resources 67 years, according to BGR). It is noted that the Reserves/Production ratio of conventional gas is 67 years according to (BP, 2004). Including the proved unconventional gas reserves - taken as 60 EJ - does not significantly change the figure of 120 years.

Assuming that only a small fraction of the unconventional gas reserves and resources will be produced until 2100, the average gas production level in this century could be 20% higher than today. This is meant to illustrate that the ratio of 'reserves plus resources' to production is relatively large for conventional gas.

Appendix D shows that the unconventional gas resources are huge. However, it is not certain to which extent unconventional gas resources might be recoverable.

3.4 Gas production scenarios 2000-2075

Global gas production scenarios are less readily available than oil production scenarios. Two scenarios are addressed here in order to illustrate the bandwidth in conventional gas resources:

- The scenario with the most conservative estimate of the world's conventional gas resources is based on (Imam *et al.*, 2004). This scenario is denoted as 'Imam *et al*'.
- Scenario 'High' is based on a supply curve in (Lako, 2002), which refers to the proved, probable, and possible conventional gas resources according to the USGS. Scenario 'High' is the scenario with the most abundant gas resource base: the future conventional gas production is estimated at 11,140 EJ, which is 68% more than BP's proved gas reserves, and 93% of the conventional gas reserves and resources according to (BGR, 2002). Therefore, scenario 'High' may be considered as optimistic but not unrealistic.

Scenario 'High' indicates that a peak in conventional gas production might occur around 2050 (Figure 3.3).

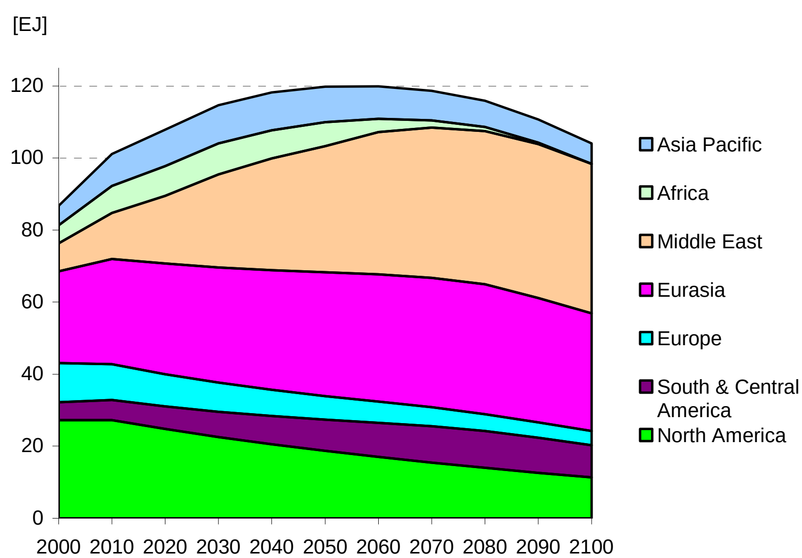

Figure 3.3 *Gas production 2000-2100 according to scenario 'High'*
Source: Lako, 2002.

According to (Imam *et al.*, 2004), a peak in conventional gas production could occur around 2020. As a matter of fact, such a scenario disregards the conventional gas resources in addition to the proved reserves. More information on the scenarios can be found in Appendix D. In order to compare the two scenarios, Table 3.2 shows their main characteristics.

Table 3.2 *Main assumptions and results of scenario 'Imam et al' and scenario 'High'*

Scenario		'Imam *et al*'	'High'
EUR (-2100)	[10^{12} m^3]	261	366
	[EJ]	9,865	13,850
EUR compared to scenario 'Imam *et al*'	[%]	100	140
Share of Middle East			
Year 2010	[%]	~10	13
Year 2020	[%]	~15	17
Year 2050	[%]	~40	29
Peak characteristics			
Peak (period)	[Year]	2019	2040-2060
Peak level	[EJ/a]	94.6	119.9
Decline after peak	[%/a]	N/A	<-1

Sources: Imam *et al*., 2004; Lako, 2002.

Scenario 'High' demonstrates that a larger resource base may defer a peak in global gas production by 30 to 40 years. However, this presumes that the peak is relatively flat ('peak period'). Gas production may decline more gradually after the peak, if the resource base is large. In scenario 'Imam *et al*', the share of gas from the Middle East rises faster (to approximately 40% in 2050) than in scenario 'High'.

In the period until 2050, a substantial production of unconventional gas is more difficult to imagine than a sizable production of unconventional oil, as production of unconventional oil is already significant today.

3.5 Preliminary conclusions

In the period 1993-2003, exploration (new gas fields) and re-evaluation (existing gas reservoirs) has been just sufficient to keep pace with increased demand for natural gas. The proved gas reserves are not evenly distributed around the globe: 41% of them are in the Middle East, and 27% in Russia. Conventional gas reserves and resources are equivalent to approximately 120 years of current production. Including the proved unconventional gas reserves - taken as 60 EJ - does not significantly change this figure. The unconventional gas resources are huge. However, it is not certain to which extent unconventional gas reserves or resources might be exploitable.

Scenario analysis shows that a peak in conventional gas production may occur between 2020 and 2050. Just like in case of scenario 'High' for oil, the resource estimate of scenario 'High' for gas draws on data from the USGS. Scenario 'High' is the scenario with the most abundant resource base: the future conventional gas production is estimated at 11,140 EJ, which is 68% more than BP's proved gas reserves, and 93% of the conventional gas reserves and resources of the BGR. So, the resource base of scenario 'High' may be deemed optimistic but not unrealistic.

(Imam *et al.*, 2004) envision a peak in conventional gas production around 2020. However, they presume a resource base for conventional gas that is only fractionally higher than BP's estimate of the proved conventional gas reserves. As a matter of fact, such a scenario disregards the conventional gas resources in addition to the proved reserves.

Therefore, a somewhat optimistic but not unrealistic scenario with a resource base roughly equal to the combined reserves and resources of conventional gas according to (BRG, 2002) could possibly cause a peak in conventional gas production around 2050. In the period until 2050, a substantial production of unconventional gas is more difficult to imagine than a sizable production of unconventional oil, as production of unconventional oil is already significant today.

4. RESOURCES AND AVAILIBILITY OF COAL

4.1 Introduction

The worldwide coal production is roughly equal to the gas production and only second to that of oil. Coal is produced in deep mines (hard coal) and in surface mines (lignite). Definitions of coal resources are presented in §4.2. § 4.3 gives an overview of the proved coal reserves, and §4.4 of the coal resources. §4.5 shortly presents depletion of coal reserves, and §4.6 gives a number of preliminary conclusions.

4.2 Definitions

The World Energy Council (WEC, 2004) defines the proved amount in place as the resource remaining in known deposits that has been carefully measured and assessed as exploitable under present and expected local economic conditions with existing available technology. The proved recoverable reserves are the tonnage within the proved amount in place that can be recovered in the future under present and expected local economic conditions with existing available technology. In the following, the proved recoverable reserves will be denoted as 'proved reserves'.

The estimated additional amount in place is the indicated and inferred tonnage additional to the proved amount in place that is of foreseeable economic interest. It includes estimates of amounts that could exist in unexplored extensions of known deposits or in undiscovered deposits in known coal-bearing areas, as well as amounts inferred through knowledge of favourable geological conditions. Speculative amounts are not included. The estimated additional reserves recoverable is the tonnage within the estimated additional amount in place that geological and engineering information indicates with reasonable certainty might be recovered in the future. In the following, the estimated reserves recoverable will be denoted as 'resources'.

4.3 Proved coal reserves

Coal reserves are rather evenly spread around the globe. After 1993, proved reserves decreased marginally by 0.5%/a on average (Figure 4.1).

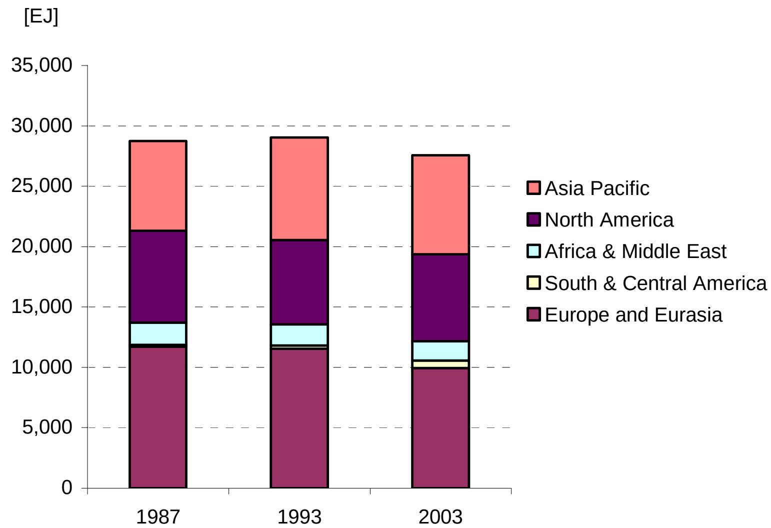

Figure 4.1 *Proved coal reserves as a function of time*
Source: BP, 2004.

Figure 4.1 and Appendix A show that 25% of the proved reserves are found in the USA, 16% in Russia, and 11.5% in China. Since the global coal reserves decreased after 1993 and coal production increased simultaneously, the Reserves/Production (R/P) ratio declined (Figure 4.2).

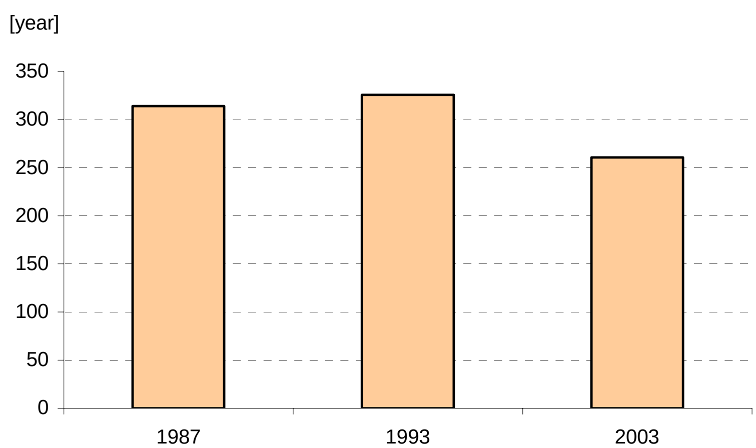

Figure 4.2 *Reserves/production ratio based on 'BP Statistical Review of World Energy'*
Source: BP, 2004.

Appendix B shows that the global coal production increased modestly during 1981-1993 by approximately 0.5%/a, and from 1993 to 2003 by 1.7%/a. The development of worldwide coal production shows substantial ups and downs during the period considered. Nevertheless, the Reserves/Production (R/P) ratio - approximately 260 years for coal according to BP (Figure 4.2) - far outstrips R/P ratios for oil (approximately 41 years) and natural gas (67 years according to BP, 53 years according to BGR).

4.4 Total coal resources

According to (BGR, 2002), the global coal resources may be estimated as follows (Table 4.1).

Table 4.1 *Reserves and resources of hard coal and lignite*

[EJ]	Reserves Hard coal	Reserves Lignite	Resources Hard coal	Resources Lignite	Reserves and resources Hard coal and lignite
North America	5,198	522	18,292	4,895	28,907
S & C America	480	0	978	92	1,550
Europe	1,054	569	11,963	1,779	15,365
Eurasia	4,460	144	45,359	3,533	53,496
Middle East	5	-	30	28	63
Africa	917	0	5,049	3	5,969
Asia Pacific	5,552	719	22,214	1,893	30,378
World	17,666	1,954	103,884	12,224	135,728

Source: BGR, 2002.

The coal resources amount to approximately 116,000 EJ, or 4.2 times the proved coal reserves according to BP (Appendix A). Therefore, the world's coal reserves and resources are really huge. However, some of the coal resources may be low-grade and/or hardly mineable.

4.5 Depletion of coal reserves

The world's coal reserves are formidable compared to current coal production (Table 4.2). Although coal is much more abundant than oil and gas on a global scale, Internet source 1 shows that coalfields can be depleted on a regional scale, e.g., in the UK (Internet source 3). A peak in global coal production within this century is not expected due to supply considerations, but in scenarios based on climate policies the upward trend in coal production may be reversed.

Table 4.2 *World coal production and reserves 2003*

Rank	Country	Production [Mton]	Production [EJ]	Production [%]	Reserves [EJ]	Reserves/production [Years]
1	China	1,667	35.4	33.5	3,206	91
2	USA	970	23.2	21.9	7,000	302
3	Australia	347	7.9	7.5	2,299	290
4	India	367	7.2	6.8	2,363	327
5	South Africa	239	5.7	5.3	1,386	245
6	Russia	275	5.2	5.0	4,396	838
7	Poland	163	3.0	2.8	622	209
8	Germany	205	2.3	2.1	1,848	813
1-8		4,233	89.9	84.9	23,120	257
	World	5,119	105.8	100.0	27,566	261

Source: BP, 2004.

The proved coal reserves are larger than the proved conventional oil reserves and the proved conventional gas reserves. As the Reserves/Production ratio of coal is relatively large, significant depletion effects on a global scale are not expected in the 21st century, although regional depletion effects will certainly occur.

4.6 Preliminary conclusions

Coal reserves are rather evenly spread around the globe: 25% are in the USA, 16% in Russia, and 11.5% in China. After 1993, proved reserves decreased by 0.5%/a on average. Nevertheless, the Reserves/Production (R/P) ratio - approximately 260 years for coal - far outstrips R/P ratios for conventional oil (approximately 41 years) and conventional gas (53 or 67 years, depending on the literature source used). The coal resources amount to approximately 116,000 EJ, or 4.2 times the proved coal reserves according to BP. However, some of the coal resources may be low-grade and/or hardly mineable.

Although coal is much more abundant than oil and gas on a global scale, coalfields can be depleted on a regional scale, e.g., in the UK. On a global scale, a peak in coal production is not expected because of supply considerations, but in scenarios based on climate policies the upward trend in coal production may be reversed.

5. ONSHORE WIND RESOURCES IN EU-15 COUNTRIES

5.1 Introduction

The potential of wind depends *inter alia* on the wind speed, which is related to the surface roughness. The (average) wind speed determines the feasibility of wind power to a large extent. This chapter focuses on the onshore wind potential in the EU-15, Norway, and Poland. §5.2 starts with definitions of the wind resource. §5.3 presents the onshore wind potential in the EU-15, Norway and Poland. §5.4 gives a number of preliminary conclusions.

5.2 Definitions of potentials

(De Noord *et al*., 2004) make use of a distinction between several wind energy potentials:

- The *theoretical* potential of a renewable energy source is the total physical energy flow of that source. In case of wind energy: the theoretical energy of the wind without taking into account conflicting land claims, spatial planning, public acceptability, and costs.
- The *technical* potential takes into account the conversion efficiency and obvious conflicts in land availability: wind turbines are not installed in urban areas. Thus, the technical potential is based on the state-of-the-art of wind turbine technology and does not consider areas that are not suitable for development of wind farms (urban areas).
- The *realistic* potential then takes into account considerations of spatial planning, environmental impacts (e.g. bird casualties), public acceptance, etc, but not costs.

Finally, the *realisable* potential takes into account the extent to which a technology is constrained by lead times, maximum deployment, growth rates, etc (Figure 5.1). On the long term, the *realisable* potential is theoretically equal to the *realistic* potential. However, in this study, the *realisable* potential may be less than the *realistic* potential as will be explained later on.

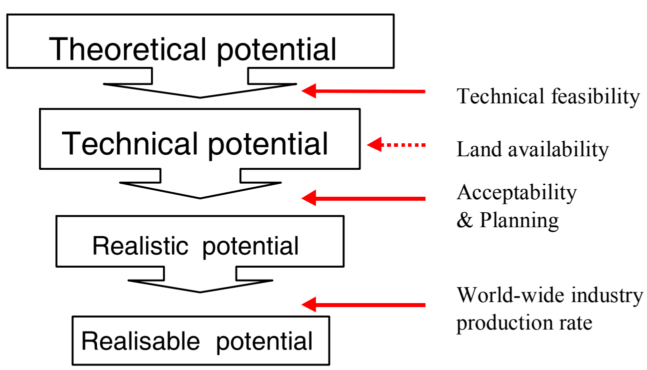

Figure 5.1 *Methodology for definition of potentials*
Source: De Noord *et al*., 2004.

De Noord *et al*. assume 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’ - average wind speed >7 m/s, see §5.3 - it is assumed 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.

5.3 Onshore wind in EU-15, Norway, and Poland

De Noord *et al*. analyse the *realistic* onshore wind power potential of the EU-15 and Norway. They distinguish four bands, corresponding to four wind classes:

- Class >7 m/s (Band 1)
- Class 6-7 m/s (Band 2)
- Class 5-6 m/s (Band 3)
- Class <5 m/s (Band 4).

Some countries - e.g. Luxembourg and (to a lesser extent) Portugal and Italy - do not have a very favourable wind regime. However, others - in particular the UK, France, Denmark, and Norway - have excellent wind regimes (at least in a large part of the country). Table 5.1 shows the results of the assessment by De Noord *et al*.

Table 5.1 *Realistic wind potential of the EU-15 and Norway (power density 10 MW/km^2)*

Wind speed	Band 1 >7 m/s [MW]	Band 2 6-7 m/s [MW]	Band 3 5-6 m/s [MW]	Band 4 <5 m/s [MW]	Total [MW]
Austria	192	362	918	1,087	2,559
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	42,227
Germany	7,090	9,457	7,093	3,546	27,186
Greece	2,182	823	1,029	1,646	5,680
Ireland	2,389	1,071	292	0	3,752
Italy	0	3,418	5,127	8,545	17,090
Luxembourg	0	9	46	37	92
Netherlands	1,206	914	311	0	2,431
Norway	17,358	1,070	1,230	107	19,765
Portugal	0	293	880	1,761	2,934
Spain	2,735	2,736	8,208	15,048	28,727
Sweden	8,782	2,553	2,127	2,127	15,589
UK	17,972	1,295	1,295	864	21,426
Total	77,304	35,960	42,052	50,472	205,788

Source: De Noord *et al*., 2004.

Estimates of the onshore potential of a few EU countries according to (WEC, 2004)[4] turn out to be lower than the *realistic* onshore wind power potential by (De Noord *et al*., 2004). Table 5.1 has been used to estimate the '*realisable* onshore wind potential' in the EU-15, Norway, and Poland (Figure 5.2). Appendix E and F provide details about the '*realisable* potential'. Poland's wind potential is estimated at 4.5 GW, based on 10.5 TWh/year in (EWEA, 2003)[5].

In areas with a favourable wind regime - >7 m/s and 6-7 m/s - a large percentage of the land could be available for wind farms. For less favourable wind regimes of 5-6 m/s and <5 m/s it is assumed that only three-quarters and approximately 10%, respectively, of the realistic potential will turn out to be available.

4 (WEC, 2004) presents estimates of the onshore wind potential of Finland (5,400-7,600 MW), Greece (3,000 MW), and Ireland (2,190 MW). These wind potentials are systematically lower than those of (De Noord *et al*., 2004).

5 EWEA = European Wind Energy Association.

Also, difficulties with transmission of electricity, e.g., in Germany with regard to both onshore and offshore wind energy (Birnbaum, 2005), may slow down the growth of wind energy. Until 2050, the potential of Table 5.1 could be utilised as follows:

- Class >7 m/s (Band 1) 88%
- Class 6-7 m/s (Band 2) 94%
- Class 5-6 m/s (Band 3) 76%
- Class <5 m/s (Band 4) 11%.

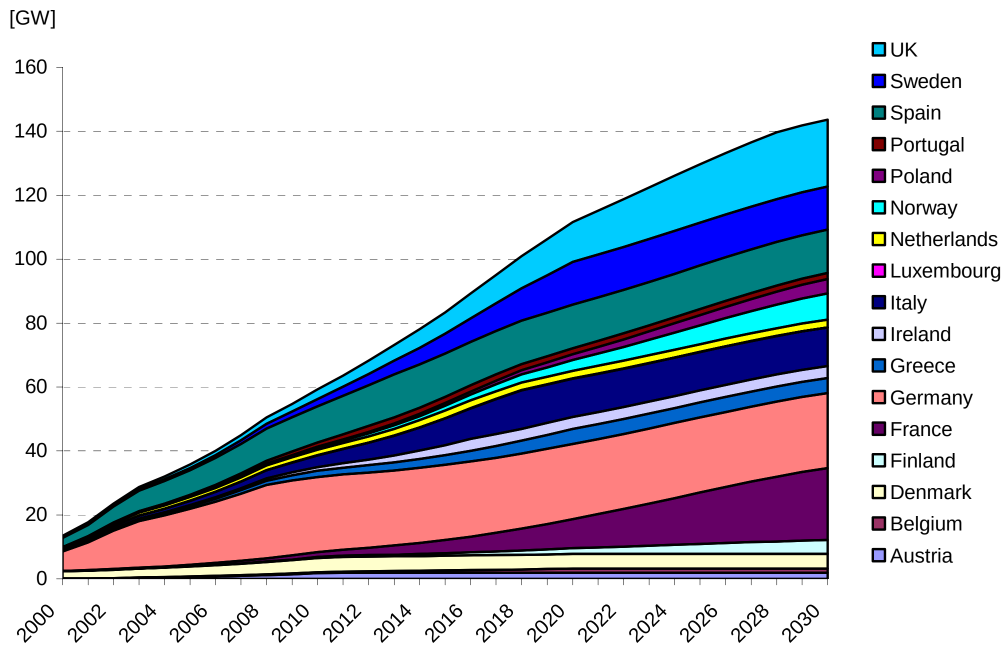

Figure 5.2 *Realisable onshore wind capacity based on realistic potential*
Note: The countries considered are the EU-15, Norway, and Poland.
Based on Table 5.1.

Figure 5.3 shows the corresponding '*realisable* onshore wind capacity' based on Appendix E.

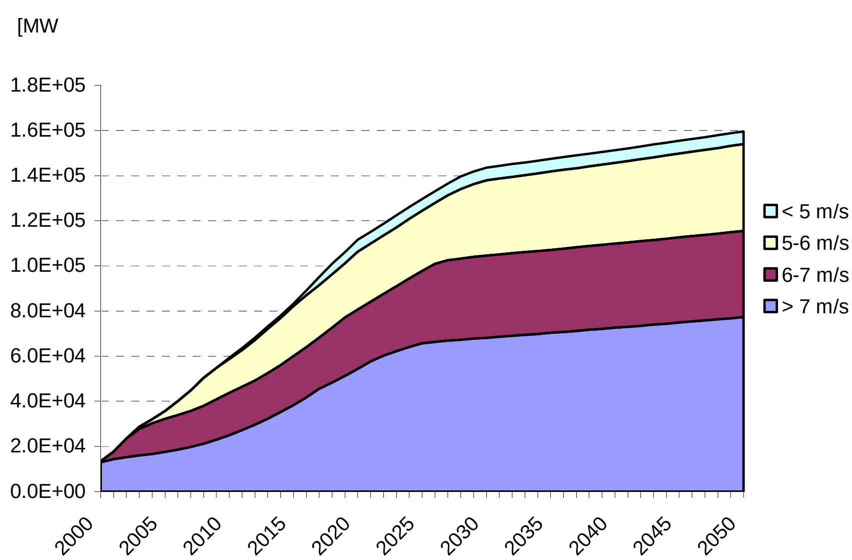

Figure 5.3 *Realisable onshore wind capacity derived from realistic potential by wind class*
Note: The countries considered are the EU-15, Norway, and Poland.

It has been assumed that the '*realisable* onshore wind potential' of 160 GW could be fully utilised in 2050. The '*realisable* onshore wind capacity' is less than the *realistic* potential due to conflicting land use, protection of landscape, etc. After 2030, additional capacity could built in:

- Norway: 100% instead of roughly 50% of the potential of '>7 m/s'
- Finland: 100% instead of approximately 50% of the potential of '6-7 m/s'
- France: 100% instead of roughly 60% of the potential of '5-6 m/s'.

Figure 5.4 shows the '*realisable* onshore wind potential' in terms of electricity output (PJ_e).

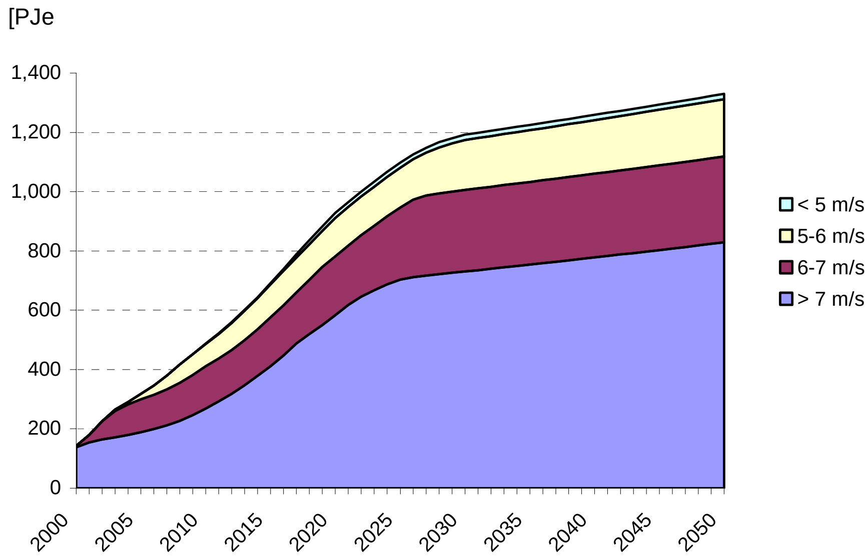

Figure 5.4 *Realisable onshore wind generation*
Note: The countries considered are the EU-15, Norway, and Poland.
Based on Figure 5.3

Figure 5.3 and Figure 5.4 indicate that the '*realisable* potential' of onshore wind could be approximately 160 GW or 1,330 PJ_e. For the EU-15, onshore wind is deemed to increase to 132.5 GW in 2035 - 5.6 times the onshore wind capacity in 2003 (Appendix G). Such a capacity could generate 1,085 PJ_e (300 TWh) on an annual base. As projections of the electricity demand of the IEA in (WEO, 2004) only pertain to 2010-2030, the electricity demand of the EU-15 has been extrapolated to 2035. Onshore wind could be equivalent to approximately 7% of the extrapolated electricity demand of the EU-15 in 2035.

5.4 Preliminary conclusions

By applying restrictions on wind power in areas with low average wind speeds the potential of onshore wind in the EU-15, Norway, and Poland may be reduced to a more realistic level of the order of magnitude of 160 GW. Also, difficulties with transmission of electricity (e.g. in the UK and Germany) may slow down the growth of onshore wind. The level of 160 GW could be reached by 2050. In areas with a favourable wind regime - >7 m/s and 6-7 m/s - a large part of the land could be available for wind farms. For less favourable wind regimes of 5-6 m/s and <5 m/s it is assumed that only three-quarters and approximately 10%, respectively, of the realistic potential will turn out to be available. In other words: the higher the wind speed, the more land is deemed preserved for wind farms.

If these restrictions are also applied to the EU-15 countries - excluding Norway and Poland - the potential deemed achievable is 132.5 GW in 2035 - 5.6 times the onshore capacity in 2003.

Such a capacity could generate 1,085 PJ_e (300 TWh) on an annual base. As projections of the electricity demand of the IEA in (WEO, 2004) only pertain to 2010-2030, the electricity demand of the EU-15 has been extrapolated to 2035. The aforementioned output from onshore wind could be equivalent to 7% of the extrapolated electricity demand of the EU-15 in 2035.

6. OFFSHORE WIND RESOURCES IN EU-15 COUNTRIES

6.1 Introduction

The potential of offshore wind in Europe is very large because of high wind speeds at the North Sea, Baltic Sea, Atlantic Ocean, etc. Definitions of e.g. *realistic* potential for onshore wind (Chapter 5) could equally apply to offshore wind. §6.2 gives a view of the period 2003-2008, §6.3 presents a scenario for the EU-15 until 2030, and §6.4 gives a few preliminary conclusions.

6.2 Period 2003-2008

(BTM, 2004) gives a forecast of offshore wind in the EU-15 until 2008. Therefore, scenarios until 2030 can only profit from BTM's projection for until 2008. According to BTM, offshore wind could show a rather 'bumpy' growth, ending with a 41% growth rate in 2008 (Table 6.1).

Table 6.1 *Forecast of offshore wind power 2003-2008 (EU-15, cumulative capacity)*

[MW]	2002	2003	2004	2005	2006	2007	2008
Belgium	0	0	0	0	100	400	400
Denmark	233	398	398	398	398	558	558
France	0	0	2	52	52	52	52
Germany	0	0	7	287	727	2,567	3,467
Ireland	0	25	85	85	103	403	628
Netherlands	19	19	19	139	139	239	339
Spain	0	0	0	0	220	220	220
Sweden	23	23	23	261	261	361	561
UK	4	64	248	624	834	1,158	2,158
Total	279	529	782	1,846	2,834	5,958	8,383
Growth rate [%]		90	48	136	54	110	41

Source: BTM, 2004.

Figure 6.1 shows the offshore wind power capacity based on Table 6.1 as a function of time.

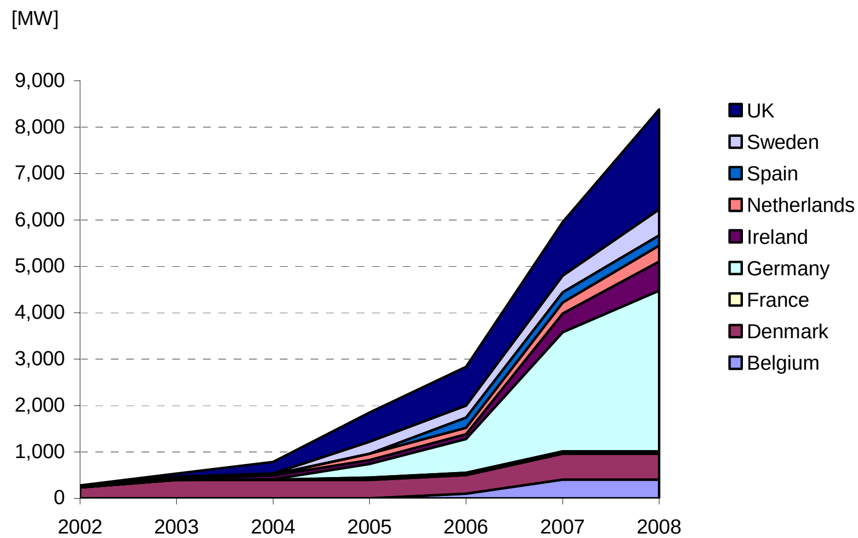

Figure 6.1 *Forecast of offshore wind capacity EU-15*
Source: BTM, 2004.

In the period 2003-2008, Germany and the UK are apparently considered to be the main markets for offshore wind.

6.3 Period 2003-2030

The growth of offshore wind is assumed to be 40% from 2008 - the last year of the forecast by (BTM, 2004) - and decreasing steadily to 5% in 2030. The offshore wind capacity in the EU-15 is estimated at 250 GW in 2030 (Figure 6.2). As there are not so many conflicting interests, the planning process is assumed to become much easier offshore than onshore, when first experience has been gained. Therefore, growth rates of offshore wind may be higher than onshore. According to a scenario developed for Greenpeace, offshore wind could be 250 GW in 2020 (Greenpeace, 2004). However, this could put serious strains on planning and logistics for offshore wind. Also, power transmission may be a constraint in, e.g., Germany (Ernst *et al*., 2004; Birnbaum, 2005).

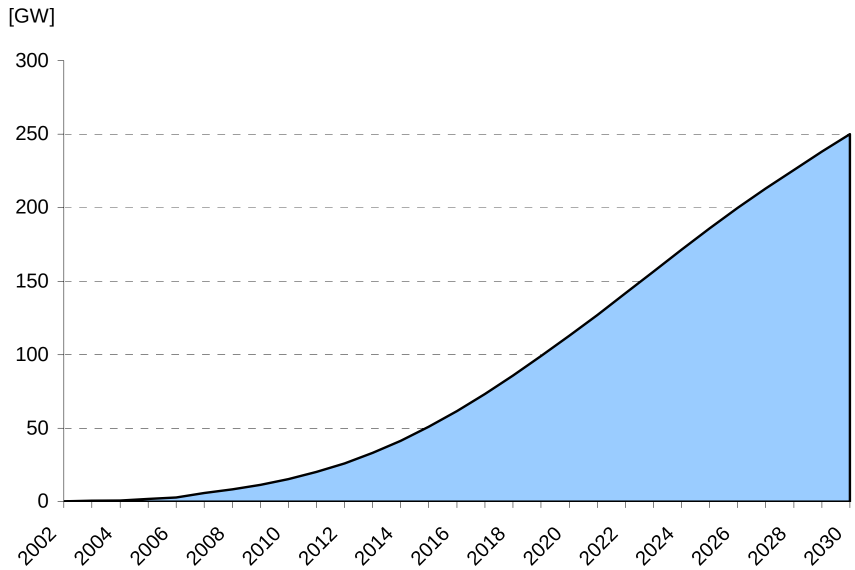

Figure 6.2 *Possible development of offshore wind capacity in Europe, 2003-2030*

Appendix G gives a view of the total contribution from onshore and offshore wind for the EU-15. An offshore wind capacity of 250 GW could generate 2,880 PJ_e (800 TWh) on an annual base. This could be equivalent to 18% of the EU-15's electricity demand in 2035.

6.4 Preliminary conclusions

The potential of offshore wind in the EU-15 is very large because of relatively high wind speeds in the North Sea, Baltic Sea, Atlantic Ocean, Irish Sea, and Mediterranean Sea. As there are not so many conflicting interests, the planning process is assumed to be much easier offshore than onshore, when first experience has been gained. Also, growth rates of offshore wind may be higher than onshore. A plausible scenario appears to be 250 GW offshore wind capacity in the EU-15 around 2030. This implies a time lag of 10 years compared to a scenario of Greenpeace. In 2035, offshore wind could provide approximately 18% of the EU-15's electricity demand.

7. PHOTOVOLTAIC RESOURCES IN EU-15 COUNTRIES

7.1 Introduction

Today, solar energy has a tiny contribution in the world total primary energy supply of less than 1‰. Although PV is growing fast, it remains small compared to e.g. wind energy. §7.2 presents a context and methodology. §7.3 analyses the potential of PV on roofs and façades of buildings in the EU-15, §7.4 explores a few PV scenarios, and §7.5 gives a few preliminary conclusions.

7.2 Context and methodology

The potential of solar energy - passive solar heat, collectors for e.g. hot water, and photovoltaic energy (PV) - is tremendous. The average annual flux on a horizontal surface is approximately 170 W/m^2. The flux varies from 300 W/m^2 in the Red Sea area and 200 W/m^2 in Australia to 105 W/m^2 in the UK. Generally, the annual solar resource varies by a factor of 2 to 3. The efficiency of solar technologies is as follows: 1 m^2 intercepting a flux of 1,000 W/m^2 of solar energy could deliver over 600 W of passive solar heat (e.g., through glass). Alternatively, PV can deliver 100 W/m^2 of peak power, and a solar thermal collector 300 W/m^2 (WEC, 2004).

The role of an individual solar technology can be enhanced by integration with other energy efficient or solar powered technologies. Substituting e.g. solar heat for electric hot water boilers or substituting innovative models for conventional electrical appliances may reduce electricity demand and increase the significance of, e.g. the contribution of PV to the whole energy budget. Assessments show that the available area of roofs and façades on buildings in the EU-15 is of the order of magnitude of 7,000 to 8,000 km^2. The assessments invariable start with inventories of roof and façade area on buildings (residential and non-residential). Then, restrictions are applied for other uses of roofs, shadowing, etc. Also, solar thermal collectors for e.g. hot water may be considered. In order to compare different assessments, a rule-of-thumb is used for solar thermal collectors. The remaining area on roofs and façades is deemed available for PV.

7.3 Maximum realistic potential based on roof and façade area in the EU-15

(Lehmann *et al*., 2002) give an estimate of the potential of PV in the EU-15 on roofs and façades of residential and non-residential buildings based on an analysis of the relation between roof area per capita and population density. A corner stone of their analysis is an assessment of the area of roofs and façades of residential and non-residential buildings in Northrine-Westfalia (Germany). In the EU-15, some 7,000 km^2 of roof and façade area on buildings - 65% and 35%, respectively - would be available for solar applications. Assessments by the IEA (IEA, 2001) and (De Noord *et al*., 2004) tend to give higher estimates of this potential (Table 7.1).

In general, the potentials on roof and façades of buildings in the EU-15 of (De Noord *et al*., 2004) are quite comparable to those of Lehmann *et al*. In general, the differences are not large. An exception is Sweden: the figures for Sweden differ by an order of magnitude. The estimate of the total EU-15 potential of roofs by De Noord *et al*. is 30% higher than that of Lehmann *et al*., but the difference for roofs and façades is only 16%, which is quite satisfactory. Therefore, a range of 7,000 to 8,000 km^2 seems to be a right yardstick for the PV potential on buildings.

Table 7.1 *Roof and façade area potential for all types of buildings in the EU-15*

[km^2]	Roof		Façade		Total	
	Lehmann *et al*.	De Noord *et al*.	Lehmann *et al*.	De Noord *et al*.	Lehmann *et al*.	De Noord *et al*.
Austria	103	139.6	55	50.3	158	189.9
Belgium	118	189.6	65	66.6	183	256.2
Denmark	65	88.0	35	30.6	100	118.6
Finland	72	127.3	37	30.6	109	157.9
France	750	1,095.9	398	385.0	1,148	1,480.9
Germany	985	1,295.9	531	465.5	1,516	1761.4
Greece	130	196.3	70	69.0	200	265.3
Ireland	49	70.4	26	24.7	75	95.1
Italy	739	763.5	392	269.2	1,131	1,032.7
Luxembourg	5	8.1	3	2.8	8	10.9
Netherlands	175	259.4	96	91.1	271	350.5
Portugal	137	185.3	71	65.1	208	250.4
Spain	528	448.8	244	145.5	772	594.3
Sweden	21	218.8	11	74.8	32	293.6
UK	692	914.7	378	346.3	1,070	1,261.0
Total	4,571	6,002.0	2,411	2,117.0	6,980	8,119.0

Sources: Lehmann *et al*., 2002; IEA, 2001; de Noord *et al*., 2004.

De Noord *et al*. assume the following yield of PV systems for 'geographical Bands' (Table 7.2).

Table 7.2 *Capacity factors and average yield of PV per Band in 2000 and in 2030*

	Capacity factor [%]	Solar radiation [$kWh/m^2/a$]	Yield 2000[a] [$kWh/m^2/a$]	Yield 2030[b] [$kWh/m^2/a$]
Band 1	18.0	>1800	157	315
Band 2	16.5	1600-1800	145	289
Band 3	14.6	1400-1600	128	255
Band 4	12.6	1200-1400	111	221
Band 5	10.7	1000-1200	94	187
Band 6	9.2	<1000	81	162

a) Based on a yield of 100 Wp/m^2 in 2000.
b) Based on a yield of 200 Wp/m^2 in 2030.
Source: De Noord *et al*., 2004.

Based on these Bands, De Noord *et al*. estimate the PV potential of the EU-15 at 810 GW with a power density of 100 Wp/m^2 (a figure representative of the year 2000). Lehmann applies a different approach in a study for Japan (Lehmann, 2003). He factors in the need for solar thermal systems. According to Lehman, collectors for e.g. hot water would require approximately 3 m^2/capita. Table 7.3 shows the PV potential in the EU-15, if the potential according to De Noord *et al*. is corrected by including 3 m^2/capita for solar thermal systems. Compared to the original estimate of De Noord *et al*., the PV potential decreases by 12.5%.

Table 7.3 *PV potential based on a power density of 100 Wp/m² for roofs and façades*[a]

[GW]	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Total
Austria			0.8	14.1	1.7		16.6
Belgium					22.5		22.5
Denmark					9.7	0.5	10.2
Finland						14.2	14.2
France			39.0	52.0	52.0		143.1
Germany					106.0	45.4	151.4
Greece	5.8	17.4					23.2
Ireland					5.8	2.5	8.3
Italy	12.9	51.6	12.9	8.6			86.0
Luxembourg					1.0		1.0
Netherlands					3.0	27.2	30.2
Portugal		14.7	7.2				21.9
Spain	7.1	23.6	16.5				47.1
Sweden						26.7	26.7
UK					27.1	81.2	108.2
EU-15	25.8	107.3	76.5	74.7	228.7	197.6	710.7

a) 3 m²/capita on roofs has been assumed preserved for solar thermal systems (e.g. for hot water).

7.4 Realisable PV potential in the EU-15

The PV potentials of §7.3 may not be achieved in practice due to competing uses of roofs and façades. Implementation of the potential will take a long period of time as PV is in the early take-off stage. In the EU, the installed PV capacity is more than an order of magnitude lower than that of wind energy. A substantial reduction of the price of PV systems is necessary.

Regions with a relatively modest yield - e.g., the UK with a flux on a horizontal surface of only 105 W/m² - will have more difficulty in developing their potential than, e.g., Greece, Italy, and Spain. Also, today the installed PV capacity in the EU-15 is a tiny 562 MW (2003) according to (Zervos, 2004). Therefore, it is necessary to factor in growth constraints with regard to deployment of PV. Figure 7.1 shows four deployment scenarios for PV in the EU-15, three of which stem from (De Noord *et al.*, 2004). The fourth scenario - ‘Achievable’ - has been added to illustrate the effect of an EU-wide PV programme.

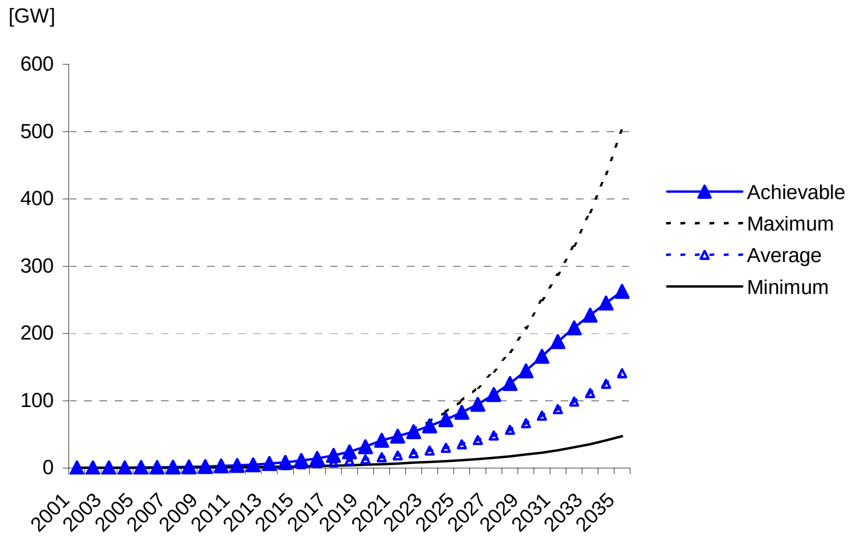

Figure 7.1 *Installed capacity of solar PV in Europe for four deployment scenarios*
Note: Three scenarios stem from (De Noord *et al*., 2004). Scenario 'Achievable' has been added.

Scenario 'Maximum' is not regarded as realistic, but scenario 'Achievable' seems to be so. Saturation effects are assumed to start occurring around 2030 in scenario 'Achievable'. Table 7.4 shows the data with regard to installed capacities on which Figure 7.1 is based.

Table 7.4 *Installed capacity of solar PV in Europe for four deployment scenarios (GW)*

Scenario	2001	2005	2010	2015	2020	2025	2030	2035
Maximum	0.276	0.80	3.00	10.95	40.0	100.0	250	503
Achievable	0.276	0.79	3.00	11.10	41.1	82.6	166	263
Average	0.276	0.67	2.00	5.66	16.0	35.3	78	141
Minimum	0.276	0.49	1.00	2.45	6.0	11.7	23	47

Table 7.5 shows the electricity generation and the growth rates of the 'Achievable' PV scenario. This scenario would be tantamount to an electricity generation of approximately 1,010 PJ_e (280 TWh) in 2035. This could be equivalent to 7% of the extrapolated electricity demand in 2035.

Table 7.5 *Solar PV electricity generation in Europe based on 'Achievable' PV scenario*

[EJ_e]	2003[a]	2005	2010	2015	2020	2025	2030	2035
Austria	0.1	0.1	0.3	1.0	3.8	7.6	15.3	24.1
Belgium	0.0	0.1	0.3	1.2	4.4	8.8	17.8	28.1
Denmark	0.0	0.0	0.1	0.5	2.0	4.0	8.0	12.7
Finland	0.0	0.0	0.2	0.6	2.4	4.8	9.6	15.2
France	0.1	0.7	2.5	9.2	34.2	68.7	138.3	218.5
Germany	1.3	0.5	2.1	7.6	28.3	56.9	114.4	180.8
Greece	0.0	0.1	0.5	1.9	7.1	14.4	28.9	45.6
Ireland	0.0	0.0	0.1	0.5	2.0	4.0	8.0	12.7
Italy	0.1	0.5	1.8	6.8	25.2	50.6	101.8	160.9
Luxembourg	0.0	0.0	0.0	0.1	0.2	0.4	0.8	1.2
Netherlands	0.1	0.1	0.4	1.4	5.1	10.3	20.8	32.9
Portugal	0.0	0.1	0.5	1.7	6.3	12.7	25.6	40.5
Spain	0.1	0.3	1.0	3.7	13.8	27.8	55.8	88.2
Sweden	0.0	0.1	0.3	1.2	4.5	9.0	18.1	28.6
UK	0.0	0.4	1.4	5.1	18.9	38.0	76.4	120.8
EU-15	1.9	3.0	11.5	42.7	158.1	318.0	639.6	1,010.6
Growth rate [%/a]		25	31	30	30	15	15	10

a) 2003 shows the potential generation based on the capacity (EU: 562 MW) by the end of 2003. The years 2005-2035 show the potential generation based on a proportional share of the potential.

7.5 Preliminary conclusions

The potential of solar energy - passive solar heat, collectors for e.g. hot water, and photovoltaic energy (PV) - is tremendous. De Noord *et al*. estimate the PV potential of the EU-15 at 810 GW with a power density of 100 Wp/m^2 (a figure representative of the year 2000). Reservation of 3 m^2/capita for solar thermal systems would decrease the estimate of De Noord *et al*. by 12.5%.

A PV capacity of 710 GW in the EU-15 could generate 1,010 PJ_e (280 TWh) on an annual base. As projections of the electricity demand of the IEA in (WEO, 2004) only pertain to 2010-2030, the electricity demand of the EU-15 has been extrapolated to 2035. The projected output of 1,010 PJ_e (280 TWh) could be equivalent to 6% of the extrapolated electricity demand in 2035.

8. BIOMASS RESOURCES AND AVAILABILITY

8.1 Introduction

The potential of biomass depends *inter alia* on land availability, demand for food, consumption patterns, the world population, etc. This chapter addresses the potential of biomass, and that of biomass trade. §8.2 presents the context, definitions, and the methodology. The potential of biomass is reported in §8.3, import of biomass in §8.4, and preliminary conclusions in §8.5.

8.2 Context, definitions, and methodology

On a global scale, the following areas are used for agriculture, forestry, fibre production, etc.:

- Agricultural land 5.0 Gha[6]
- Land for forestry and fibre production 4.0 Gha
- Remaining land (*inter alia* mountains, savannah, steppe, and grassland) 4.2 Gha

(Hoogwijk, 2004) gives the following definitions of biomass potentials:

- *Theoretical potential*: the theoretical upper limit of primary biomass, i.e. the biomass produced at the total earth surface by the process of photosynthesis.
- *Geographical potential*: the theoretical biomass potential on a certain land area.
- *Technical potential*: the geographical potential excluding the losses due to converting of primary biomass in secondary energy carriers.
- *Economic potential*: the fraction of the technical potential that can be realised at a competitive cost level, depicted by a cost-supply curve of secondary biomass energy.
- *Implementation potential*: the fraction of the economic potential that can be implemented within say 50 years, taking into account institutional constraints and incentives.

Table 8.1 shows the resource categories for biomass and residues distinguished by Hoogwijk.

Table 8.1 *Biomass resource categories*

Category	Type of land/product	Specification of biomass or waste
I	Surplus agricultural land	Biomass produced on surplus agricultural land
II	Degraded land	Biomass produced on deforested or marginal land
III	Agricultural residues	Residues from food production and processing
IV	Forest residues	Residues from wood production and processing
V	Animal manure	Biomass from animal manure
VI	Organic wastes	Waste wood or municipal solid waste.
VII	Bio-materials	Biomass used as a feedstock for materials (pulp, fibre, etc.)

Source: Distinguished by Hoogwijk, 2004.

[6] Hoogwijk assumes that the area available for food production will remain approximately 5 Gha.

Figure 8.1 shows in a simplified way how the potential of energy crops has been determined.

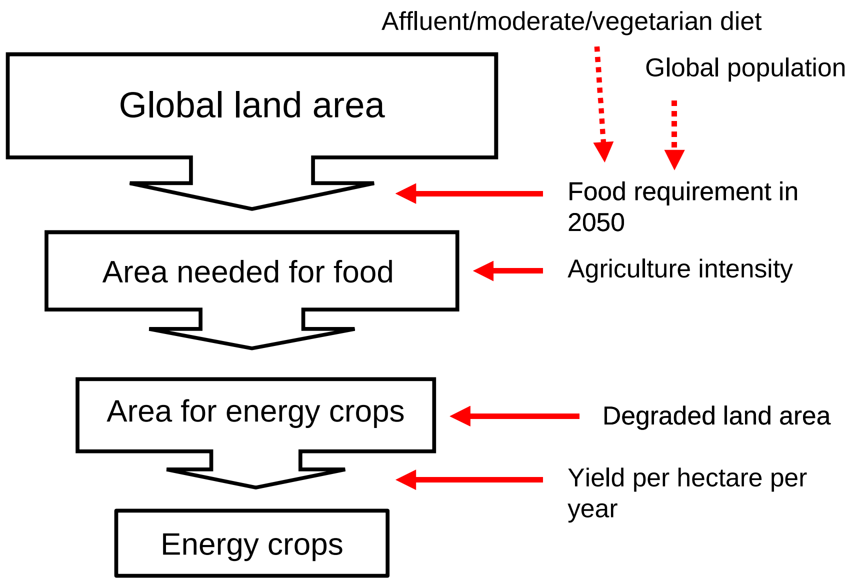

Figure 8.1 *Method to determine the potential of energy crops*

8.3 Potential of biomass and residues in Europe and the rest of the world

8.3.1 Geographical potential

(Hoogwijk, 2004) gives an assessment of the *geographical potential* of biomass by world region. She presents estimates of the biomass potential, differentiating between 17 world regions. In this study, Hoogwijk's estimates of the *geographical biomass potential* are presented. In Appendix H the way in which Hoogwijk determines this potential is explained, whereas Appendix I shows biomass potentials by world region and scenario. According to Hoogwijk, the *geographical potential* ranges from 305 to 660 EJ/a in 2050, and from 395 to 1,165 EJ/a in 2100. For OECD Europe these ranges are 10 to 16 EJ/a in 2050, and 15 to 21 EJ/a in 2100 (Table 8.2).

Table 8.2 *Geographical potential energy crops in OECD Europe by IPCC-SRES scenario*

[EJ/a]	2050				2100			
Kind of land-use *Scenario*	A1	A2	B1	B2	A1	A2	B1	B2
Abandoned agricultural land	9	10	9	15	16	11	14	17
Low-productive land	0	0	0	0	0	0	0	0
Remaining land (savannah, etc.)	4	4	1	1	5	4	1	1
Total available land area	13	14	10	16	21	15	15	18

Source: Hoogwijk, 2004.

8.3.2 Realisable potential of energy crops, agricultural and forestry residues, and waste

The preceding paragraph addressed the *geographical biomass potential* of world regions, e.g. of OECD Europe. This potential has to be narrowed to make an educated guess of the *realisable biomass potential* in the EU-15. (De Noord *et al*., 2004) developed a methodology to determine the *realisable potential*[7] of the EU-15+: EU-15, Norway, and Switzerland (Table 8.3).

Table 8.3 *Realisable potential of energy crops in EU-15+[a] according to De Noord et al.*

	Agricultural area [1000 ha]	Available area [1000 ha]	Yield/harvest[b] [ton ODM/ha][c]	Potential [PJ/a][d]
Austria	3,470	160	7.0	31
Belgium	1,544	72	8.2	16
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	123	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	145,460	14,930		1,941

a) EU-15+ = EU-15, Norway, and Switzerland.
b) Harvest index 0.6.
c) ODM = Oven Dry Matter.
d) Lower heating value 16.5 GJ/ton.
Source: De Noord *et al*., 2004.

The order of magnitude of the *realisable* potential of energy crops in the EU-15 estimated by De Noord *et al*. - approximately 1.9 EJ/year - is confirmed by (Frey *et al*., 2004), as depicted by Figure 8.2.

7 The *realisable* potential according to De Noord *et al*. could be equal to the *implementation potential* of Hoogwijk.

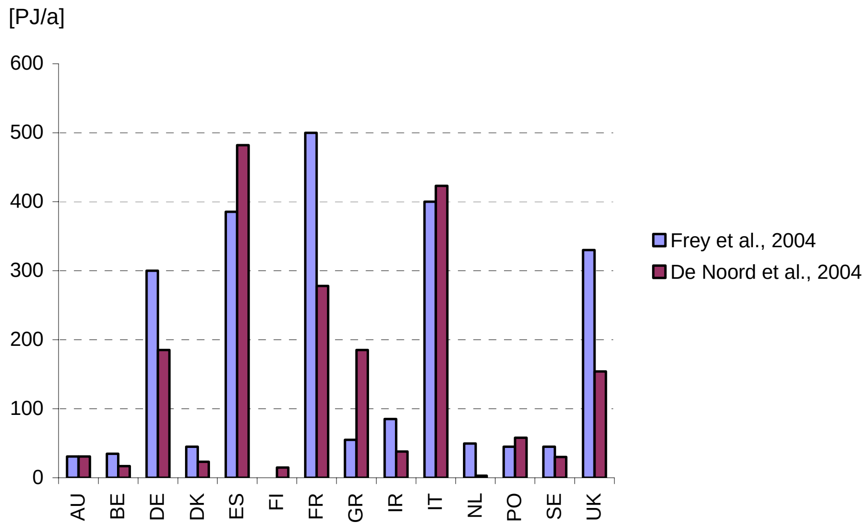

Figure 8.2 *Possible development of the realisable potential of energy crops in the EU-15*
Sources: De Noord et al., 2004; Frey *et al*., 2004.

Frey *et al*. give the following *realisable* potentials for *biomass in the broad sense of the word* - energy crops, agricultural and forestry residues, and organic waste - in the EU-15 (Figure 8.3).

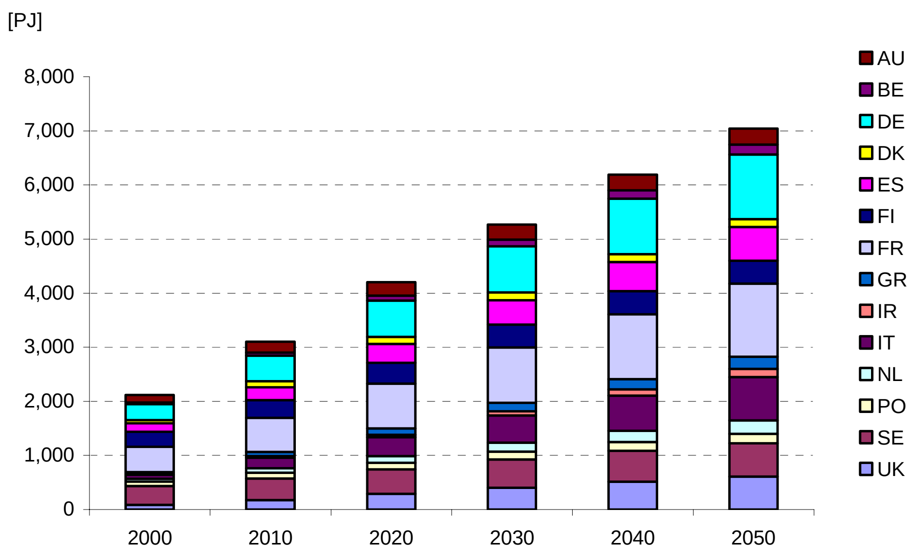

Figure 8.3 *Possible development of biomass, waste, and energy crops by EU-15 country*
Source: Frey *et al*., 2004.

Table 8.4 presents the data on biomass, waste, and energy crops on which Figure 8.2 is based. According to Frey *et al*., the use of biomass *in the broad sense of the term* - energy crops, agricultural and forestry residues, and organic waste - in the EU-15 may increase from 2.1 EJ/a in 2000 to 7 EJ/a in 2050 (with a compounded average growth of about 2.5%/a). About one-third of the aforementioned potential could be made available by energy crops. The figure of 7 EJ/a in (Frey *et al*., 2004) is underpinned by country-specific estimates for Austria, Denmark, Finland, Germany, the Netherlands, and Sweden. Therefore, the conclusion is that the *realisable potential* of biomass (in the broad sense of the term) of the EU-15 may be 7 EJ/a.

Table 8.4 *Possible development of biomass, waste, and energy crops in the EU-15*

	2000 [PJ/a]	2010 [PJ/a]	2020 [PJ/a]	2030 [PJ/a]	2040 [PJ/a]	2050 [PJ/a]	Growth rate 2000-2050 [%/a]
AU	140	200	250	275	290	300	1.5
BE + LU	24	55	90	125	155	180	4.1
DE	295	475	675	850	1,025	1,200	2.8
DK	64	110	130	145	145	145	1.6
ES	153	240	350	450	540	620	2.8
FI	282	330	385	425	425	425	0.8
FR	468	625	825	1,025	1,200	1,350	2.1
GR	42	80	120	155	190	225	3.4
IR	6	25	45	80	115	150	6.6
IT	71	200	350	500	650	800	5.0
NL	50	80	120	165	210	250	3.3
PO	86	105	125	145	160	175	1.4
SE	351	400	450	525	575	620	1.1
UK	82	175	290	400	510	605	4.1
EU-15	2,114	3,100	4,205	5,265	6,190	7,045	2.4

Source: Frey *et al*., 2004.

8.4 Import of biomass

Several world regions appear to have a much larger biomass potential than others and could become net exporters. The FSU, Oceania, and East Africa may have excess potential (Figure 8.4).

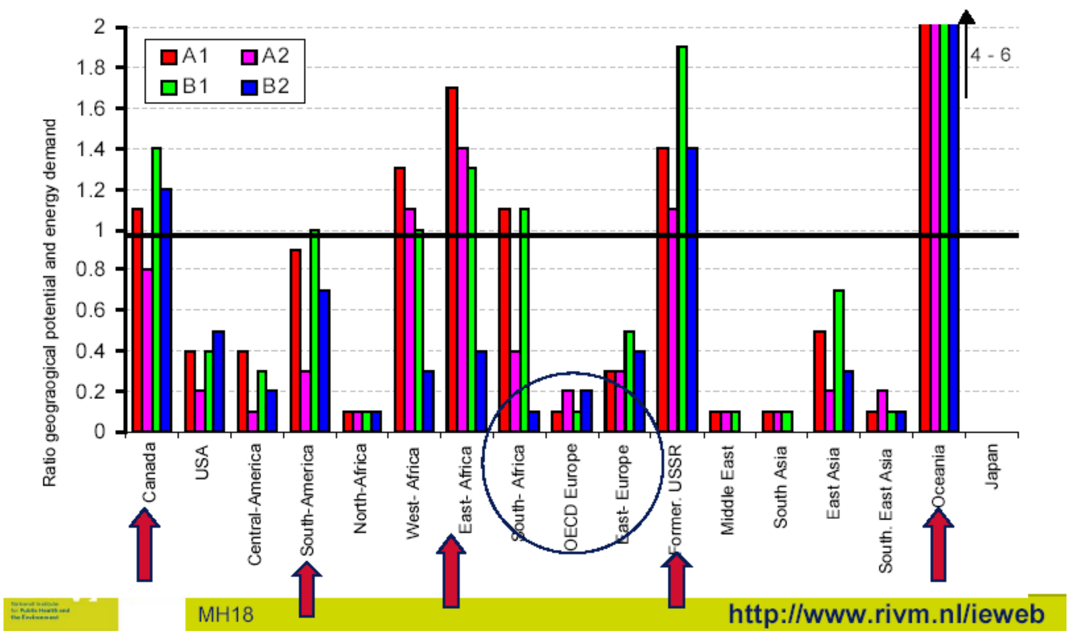

Figure 8.4 *Self-sufficiency with regard to biomass and regional interdependence based on IPCC SRES scenarios*

Source: Internet source 4.

At a regional level, the Former Soviet Union (FSU), China, and South America have the highest *geographical potential*. Other regions do not have much potential compared to their primary energy demand, notably Japan, the Middle East, South and South East Asia, and OECD Europe.

On the long term, countries with surplus biomass potential could develop into exporters of bioenergy (biofuels from biomass). Bioenergy trade has increased rapidly during the past ten years thanks mainly to the dynamic growth in the use of biomass for district heating, especially in Northern Europe. If the bioenergy potential of other regions of the world could be tapped in a sustainable and effective manner, an international system for trade of energy from biomass could be effective way to utilise the bioenergy (Yamashita *et al*., 2004). According to (Faaij, 2003), the trade in bioenergy may develop in different ways (Table 8.5).

Table 8.5 *Possible ways of bioenergy trade*

Exporter	Transport/transfer/storage	Importer
Biomass production	'Raw' biomass	Full conversion
Biomass production & pre-treatment	Pre-treated biomass (pellets, bales, a crude oil from biomass)	Partial conversion
Biomass production & conversion	Fuels (H_2, MeOH, EtOH, hydrocarbons)	End-use
Biomass production & electricity generation	Electricity	End-use
Biomass production	'Conversion-along-the-way'	End-use

Source: Faaij, 2003.

Yamashita *et al*. and Faaij investigated the energy penalty of biomass transport by ship for 'raw' biomass (logs, chips) or for refined biofuels. Invariably, the energy penalty proves to be not an insurmountable problem. The cost of electricity based on imported biomass could be high compared to conventional alternatives: 6.4-8 €ct/kWh and 3-5 €ct/kWh, respectively (Table 8.6).

Table 8.6 *Cost of electricity generation in the Netherlands based on imported biomass*

Origin	Sweden				Estonia	Ecuador
[€ct/kWh]	Bales from logging residues	Bundles of trees from thinning	Pellets from logging residues	Willow chips	Logs	Eucalyptus logs
Generation	2.9	2.9	2.4	2.6	2.9	3.0
Transport	1.9	2.55	0.65	2.3	2.0	3.0
Treatment			2.7			
Biomass	2.3	2.3	2.3	3.3	1.5	2.0
Total	7.1	7.75	8.05	8.2	6.4	8.0

Source: Faaij, 2003.

8.5 Preliminary conclusions

On a global scale, the following areas are used for agriculture, forestry, fibre production, etc.:

- Agricultural land 5.0 Gha
- Land for forestry and fibre production 4.0 Gha
- Remaining land (*inter alia* mountains, savannah, steppe, and grassland) 4.2 Gha

Hoogwijk assumes that the area available for food production will remain approximately 5 Gha. The global *geographical potential* (the theoretical biomass potential on a certain land area.) of biomass is estimated at 305-660 EJ/a in 2050, and 395- 1,165 EJ/a in 2100. The *geographical potential* of OECD Europe appears to range from 10 to 16 EJ/a in 2050, and from 15 to 21 EJ/a in 2100.

This *geographical potential* has to be narrowed to make an educated guess of the *realisable potential* of biomass in the EU-15. The use of biomass *in the broad sense of the term* - energy crops, agricultural and forestry residues, and organic waste - in the EU-15 may increase from 2.1 EJ/a in 2000 to 7 EJ/a in 2050. About one-third of the *realisable biomass potential* could be made available by energy crops.

Besides, Europe could import biomass from overseas. There are several world regions that could have export potential, e.g. the FSU, Oceania, and East Africa. Studies by Yamashita *et al*. and Faaij prove invariably that the energy penalty of biomass transport by ship for 'raw' biomass is not an insurmountable problem. The cost of electricity based on imported biomass could be high compared to conventional alternatives: 6.4-8 €ct/kWh and 3-5 €ct/kWh, respectively.

9. URANIUM AND THORIUM RESOURCES AND AVAILABILITY

9.1 Introduction

Nuclear power generation has a share in global power generation of 16%. Nuclear power plants are based on uranium mined in surface mines, or by *in situ* leaching. §9.2 presents definitions of uranium resources, and §9.3 estimates of reserves and resources of uranium and thorium. Scenarios for the period until 2060 are presented in §9.4, and a few preliminary conclusions in §9.5.

9.2 Definitions

The World Energy Council (WEC, 2004) defines three main resource categories (Appendix J):

- Reasonably Assured Reserves (RAR). These 'proved' reserves have a high assurance of existence. The WEC follows the practice of the NEA/IAEA and defines reserves in terms of uranium recoverable from mineable ore, allowing for mining and processing losses. Resource estimates are expressed in terms of tonnes of recoverable uranium (U).
- Estimated Additional Reserves (EAR). These have a lower level of confidence than the RAR. RAR and EAR are further separated into categories based on the cost of production, viz. <$40/kgU; $40-80/kgU and $80-130/kgU. Costs include the direct costs of mining, transporting and processing uranium ore, the associated costs of environmental and waste management, and the general costs associated with running the operation.
- Undiscovered, recoverable at up to $130/kgU. These uranium resources have the lowest level of confidence, representing more speculative resources yet undiscovered but believed to exist based on geologic evidence, and recoverable at up to $130/kgU.

9.3 Uranium and thorium reserves and resources

Appendix J presents data on uranium and thorium resources. Figure 9.1 shows the U resources by world region. Up to 99 percent of the reserves recoverable at <$40/kgU are in 10 countries[8].

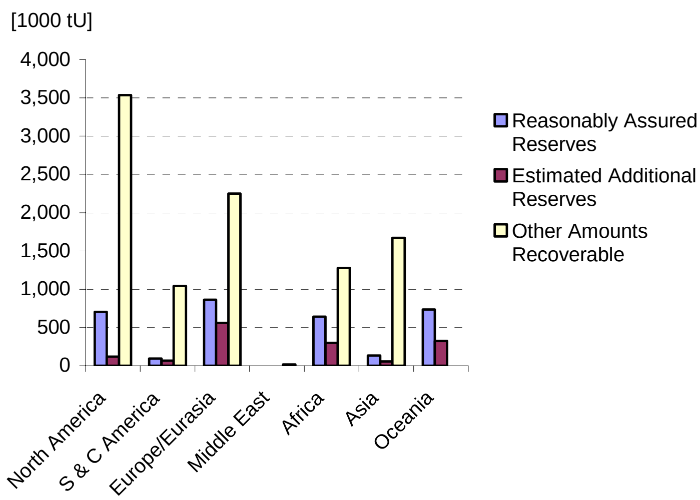

Figure 9.1 *Global uranium reserves (RAR, EAR and other amounts recoverable)*
Source: WEC, 2004.

8 Australia, Kazakhstan, Canada, Niger, South Africa, Namibia, Uzbekistan, Russian Federation, China, and Brazil possess 2,480 ktU recoverable at <$40/kgU, which is 99% of the RAR and EAR in this cost category (2,514 ktU).

The top-5 of these countries, representing 85% of RAR & EAR reserves at <$40/kgU, is:

- Australia 965 ktU (689 ktU RAR + 276 ktU EAR)
- Kazakhstan 422 ktU (281 ktU RAR + 131 ktU EAR)
- Canada 384 ktU (297 ktU RAR + 87 ktU EAR)
- Niger 215 ktU (90 ktU RAR + 125 ktU EAR)
- South Africa 168 ktU (119 ktU RAR + 49 ktU EAR)

RAR and EAR - the ‘known conventional resources’ of uranium - represent 4.59 MtU. If the more speculative resources yet undiscovered but believed to exist based on geologic evidence (Undiscovered, recoverable at up to $130/kgU) are added to that, the resource base of uranium may be even 14.39 MtU. Based on the world’s reactor-related requirements in 2003, viz. 68,435 tU (ATW, 2004), the resources would be sufficient for 210 years of current U demand, viz. 46 years for RAR, 21 years for EAR, and 143 years for ‘Undiscovered, etc.’ resources, - based on the current mix of the once-through process and reprocessing of spent reactor fuel.

In the last decade, uranium production ranged from 32.2 to 37.3 ktU, well below the annual demand for civil reactors. The balance is met from uranium kept in stock at nuclear power plants and in increasing amounts from conversion of high-enriched uranium and plutonium from military stockpiles to low-enriched uranium (by blending with depleted uranium) and MOX fuel respectively. Besides uranium, there are also resources of Thorium (Th). Table 9.1 shows how U and Th resources compare with the uranium demand for civil reactors in 2003. The uranium requirement for civil nuclear reactors was 68,425 tU according to (ATW, 2004). Probably, the Th reserves and resources shown are a conservative estimate as resource data on Th are scarce.

Table 9.1 *Reserves and resources of Uranium and Thorium by world region*

	U RAR [EJ]	U EAR [EJ]	U Other [EJ]	Th Reserves [EJ]	Th Resources [EJ]	U & Th [EJ]	Total U/U demand 2003 [Year]	U & Th/U demand 2003 [Year]
North America	282	47	1,414	108	176	2,027	64	74
S & C America	38	27	417	255	293	1,031	18	38
Europe/Eurasia	345	223	899	252	293	2,013	54	74
Middle East	0	0	6			6	0	0
Africa	256	119	512	21	176	1,084	32	40
Asia	54	22	669	270	59	1,074	27	39
Oceania	294	129	0			423	15	15
Total World	1,270	568	3,918	906	997	7,658	210	280

Note: The unit of kgU has been transformed into EJe based on a conversion ratio of 0.4 PJ/1,000 kgU.
Sources: WEC, 2004; BGR, 2002; ATW, 2004.

9.4 Scenarios for the next 25-50 years

Appendix K presents a few scenarios for the period 2000-2030 from the IAEA (IAEA, 2004) and the IEA (WEO, 2004), including the contribution from nuclear energy. The nuclear capacities assumed in 2030 are ‘frozen’ until 2060 and the cumulative uranium requirements from these scenarios have been calculated. Figure 9.2 shows the cumulative uranium demands from the scenarios in the perspective of the uranium reserves (RAR and EAR), the total uranium resources (RAR, EAR, and speculative resources), and the total uranium and thorium resources. In 2003, nuclear generation amounted to 2,524 TWh according to (IAEA, 2004), and the uranium requirement for civil nuclear reactors was 68,425 tU according to (ATW, 2004). These key data have been used to calculate the cumulative uranium demand for the period 2000-2030. The reserves of uranium in the categories RAR and EAR would be sufficient until 2040-2050.

It is noted that the additional, more speculative uranium reserves, would triple the resource base of uranium, presumed that these additional reserves would prove to be available. On top of that, thorium reserves and resources are at least equal to the RAR and EAR of uranium (§9.3).

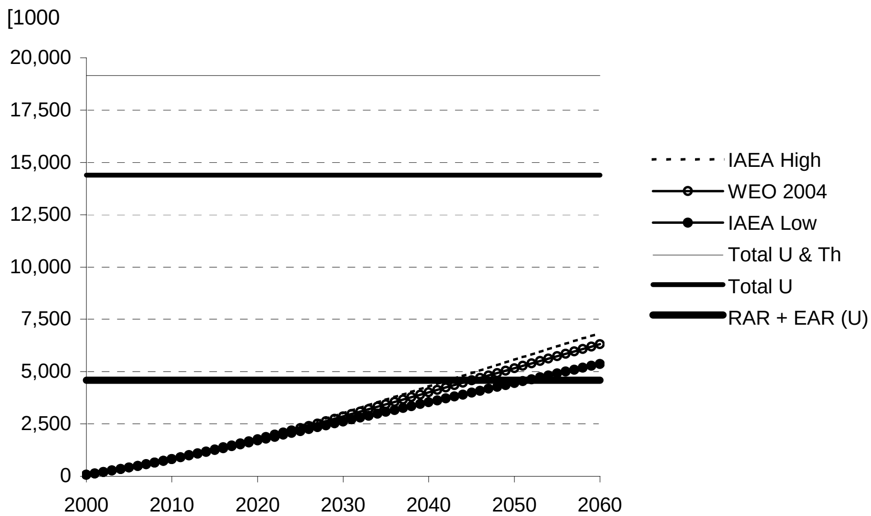

Figure 9.2 *Cumulative global uranium requirements for three scenarios to 2030*
Note: Uranium requirement: ratio of 'uranium requirement 2003'/'nuclear generation 2003'. Installed nuclear capacities in 2030 are assumed 'frozen' towards 2060.
Sources: IAEA, 2004; WEO, 2004; EIA, 2004; ATW, 2004.

Beyond the uranium and thorium reserves and resources, unconventional uranium resources might become available by extraction of uranium from seawater. These speculative uranium resources are estimated at 4,000 MtU (Gruppelaar *et al*., 1998). It is difficult to envision whether and to which extent extraction of uranium from seawater would be feasible from technical, economical, and environmental considerations. However, the potential is huge indeed.

9.5 Preliminary conclusions

The Reasonably Assured Reserves (RAR) and Estimated Additional Reserves (EAR) of uranium - together the 'known conventional resources' - represent 4.59 MtU. This is equivalent to approximately 67 years of current uranium (U) demand for civil nuclear reactors - based on the current mix of the once-through process and reprocessing of spent reactor fuel. If the more speculative resources yet undiscovered but believed to exist based on geologic evidence are added, the resource base may be even 14.39 MtU. This is equivalent to 210 years of current U demand. Uranium reserves in the categories RAR and EAR will not be depleted before 2040, based on scenarios from IAEA and IEA. The additional, more speculative uranium reserves, would triple the resource base if these additional reserves would prove to be available. On top of that, thorium reserves and resources are at least equal to the RAR and EAR of U. All conventional uranium and thorium reserves and resources are equal to about 280 years of current U requirements for civil nuclear reactors.

Beyond the uranium and thorium reserves and resources, unconventional uranium resources might become available by extraction of uranium from seawater. These may be approximately 4,000 MtU. It is difficult to envision whether extraction from seawater would be feasible. However, the potential of the unconventional uranium resources is huge indeed.

10. CONCLUSIONS

The fossil energy sources covered by this study are oil, gas, and coal; the renewables are wind, solar, and biomass; and the fissile energy sources are uranium and thorium. Preliminary conclusions pertain to resources and availability of oil, gas, coal, and uranium and thorium, and to the chance of a peak in production of those energy sources in the next 50 years. Geographical distribution of reserves and resources is important. If resources are found in only a few world regions, limited access to those regions may adversely influence the security of supply.

The results with regard to availability of the 'renewables' wind, solar and biomass are far more conditional. These energy sources are bounded by geographical constraints, e.g., wind and solar energy, as (long-distance) transport of electricity based on wind or solar energy is very costly.

Oil

Oil is the fossil fuel that is most in danger to become short in supply. Its use outstrips that of natural gas, coal, hydro power, nuclear power, biomass, wind power, etc. Oil is mainly produced from conventional reservoirs and to a lesser extent from unconventional oil (extra heavy oil, tar sand, etc.). New oil finds prove to be insufficient to keep pace with increased demand for oil. The Middle East is the dominant oil province of the world, covering 63% of the conventional *reserves*. Conventional oil is equivalent to approximately 60 years of current production (*reserves* 40 years, *resources* 20 years). The conventional oil *reserves* and *resources* combined with the unconventional oil *reserves* would be sufficient for 80 years of current production. Unless unconventional oil *resources* would be producible in the 21^{st} century, oil production is set to decline in the near future. 'Peak Oil' may be deferred to, e.g., 2035, if the next conditions would be fulfilled:

- Global oil demand does not increase significantly.
- Resources of conventional oil (e.g. Middle East) prove to be relatively large.
- Unconventional oil resources turn out to be large and producible in sizeable quantities.

The oil price hinges on the balance between oil demand and supply. The oil market will tighten when 'Peak Oil' approaches. If this happens in the near future, the oil price could remain high.

Gas

The *reserves* and *resources* of conventional gas are comparable in size to those of conventional oil, but global gas consumption is still considerably lower than that of oil. The proved gas reserves are not evenly distributed around the globe: 41% of them are in the Middle East, and 27% in Russia. Conventional gas *reserves* and *resources* are equivalent to approximately 120 years of current production. Including the proved unconventional gas reserves does not significantly change this figure. A peak in conventional gas production may occur between 2020 and 2050. Some energy analysts envision a peak around 2020. However, they presume a resource base for conventional gas that is only fractionally higher than the proved conventional *reserves*. Such a scenario disregards the conventional gas *resources* in addition to the proved reserves. The unconventional gas *resources* are huge. However, it is not certain to which extent unconventional gas *reserves* or *resources* might be recoverable.

Coal

Coal *reserves* are rather evenly spread around the globe: 25% are in the USA, 16% in Russia, and 11.5% in China. The *Reserves/Production* (R/P) *ratio* - approximately 185 or 260 years depending on the literature source used - far outstrips R/P ratios for conventional oil (40 years) and conventional gas (>50 years). Coal *resources* are deemed to be 4.2 times as large as proved *reserves*, but some of them may be low-grade and/or hardly mineable. Although coal is much more abundant than oil and gas on a global scale, coalfields can be depleted on a regional scale.

On a global scale, a peak in coal production is not expected because of supply considerations, but in scenarios based on climate policies the upward trend in coal production may be reversed.

Wind energy

Analysis of the wind resource is particularly relevant on a regional scale (Europe) as wind energy is intermittent and long-distance transport of electricity based on wind or solar energy is very costly. For the EU-15, Norway, and Poland, the '*realisable* potential' of onshore wind is estimated at 160 GW or 1,330 PJ_e. For the EU-15, these figures are 132.5 GW and 1,085 PJ_e (300 TWh), respectively, equivalent to 7% of the extrapolated electricity demand in 2035.

Offshore wind energy is in the take-off stage. The growth of offshore wind is assumed to decrease from 40%/a around 2008 to about 5%/a in 2030. Offshore wind may reach 250 GW, or 2,880 PJ_e (800 TWh), in 2030. Greenpeace assumes that offshore wind could attain the level of 250 GW by 2020. However, this could put serious strains on the planning and logistics needed for offshore wind. Also, electricity transmission may be a constraint, e.g., in Germany. The figure of 800 TWh could be equivalent to 18% of the extrapolated electricity demand in 2035.

Solar PV

The potential of solar energy - passive solar heat, collectors for e.g. hot water, and photovoltaic power (PV) - is tremendous. In the EU-15, some 7,000 km^2 of roof and façade area on buildings would be available for solar applications. If approximately 3 m^2/capita is reserved for solar thermal applications (hot water), the potential for PV is estimated at 700 GW (assuming a yield of 100 Wp/m^2, a figure representative of the year 2000. Today, PV is lagging behind wind energy in terms of installed capacity. Scenarios with regard to the deployment of solar PV in the EU-15 show that the installed PV capacity could be around 260 GW in 2035, with an annual output of 1,010 PJ_e (280 TWh), equivalent to 6% of the extrapolated electricity demand in 2035.

Biomass

For biomass, several potentials may be used. The *geographical* potential - the theoretical potential of biomass on a certain land area - of the OECD Europe ranges from 0 to 16 EJ/year in 2050, and from 0 to 21 EJ/year in 2100. This potential is highly dependent on assumptions with regard to land use, food consumption pattern, and agriculture intensity. However, the *realisable* potential of energy crops in the EU-15 is estimated at 2 EJ/year around 2050. The use of biomass - energy crops, agricultural and forestry residues, and organic waste - in the EU-15 may possibly increase from 2.1 to 7 EJ/a in the period 2000-2050. Approximately one-third of this potential could be made available by energy crops. On the long term, countries with surplus biomass potential could develop into exporters of bioenergy (biofuels from biomass). There are several world regions that could have export potential, e.g. the FSU, Oceania, and East Africa. Studies prove invariably that the energy penalty of biomass transport by ship for 'raw' biomass is not an insurmountable problem. The cost of electricity based on imported biomass could be high compared to conventional alternatives: 6.4-8 €ct/kWh and 3-5 €ct/kWh, respectively.

Uranium and Thorium

The Reasonably Assured Reserves (RAR) and Estimated Additional Reserves (EAR) of uranium - together the 'known conventional resources' - represent 4.59 MtU. This is equivalent to approximately 67 years of current uranium (U) demand for civil nuclear reactors. If the more speculative resources yet undiscovered but believed to exist based on geologic evidence are added, the resource base may be even 14.39 MtU. This is equivalent to 210 years of current U demand. Uranium reserves in the categories RAR and EAR will not be depleted before 2040, based on scenarios from IAEA and IEA. The additional, more speculative uranium reserves, would triple the resource base if these additional reserves would prove to be available. On top of that, thorium reserves and resources are at least equal to the RAR and EAR of U. All conventional uranium and thorium reserves and resources are equal to about 280 years of current U requirements for civil nuclear reactors.

Beyond the uranium and thorium reserves and resources, unconventional uranium resources might become available by extraction of uranium from seawater. These may be approximately 4,000 MtU. It is difficult to envision whether extraction from seawater would be feasible. However, the potential of the unconventional uranium resources is huge indeed.

Appendix A PROVED RESERVES OF FOSSIL FUELS

This Appendix presents data of proved reserves of fossil fuels, viz. of oil, gas, and coal. 'BP Statistical Review of World Energy 2004' (BP, 2004) provides data of proved reserves of oil, natural gas and coal, as well as production or consumption data for oil, gas, coal, hydro and nuclear power. According to BP's latest data (BP, 2004), the Middle East covers 63% of the world's proved oil reserves - totalling 1,148 billion barrels (Gb) or 6,575 EJ (Table A.2). Saudi Arabia even possesses 23% of those reserves (263 Gb or 1,505 EJ). However, some analysts do not regard the official estimates of the proved oil reserves of Middle East countries as dependable.

Table A.3 shows BP's latest reserve estimates of natural gas. Of the proved gas reserves - totalling 176 10^{12} m^3 (Tm^3) or 6,645 EJ - 41% are in the Middle East, and 27% in Russia. What Saudi Arabia is for world's oil reserves is Russia for the natural gas reserves of the world.

Finally, Table A.4 provides BP's latest reserve estimates for coal. Table A.1 shows that the global coal reserves are relatively large compared to global coal production. Also, coal reserves are rather evenly spread around the globe. The Reserves/Production (R/P) ratio - approximately 260 years for coal - far outstrips R/P ratios for oil (about 41 years) and natural gas (about 67 years).

Table A.1 *Coal production and reserves 2003 for the world's top-eight of coal production*

Rank	Country	Production			Reserves	Reserves/production
		[Mton]	[EJ]	[%]	[EJ]	[Year]
1	China	1,667	35.4	33.5	3,206	91
2	USA	970	23.2	21.9	7,000	302
3	Australia	347	7.9	7.5	2,299	290
4	India	367	7.2	6.8	2,363	327
5	South Africa	239	5.7	5.3	1,386	245
6	Russia	275	5.2	5.0	4,396	838
7	Poland	163	3.0	2.8	622	209
8	Germany	205	2.3	2.1	1,848	813
1-8		4,233	89.9	84.9	23,120	257
	World	5,119	105.8	100.0	27,566	261

Source: BP, 2004.

The Reserves/Production ratio is a good yardstick for the magnitude of reserves of fossil fuels, as the global production of coal is roughly equal to that of gas and 35% lower than that of oil (Appendix B). Also, the definitions of the reserves of oil, gas, and coal are more or less comparable.

Table A.2 *Proved oil reserves*

	End 1983 [Gb]	End 1993 [Gb]	End 2003 [Gb]	End 1983 [EJ]	End 1993 [EJ]	End 2003 [EJ]	Fraction [%]
USA	35.6	30.2	30.7	204	173	176	2.7
Canada	9.6	10.0	16.9	55	57	97	1.5
Mexico	49.9	50.8	16.0	286	291	92	1.4
Total North America	*95.2*	*91.0*	*63.6*	*545*	*521*	*364*	*5.5*
Argentine	2.4	2.0	3.2	14	11	18	0.3
Brazil	2.1	5.0	10.6	12	29	61	0.9
Colombia	0.6	3.2	1.5	3	18	9	0.1
Ecuador	0.9	2.3	4.6	5	13	26	0.4
Peru	0.7	0.8	1.0	4	5	6	0.1
Trinidad & Tobago	0.5	0.6	1.9	3	3	11	0.2
Venezuela	25.9	64.4	78.0	148	369	447	6.8
Other S. & Cent. America	0.5	0.9	1.5	3	5	9	0.1
Total S. & Cent. America	*33.7*	*79.1*	*102.2*	*193*	*453*	*585*	*8.9*
Azerbaijan			7.0	0	0	40	0.6
Denmark	0.3	0.7	1.3	2	4	7	0.1
Italy	0.6	0.6	0.7	3	3	4	0.1
Kazakhstan			9.0	0	0	52	0.8
Norway	3.8	9.5	10.1	22	54	58	0.9
Romania	1.6	1.0	0.9	9	6	5	0.1
Russian Federation			69.1	0	0	396	6.0
Turkmenistan			0.5	0	0	3	0.0
United Kingdom	6.9	4.5	4.5	40	26	26	0.4
Uzbekistan			0.6	0	0	3	0.1
Other Europe and Eurasia	86.8	64.1	2.1	497	367	12	0.2
Total Europe and Eurasia	*100.1*	*80.4*	*105.9*	*573*	*461*	*607*	*9.2*
Iran	55.3	92.9	130.7	317	532	749	11.4
Iraq	65.0	100.0	115.0	372	573	659	10.0
Kuwait	67.0	96.5	96.5	384	553	553	8.4
Oman	3.5	5.0	5.6	20	29	32	0.5
Qatar	3.3	3.1	15.2	19	18	87	1.3
Saudi Arabia	168.8	261.4	262.7	967	1,498	1,505	22.9
Syria	1.5	3.0	2.3	9	17	13	0.2
United Arab Emirates	32.3	98.1	97.8	185	562	560	8.5
Yemen		0.1	0.7	0	1	4	0.1
Other Middle East	0.2	0.1	0.1	1	1	1	0.0
Total Middle East	*396.9*	*660.1*	*726.6*	*2,274*	*3,782*	*4,163*	*63.3*
Algeria	9.2	9.2	11.3	53	53	65	1.0
Angola	1.7	1.9	8.9	10	11	51	0.8
Cameroon	0.4	0.3	0.2	2	2	1	0.0
Republic of Congo	0.7	0.7	1.5	4	4	9	0.1
Egypt	4.0	3.4	3.6	23	19	21	0.3
Gabon	0.5	0.7	2.4	3	4	14	0.2
Libya	21.8	22.8	36.0	125	131	206	3.1
Nigeria	16.6	21.0	34.3	95	120	196	3.0
Sudan	0.3	0.3	0.7	2	2	4	0.1
Tunisia	2.5	0.4	0.5	14	2	3	0.0
Other Africa	0.5	0.3	2.3	3	2	13	0.2
Total Africa	*58.2*	*60.9*	*101.8*	*333*	*349*	*583*	*8.9*
Australia	1.9	3.3	4.4	11	19	25	0.4
Brunei	1.5	1.3	1.1	9	7	6	0.1
China	18.2	29.5	23.7	104	169	136	2.1
India	3.6	5.9	5.6	21	34	32	0.5
Indonesia	10.1	5.2	4.4	58	30	25	0.4
Malaysia	2.6	5.0	4.0	15	29	23	0.3
Papua N. Guinea		0.5	0.4	0	3	2	0.0
Thailand		0.2	0.7	0	1	4	0.1
Vietnam		0.6	2.5	0	3	14	0.2
Other Asia Pacific	1.1	0.7	0.9	6	4	5	0.1
Total Asia Pacific	*39.0*	*52.0*	*47.7*	*223*	*298*	*273*	*4.2*
Total World	*723.0*	*1,023.6*	*1,147.7*	*4,142*	*5,864*	*6,575*	*100.0*

Source: BP, 2004.

Table A.3 *Proved gas reserves*

	End 1983 [10^{12} m^3]	End 1993 [10^{12} m^3]	End 2003 [10^{12} m^3]	End 1983 [EJ]	End 1993 [EJ]	End 2003 [EJ]	Fraction [%]
USA	5.61	4.55	5.23	212	172	198	3.0
Canada	2.61	2.23	1.66	99	84	63	0.9
Mexico	2.18	1.97	0.42	82	74	16	0.2
Total North America	*10.40*	*8.75*	*7.31*	*393*	*331*	*276*	*4.2*
Argentine	0.68	0.52	0.66	26	20	25	0.4
Bolivia	0.13	0.12	0.81	5	5	31	0.5
Brazil	0.10	0.19	0.25	4	7	9	0.1
Colombia	0.11	0.21	0.11	4	8	4	0.1
Peru	0.03	0.33	0.25	1	12	9	0.1
Trinidad & Tobago	0.32	0.24	0.74	12	9	28	0.4
Venezuela	1.56	3.69	4.15	59	139	157	2.4
Other S & C America	0.25	0.24	0.22	9	9	8	0.1
Total S & C America	*3.18*	*5.54*	*7.19*	*120*	*209*	*272*	*4.1*
Azerbaijan			1.37	0	0	52	0.8
Denmark	0.10	0.13	0.09	4	5	3	0.1
Germany	0.32	0.20	0.21	12	8	8	0.1
Italy	0.25	0.33	0.22	9	12	8	0.1
Kazakhstan			1.90	0	0	72	1.1
The Netherlands	1.94	1.88	1.67	73	71	63	1.0
Norway	0.47	1.76	2.46	18	67	93	1.4
Poland	0.09	0.16	0.12	3	6	5	0.1
Romania	0.23	0.45	0.31	9	17	12	0.2
Russian Federation			47.00	0	0	1,777	26.7
Turkmenistan			2.90	0	0	110	1.6
Ukraine			1.11	0	0	42	0.6
United Kingdom	0.71	0.63	0.63	27	24	24	0.4
Uzbekistan			1.85	0	0	70	1.1
Other Europe/Eurasia	36.37	58.10	0.46	1375	2196	17	0.3
Total Europe/Eurasia	*40.48*	*63.62*	*62.30*	*1,530*	*2,405*	*2,355*	*35.4*
Bahrain	0.22	0.16	0.09	8	6	3	0.1
Iran	14.05	20.70	26.69	531	782	1,009	15.2
Iraq	0.82	3.10	3.11	31	117	118	1.8
Kuwait	1.04	1.49	1.56	39	56	59	0.9
Oman	0.17	0.20	0.95	6	8	36	0.5
Qatar	3.40	7.07	25.77	129	267	974	14.7
Saudi Arabia	3.54	5.25	6.68	134	198	253	3.8
Syria	0.10	0.23	0.30	4	9	11	0.2
Unit. Arab. Emirates	3.05	5.80	6.06	115	219	229	3.4
Yemen		0.43	0.48	0	16	18	0.3
Other Middle East			0.05	0	0	2	0.0
Total Middle East	*26.38*	*44.43*	*71.72*	*997*	*1,679*	*2,711*	*40.8*
Algeria	3.53	3.70	4.52	133	140	171	2.6
Egypt	0.20	0.60	1.76	8	23	67	1.0
Libya	0.64	1.29	1.31	24	49	50	0.7
Nigeria	1.37	3.68	5.00	52	139	189	2.8
Other Africa	0.55	0.75	1.19	21	28	45	0.7
Total Africa	*6.29*	*10.01*	*13.78*	*238*	*378*	*521*	*7.8*
Australia	0.50	0.56	2.55	19	21	96	1.5
Bangladesh	0.31	0.30	0.34	12	11	13	0.2
Brunei	0.22	0.40	0.35	8	15	13	0.2
China	0.75	1.03	1.82	28	39	69	1.0
India	0.46	0.72	0.85	17	27	32	0.5
Indonesia	1.19	1.82	2.56	45	69	97	1.5
Malaysia	1.40	1.83	2.41	53	69	91	1.4
Myanmar	0.25	0.27	0.36	9	10	14	0.2
Pakistan	0.51	0.64	0.75	19	24	28	0.4
Papua New Guinea		0.55	0.43	0	21	16	0.2
Thailand	0.10	0.17	0.44	4	6	17	0.3
Vietnam		0.11	0.23	0	4	9	0.1
Other Asia Pacific	0.26	0.36	0.39	10	14	15	0.2
Total Asia Pacific	*5.95*	*8.73*	*13.47*	*225*	*330*	*509*	*7.7*
Total World	*92.68*	*141.08*	*175.78*	*3,503*	*5,333*	*6,644*	*100.0*

Source: [BP, 2004].

Table A.4 *Proved coal reserves*

	End 1987 [Gt]	End 1993 [Gt]	End 2003 [Gt]	End 1983 [EJ]	End 1993 [EJ]	End 2003 [EJ]	Fraction [%]
USA	263.8	240.6	250.0	7,388	6,736	7,000	25.4
Canada	6.6	6.6	6.6	184	184	184	0.7
Mexico	1.9	1.7	1.2	54	48	34	0.1
Total North America	*272.3*	*250.9*	*257.8*	*7,626*	*6,968*	*7,218*	*26.2*
Brazil	2.3	2.4	11.9	66	66	334	1.2
Colombia	1.0	4.5	6.6	29	127	186	0.7
Venezuela	0.4	0.4	0.5	10	12	13	0.0
Other S & C America	1.3	2.4	2.7	37	67	75	0.3
Total S & C America	*5.1*	*9.7*	*21.8*	*142*	*272*	*608*	*2.2*
Bulgaria			2.7			76	0.3
Czech Republic			5.7			159	0.6
France	0.4	0.2	0	11	6	1	0.0
Germany	80.1	80.1	66.0	2,242	2,242	1,848	6.7
Greece	3.0	3.0	2.9	84	84	80	0.3
Hungary			1.1			31	0.1
Kazakhstan			34.0			952	3.5
Poland	42.7	41.2	22.2	1,196	1,154	620	2.2
Romania			1.5			41	0.1
Russian Federation			157.0			4,396	15.9
Spain	0.9		0.7	25		18	0.1
Turkey	4.9	7.1	3.7	136	200	103	0.4
Ukraine			34.2			956	3.5
United Kingdom	9.5	3.8	1.5	266	106	42	0.2
Other Europe/Eurasia	276.9	276.9	22.3	7,753	7,753	626	2.3
Total Europe/Eurasia	*418.3*	*412.4*	*355.4*	*11,713*	*11,545*	*9,950*	*36.1*
South Africa	58.4	55.3	49.5	1,635	1,549	1,387	5.0
Zimbabwe	0.7	0.7	0.5	21	21	14	0.1
Other Africa	6.8	6.0	5.3	190	168	150	0.5
Middle East		0.2	1.7		5	48	0.2
Africa & Middle East	*65.9*	*62.3*	*57.1*	*1,845*	*1,744*	*1,598*	*5.8*
Australia	74.4	90.9	82.1	2,084	2,546	2,299	8.3
China	170.0	114.5	114.5	4,760	3,206	3,206	11.6
India	14.2	62.5	84.4	397	1,751	2,363	8.6
Indonesia	3.0	32.1	5.4	84	898	150	0.5
Japan	1.0	0.8	0.8	28	24	22	0.1
New Zealand	0.2	0.1	0.6	7	3	16	0.1
North Korea			0.6			17	0.1
Pakistan			2.3			63	0.2
South Korea	0.1	0.2	0.1	4	6	2	0.0
Thailand			1.3			36	0.1
Vietnam			0.1			4	0.0
Other Asia Pacific		2.6	0.4	41	73	11	0.0
Total Asia Pacific	*264.5*	*303.9*	*292.5*	*7,406*	*8,510*	*8,189*	*29.7*
Total World	*1,026.1*	*1,039.2*	*984.5*	*28,732*	*29,097*	*27,565*	*100.0*

Source: [BP, 2004].

Appendix B PRODUCTION DATA OF OIL, GAS, AND COAL

This Appendix presents historical production data for oil, gas, and coal. Figure B.1 shows historical oil production data (BP, 2004). From 1973 to 1993, oil production increased by 0.6%/a on average, and from 1993 to 2003 by 1.4%/a. It seems that record oil prices (1974, 1979) coincide with years of record oil production. Maybe, year 2004 - with oil prices in excess of $50/barrel[9] (EnsocWeekly, 2004a-b) - is comparable to the record years 1974 and 1979.

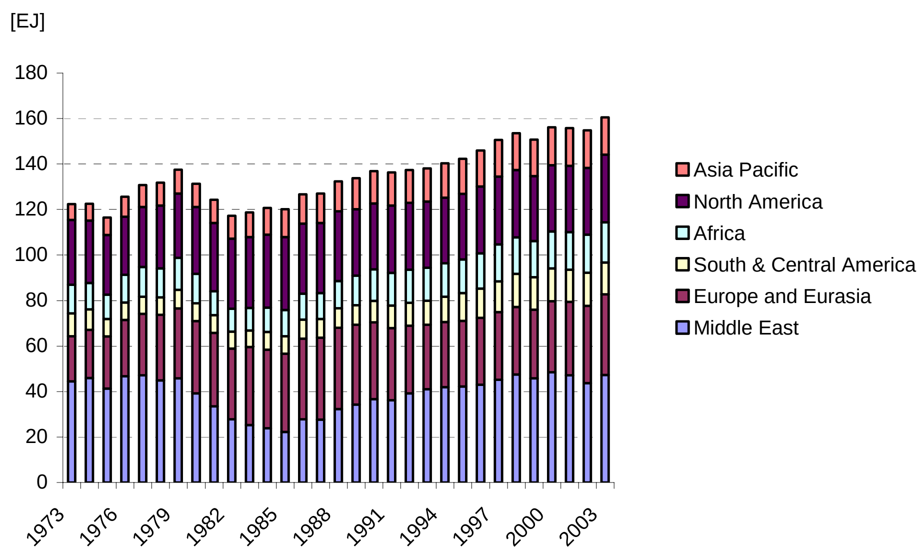

Figure B.1 *World oil production 1973-2003*

Figure B.2 shows the development of gas production for the period 1973-2003 (BP, 2004). Unlike oil, production of gas does not show any decline in growth of production so far. Production of natural gas in the Middle East is still relatively marginal compared to the resource base.

[9] At the futures market in the Far East US oil noted $53.92/barrel (159 l). North Sea oil (Brent) noted a record of $51.94/b, and the in the New York futures market US oil noted a record of $55.67/b at October 25, 2004.

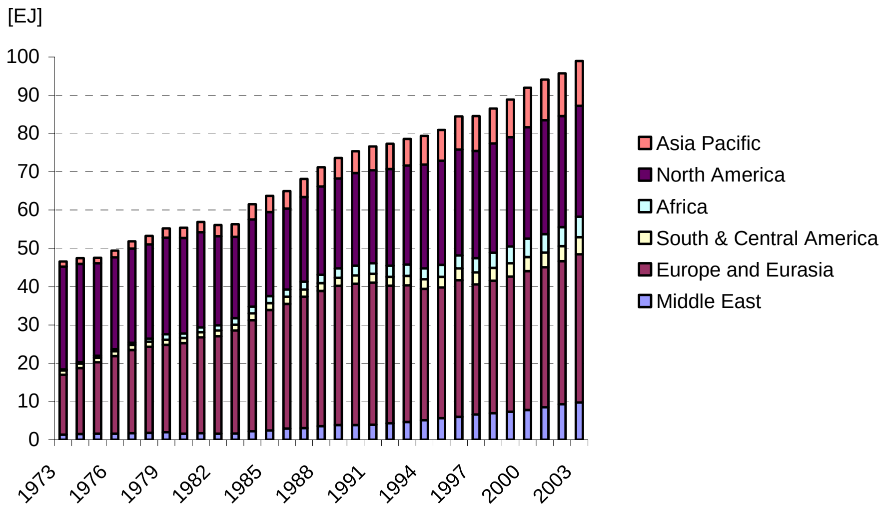

Figure B.2 *World gas production 1973-2003*

Figure B.3 shows historical coal production data. From 1981 to 1993, global coal production showed a modest increase by approximately 0.5%/a, and from 1993 to 2003, coal production increased by 1.7%/a. Worldwide coal production shows substantial ups and downs during the period considered (1981-2003).

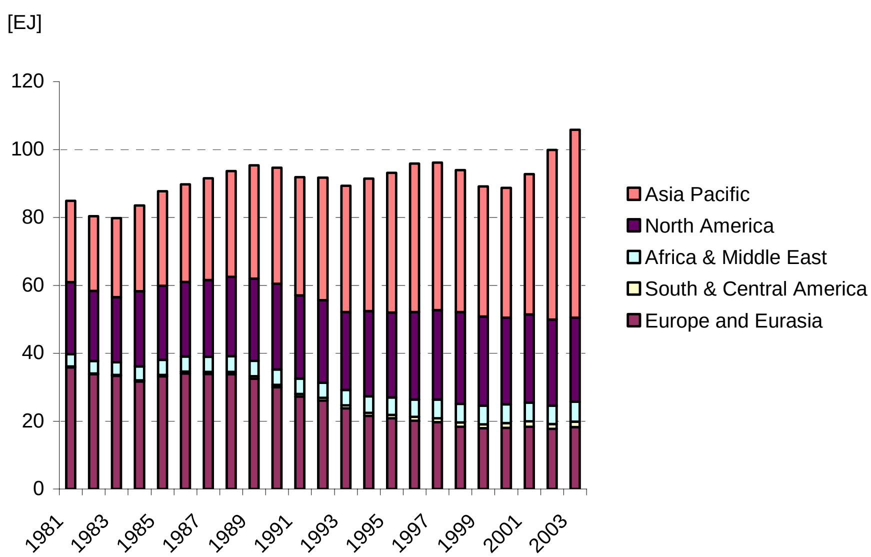

Figure B.3 *World coal production 1981-2003*
Source: BP, 2004.

Appendix C GLOBAL OIL PRODUCTION SCENARIOS

Evidence for a peak in global oil production

The consultant geologist Campbell is of the opinion that the present high oil prices are due to an anticipated peak in global oil production, called ‘Peak Oil’, to be followed by continuous decline (Campbell, 2002). Campbell - founder of ASPO, the Association for the Study of Peak Oil & Gas - warns for such a peak for more than a decade (Campbell, 1991). This viewpoint is endorsed by *inter alia* (Salameh, 2003). Others contend that a peak in global oil production is imminent (Lynch, 2004). They regard political factors - attacks on oil pipelines in Iraq, a general strike in Nigeria, a strike of workers on platforms in Norway - as the major cause of the current high oil prices. According to Campbell, ‘Peak Oil’ might occur within a few years. The date of a peak in global oil production depends on the size of the conventional oil resources as well as of the unconventional oil resources, viz.:

- Extra-heavy oil (Venezuela, in the production stage)
- Tar sands (Canada, in the production stage)
- Oil shale (e.g. the USA, still in the demonstration stage).

In 2000, tar sands in Canada and (extra-) heavy oil in Venezuela produced 1.4 million barrels/day (Mb/d), accounting for about 2% of global oil production (Campbell, 2002).

(Bedi *et al.*, 2004) say that there is mounting evidence for a peak in conventional oil production:

- The oil industry is spending huge amounts of money and using all available technologies to find new oil in unfavourable areas (the Arctic region, deep sea areas).
- A survey covering 145 energy companies (1996-2000) shows that $410 billion was spent on exploration and development, whereas production remained flat. The big five oil companies spent $150 billion during 1999-2002 for 4% growth, or 0.6 Mb/d.
- Combined production peak of all non-OPEC countries occurred around the year 2000.
- Non-OPEC, non-FSU (Former Soviet Union) supply has been flat for seven years.
- 120 giant fields (mostly old) make up 47% of global oil supply (14 of them 20%).
- BP downscaled its production goals three times within the year 2001.

Figure C.1 illustrates that big new oil fields become more difficult to find (Dimitroff, 2003). The declining magnitude of new oil fields is in agreement with the experience that the global conventional oil reserves tend to level off in the last few years (Chapter 2, Figure 2.2).

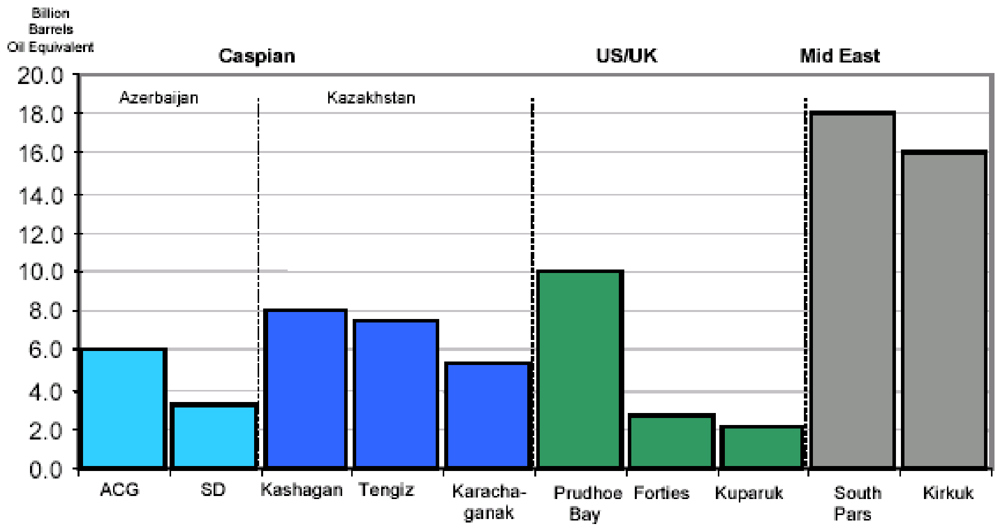

Figure C.1 *World's giant oil fields*
Note: The fields are ordered by region and ranked by date of discovery from left to right.
Source: Dimitroff, 2003.

2004 scenario

In his '2004 scenario', Campbell (Internet sources 1-2) dates 'Peak Oil' in 2006 (
Figure C.2).

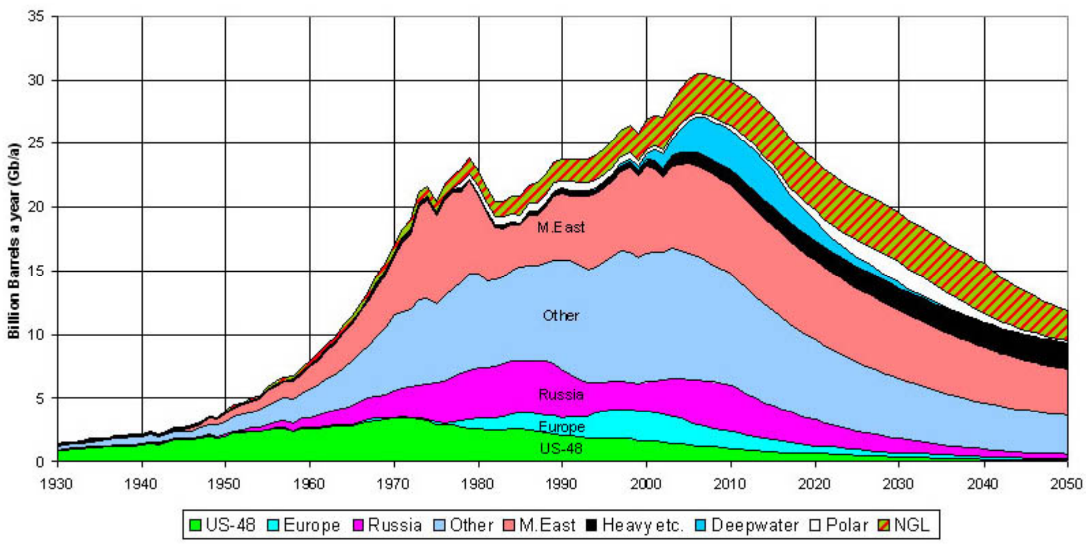

Figure C.2 *Oil production 1930-2050 by world region '2004 scenario' (Campbell)*
Sources: Campbell, 2002; Internet sources 1-2.

Table C.1 shows the ultimately available oil resources according to Campbell's '2004 scenario' and Table C.2 the oil production by world region (Aleklett *et al.*, 2002; ASPO, 2004).

Table C.1 *Ultimate recovery of oil according to Campbell's '2004 scenario'*

	Past [10^9 barrel]	Future [10^9 barrel]	EUR [10^9 barrel]	Past [EJ]	Future [EJ]	EUR [EJ]
'Regular oil'						
Known fields	920	780	1,700	5,270	4,468	9,739
New fields		150	150	0	859	859
Non-regular oil[10]	70	580	650	401	3,323	3,724
Total	990	1,510	2,500	5,672	8,650	14,322

Sources: Campbell, 2002; Internet sources 1-2.

Table C.2 *World oil production 2005-2050 cf. Campbell's '2004 scenario'*

	Oil production [million b/d]				EUR	Oil production [EJ/a]				EUR	Peak
	2005	2010	2020	2050	[Gb]	2005	2010	2020	2050	[EJ]	[Year]
'Regular oil'											
US-48	3.7	2.8	1.7	0.4	200	7.7	5.9	3.6	0.8	1,146	1971
Europe	5.1	3.6	1.8	0.3	75	10.7	7.5	3.8	0.6	430	2000
Russia	9.1	10.0	5.3	0.9	210	19.0	20.9	11.1	1.9	1,203	1987
Middle East	19.0	19.0	17.0	10.0	675	39.7	39.7	35.6	20.9	3,867	1974
Other	27.0	29.0	25.0	11.0	690	56.5	60.7	52.3	23.0	3,953	2012
Subtotal	64.0	58.0	43.0	20.0	1,850	133.9	121.3	89.9	41.8	10,598	2005
Heavy etc.	2.6	3.0	4.0	5.0	195	5.4	6.3	8.4	10.5	1,117	~
Deepwater	4.7	7.0	5.0	0	55	9.8	14.6	10.5	0.0	315	2014
Polar	0.9	1.0	2.0	0	50	1.9	2.1	4.2	0.0	286	2030
NGL	8.2	9.0	11.0	6.0	270	17.2	18.8	23.0	12.5	1,547	2027
Other					80					458	
Total	80.0	78.0	65.0	32.0	2,500	167.3	163.1	136.0	66.9	14,322	2006

Campbell assumes an 'Estimated Ultimate Recovery', including oil production in the past, of 2,500 Gb (14,320 EJ). Others - e.g. (Lako, 2002) - deem 50% more (3,700 Gb or 21,265 EJ) to be recoverable until 2100.

Table C.3 compares the '2004 scenario' until 2075 (ASPO) with estimates of the reserves and resources of conventional and unconventional oil by the German BGR (BGR, 2002).

[10] Non-regular oil = 'Heavy etc.', 'Deepwater', 'Polar' and NGL.
Heavy etc. = Extra-heavy oil (e.g. Venezuela), tar sands (e.g. Canada), oil shale (e.g. USA), etc.
Deepwater = offshore oil, water depth 500 m and more.
Polar = oil from Arctic regions (Alaska, North Pole, Antarctica).
NGL = Natural Gas Liquids (from gas fields).
US-48 = Oil from 'Lower' 48 States USA (Alaska = Polar oil).

Table C.3 *Oil reserves/resources cf. ‘2004 scenario’ and the German BGR respectively*

	Conventional oil			Unconventional oil				
	ASPO	BGR	ASPO	ASPO	BGR		ASPO	ASPO
	Future until 2075	Reserves & Resources	as a fraction of BGR’s Reserves & Resources	Future until 2100	Reserves	Reserves & Resources	as a fraction of BGR’s reserves	as a fraction of BGR’s Reserves & Resources
	[EJ]	[EJ]	[%]	[EJ]	[EJ]	[EJ]	[%]	[%]
‘Regular oil’								
North America	395	291			1,297	6,820		
S & C America	402	1,519			460	2,343		
Europe	248	904			42	126		
Eurasia	695	4,865			397	1,652		
Middle East	3,215	520			418	920		
Africa	545	927			21	272		
Asia Pacific	376	850			126	1,088		
Subtotal	5,876							
Deepwater	383							
Polar	321							
NGL	1,310							
Total	7,890	9,876	80	1,575[1]	2,761	13,221	57	12

1) This amount (1,575 EJ) is the sum of 1,117 EJ ‘Heavy etc’ and 458 EJ ‘Other’ in Table C.2.
Sources: Aleklett *et al.*, 2002; ASPO, 2004; BGR, 2002.

As Campbell does not regard the official reserve data of the Middle East as dependable, ‘Future until 2075’ is only 80% of the estimate of ‘*Reserves & Resources*’ of conventional oil of the BGR. Campbell’s ‘Future unconventional oil production’ is no more than 57% of the *reserves* according to BGR, and merely 12% of BGR’s ‘*Reserves & Resources*’.

Alternative oil production scenarios

In the following, three scenarios are introduced based on more ample oil resources (Table C.4).

Table C.4 *Oil production scenarios ‘Medium’ and ‘High’ compared to ‘ASPO 2002’*

	Production 2002-2075			Scenario ‘Medium’			Scenario ‘High’		
	ASPO	Medium	High	2010	2020	2050	2010	2020	2050
	[EJ]	[EJ]	[EJ]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]
‘Regular oil’									
North America	395	853	1,310	18.0	17.5	9.0	20.5	22.0	16.5
S & C America	402	598	793	10.5	9.5	7.0	12.5	13.0	9.6
Europe	248	312	376	9.7	6.3	1.8	10.1	7.3	2.8
Eurasia	695	1,031	1,367	22.2	18.3	11.0	22.2	22.2	16.3
Middle East	3,215	3,240	3,265	29.04	25.0	52.3	23.8	17.3	58.0
Africa	545	587	629	10.8	9.5	6.5	11.1	9.9	7.2
Asia Pacific	376	561	746	11.3	11.5	5.5	11.3	12.4	9.1
Subtotal	5,876	7,182	8,485	111.5	97.6	93.0	111.5	104.2	119.5
Heavy etc.	1,015	1,015	1,015	9.0	11.6	15.5	9.0	11.6	15.5
Deepwater	383	383	383	19.0	10.4	0.7	19.0	10.4	0.7
Polar	321	321	321	3.8	11.9	1.4	3.8	11.9	1.4
NGL	1,310	1,310	1,310	23.9	29.2	13.8	23.9	29.2	13.8
Total	8,905	10,210	11,515	167.3	160.7	124.4	167.3	167.3	150.9

The alternative oil production scenarios are:

- *‘ASPO 2002’*: ASPO’s ‘2002 Base Case Scenario’ until 2075 (Aleklett, K. *et al*, 2002).

- Scenario '*Medium*', resembling '*ASPO 2002*', but based on a larger resource base for 'Regular oil' (excluding 'Heavy etc.', 'Deepwater', 'Polar' and NGL).
- Scenario '*High*', based on conventional oil resources in (Lako, 2002). This study draws on data of global oil reserves and resources from the USGS that are optimistic but not unrealistic. Scenario 'High', the scenario with the most abundant resources - an Estimated Ultimate Recovery (EUR)[11] of 20,000 EJ (3,500 Gb) - presumes a levelling off of global oil production in the period 2003-2035, and a steady decline after that date.

Scenario '*ASPO 2002*' is shown in Figure C.3. This scenario may be considered as a variant of the '2004 scenario'. Oil production peaks in 2010 and it declines by 1.65%/a after that.

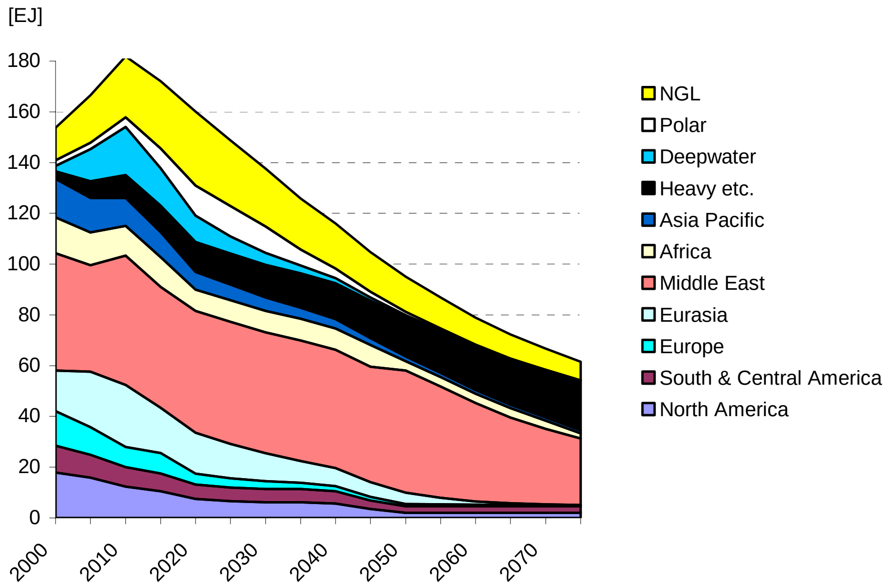

Figure C.3 *Oil production 2000-2075 according to scenario 'ASPO 2002'*

The resource base of '*Medium*' allows a plateau production of 80 Mb/d until 2010. After that, production declines by 0.85%/a on average (Figure C.4). Scenario 'Medium' resembles a scenario in (Duncan, 2004), in which global oil production peaks around 2010. Duncan assumes an 'Estimated Ultimate Recovery' of 3,300 Gb, 32% more than in Campbell's '2004 scenario'.

[11] Estimated Ultimate Recovery (EUR) = oil producible until 2100, inclusive of cumulative production

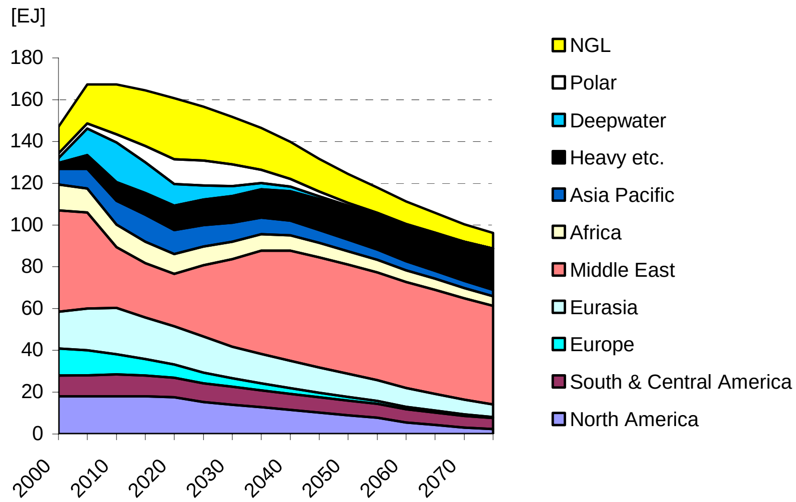

Figure C.4 *Oil production 2000-2075 according to scenario 'Medium'*

The resource base of scenario '*High*' allows a plateau production of 80 Mb/d from 2005 to 2035. Global oil production declines by 0.8%/a on average after 2035 (Figure C.5).

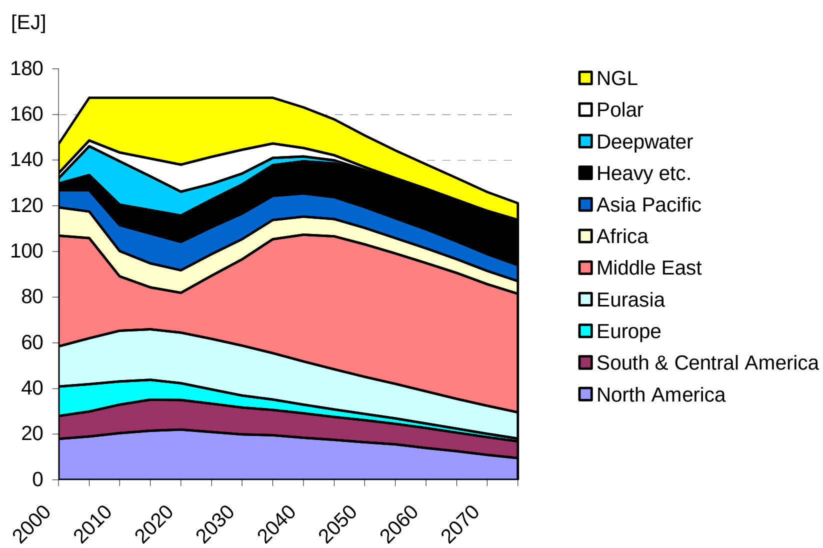

Figure C.5 *Oil production 2000-2075 according to scenario 'High'*

Table C.5 summarises main characteristics of the '2004 scenario' and the three other scenarios.

Table C.5 *Main characteristics and results of '2004 scenario' and alternative scenarios*

Scenario		2004 scenario	ASPO 2002	Medium	High
EUR	[Gb]	2,500	2,800	3,175	3,500
	[EJ]	14,320	16,050	18,190	20,065
Compared to '2004 scenario'	[%]	100	112	127	140
Share of Middle East					
Year 2010	[%]	24	28	17	14
Year 2050	[%]	31	51	42	38
Year 2075	[%]	N/A	N/A	49	43
Peak characteristics					
Peak (period)	[Year]	2006	2010	2005-2010	2005-2035
Decline after peak	[%/a]	-2.0	-1.65	-0.85	-0.80

Appendix D GLOBAL GAS PRODUCTION SCENARIOS

A peak in global conventional gas production

Although the proved gas reserves are comparable in size to the proved oil reserves, and the level of gas production is still substantially lower than oil production, a peak in conventional gas production might occur between 2020 and 2050. Two scenarios (Table D.1) are used to illustrate the bandwidth in conventional gas resources. One scenario - called 'Imam *et al*' - is based on (Imam *et al.*, 2004), and the other one - 'High' - is based on ample gas resources (Lako, 2002).

Table D.1 *Scenarios for conventional gas production 'Imam et al' and 'High'*

	Production 2002-2100		Scenario 'Imam *et al*'			Scenario 'High'			
	'Imam'	'High'	2010	2020	2050	2010	2020	2050	2100
	[EJ]	[EJ]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]	[EJ/a]
North America	652.7	1,895.4	n/a	n/a	n/a	27.3	24.8	18.7	11.3
S & C America	412.1	814.3	n/a	n/a	n/a	5.6	6.3	8.7	9.0
Europe	275.0	670.5	n/a	n/a	n/a	9.9	8.9	6.5	3.8
Eurasia	2,392.7	3,278.5	n/a	n/a	n/a	29.2	30.7	34.3	32.7
Middle East	2,375.4	3,137.8	n/a	n/a	n/a	12.8	18.8	35.0	41.5
Africa	412.8	481.2	n/a	n/a	n/a	7.5	8.3	6.7	0.0
Asia Pacific	638.7	858.9	n/a	n/a	n/a	8.9	10.0	9.9	5.6
Total World	7,159.3	11,136.5	~90	~94.6	~75	101.1	107.8	119.9	104.0

Sources: Imam *et al*., 2004; Lako, 2002.

(Imam *et al.*, 2004) anticipate a peak in conventional gas production around 2020, and the future gas production (7,160 EJ) is only 8% higher than BP's estimate (

Table A.3) of the proved gas reserves, and 60% of the total conventional gas resources of the German BGR (Chapter 3, Table 3.1). The future production in scenario 'High' is approximately 11,140 EJ, which is 68% more than BP's proved gas reserves, and 93% of the total conventional gas resources of (BGR, 2002). Because of different assumptions with regard to gas resources, Imam *et al*. predict a peak around 2020, whereas in scenario 'High' the peak would occur around 2050 (Figure D.1).

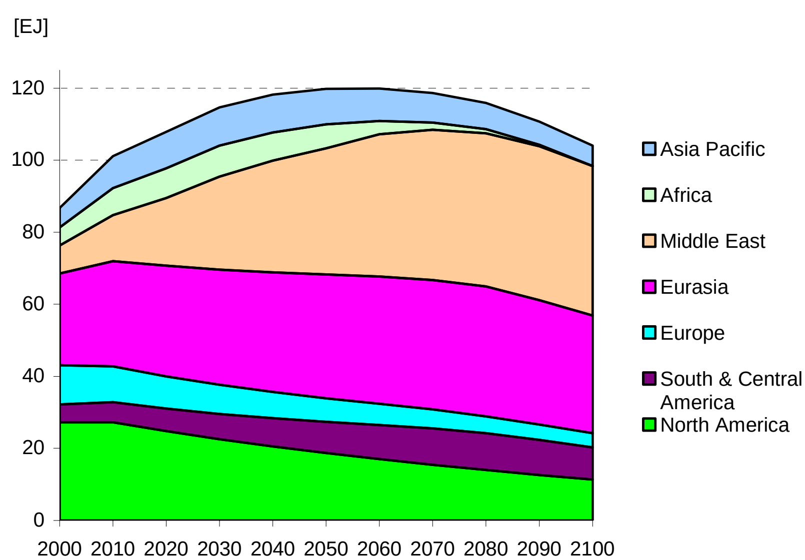

Figure D.1 *Gas production 2000-2100 according to scenario 'High'*
Source: Lako, 2002.

In order to compare the two scenarios, Table D.2 shows their main characteristics.

Table D.2 *Main assumptions and results of scenario 'Imam et al' and scenario 'High'*

Scenario		'Imam *et al*'	'High'
EUR (-2100)	[10^{12} m^3]	261	366
	[EJ]	9,865	13,850
EUR compared to scenario 'Imam *et al*'	[%]	100	140
Share of Middle East			
Year 2010	[%]	~10	13
Year 2020	[%]	~15	17
Year 2050	[%]	~40	29
Peak characteristics			
Peak (period)	[Year]	2019	2040-2060
Peak level	[EJ/a]	94.6	119.9
Decline after peak	[%/a]	N/A	<-1

Sources: Imam *et al*., 2004; Lako, 2002.

Scenario 'High' demonstrates that a larger resource base may defer a peak in global gas production by 30 to 40 years, presumed that the peak is not steep. Gas production may decline more gradually after the peak, if the resource base is large. In scenario 'Imam *et al*', the share of gas from the Middle East rises faster (to approximately 40% in 2050) than in scenario 'High'.

Unconventional gas resources

There are several other sources of natural gas, called 'unconventional gas', viz.:

- Tight gas
- Coal gas (coal-bed methane)
- Aquifer gas
- Gas hydrates.

Table D.3 presents unconventional reserves and resources, based on (BGR, 2002; Gerling, 2004). The data presented in Table D.3 are based on two different sources. Therefore, they do not always sum up: the total of tight gas, coal gas, and aquifer gas differs from the subtotal.

Table D.3 *Estimate of unconventional gas resources*

[EJ]	Tight gas	Coal bed methane[a]	Aquifer gas	Subtotal	Methane hydrates
North America	425			5,851	
South & Central America	140			4,560	
Europe	140			1,869	
Eurasia	1,375			6,073	
Middle East	445			3,649	
Africa	165			2,764	
Asia Pacific	330			8,012	
Total World	3,020	3,200	30,240	32,779	18,900

a) Reserves in case of coal bed methane.

Sources: BGR, 2002; Gerling, 2004.

Table D.3 shows that the unconventional gas reserves/resources are quite large. However, it is not certain to which extent unconventional gas reserves or resources might be recoverable.

Appendix E REALISABLE ONSHORE WIND POTENTIAL

The onshore wind capacity in the EU-15 plus Norway and Poland is bounded by the '*realistic* onshore wind potential' - by wind class: >7 m/s, 6-7 m/s, 5-6 m/s, and <5 m/s - defined by (De Noord *et al*., 2004). However, also maximum growth rates[12] are estimated by country in Annex 2. Table E.1 shows the resulting '*realisable* onshore wind potential' of the 'EU-15+'.

Table E.1 *Realisable onshore wind potential EU-15 plus Norway and Poland [MW]*

Country	2000	2003	2005	2010	2015	2020	2025	2030
Austria	77	415	628	1,768	1,900	1,900	1,900	1,900
Belgium	19	78	118	309	706	1,300	1,300	1,300
Denmark	2,291	2,667	3,088	4,453	4,600	4,600	4,600	4,600
Finland	39	53	90	298	805	1,765	3,110	4,350
France	63	274	467	1,541	4,164	9,126	16,076	22,500
Germany	6,107	14,612	17,520	23,500	23,500	23,500	23,500	23,500
Greece	274	538	775	1,928	3,035	4,700	4,700	4,700
Ireland	122	205	312	777	2,099	3,750	3,750	3,750
Italy	424	922	1,395	3,648	8,342	12,000	12,000	12,000
Luxembourg	15	15	23	64	70	70	70	70
The Netherlands	473	938	1,125	1,771	2,369	2,400	2,400	2,400
Norway	13	100	170	562	1,520	3,331	5,867	8,200
Poland	3	55	94	309	836	1,832	3,227	4,500
Portugal	11	311	471	1,325	1,900	1,900	1,900	1,900
Spain	2,836	6,420	7,698	11,356	13,600	13,600	13,600	13,600
Sweden	252	405	690	2,279	6,158	13,400	13,400	13,400
UK	421	695	1,051	2,960	6,770	12,468	18,312	20,900
'EU-15 +'	13,440	28,703	35,714	58,847	82,374	111,641	129,712	143,570

The *realisable* onshore wind potential in the period 2003-2030 is estimated as follows:

- 1,900 MW in Austria between 2010 and 2015, if Band 1-3 and 40% of Band 4 (<5 m/s) would be developed.
- 1,300 MW in Belgium between 2015 and 2020, if Band 1-3 and 40% of Band 4 (<5 m/s/) would be developed.
- 4,600 MW in Denmark between 2010 and 2015, if Band 1 and 2 would be developed.
- 4,350 MW in Finland around 2030, if Band 1 (>7 m/s) and approximately 50% of Band 2 (6-7 m/s) would be developed.
- 22,500 MW in France around 2030, if Band 1-2 and approximately 60% of Band 3 (5-6 m/s) would be developed.
- 23,500 MW in Germany around 2010, if Band 1-3 would be almost fully developed.
- 4,700 MW in Greece around 2020, if Band 1-3 and 40% of Band 4 would be developed.
- 4,750 MW in Ireland around 2020, if Band 1-3 would be fully developed.
- 12,000 MW in Italy around 2020, if Band 2-3 and 40% of Band 4 would be developed.
- 70 MW in Luxembourg around 2010, if Band 2-3 and 40% of Band 4 would be developed.
- 2,400 MW in the Netherlands in 2020, if Band 1-3 would be almost fully developed.
- 8,200 MW in Norway in 2030, if approximately 50% of Band 1 would be developed.
- 4,500 MW in Poland around 2030, if Band 1-2 would be developed[13].
- 1,900 MW in Portugal between 2010 and 2014, if Band 2-3 and 40% of the Band 4 would be developed.
- 13,600 MW in Spain around 2015, if Band 1-3 would be almost completely developed.

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[12] (De Noord *et al*., 2004) present data with regard to maximum growth rates for the different periods of time.
[13] Poland's *realistic* onshore wind potential is assumed to be 2,250 MW in Band 2, and 2,250 MW in Band 3.

- 13,400 MW in Sweden, if Band 1-3 would be almost completely developed.
- 20,900 MW in the UK in 2030, if Band 1-3 and 40% of Band 4 would be developed.

The extent to which the '*realistic* onshore wind potential' according to De Noord *et al*. (2004) is utilised in the '*realisable* onshore wind potential' in 2030 is summarised in Table E.2.

Table E.2 *Extent to which 'Realistic onshore wind power potential' is utilised in 2030*

Wind speed [%]	Maximum utilization of potential by wind class in 2030 (%)					Maximum in 2030
	Band 1 >7 m/s	Band 2 6-7 m/s	Band 3 5-6 m/s	Band 4 <5 m/s	Total	[MW]
Austria	100	100	100	~40	74	1,900
Belgium	100	100	100	~40	98	1,300
Denmark	100	100	-	-	77	4,600
Finland	100	~50	-	-	48	4,350
France	100	100	~60	-	53	22,500
Germany	100	100	100	-	86	23,500
Greece	100	100	100	~40	83	4,700
Ireland	100	100	100	n/a	100	3,750
Italy	n/a	100	100	100	70	12,000
Luxembourg	n/a	100	100	100	76	70
Netherlands	100	100	100	n/a	99	2,400
Norway	~50	-	-	-	41	8,200
Poland	n/a	100	100	n/a	100	4,500
Portugal	n/a	100	100	~40	65	1,900
Spain	100	100	100	-	47	13,600
Sweden	100	100	100	-	86	13,400
UK	100	100	100	~40	98	20,900
Total	88	94	76	11	68	143,570

Note: The countries considered are the EU-15, Norway, and Poland.

Maximum growth rates applied for each of the countries are presented in Appendix F (Maximum growth rates for onshore wind). The '*realisable* onshore wind capacity' is less than the *realistic* potential due to conflicting land use, protection of landscape, etc. The *realisable* onshore wind potential is estimated at 144 GW in 2030, presuming 'maximum' use of wind energy in the 'EU-15+' - 144 GW in 2030 is equivalent to a nearly fivefold increase compared to 2003.

In the Netherlands, the installed capacity at the end of 2003 was 938 MW, and the official target for onshore wind is 1,500 MW. The 'realisable potential' of 2,400 MW is 60% more than the target and a 155% increase compared the capacity in 2003. It is assumed that the potential in band 1-3 (average wind speed >5 m/s) would be fully developed in several countries, amongst which Germany and Spain. In Germany, the installed capacity by the end of 2003 was 17,520 MW. The 'realisable potential' is estimated at 23,500 MW, which is 34% more than the capacity in of 2003. In Spain, the installed capacity by the end of 2003 was 6,420 MW. The 'realisable potential' is estimated at 13,600 MW, which is 110% more than the capacity in 2003.

In three countries, the onshore wind capacity could be expanded significantly after 2030, viz.:

- Norway: if 100% of the potential in the classes of '>7 m/s' (Band 1) and '6-7 m/s' (Band 2) would be utilised, the additional potential after 2030 would be about 10,200 MW.
- Finland: if - besides 100% of Band 1 (>7 m/s) - 100% of Band 2 (6-7 m/s) would be utilised, the additional potential after 2030 would be about 1,150 MW.
- France: if - besides 100% of Band 1 (>7 m/s) and 100% of Band 2 (6-7 m/s) - 100% of Band 3 (5-6 m/s) would be utilised, the additional potential would be about 5,000 MW.

Assuming such a remaining potential, the *realisable* onshore wind potential in 2050 could be approximately 160 GW (Figure E.1). In 2030, 90% of this potential could be fulfilled.

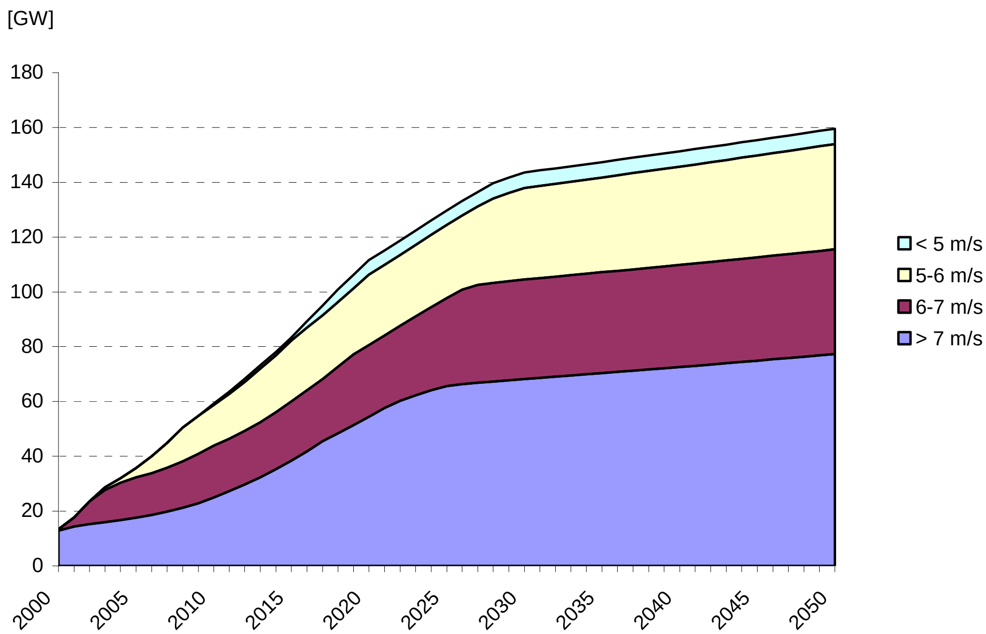

Figure E.1 *Realisable onshore wind capacity including 'remaining potential' after 2030 in Norway, Finland, and France*

Note: The countries considered are the EU-15, Norway, and Poland.

De Noord *et al*. apply the following load factors as a function of wind class (Table E.3).

Table E.3 *Load factor of wind capacity by wind class*

Band	Mean annual wind speed at hub height 50 m [m/s]	Load factor of wind capacity [%]
1	>7	34
2	6-7	24
3	5-6	16
4	<5	10

If these load factors are applied, it turns out that in 2030 possibly 90% of the '*realisable* onshore wind potential' in [PJ_e] - approximately 1,330 PJ_e - could be realised (Figure E.2).

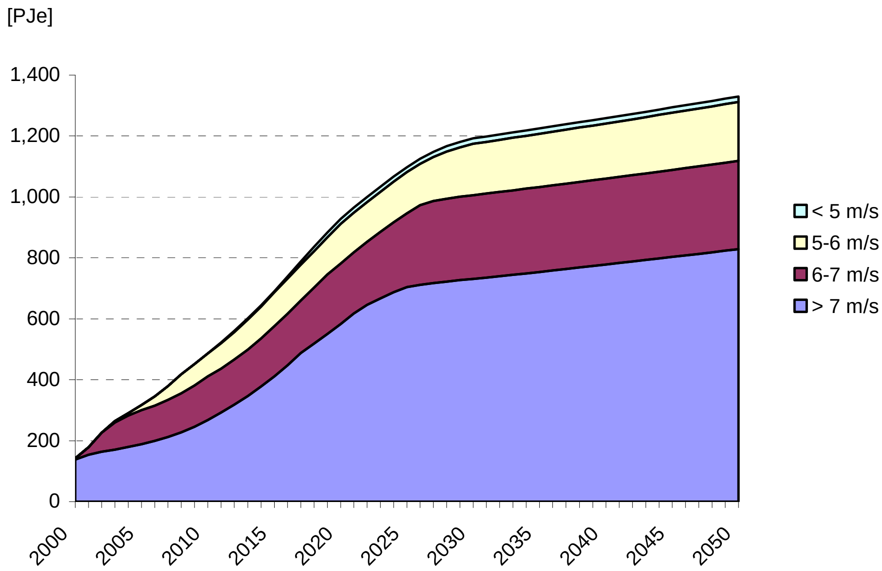

Figure E.2 *Realisable onshore wind generation potential including 'remaining potential'*

Appendix F MAXIMUM GROWTH RATES ONSHORE WIND

The onshore wind capacity in the EU-15 plus Norway and Poland is bounded by the 'Realistic onshore wind power potential' - by wind class: >7 m/s, 6-7 m/s, 5-6 m/s, and <5 m/s, based on De Noord et al. (2004) - (Annex 1) as well as maximum growth rates. These maximum growth rates have been determined for each of the EU-15 countries, Norway and Poland (Table F.1).

Countries with the highest growth rates (31% in 2004, decreasing linearly to 5% in 2030) are Finland, France, Norway, and Poland. These countries have relatively low installed capacities up to now and a relatively large potential compared to these installed capacities. Two other countries - Ireland and Sweden - may also experience high growth rates. The growth rate is assumed to decrease from 31% in 2004 to zero in 2017 in Ireland, and in 2021 in Sweden.

Legging behind these four countries is the UK, with a growth rate of 23% in 2004-2010, decreasing to zero in 2029. The UK has one of the largest onshore wind potentials in Europe and the installed capacity in 2003 is still relatively modest. Five countries are assumed to have a growth rate of 23% in 2004, decreasing to zero in 2012 in Austria and Belgium, in 2013 in Portugal, in 2019 in Italy, and in 2021 in Belgium. Also Greece is assumed to start with a relatively high growth rate of 20% in 2004, declining to zero in 2021.

Germany, Spain, and the Netherlands have a relatively saturated onshore wind market compared to the preceding 13 countries. The growth rate is assumed to be 10% in 2004, declining to zero in 2010 in Germany, in 2014 in Spain, and in 2016 in the Netherlands. Finally, Denmark is assumed to have the lowest growth rate of 8% in 2004, declining to zero in 2012.

High growth rates - 31% and 20-23% for the 'high growth countries' and the 'medium growth countries' respectively, in 2004 - have been observed in the years 2001-2003 in the 'EU15+' (the EU15 plus Norway and Poland), as shown by the last column ('Total') of Table F.1. Much lower growth rates for onshore wind energy have been observed in e.g. Denmark (Table F.1).

Table F.1 *Growth factors onshore wind EU-15 plus Norway and Poland*

	A	B	DK	SF	F	D	GR	IRL	I	L	NL	N	PL	P	E	UK	Total
2001	1.22	1.79	1.05	1.03	1.83	1.43	1.31	1.06	1.65	1.00	1.11	1.31	8.00	13.91	1.25	1.24	1.32
2002	1.48	1.32	1.11	1.10	1.59	1.37	1.29	1.29	1.15	1.00	1.39	5.71	2.25	1.33	1.42	1.09	1.33
2003	2.99	1.73	1.00	1.20	1.50	1.22	1.16	1.23	1.14	1.00	1.29	1.03	1.02	1.52	1.27	1.23	1.22
2004	1.23	1.23	1.08	1.31	1.31	1.10	1.20	1.31	1.23	1.23	1.10	1.31	1.31	1.23	1.10	1.23	1.11
2005	1.23	1.23	1.08	1.30	1.30	1.10	1.20	1.30	1.23	1.23	1.10	1.30	1.30	1.23	1.10	1.23	1.12
2006	1.23	1.22	1.08	1.29	1.29	1.10	1.20	1.29	1.22	1.23	1.10	1.29	1.29	1.23	1.10	1.23	1.12
2007	1.23	1.22	1.08	1.28	1.28	1.10	1.20	1.28	1.22	1.23	1.10	1.28	1.28	1.23	1.10	1.23	1.12
2008	1.23	1.21	1.08	1.27	1.27	1.10	1.20	1.27	1.21	1.23	1.10	1.27	1.27	1.23	1.10	1.23	1.12
2009	1.23	1.21	1.08	1.26	1.26	1.02	1.20	1.26	1.21	1.23	1.10	1.26	1.26	1.23	1.06	1.23	1.08
2010	1.23	1.20	1.08	1.25	1.25	1	1.20	1.25	1.20	1.23	1.10	1.25	1.25	1.23	1.06	1.23	1.08
2011	1.07	1.20	1.03	1.24	1.24	1	1.10	1.24	1.20	1.10	1.06	1.24	1.24	1.20	1.06	1.20	1.07
2012	1	1.19	1	1.23	1.23	1	1.10	1.23	1.19	1	1.06	1.23	1.23	1.20	1.06	1.19	1.07
2013	1	1.18	1	1.22	1.22	1	1.10	1.22	1.18	1	1.06	1.22	1.22	1	1.06	1.18	1.07
2014	1	1.17	1	1.21	1.21	1	1.10	1.21	1.17	1	1.06	1.21	1.21	1	1.01	1.17	1.06
2015	1	1.16	1	1.20	1.20	1	1.10	1.20	1.16	1	1.06	1.20	1.20	1	1	1.16	1.07
2016	1	1.15	1	1.19	1.19	1	1.10	1.19	1.15	1	1.01	1.19	1.19	1	1	1.15	1.07
2017	1	1.14	1	1.18	1.18	1	1.10	1.01	1.14	1	1	1.18	1.18	1	1	1.14	1.07
2018	1	1.13	1	1.17	1.17	1	1.10	1	1.10	1	1	1.17	1.17	1	1	1.13	1.07
2019	1	1.12	1	1.16	1.16	1	1.10	1	1	1	1	1.16	1.16	1	1	1.12	1.06
2020	1	1.11	1	1.15	1.15	1	1.08	1	1	1	1	1.15	1.15	1	1	1.11	1.05
2021	1	1	1	1.14	1.14	1	1	1	1	1	1	1.14	1.14	1	1	1.10	1.03
2022	1	1	1	1.13	1.13	1	1	1	1	1	1	1.13	1.13	1	1	1.09	1.03
2023	1	1	1	1.12	1.12	1	1	1	1	1	1	1.12	1.12	1	1	1.08	1.03
2024	1	1	1	1.11	1.11	1	1	1	1	1	1	1.11	1.11	1	1	1.07	1.03
2025	1	1	1	1.10	1.10	1	1	1	1	1	1	1.10	1.10	1	1	1.06	1.03
2026	1	1	1	1.09	1.09	1	1	1	1	1	1	1.09	1.09	1	1	1.05	1.03
2027	1	1	1	1.08	1.08	1	1	1	1	1	1	1.08	1.08	1	1	1.05	1.03
2028	1	1	1	1.07	1.07	1	1	1	1	1	1	1.07	1.07	1	1	1.04	1.02
2029	1	1	1	1.06	1.06	1	1	1	1	1	1	1.06	1.06	1	1	1	1.02
2030	1	1	1	1.05	1.05	1	1	1	1	1	1	1.05	1.04	1	1	1	1.01

Appendix G ONSHORE AND OFFSHORE WIND IN THE EU

Table G.1 presents the potential electricity generation from onshore and offshore wind based on capacities and generation data for onshore wind (Chapter 5) and offshore wind (Chapter 6). For offshore wind a capacity factor of 36.5% has been assumed based on (Herman *et al*., 2004) - a study by ECN Wind on the potential of offshore wind in the Netherlands.

Table G.1 *Projected generation from on- and offshore wind (EU-15, Norway and Poland)*

[PJ_e]	2002	2005	2010	2015	2020	2025	2030
Onshore	226	317	487	691	928	1,098	1,192
Offshore	3	21	177	586	1,300	2,141	2,878
Total	229	339	665	1,277	2,228	3,239	4,070
Growth rate [%/a]		14	14	14	12	8	5

Note: The growth rates pertain to average growth in the years preceding the year on top of the column.

Table G.1 shows that the generation from offshore wind would take over onshore wind generation around 2020. The growth rate of wind is assumed to decline to 5% in the period 2025-2030.

In 2030, the generation from offshore wind could amount to 2,878 PJ_e or 800 TWh. (EWEA, 2003) puts the potential of offshore wind in Europe at approximately 315 TWh, assuming development only in waters up to 20m depth, and largely in the 10-30km offshore range. The figure of 800 TWh is based on (Greenpeace, 2004), but with a different time scale (2030 instead of 2020) and a higher average capacity factor assumed, shifting the output from 720 to 800 TWh/a.

As projections of the electricity demand of the IEA in (WEO, 2004) only pertain to 2010-2030, the electricity demand of the EU-15 has been extrapolated to 2035. The output from onshore wind of 1,085 PJ_e (300 TWh) - Chapter 4 - could be equivalent to 7% of the extrapolated electricity demand in 2035. The projected output from offshore wind of 2,880 PJ_e (800 TWh) could be equivalent to 18% of the extrapolated electricity demand in 2035.

Appendix H BIOMASS POTENTIAL

(Hoogwijk, 2004) gives an assessment of the *geographical potential* of biomass in different world regions. First the potential of surplus agricultural and degraded land (category I and II, respectively), is analysed. Then, an assessment of the *geographical potential* of biomass is presented.

Biomass for energy on surplus agricultural land (category I)

Hoogwijk makes use of combinations of three global population scenarios - Low, Medium, and High - and three patterns of food consumption - vegetarian, moderate, and affluent. The future global food demand may range from 4.1 to 17.7 billion kg of dry-weight grain equivalent (DGE). This is equal to 80 to 350% of the current global food demand (Table H.1).

Table H.1 *Food demand for different food consumption patterns and population scenarios*

		2003	Vegetarian diet			Moderate diet			Affluent diet		
			L	M	H	L	M	H	L	M	H
Population	$[10^9]$	6.0	8.7	9.4	11.3	8.7	9.4	11.3	8.7	9.4	11.3
Global food demand	$[10^{12}$ kg of grain equiv.][a]	5.0	4.1	4.5	5.4	7.6	8.2	9.9	13.3	14.4	17.7

a) Grain equivalent = Dry-weight Grain Equivalent (DGE).
Source: Hoogwijk, 2004.

Hoogwijk also assumes two levels of intensity of agricultural production (Table H.2), viz.:

- The High External Input system (HEI), based on maximum crop production realised under optimum management, and with an efficient use of resources (e.g. fertilisers).
- The Low External Input system (LEI), based on biological farming without chemical fertilisers, biocides etc. Herbicide is presumably replaced by mechanical weeding.

Table H.2 shows that the amount of food producible with a Low External Input (LEI) agricultural system would suffice for a moderate diet on a global scale and would be ample for a vegetarian diet. A global affluent diet would require a High External Input (HEI) agricultural system.

Table H.2 *Land area for food production, potential yields, and potential food production*

Type of cultivation	Area[a]	Global mean yield		Potential global food production	
		HEI	LEI	HEI	LEI
	[Gha]	[t DGE/ha][b]	[t DGE/ha]	[t DGE/a]	[t DGE/a]
Irrigated	0.75	14.3	4.1	10.7	3.1
Rain-fed	0.75	5.9	2.1	4.4	1.6
Grassland	3.50	5.9	2.1	20.5	7.4
Total	5.00			35.6	12.0

a) The land area available for food production is assumed to be equal to the current area (~ 5 Gha).
b) DGE = Dry-weight Grain Equivalent.
Source: Hoogwijk, 2004.

Hoogwijk uses a factor of 2 to account for inefficiencies in the chain of food production and supply, variations in food production on an annual base and differences between world regions. This factor is also needed to guarantee that poor people may have sufficient food in quantity and quality. Based on this factor 2, the land area for food and biomass is as follows (Table H.3).

Table H.3 shows that the area available for biomass (for energy) may be large if a vegetarian diet would be practised globally. However, in case of a globally practised moderate diet, land would only be available if a High External Input (HEI) agricultural system would be applied. Also, the affluent diet only shows some biomass potential if a HEI agricultural system would be applied.

Table H.3 *Land area for food and for biomass for energy based on Tables H.1 and H.2*

Agriculture intensity [Gha]	Vegetarian diet			Moderate diet			Affluent diet		
	L	M	H	L	M	H	L	M	H
	Global land area needed for food production								
HEI	1.2	1.3	1.5	2.1	2.3	2.8	3.7	4.0	5.0
LEI	3.4	3.8	4.5	6.3	6.8	8.3	11.1	12.0	14.8
	Global land area available for biomass for energy								
HEI	3.8	3.7	3.5	2.9	2.7	2.2	1.3	1.0	0.0
LEI	1.6	1.3	0.5	-1.3	-1.8	-3.3	-6.1	-7.0	-9.8

Source: Hoogwijk, 2004.

Biomass for energy on degraded land (category II)

Besides surplus agricultural land, degraded land is a potential source of biomass for energy. (Hoogwijk, 2004) analysed studies exploring the potential of degraded land for biomass production. These studies identify areas of the world in which human activities have induced soil and/or vegetation degradation. Those areas are not suitable for agriculture. However, they have been evaluated for the purpose of reforestation or energy crops. According to (Hoogwijk, 2004), 0.43-0.58 Gha would be suitable for energy crops, in particular short rotation forestry.

Geographical potential of energy crops on surplus agricultural and degraded land

According to (Hoogwijk, 2004), the yield of woody short rotation crops ranges from 10 to 20 ton/ha/a on surplus agricultural land, and from 1 to 10 ton/ha/a on degraded land. The heating value of woody biomass is 17.7 GJ/tonne[14] (Baehr, 1978). Hoogwijk narrows the 18 variants of Table H.3 to attain realistic estimates of the potential of biomass, omitting the cases with a global vegetarian diet, and the cases with a Low External Input (LEI) agricultural system. Table H.4 shows the resulting *geographical potential* of energy crops on surplus agricultural land.

Table H.4 shows that the energy yield may range from 0 in case of the affluent diet combined with the high population growth until 2050, to 920 EJ/a in case of the moderate diet and the low population scenario. Hoogwijk also presents an estimate of biomass on degraded land of 8-110 EJ/a, depending on the land area available (see Table H.3) and the yield on degraded land.

Table H.4 *Geographical potential on surplus agricultural land (excluding vegetarian diet)*

Agriculture intensity [EJ/a]	Moderate diet			Affluent diet		
	L	M	H	L	M	H
HEI	920	860	700	410	320	0

Source: Hoogwijk, 2004.

[14] Woody biomass has a higher heating value of 19 GJ/t (Hoogwijk, 2004). The lower heating value - neglecting the heat of condensation of water vapour - is, however, a more appropriate yardstick for the energy content of biomass.

Geographical potential of biomass for world regions

Hoogwijk uses IPCC-SRES scenarios (Table H.5) to analyse the land availability dependent on:

- Population dynamics
- Diet - food consumption pattern, e.g. the consumption of meat
- Agricultural technological change.

Table H.5 *IPCC-SRES scenarios used to estimate the global biomass potential*

	Global	*Regional*
Material/economic	**A1** Food trade: maximum Technology development: high Population 2100: 7.1 billion GDP world 2100: 86.2 trillion $95/a	**A2** Food trade: low Technology development: low Population 2100: 15.1 billion GDP world 2100: 17.9 trillion $95/a
Social/environment	**B1** Food trade: high Technology development: high Population 2100: 7.1 billion GDP world 2100: 53.9 trillion $95/a	**B2** Food trade: low Technology development: low Population 2100: 10.4 billion GDP world 2100: 27.7 trillion $95/a

Source: Hoogwijk, 2004.

Appendix I shows the *geographical potential* of energy crops on three kinds of land-use and for the scenarios of Table H.5. The first kind of land-use refers to abandoned or surplus agricultural land. The second refers to degraded land that may be suitable for energy crops, albeit with a low productivity (low-productive land). The third is remaining land - mountains, savannah, steppe, etc. - that could be made suitable for production of energy crops (total 4.2 Gha, §8.3.1).

Figure H.1 and Figure H.2 show the *geographical potentials* of energy crops for the world regions distinguished by (Hoogwijk, 2004) and by world region, for the two most contrasting scenarios.

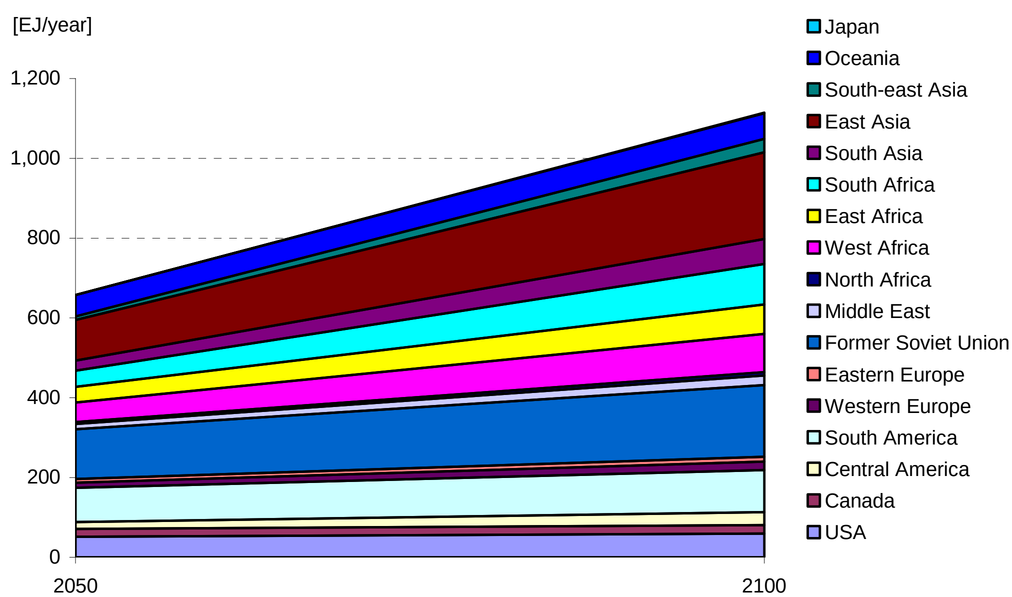

Figure H.1 *Geographical potential of energy crops for IPCC-SRES scenario A1*

Note: Western Europe = OECD Europe.

Source: Hoogwijk, 2004.

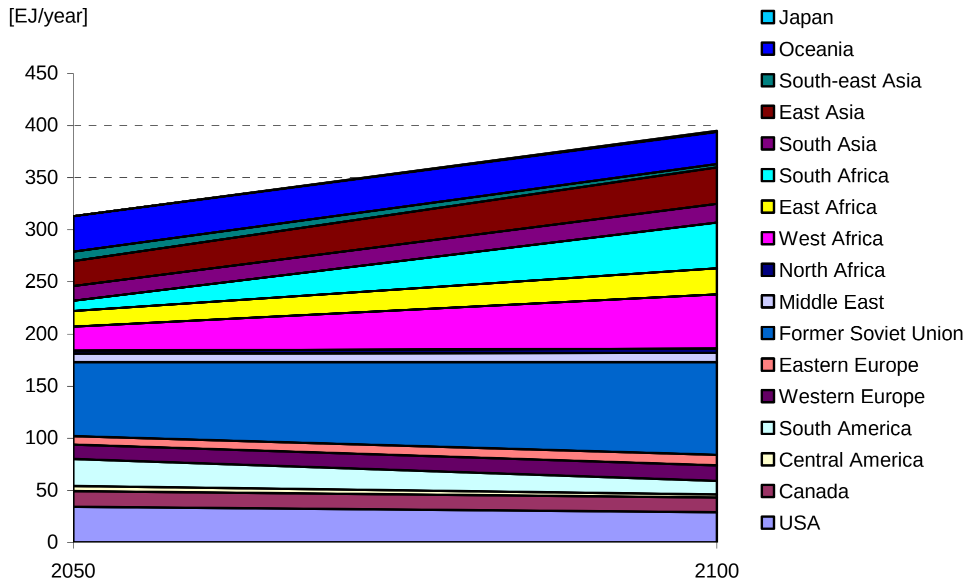

Figure H.2 *Geographical potential of energy crops for IPCC-SRES scenario A2*
Source: Hoogwijk, 2004.

Appendix I GEOGRAPHICAL POTENTIAL OF ENERGY CROPS

Table I.1 presents the *geographical potential* of energy crops at three land-use categories and for four IPCC-SRES scenarios by world region, according to (Hoogwijk, 2004).

Table I.1 *The regional geographical potential of energy crops at three land-use categories and four IPCC-SRES scenarios for the year 2050 and 2100*

	Energy crops on abandoned agricultural land [EJ/a]								Energy crops on low-productive land [EJ/a]								Energy crops on remaining land [EJ/a]							
	A1		A2		B1		B2		A1		A2		B1		B2		A1		A2		B1		B2	
	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
USA	32	39	18	20	33	31	46	55	0	0	1	0	0	0	1	0	19	21	15	9	3	3	3	3
Canada	14	17	9	10	13	12	12	15	2	1	3	2	2	2	3	2	4	3	3	2	1	0	1	0
NAM	46	56	27	30	46	43	58	70	2	1	4	2	2	2	4	2	23	24	18	11	4	3	4	3
CAM	8	22	1	1	10	19	4	10	0	0	0	0	0	0	0	0	9	10	4	2	2	2	1	1
SAM	53	73	1	1	56	70	37	41	1	0	1	0	1	0	1	1	32	33	24	12	6	5	6	5
WE	9	16	10	11	9	14	15	17	0	0	0	0	0	0	0	0	4	5	4	4	1	1	1	1
EE	9	12	8	10	8	10	9	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FSU	97	147	47	63	83	101	74	106	1	0	3	1	2	1	2	1	27	33	21	25	5	4	4	5
ME	2	13	1	2	2	10	1	2	0	0	0	0	0	0	0	0	11	11	7	7	2	2	2	1
NA	2	5	1	2	2	5	1	2	0	0	0	0	0	0	0	0	3	3	2	2	1	0	0	0
WA	20	69	3	36	22	58	2	25	0	0	0	0	0	0	0	0	29	27	20	16	5	4	4	3
EA	15	49	1	13	17	41	2	5	0	0	0	0	0	0	0	0	24	25	14	12	4	4	3	2
SA	24	83	1	36	26	66	1	35	0	0	0	0	0	0	0	0	17	18	9	8	4	3	2	2
SAS	12	49	3	8	11	38	4	15	0	0	0	0	0	0	0	0	13	14	11	10	3	2	1	1
EAS	79	181	7	11	74	127	43	61	1	1	1	1	1	1	1	1	22	35	16	23	4	4	3	4
SEAS	1	28	1	1	1	19	2	10	0	0	0	0	0	0	0	0	8	6	8	2	2	1	1	1
O	32	42	17	17	31	34	26	36	0	0	0	0	0	0	0	0	21	22	17	14	4	4	3	3
Japan	0	2	0	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total world	409	847	129	243	398	656	279	448	5	2	9	4	6	4	8	5	243	266	175	148	47	39	35	32

Note: NAM = North America; CAM = Central America; SAM = South America; WE = Western Europe; EE = Eastern Europe; FSU = Former Soviet Union; ME = Middle East; NA = North Africa; WA = West Africa; EA = East Africa; SA = South Africa; SAS = South Asia; EAS = East Asia; SEAS = South East Asia; O = Oceania.

Source: Hoogwijk, 2004.

Appendix J URANIUM RESOURCES AND PRODUCTION

With regard to uranium, resource estimates are divided into separate categories according to different levels of confidence in the quantities reported. A distinction is made between the categories ‘Reasonably Assured Reserves’ (RAR) and ‘Estimated Additional Resources’ (EAR). Reserves with the highest level of confidence are called Reasonably Assured Reserves (RAR). RAR and EAR together are considered as the ‘known conventional resources’ of uranium.

Table J.1 shows the Reasonably Assured Reserves (RAR) of uranium at 1 January 2003, as reported by (WEC, 2004). These are further separated into categories based on the cost of production. The cost categories are: less than \$40/kgU; \$40-80/kgU and \$80-130/kgU. Costs include the direct costs of mining, transporting and processing uranium ore, the associated costs of environmental and waste management, and the general costs associated with running the operation.

The WEC follows the practice of the NEA/IAEA and defines estimates of discovered reserves in terms of uranium recoverable from mineable ore and not uranium contained in the ore (i.e. to allow for mining and processing losses). All resource estimates are expressed in terms of tonnes of recoverable uranium (U), not uranium oxide (U_3O_8). Table J.1 shows that the RAR amount to 3.17 MtU. Australia and Kazakhstan possess 20% and 17% respectively the proved reserves (RAR), and the US, Canada and South Africa each approximately 10%.

Table J.2 presents the Estimated Additional Resources (EAR) at 1 January 2003 (WEC, 2004). These are further separated into categories based on the cost of production. Table J.2 also contains a column ‘Undiscovered, recoverable at up to \$130/kgU’ referring to uranium in excess of RAR and EAR. EAR amounts to 1.42 MtU, and the ‘Undiscovered, etc.’ amounts to 9.79 MtU.

RAR and EAR - the ‘known conventional resources’ of uranium - represent 4.59 MtU. If the more speculative resources yet undiscovered but believed to exist based on geologic evidence (Undiscovered, recoverable at up to \$130/kgU) are added to that, the resource base of uranium may be even 14.39 Mt U. Based on the world’s reactor-related requirements in 2003, viz. 68,435 tU (ATW, 2004), the resources would be sufficient for 210 years of current production, viz. 46 years for RAR, 21 years for EAR and 143 years for ‘Undiscovered, etc.’ resources.

Figure J.1 shows the uranium production in the western world during the past five decades.

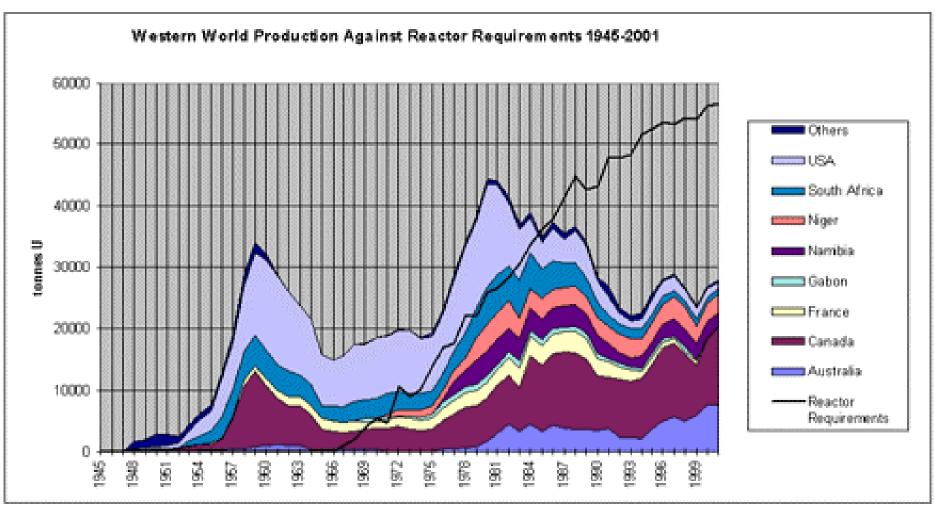

Figure J.1 *Uranium production in the western world, 1945-2001*
Source: Internet source 5.

In the last few years, uranium production ranged from 32,200 to 37,300 tU, well below the annual demand for civil reactors of 60,000 tU or more. The balance is met from uranium kept in stock at nuclear power plants and in increasing amounts from conversion of high-enriched uranium and plutonium from military stockpiles to low-enriched uranium (by blending with depleted uranium) and MOX fuel respectively.

Table J.1 *Proved uranium reserves (Reasonably Assured Reserves, RAR), 1 January 2003*

	Reasonably Assured Reserves [1000 t U] recoverable at					Fraction
	<$40/kgU	$40-80/kgU	<$80/kgU	$80-130/kgU	Up to $130/kgU	[%]
USA			102.0	243.0	345.0	10.9
Canada	297.3	36.6	333.8		333.8	10.5
Greenland				20.3	20.3	0.6
Mexico				1.3	1.3	0.0
Total North America	*297.3*	*36.6*	*435.8*	*264.6*	*704.1*	22.2
Argentina	4.8	0.1	4.9	2.2	7.1	0.2
Brazil	26.2	60.0	86.2		86.2	2.7
Chile					0.6	0.0
Peru			1.2		1.2	0.0
Total S & C America	*31.0*	*60.1*	*92.3*	*2.2*	*95.0*	3.0
Bulgaria	1.7	4.2	5.9		5.9	0.2
Czech Republic		0.8	0.8		0.8	0.0
Finland				1.1	1.1	0.0
Germany				3.0	3.0	0.1
Greece	1.0		1.0		1.0	0.0
Italy			4.8		4.8	0.2
Kazakhstan	280.6	104.0	384.6	145.8	530.5	16.7
Portugal			7.5		7.5	0.2
Romania				3.3	3.3	0.1
Russian Federation	52.6	71.4	124.1	19.0	143.0	4.5
Slovenia		2.2	2.2		2.2	0.1
Spain		2.5	2.5	2.5	4.9	0.2
Sweden				4.0	4.0	0.1
Turkey		6.8	6.8		6.8	0.2
Ukraine	15.4	19.3	34.6	30.0	64.7	2.0
Uzbekistan	61.5		61.5	18.1	79.6	2.5
Total Europe/Eurasia	*402.8*	*211.2*	*636.3*	*226.8*	*863.1*	27.2
Iran				0.4	0.4	0.0
Total Middle East				*0.4*	*0.4*	0.0
Algeria			19.5		19.5	0.6
Central African Republic			6.0	6.0	12.0	0.4
Republic of Congo			1.4		1.4	0.0
Gabon				4.8	4.8	0.2
Malawi			8.8		8.8	0.3
Namibia	57.3	82.0	139.3	31.2	170.5	5.4
Niger	89.8	12.4	102.2		102.2	3.2
Somalia				5.0	5.0	0.2
South Africa	119.2	112.5	231.7	83.7	315.3	9.9
Zimbabwe			1.4		1.4	0.0
Total Africa	*266.3*	*206.9*	*510.2*	*130.7*	*640.8*	20.2
Australia	689.0	13.0	702.0	33.0	735.0	23.2
China	26.2	8.8	35.1		35.1	1.1
India					41.0	1.3
Indonesia		0.3	0.3	4.3	4.6	0.1
Japan					6.6	0.2
Mongolia	8.0	38.3	46.2		46.2	1.5
Thailand				N	N	
Vietnam					1.0	0.0
Total Asia Pacific	*723.2*	*60.4*	*783.6*	*37.3*	*869.5*	27.4
Total World	*1,720.6*	*575.2*	*2,458.2*	*662.0*	*3,172.9*	100.0

Source: WEC, 2004.

Table J.2 *Estimated Additional Resources (EAR) of uranium, 1 January 2003*

	Reasonably Assured Reserves [1000 t U] recoverable at					Undiscovered, recoverable at
	<$40/kgU	$40-80/kgU	<$80/kgU	$80-130/kgU	Up to $130/kgU	Up to $130/kgU
USA	NA	NA	NA	NA	NA	850.0
Canada	86.6	18.2	104.7		104.7	60.0
Greenland				12.0	12.0	13.0
Mexico				0.5	0.5	2,613.0
North America	*86.6*	*18.2*	*104.7*	*12.5*	*117.2*	*3,536.0*
Argentina	2.9		2.9	5.7	8.6	1.4
Brazil		57.1	57.1		57.1	620.0
Chile					0.9	4.7
Colombia						228.0
Peru			1.3		1.3	26.3
Venezuela						163.0
Total S & C America	*2.9*	*57.1*	*61.3*	*5.7*	*67.9*	*1,043.4*
Bulgaria	1.7	4.7	6.3		6.3	18.2
Czech Republic		0.1	0.1		0.1	179.2
France				9.5	9.5	
Germany				4.0	4.0	74.0
Greece			6.0		6.0	6.0
Hungary				13.8	13.8	
Italy			4.8	1.3	1.3	10.0
Kazakhstan	131.2	106.6	237.8	79.4	317.2	810.0
Portugal			1.5		1.5	6.5
Romania				3.6	3.6	6.0
Russian Federation	15.9	18.4	34.3	87.0	121.2	649.5
Slovenia		5.0	5.0	5.0	10.0	1.1
Spain				6.4	6.4	
Sweden				6.0	6.0	
Ukraine	0.9	3.8	4.7	6.7	11.4	256.6
Uzbekistan	31.8		31.8	7.1	38.8	231.6
Total Europe/Eurasia	*181.5*	*138.6*	*327.5*	*229.8*	*557.1*	*2,248.7*
Iran				0.7	0.7	13.9
Total Middle East				*0.7*	*0.7*	*13.9*
Congo (DR)			1.3		1.3	
Egypt						0.1
Gabon				1.0	1.0	
Namibia	57.1	16.4	73.6	13.5	87.1	
Niger	125.4		125.4		125.4	9.5
Somalia				2.6	2.6	
South Africa	49.3	17.6	66.9	13.4	80.3	1,223.2
Zambia						22.0
Zimbabwe			1.4			25.0
Total Africa	*231.8*	*34.0*	*267.2*	*30.5*	*297.7*	*1,279.8*
Australia	276.0	11.0	287.0	36.0	323.0	
China	5.9	8.8	14.7		14.7	7.7
India					18.9	32.5
Indonesia				1.2	1.2	4.1
Mongolia	8.3	7.5	15.8		15.8	1,390.0
Thailand				N	N	
Vietnam			0.8	4.6	5.4	237.9
Total Asia Pacific	*290.2*	*27.3*	*318.3*	*41.8*	*379.0*	*1,672.2*
Total World	*793.0*	*275.2*	*1,079.0*	*321.0*	*1,419.6*	*9,794.0*

Source: WEC, 2004.

During the last few years, uranium production remained substantially below demand for civil reactors due to declining stocks at nuclear power plants and conversion of high-enriched uranium and plutonium. Table J.3 presents recent uranium production data (Internet source 6).

Table J.3 *Worldwide uranium production 2001-2003*

[tU]	2001	2002	2003
USA	1,011	919	857
Canada	12,520	11,604	10,457
Total North America	*13,531*	*12,523*	*11,314*
Argentina	0	0	20
Brazil	58	270	310
Total S & C America	*58*	*270*	*330*
Czech Republic	456	465	345
France	195	20	0
Germany	27	212	150
Kazakhstan	2,050	2,800	3,300
Portugal	3	2	0
Romania	85	90	90
Russia (est.)	2,500	2,900	3,150
Spain	30	37	30
Ukraine (est.)	750	800	800
Uzbekistan	1,962	1,860	1,770
Total Europe/Eurasia	*8,058*	*8,786*	*9,635*
Namibia	2,239	2,333	2,036
Niger	2,920	3,075	3,143
South Africa	873	824	758
Total Africa/Middle East	*6,032*	*6,232*	*5,937*
Australia	7,756	6,854	7,572
China (est.)	655	730	750
India (est.)	230	230	230
Pakistan	46	38	45
Total Asia Pacific	*8,687*	*7,852*	*8,597*
Total world	*36,366*	*36,063*	*35,813*

Source: Internet source 6.

Appendix K NUCLEAR GENERATION & URANIUM DEMAND

Studies of the IAEA (IAEA, 2004) and the IEA ('World Energy Outlook 2004') present scenarios until 2030, including the contribution from nuclear power. Figure K.1 shows the two scenarios of the IAEA - 'IAEA High' and 'IAEA Low' - and IEA's default scenario in (WEO, 2004).

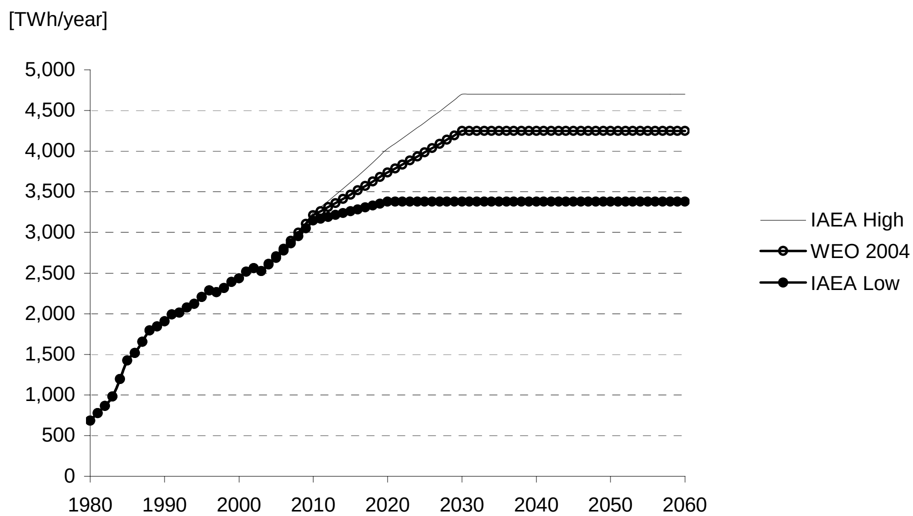

Figure K.1 *Global electricity generation based on nuclear power, 1980-2060*
Sources: IAEA, 2004; WEO, 2004; EIA, 2004.

The nuclear capacities in 2030 are 'frozen' until 2060 and the cumulative uranium requirements from these scenarios have been calculated. Figure K.2 shows the cumulative uranium demands from the scenarios in the perspective of the uranium reserves (RAR and EAR), the total uranium resources (RAR, EAR, and speculative resources), and the total uranium and thorium resources.

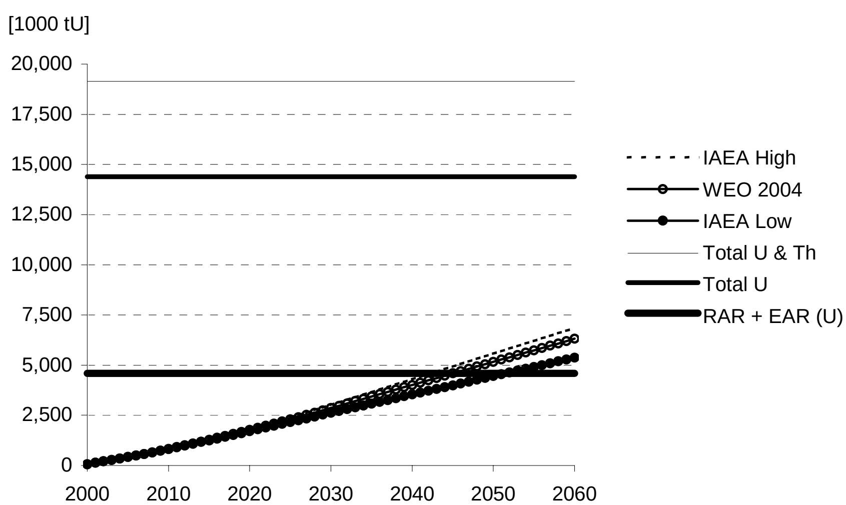

Figure K.2 *Cumulative global uranium requirements for three scenarios to 2030*

Note: Uranium requirement: ratio of 'uranium requirement 2003'/'nuclear generation 2003'. Installed nuclear capacities in 2030 are assumed 'frozen' towards 2060.
Sources: IAEA, 2004; WEO, 2004; ATW, 2004.

In 2003, the nuclear generation amounted to 2,524 TWh according to (IAEA, 2004) and the uranium requirement for civil nuclear reactors was 68,425 tU, according to (ATW, 2004). These key data have been used to calculate the cumulative uranium demand for the period 2000-2030. The reserves of uranium in the categories RAR and EAR would be sufficient until 2040-2050.

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