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Analysis of Long-term Energy Scenarios

by Jacob Lemming and Poul Erik Morthorst

Risø National Laboratory, Roskilde
January 1999

Preface

This is the final report on long-term scenarios of Risø National Laboratory made as a contribution to the Macro Task SE0 (projections of economical and social scenario), part of the programme of Socio-Economic Research on Fusion (SERF).

Jacob Lemming and Poul Erik Morthorst carried out the study in the period February-July 1998 at RISØ National Laboratory, Roskilde, Denmark.

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1. Introduction

When addressing the role of fusion energy in the 21st century, the evaluation of possible future structures in the electricity market and the energy sector as a whole, can be a useful tool. Because fusion energy still needs demonstration, commercialized fusion energy is not likely to be a reality within the next few decades. Therefore long-term scenarios are needed describing the energy markets, which fusion energy eventually will be part of.

This report performs an analysis of two of the most detailed existing long-term scenarios describing possible futures of the energy system. The aim is to clarify the frames in which the future development of the global energy demand, as well as the structure of the energy system can be expected to develop towards the year 2100.

2. Object of the study

The allocation of funds for an ambitious project such as fusion energy raises two fundamental questions. First a question of technical prospects, when could fusion energy have the necessary technical potential? Secondly a matter of future structures in the energy sector. The frames in which structural aspects such as level of energy demand, type of required energy services, and possible supply side structures could develop, provide an insight in the possible future role of an energy source like fusion energy. This study will focus on the latter by analyzing two detailed long-term scenarios.

Energy scenarios provide a view of the future as it might look given a set of key assumptions regarding the driving forces of change. In order to interpret and compare the results of such scenarios the different assumptions made concerning these parameters need evaluation.

When considering the future structure of the energy system, there are several essential parameters. The demand for energy will depend on factors such as growth in population, growth rates of the economy, efficient use of energy etc. On the supply side efficiencies of various technologies used to convert primary energy into final energy as well as industrial and political measurements will set the agenda. This report will focus on such key parameters in order to evaluate and explain the differences and similarities between the results of the long-term scenarios chosen.

Our report is based on the following studies.

- WEC/IIASA study "Global Energy Perspective to 2050 and beyond" containing six different scenarios.

- IPCCs " Climate changes 1995" with five different scenarios.

- The IPS92a scenario is part of six scenarios (a-f) prepared for IPCC Working Group 1 in 1992 and will be partially used for comparison.

These scenarios have been chosen because they represent the most detailed studies available considering the time perspective to 2100.

The database prepared for the IPCC Special report on emission scenarios by Morita and Lee [3] contains a vast amount of scenarios. Over 370 scenarios including the IPS92 and WEC (95)-scenarios are treated. The median value of these scenarios has been calculated for a number of key parameters. To broaden the perspective the key parameters in the scenarios chosen will be compared with median values and range of intervals listed in this database.

As explained in the two studies, the scenarios are not to be considered forecasts but rather alternative images of the future given a set of assumptions about the driving forces of change. This study aims to explain the different results of the scenarios and to point out strengths and weaknesses in methodology relevant to a new scenario generation including fusion energy.

Because of the considerable differences in basic assumptions concerning important parameters like political measures and the growth rate in energy consumption, a number of studies including the WEC [1] and IPCC [2]-study have divided the scenarios into different categories. When comparing the studies these categories can be useful because they allow us to highlight the different paths envisioned in scenarios each holding a similar set of key assumptions.

Finally, we emphasize on the future role of renewables. Biomass, wind, and solar power are treated separately. More recent projections are included to broaden the perspective.

In section 3 the scenarios are described and section 4 briefly treats scenario-categories. Section 5 analyses the demand side and section 6 treats the supply side structure. Finally in section 7 we treat renewables in detail focusing especially on wind energy.

3. The long-term (1990-2100) scenarios

The time frame considered in this study is of considerable magnitude. The IPCC [2] states that by the year 2100 the global commercial systems will have been replaced two to three times. Given such an assumption, the technological developments of the coming decades will have reached a state of implementation and perhaps even replaced with future technologies within the timeframe of the scenarios (1990-2100). This emphasizes that the crucial parameter for energy suppliers will be the ability to match the demands of consumers and governments through technological innovation.

In this section we describe the scenarios in each of the chosen studies. General assumptions valid for all of scenarios within a given study are outlined and commented.

3.1 The WEC scenarios

The (WEC/IIASA, 1995) study is significant in its detail and broadness. It presents three cases A, B and C, which are in turn divided into a total of six scenarios. The cases A, B and C differ in their assumptions concerning political measurements and rate of technological development. The cases resemble the often-used distinction of ecological and non-ecological scenarios.

- Case A contains three scenarios based on a high level of technological innovation giving rise to significant growth in global economy.

- Case B presents a single scenario with a more modest level of technological ingenuity and a slowly changing global energy policy towards sustainability that present no immediate drastic changes.

- Case C consists of two scenarios that envisage a high level of technological development combined with a high level of international co-operation towards sustainable energy policies.

3.1.1 Commonalties of cases A, B and C

The study incorporates a series of assumptions that apply to all of the three cases, these basic assumptions form the foundation of the scenarios and are briefly summarised in the following.

- Historically the consumers have been experiencing an overall increasing level of income and as a result they desire energy services that are more efficient, clean and convenient. This trend is expected to continue and will to a large extent govern the demand side structure of the energy system.

This is a central message of the WEC-study. As the welfare increases people will demand energy services that contribute to the welfare accordingly. Since this is one of the fundamental assumptions of the study it is not surprising that the parameters concerning the demand side structure of the energy system are more identical among the three cases than those of the supply side.

- The development of final energy patterns of the future is identical in all three cases. The use of cleaner end-use fuels such as electricity, gas and synthetic liquids will increase at the expense of solids.

This convergence is a result of the basic assumption concerning consumer interest as well as the development of and casualties between the parameters of the energy systems demand side.

- Population growth is assumed identical in the six scenarios whereas the development of parameters such as economic growth and energy intensity differs among the three cases.

The study incorporates only a weak direct relationship between growth in population and growth in the economy. The reverse relationship however as illustrated by the historically observed decline in fertility rates as a result of economic growth is incorporated in all of the scenarios. However since the rate of population growth is identical in all scenarios, the levels of economic growth, though considerably different in the three cases, especially for the developing countries (DC's), have the same effect on demographics in all cases.

The pleasant effect of the identical population growth assumption, is the elimination of population growth as a parameter when analysing differences between the scenarios.

The industrialisation of established economies succeeded by a catch-up effect is incorporated in the scenarios. This give rise to a decreasing trend in economic growth rates for regions representing today's (late 20th century) established economies and accelerating growth rates for DC's that are currently in the "catching-up" process. The assumption is supported by historical developments in the different regions as illustrated by the economic growth rates vs. degree of economic development in Figure 3.1.

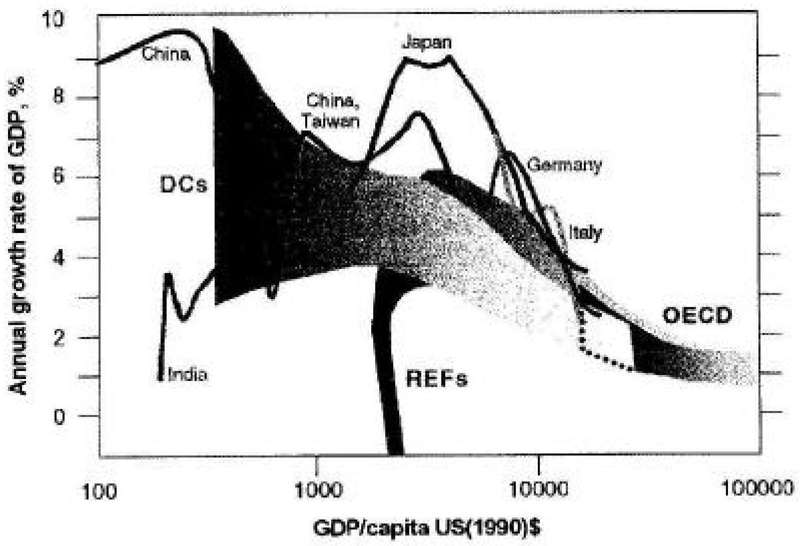

Figure 3.1: **Economic growth rates (% per year GDP) versus degree of economic development [US(1990)$ GDP per capita]. Source WEC [1].**

The figure also illustrates that the curves representing the different regions seem to consist of more than one peak, and that these peaks seem to occur at different levels of economic development. Though the scenarios might not be able to incorporate this without assuming future major discontinuities it is worth noticing. It illustrates the uncertainty linked with the factors that determine an economy's point of acceleration and peak in growth rate. Therefore, the envisioned regional and global economic growth rates become important parameters when comparing different scenarios.

The study presents a set of basic assumptions concerning the overall energy intensity trends. It is assumed that economic growth gives rise to improvements in energy intensities and countries are expected to reach similar levels of energy intensity at similar levels of Gross Domestic Product (GDP) per capita. A central element is technological progress controlled by factors such as policies and economic opportunities. Though all cases assume a future of technological innovation this is a factor that varies significantly and causes the scenarios to differ in their prediction of future energy intensity values.

3.1.2 Differences between the six scenarios

The differences between the six scenarios are many and the most important assumptions as well as the results will be analysed in the following chapters. This section will just briefly point out some of the main areas of difference.

The differences between the three cases are primarily based on demand and environment.

- The cases A and B vary principally in their level of economic growth rates and technological developments. High levels are assumed in case A and more moderate levels in case B. As a consequence the scenarios also differ in their view on associated parameters like geopolitics and level of international trade.

The two cases are described as being descriptive (case B) and partly descriptive (case A). Considering the current line of policies pursued (Kyoto conference) it seems that neither the cases A, B nor the case C are political business as usual scenarios and that both categories should be considered somewhat normative.

- Case C distinguishes itself from A and B by envisioning strong international effort towards both equity and environmental protection. The economic growth follows the level of case B but the energy intensities are improved radically through political measures to reduce carbon emissions like environmental taxes and CO_2 constraints.

Case A and case C diverge in their view on the supply side of the future energy system, in the sense that different technologies dominate the primary energy production in the different scenarios.

- Case A is divided into three scenarios each representing certain paths along which the considered range of technologies is expected to develop. Case A1 envisions technological developments favouring oil and gas conversion, in A2 improvements in coal converting technologies are assumed cost competitive, and A3 favours renewables and nuclear energy technologies.

- Case C is divided into two scenarios based on a somewhat similar analogy. Focus is on whether or not nuclear technologies will be able to surpass the social resistance previously experienced. In Case C1 nuclear energy is phased out toward the end of the century. In Case C2 nuclear energy slowly expands in market share from 12% in the year 2050 to a level short of 20% in the year 2100. These differences form the basis of the results concerning the future supply side structure of the energy system obtained in each of the scenarios.

3.2 The IPCC study

The IPCC presents five scenarios called LESS-variants (Low CO_2-Emitting Supply Systems) [2]. The LESS-variants are described as indicators of what is possible to accomplish given that a particular technological strategy is followed. As stated the actual strategies might involve elements from some or all of the variants. This makes the nature of the IPCC study quite different from that of the WEC study. The matter of consumer interests, which is one of the fundamentals of the WEC study, is not treated separately in the LESS-variants. Instead the consumers are assumed to be part of a society with deep CO_2 reductions on the agenda.

Five variants are presented. Four of those differ in the use of different sources for primary energy and a fifth explores the options available given a higher level of energy demand. Before constructing the variants the state of development and options for each of the considered technologies are thoroughly treated. The four low demand variants include a biomass intensive variant (BI), a nuclear intensive variant (NI), a coal intensive variant (CI), and a natural gas intensive variant (NGI).

3.2.1: Commonalties/differences between the LESS-variants.

The LESS-variants are described as being thought experiments of what might be accomplished by following a particular technological strategy. Thus the four energy efficient variants differ only in their portfolio of different technologies capable of penetrating the future energy markets.

- Unlike the WEC scenarios the LESS-variants do not differ in assumptions concerning the demand side structure of the energy system except for the high demand (HD) variant which envisions a considerably higher level of primary energy than the four other variants.

This consistence in demand side structures gives the IPCC study a more normative character than the WEC study. Policies towards deep reductions in CO_2 emissions as well as high levels of energy intensity improvements are assumed for all of the five variants.

- A global environmental standard corresponding to the most stringent in place today is incorporated in all the variants within the timeframe.

Such an assumption indirectly requires a significant political agreement on a global scale (as assumed in the WEC case C scenarios) to ensure the necessary technology transfer and development.

Keeping the structure of the WEC study in mind, the energy efficient LESS-variants resemble four scenarios in the same case. As in the different case A or C variants of the WEC-study, the central element in the four energy efficient LESS-variants is the differences in technological developments.

The study concludes that the deep reductions in CO_2 emissions are possible in the four energy efficient variants with a high degree of flexibility in the energy supply system. Also the high demand variant is considered possible though with a smaller degree of flexibility as a consequence.

3.3: The IS92 study.

The IS92-study [6] presents six scenarios (a-f) with IS92a and IS92b as reference scenarios. The cases vary in assumptions concerning population growth, economic growth, resource availability etc. The scenarios are no-climate-policy scenarios, traditionally called business as usual. Since environmental focus in the energy sector has been intensified since 1992 the term business as usual has of course changed. Because IS92a is used for comparison we list some of its main characteristics.

Since no major political measurements are enacted the changes in supply side structure are primarily a result of the following:

- Increasing prices on fossil fuel recovery lowering the positive cost effect achieved through technological developments.
- Nuclear energy costs in constant 1990 prices, increase in the period 1990-2050 because the nuclear industry is unable to overcome public concern.
- Solar energy and bio-fuels improve in cost effectiveness and the market share in primary energy production held by non-fossil fuels by 2100 is 43% opposed to 12% in 1990.
- Despite supply side trends similar to the WEC and IPCC (1995) studies, global CO_2-emissions grow at an average annual rate of 1.1% in the period 1990-2100. The resulting level exceeds the level of approximately 2Gt C/year envisioned in the IPCC LESS-variants by more than a 10 fold.

Comparison of WEC B and IS92a illustrates the speed at which the outlook formed by a business as usual scenario changes. Using CO_2-emissions with all values in Gt C/year as an example, the IS92a variant envisions total global levels of 14.5 in 2050 and 20.3 by 2100 opposed to the WEC case B values of 10 in 2050 and 14 in 2100.

4. Methodology and description of categories

The section briefly elaborates on the idea of categorizing the scenarios. When comparing scenarios the differences in political measures and level of primary energy demand create diverging images of the future energy system. By categorizing the scenarios the task of comparing the future images presented by scenarios in different studies can be simplified.

When scenarios are categorized within a study the difference in one or more key parameters form the basic distinction. In the scenarios chosen (as in most scenarios available) the key parameters are political measures and level of global energy requirements. In this paper we will use these two key parameters when comparing the scenarios by viewing the scenarios as either Ecological or High demand driven.

- Ecologically driven scenarios. Scenarios with intensive development in technology and a massive focus on ecology and environmental protection.

- High demand driven scenarios. Economy intensive scenarios focusing on high growth rates in global energy demand.

The high growth variant WEC Case A and the LESS High demand variant are both variants of rapidly growing energy requirements. In the category of high demand variants they should provide an overview of the most likely supply-side structures given that our capability of deploying global energy resources is pushed to the limits.

The Case B envisions neither high demand nor strict ecological policies and does not fit any of the two categories.

Case C and the energy efficient LESS-variants, the latter assuming strict political measurements towards sustainability, are considered ecologically driven.

The high demand-LESS variant could be considered both high demand and ecologically driven but we will argue that the latter is the most appropriate. The IPCC study does not explicitly specify factors leading to the higher level of demand represented in the high demand variant. Since economic and population growth rates are similar to those in the energy efficient variants, different political instruments such as emission constraints and level of R&D funding would most likely explain the different levels of future primary energy requirements. If this is assumed to be the case, the level of demand seems to outrank strict policy measures towards sustainability, and the scenario is considered high demand driven.

It should be noted that both categories envision a policy towards a cleaner environment and lower rates of CO_2 emission to some extent. Therefore the purpose of these categories is not to reflect extreme political point of views, but rather to show different degrees of engagement.

5. Comparison of demand side structures

This section treats the projection of key parameters governing the demand for primary and final energy. For each of the parameters the forecasts used in the scenarios are described and compared. This is followed by an analysis of the different parameter projections.

In the analysis of projections focus is on the following two key issues:

1. What assumptions underlie the different parameter projections?
2. What correlation between parameter growth and growth in energy demand is assumed?

As indicated in the previous section the expected level of future primary energy requirements is one of the central issues affecting the possible role of fusion energy.

An energy system with a high level of demand for energy would at first glance seem to work in favor of energy sources with a large potential like fusion. In a scenario with a more moderate increase in the energy demand new energy sources like fusion would face a more challenging and competitive market. However the future level of demand is strongly correlated with the regional policies pursued. Sustainable energy policies are likely to lead towards more energy efficient and less CO_2-emmiting energy structures, that can decrease the trend in the rising demand for final energy. Being a low CO_2-emmiting energy source fusion energy would most likely benefit from such sustainable policies even in a market with a relative "low" level of demand for energy. Such causalities between policies and level of energy demand are elaborated in the analysis of the projections.

The analysis will cover the following subsets:

- Analysis of the key parameters that directly influence future energy demand i.e. population growth, economic growth and energy intensity.

- The level of future primary energy demand projected in the scenarios using the database as a basic reference.

- Final energy-use with emphasis on the role of electricity, since this would be the primary market for fusion energy.

5.1 Population growth

Unlike the series of IPS92 scenarios the two studies considered have used identical population projections in all scenarios. The WEC-study uses 1992 data from World Bank which is a level of half a billion above the IPCC-study's in 2050 and approximately one billion higher in the year 2100. The magnitude of this difference is set in perspective in Figure 5.1.

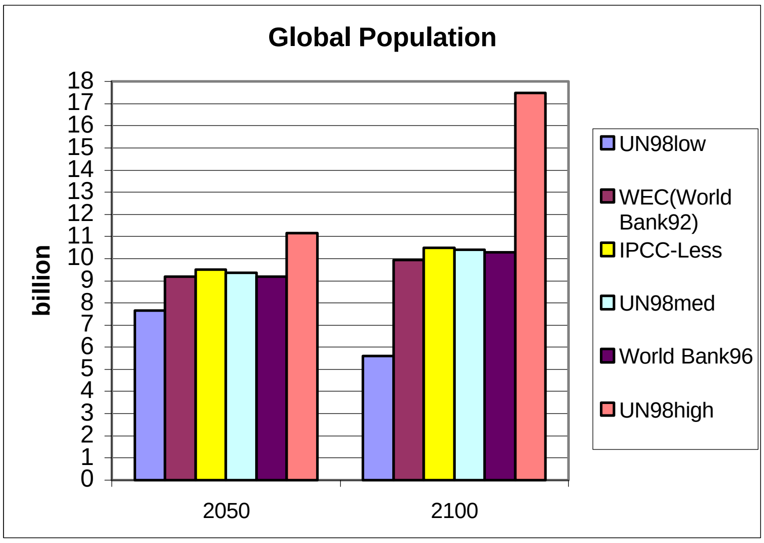

Figure 5.1: **Different projections of future global population [1,2].**

The projections used in the two studies differ as described but so does the World Bank projections of 1992 and 1996. The high and low projections from UN98 are of an entirely different magnitude. Both studies incorporate population forecasts located in the vicinity of medium variants like UN98med and the geographical locations of development are similar as well.

The population in the developing countries approximately doubles while the OECD and REF (reforming economies Soviet Union and Eastern Europe) remains roughly constant at their present levels throughout the 21st century.

The most compelling argument for using only a single population forecast seems to be the recognition of a significant direct correlation between growth in population and rising energy demand. The argument that different population forecasts can blur the effect of other central parameters is a strong one. If scenarios are constructed using different projections the effect of other parameters is less obvious and the differences caused by different story lines might not be as easily identified.

If growth in energy demand as a function of population growth is accepted, the accuracy of the population forecast becomes a central issue. When using only one projection the estimate must either have a high degree of certainty, or sensitivity analysis should be performed to evaluate the effects of parameter variation.

Projections undertaken by the same agencies tend to vary quite noticeably within relatively short periods of time (5-10 years) and the differences between high and low estimates are comprehensive. As an example the UN long-term medium variant has changed significantly from the 1992 version to the 1998 version. Where the 1992 variant estimated a global population of 10.4 billion in the year 2100 the similar estimate of the 1998 variant was 11.2 billion.

It is however worth noticing that projections for the MDC's (More Developed Countries) which in all forecasts include Western Europe have remained roughly constant in the last decade. In scenarios treating only Western Europe, growth in population is therefore considered a parameter estimated with a relatively high degree of certainty.

5.2 Economic growth

According to the scenarios growth in global economy will exceed the growth in population and energy demand by far. Almost 80% of 137 different scenarios in Morita/Lee as well as the WEC- and IPCC scenarios envision an increase in the level of global GDP from approximately 21 * 10^{12} US$ to at least 200 * 10^{12} US$ in the period 1990-2100. Here GDP is calculated using 1990 market exchange rates to convert different currencies into US$ and the projection is constructed using constant 1990 prices. The WEC also states the economic growth in GDP_{ppp} (Purchasing power parities) developed by UNDP to correct for the differences in domestic and international prices, especially visual in the developing countries. Since the IPCC LESS-variants use the values set forth in a set of scenarios made by the Response Strategies Working Group in 1990 [9] and these are measured in standard GDP (i.e. not corrected) we will use this unit of measurement for comparison.

The most rapid development is expected in the developing countries as described in sections 3.1 and 3.2. The different projections of Gross World Product (GWP) in the two studies and the median of the database are depicted in Figure 5.2.

The figure clearly illustrates that the IPCC study incorporates a very optimistic level of economic growth compared to other existing scenarios. The levels assumed in the three WEC cases are much more in line with the values of the database. If the average global GDP values of the three cases are calculated they are very similar to the median value of the database within the timeframe.

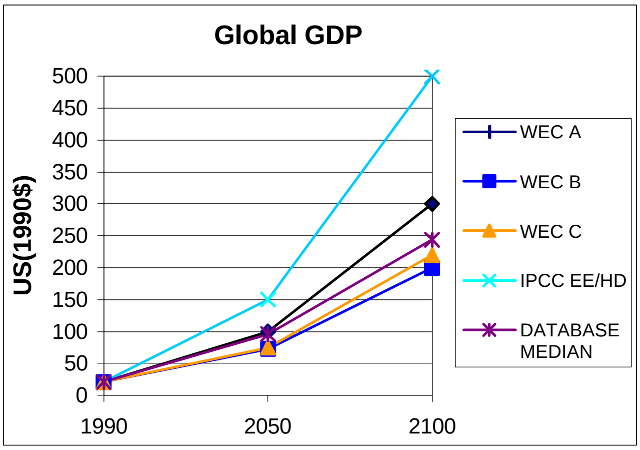

Figure 5.2: **Global GDP in 10^{12} (1990) US$ [1,4].**

One must however keep the different structures of the studies in mind. The IPCC study does not focus on the demand side but incorporate exogenous values of the key parameters.

In the following the assumptions leading to the different projections in the scenarios are analyzed.

The IPCC uses the high economical growth variant of the RSWG's Accelerated Policies study[1]. Two arguments are presented for using this variant. First the reductions in CO_2 will not come about as a result of stagnation in global economy. Secondly the technological innovation needed would require a rapidly changing supply side system which would not be likely in a stagnating economy. If this is accepted the effect of different economical growth rates does not seem less interesting. The conclusions of the IPCC study are based on a single assumed level of global economic growth. As illustrated in Figure 5.2 this level is relatively high even compared to other high growth scenarios. What could be realized with slower economical developments would be an interesting result of sensitivity analysis or lower economical growth variants.

Another approach is taken in the WEC study. Here a range of parameters such as international trade and geopolitics is incorporated in order to determine the demand side parameters endogenously.

The WEC study separates the scenarios in three cases basically by making different assumptions concerning economic growth.

- In case A, free trade and favorable geopolitics form the foundation for high levels of economic growth.
- A less optimistic view on these two parameters lower the economic growth in case B.
- Case C assumes strong political efforts towards international equality and environmental protection. A massive transfer of founds and technology from north to south is a strong assumption in this variant.

Again the different approaches in scenario construction is highlighted. The WEC scenarios analyze how the supply side is expected to develop given assumptions on demand side parameters. The scenarios differ primarily in their demand side structures as a result of this. The IPCC scenarios analyze how the supply side might develop given a set of demand side characteristics.

5.3 Energy intensities

The energy intensities measured as the required energy per unit of GDP has historically been decreasing along with the industrialization and urbanization of the 20th century. Reviewing the development in population growth and economic growth and considering the link between these parameters and growth in primary energy demand, continuing improvements of the energy efficiency are a necessary.

The WEC study argues in favor of two stylized facts that underlie the overall energy intensity. Growth in GDP per capita is the primary driving source of energy intensity improvements and energy intensities converge among regions over time. The first is a result of technological development favoring more efficient end-use devices and energy carriers. The latter simply states that people at similar income levels use similar amounts of energy independent of time.

In the three WEC cases all technologies are developed through specific learning curves and penetrate the market when costs are mature. In case A all new marginal production and conversion technologies experience substantial learning curve effects. Case B has effects approximately 30% lower and case C uses a mixture of the two with case A-levels for low CO_2 emitting sources.

[1] Emission scenarios developed by the Response Strategy Working Group (RSWG) of IPCC 1990.

The IPCC addresses the specific technologies and the message is the same. Introduction of new technologies combined with increased economic growth will decrease energy intensities.

5.4 Level of primary energy demand

The historical growth rate of the global primary energy need is approximately 2 percent when calculated for the time frame 1930-1985. A common trend in all of the scenarios in the Morita/Lee database as well as in the scenarios considered in this study is a relatively high growth rate until the year 2050. After this point the growth rate decreases towards the year 2100.

The future levels of primary energy demand envisioned in the WEC- and IPCC scenarios are depicted in Figure 5.3. The median value of the scenarios in the Morita/Lee database is included as a point of reference.

As would be expected the ecologically driven scenarios IPCC EE and WEC C envision the more modest increase in demand for primary energy. Together the scenarios outline a future where the result of strict policy measures towards sustainability is an increase in primary energy requirements of 'merely' 50% by the year 2050 and approximately 100% by 2100 ranging from 17 to 21 Gtoe. The most apparent difference between the two is the relationship between the descents in the two periods 1990-2050 and 2050-2100. Where the WEC study's energy demand curve has a steeper descent for the period 2050-2100, the IPCC envisions a lower increase in absolute value in the period 2050-2100 than in the period 1990-2050. This indicates the optimistic trend in the IPCC LESS-variants relative to other existing scenarios especially regarding the late half of the 21st century.

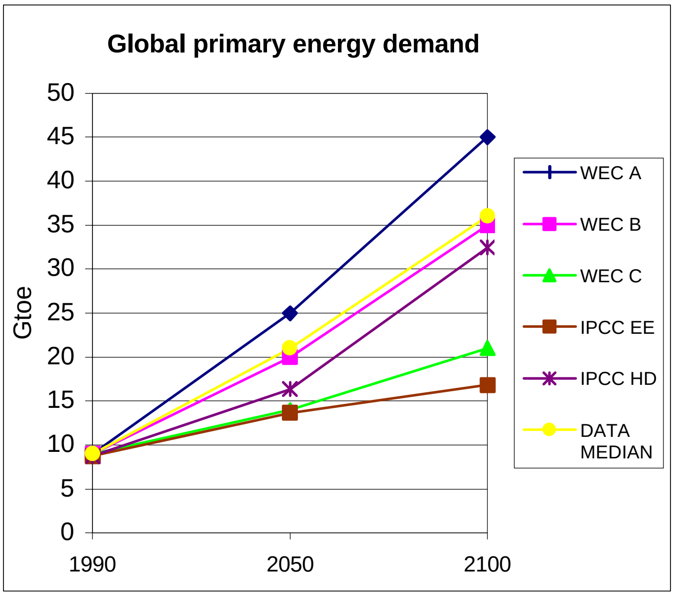

Figure 5.3: **Future primary energy demand envisioned in the scenarios (Gtoe)[2] [1,4].**

The high demand variants WEC A and IPCC HD differ noticeably. Where the latter follows a path of energy demand only slightly higher than the ED scenarios up until the year 2050 the WEC A scenarios almost triple the 1990 level within this timeframe. The envisioned level of

[2] Data for IPCC EE & HD are taken from [4]. Values for the reference cases are used for EE since NGI and CI values do not differ significantly.

primary energy demand in the two scenarios ranges from 16-25 Gtoe which encapsulates the values of the WEC B scenario (20Gtoe) and the median value (21Gtoe) of the 127 different scenarios that make up the Morita/Lee data on primary energy demand.

In the period 2050-2100 the IPCC HD exceeds the ecologically driven scenarios significantly reaching a level of approximately 29 Gtoe. The level in the WEC A scenario increases at an even higher rate to 45 Gtoe. Similar to the preceding period the WEC B case and the database median value represent almost identical levels in the middle of the interval made up by the two high demand variants.

The fact that the level of demand in the high demand variant of the IPCC study is well below even the business as usual-variant in the WEC study seems optimistic. One must however keep in mind that the bottom-up LESS-variants are constructed by making a basic assumption concerning the level of energy demand as described in section 3.2. The high demand variant is projected to meet the level set forth in the IPS92a scenario. At the time of construction this scenario was created as a business as usual scenario.

5.5 Final energy

An assumption underlying all the scenarios considered is the gradual shift towards clean, flexible and convenient energy end-use patterns. This is consistent with the central role of consumer demands assumed in the WEC study and is supported by the conclusions of the IPCC LESS-variants. The assumption involves a shift away from direct end-use of energy in its original form. Instead conversion strategies especially focusing on methanol and hydrogen production are pursued combined with increased use of electricity. This recognition of electricity and hydrogen as primary non CO_2-emmiting end use fuels available in the next century, is an important element in all the scenarios treated here. The IPCC study describes a range of characteristics that distinguish the two:

	Hydrogen	Electricity
Possibility of storage.	+	-
Processing, transmission and storage of information.	-	+
Transmit energy without moving material.	-	+
Serve as chemical or material feedstock.	+	-

The differences shown in the table, if not changed by technological developments, would give rise to future complementary roles of electricity and hydrogen in the energy economy.

The share of final energy forms making use of grids increases in all the scenarios considered (illustrated in Figure 5.4). Pipelined gas, electricity lines, and hydrogen/methanol all expand as energy carriers.

Opposed to the diverging pattern of primary energy production the structure of final energy consumption converges. As illustrated in Figure 5.4 the use of solids decrease and electricity combined with gas and district heat expand. This seems to be true not only in the scenarios within a single study but among all the scenarios considered.

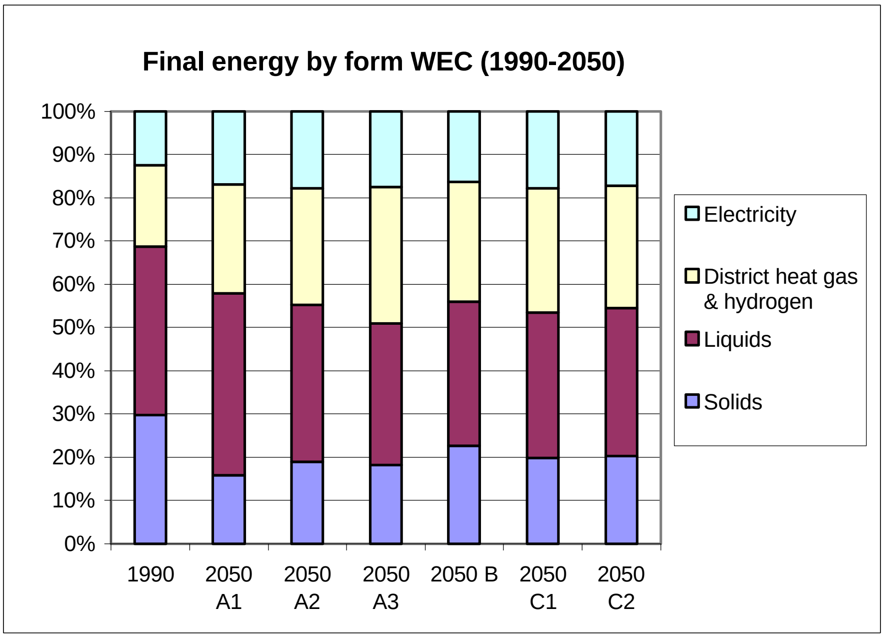

Figure 5.4 **– The share of final energy forms in the WEC-scenarios**

5.5.1 Synthetic fuels

The lack of ability to store surplus electricity production will pose challenges especially with an increased use of intermittent renewables. Climate friendly synthetic fuels unlike electricity are capable of clean energy transportation as well as storage. In both studies hydrogen is given much attention but is not projected a significant role in the first half of the next century. Instead methanol (60% derived from natural gas in 2025 according to IPCC) is used as the transport fuel of choice.

In the late half of the century hydrogen production increases to reach a level similar to methanol by 2100. The introduction of low-temperature fuel cells based on methanol eventually followed by hydrogen fuel cells is an important assumption regarding future technology underlying the IPCC-LESS-variants.

The IPCC LESS-variants focus on thermochemical conversions since this option is projected significantly more cost-competitive than electrolysis Willams [4]. Electrolysis technologies for hydrogen production though more expensive than thermochemical conversions could however become commercialized in specific energy systems. The intermittent nature of wind and solar energy would provide periodical excess electricity, which could serve as energy base for hydrogen electrolysis. An option most likely relevant in systems based on a large degree of intermittent renewables [5]. The LESS-variants incorporate electrolysis to some extent, i.e. one third of all hydrogen production is generated by solar sources in NI/BI by 2100. However in the scenarios [2] this is a result of land constraints on biomass rather than geographical based deployments of intermittent renewable energy strategies.

The WEC study is more cautious on the subject of hydrogen technology development in the first half of the 21st century and chose to focus on the electricity sector.

5.5.2 Electricity

The wide range of energy sources available for electricity production and the environmental advantages of electricity as an end-use fuel are valued high in the scenarios and the commonalty is a positive outlook. The use of electricity in the 20^{th} century has been increasing and the trend is expected to continue in both the IPCC and WEC study.

Though the positive trend is the same in the scenarios there is a profound difference between the predicted values.

- In the IPCC LESS reference variants electricity consumption triples by 2050 compared to a primary energy increase of a factor 1,6.

- In the WEC C-variants the level of primary energy consumption is comparable with the IPCC reference variants but the absolute level of electricity 'only' doubles by 2050.

As mentioned before in this report the demand side projections used in the two studies are very different. Scenario projections have a history of rapid change and the fact that the AP scenario used by IPCC was conducted five years earlier than the data used in the WEC-study is likely to be one of the primary reasons for their differences.

In the business as usual variant (case B) as in the LESS reference variant, the consumption of electricity triples and the case A-variants quadruples the level by 2050 opposed to the doubling in the case C scenarios. However, since the level of final energy consumption is higher in the case A and B variants than in the C-variants the market share of electricity is almost identical in the six scenarios (WEC) increasing from 12% to 16-18% in the period 1990-2050.

6. Comparison of supply side structures

The question of how future energy demands will be supplied is ultimately a matter of cost as stated in the IPCC LESS-variants: "Market penetration and continued acceptability of different technologies ultimately depends on their relative cost, performance (including environmental performance), institutional arrangements, and regulations and polices."

In this section the supply side structures in each of the scenarios of the WEC and IPCC-studies are reviewed. The various degrees of technological innovation, that are expected in the areas of primary energy production, form the basis of the supply side structure and are therefore analyzed here. To provide an overview on the future prospects of different sources of primary energy, the scenarios are compared and the pictures that emerge for fossil fuels, renewables and nuclear energy are described. Since politics and consumer interests will influence the cost efficiency of different technologies we start out by treating their role in the scenarios.

6.1 Political, industrial and consumer interests

There are different players at work when considering the future energy system. Especially consumers and policy makers can be expected strongly to affect the possibilities of different energy sources. The choices made by such parties will decide to what extent the next century will be ecologically or high-demand driven.

Political demands: Areas related to politics such as international trade, taxes, legislation and funding are closely linked with technological development of the future. Like most technologies in the research phase fusion energy will be highly dependent on the right amount of funding as well as the possibilities for competing technologies. The message of the scenarios is clear. The future policies that will be pursued are main parameters with direct influence on the future of the global energy systems supply-side.

The issue of future politics is probably the parameter that most clearly distinguishes the two studies chosen. Where the WEC-study incorporates learning curves favouring different technologies partially dependent on the policies pursued, all the LESS-variants of the IPCC study assume one line of policy with deep reductions in CO_2-emissions as the primary goal.

Geographical divergence in environmental policies pursued is not considered in either of the scenarios. The WEC-study treats the cumulative investments in the energy sector by regions but with an overall global political convergence. Especially in case B where low international trade levels are assumed, regional differences in environmental policies would be likely to occur. Since common global environmental standards are not a phenomenon supported well in history the general disregard of regional differences might yield optimistic results.

Consumer demands. Another key-player is the consumer. The role of the consumer seems to be of a more indirect nature than politics when addressing technological developments. The IPCC-study does not explicitly treat consumer demands opposed to the WEC-study where a central assumption is that the consumer will probably get what he desires which in turn is cleaner, more flexible and convenient energy. The assumption of such consumer interests is the primary reason for development in specific forms of final energy and end-use devices, electricity etc. The source of the provided energy service is of less importance hence the indirect nature.

6.2 Supply side of the scenarios.

Each of the scenarios is reviewed and the most important technological assumptions leading to the supply side structure are described.

6.2.1: The WEC scenarios.

To project the development of the 1500 technologies considered, the WEC study incorporates learning curves. These curves reflect the lowering of cost with increased experience and their shapes vary among the three different cases. The scenarios within the cases differ as a result of different assumptions concerning political issues, technological performance and resource availability.

A1: Technologies favouring fossil fuels are the more innovative. Both environmental improvements in fossil fuels conversion as well as the use of unconventional resources[3] are important factors.

A2: Here technologies favouring coal conversion are dominant. The declining curve of market share for coal is turned around and it regains shares in primary global energy production of 40% in 2100. Unlike the coal-intensive (CI) LESS-variant CO_2-emissons are not stabilized and reach a level of 22Gtoe/year opposed to only 2 Gtoe/year in the CI-variant.

A3: Given a complementary role renewables and nuclear energy technology both become cost competitive in a future without the presence of strict environmental constraints. Combined with natural gas their market share is close to 100% by 2100. The increase in renewables is primarily due to major technological developments, a technology push.

B: Technologies develop more slowly than in the other scenarios. The learning curve effects slowly increase the use of renewables, and the use of more costly fossil fuel causes mainly oil consumption to decrease significantly in the late half of the century.

C1: Strict policy measures towards sustainability are the primary reason for the declining market share of fossil fuels in these (C) scenarios. Technological progress is assumed the same for fossil fuels as in the B-cases. However, carbon taxes and a significantly higher level of technological progress for renewables technologies (case A corresponding) promote a non CO_2 emitting supply side. The increased use of renewables is here the primary result of a policy pull.

C2: This case distinguishes itself from C1 by assuming a brighter future for the nuclear industry. The application of small scale plants producing heat as well as electricity is assumed. This way the nuclear industry like renewables adapt to the more decentralized small scale energy system described in the WEC-study, but technologies to diminish the amount of radioactive waste and for storage need to be considered further if resistance in populations are to be lowered. In both C-cases the CO_2-emission levels of approximately 5Gtoe/year in 2050 and 2Gtoe/year in 2100 correspond to those envisioned in the LESS-variants.

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[3] In the WEC study unconventional resources are given one or more of the following characteristics opposed to conventional resources: 1) They occur in significantly lower concentrations 2) They require unusual or extreme technological prerequisites for their recovery. 3) They need complex and capital intensive conversion for modern day use. 4) They have significant environmental implications.

6.2.2: The IPCC LESS-variants.

The future costs of the different technologies considered are key elements in the LESS-variants. A Comparable Cost Criterion for Climate-Friendly Energy Technologies is incorporated. For coal and biomass identical conversion technologies are assumed and breakeven prices are calculated given certain features characterising the two competing feedstocks. For intermittent renewables a SUTIL [9] simulation is used to calculate the cost per kWh given various sets of supply mix. The model uses the demand profile for a given region, dispatching characteristics of thermal-electric plants and variable output of intermittent renewables on an hour-by-hour basis. As described in Willams [4] new projections of coal and biomass presenting lower future prices estimates for coal and biomass indicate the uncertainty of these estimates. This emphasises that the transition to renewable energy sources at the rate envisioned in the LESS-variants is not likely to occur without increased political efforts IPCC [2].

A common assumption in all the LESS-variants is the sequestering of generated CO_2 in exhausted natural gas fields or saline aquifers. The cumulative requirements of this action within the scenario time frame differ significantly in the five variants. The range is from less than 10 Gt C (in CO_2 form) in the reference variants to 145 Gt C in the coal intensive variant and above 321 Gt C in the HD variant depicted in Figure 6.1. ECN mentions the need to overcome present technological barriers posing difficulties for this technology. Even with the assumption of a smooth development of such technology the idea faces many geographical challenges. Especially the shipment of coal and biomass to depleted natural gas fields (CI and HD) seem to face major difficulties in the form of national barriers since the dependence on natural gas will most likely differ widely geographically. Assumptions regarding international transfer of technology and trade of a magnitude at least equal to that of the WEC C cases seem essential. Another important assumption is the relative low natural gas prices assumed for the first quarter of the 21st century.

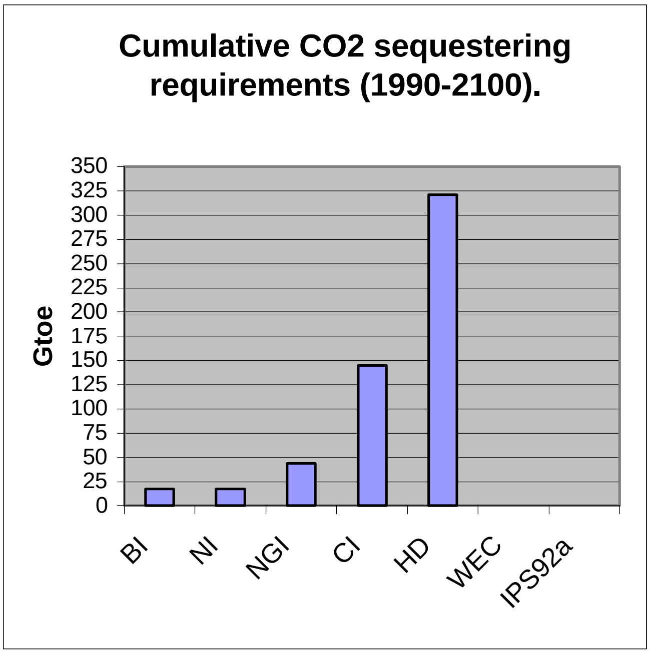

Figure 6.1: **Sequestering needs in the five LESS-variants, WEC and IPS92a. Sources [1,4,17].**

BI: In this reference variant biomass increase as the fuel of choice assisted by mainly natural gas until 2050 and thereafter increasingly by renewables. Strong assumptions concerning location, fuelstock and technological development/transfer are needed to realize the intense deployment of biomass in this variant. Land requirements of 572 million hectares by 2100 and an average productivity of 20 dry tons/hectare/year with 227.5 EJ/year as the net result are assumed. Since more than 65% of the plantation land as well as energy production is projected in developing countries[4], technology transfer and regional energy policies are crucial parameters.

NI: The variant only differs from the BI-variant in the electricity sector. The essential technological development is breeder reactors available from 2025. The use of nuclear energy for heat production is not incorporated. Social acceptance in problem areas such as disposal and transportation of nuclear waste is assumed.

NGI: The variant is based on an estimate of recoverable natural gas resources approximately 40% higher than those of the reference cases. This would emphasize the relatively low natural gas prices envisioned in the first part of the century and increase the use noticeably by 2050. However, after 2050 the general picture resembles that of the reference cases where intermittent renewables and biomass take over. The variant naturally increases the dependence on CO_2 sequestering technologies.

CI: The coal intensive variant differs from the reference cases by increasing the use of coal at the expense of biomass. This poses fewer challenges to technologies for biomass conversion, land use etc., but the extensive use of coal in a low CO_2-emitting world naturally poses severe sequestering problems already commented upon. Oxygen blown coal gasifiers needed for methanol and hydrogen production are stressed as a necessary development. In all considered scenarios coal to some degree plays the role of transition fuel. With this in mind developments in technologies like gasifiers also favouring cleaner conversion of coal seems highly likely. The problems arising from shipment and sequestering of CO_2 is much more challenging considering the magnitude required (figure 6.1).

HD: In the period 1990-2050 the increased electricity demand in this variant is provided by an increased use of natural gas and coal; all other sources are identical with the levels in the BI-variant. In the period 2050-2100 intermittent renewables and coal provide the excess demand, the former providing electricity and the latter providing fuels used directly. The heavy reliance on coal causes an even more daunting task of sequestering CO_2 from fuels used directly.

6.3 Future market shares

Assumptions concerning the development and deployment of technologies are the basis of this section. If fusion energy is to become a part of tomorrow's energy system technological thresholds must be passed. The scenarios concerned have chosen not to consider fusion because at present the necessary technology is not available. They do however make assumptions regarding the general rate of innovation and the further development of existing technologies. The trend in these assumptions indicates the possibilities and obstacles in the electricity sector as well as the energy system as a whole.

[4] The regions considered are Africa, Latin America, South and East Asia and Centrally planned Asia. All regions characterised as DC's when using the WEC-study definition WEC [1 page.2].

6.3.1 Fossil fuels.

Throughout the 20th century fossil fuels have increasingly been the fuels of choice and the exhaustion of global resources within the timeframe is not considered likely in any of the scenarios considered. Policies towards the reduction of GHG emissions and a shift to liquids and gaseous forms of final energy pose two of the major challenges the fossil fuel industry and the coal industry in particular will face in the next century.

Coal: Though coal is the fossil fuel holding the largest conventional reserves [10], the scenarios outline an uncertain future for the industry with many obstacles. The market share held by coal industries will primarily depend on technological developments that can keep coal cost-competitive.

The diversified outlook of the industry is clearly illustrated when comparing the WEC and IPCC study. The scenarios in the WEC study range from practical phase out of coal in scenarios A3, C1 and C2 to a revival of the industry with market shares close to 40% in A2 by 2100. The strict CO_2 emission constraints in the case C scenarios indirectly diminish the interest in R&D in the coal industry by favouring the low carbon emitting fuels through learning curve effects. This is not the case in the coal-intensive LESS variant which completes the picture by exploring the possibility of technological developments favouring coal combined with biomass in a GHG-constrained world.

The ecological outlook naturally poses the toughest challenges on the industry, coal being the dirtier direct-to-use of most energy sources. The prospects of coal in the ecologically driven IPCC scenarios are indicated in Figure 6.2. The data of the WEC ecologically driven scenarios are almost identical to those of the IPCC reference variants.

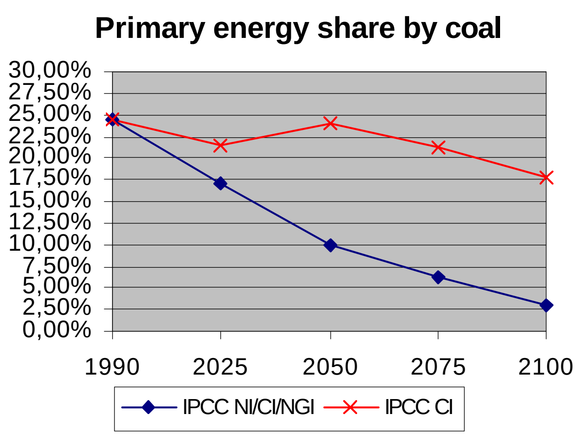

Figure 6.2: **Coal consumption in ecologically driven scenarios 1990-2050 [2].**

In the ecologically driven scenarios, coal is expected to have a future role as more than a transition fuel only in the coal-intensive LESS-variant[5]. The CI-variant envisions a market share in global primary energy in the range 15-25% during the period 2050-2100 (Willams [4]), resulting in an increased coal use of 47% by 2075. This seems extremely high compared to the other ecological scenarios considered though it should be noted that the IPCC variants,

[5] Characterising coal as a "transition fuel" should be seen in context with the expected rapid increase in the demand for primary energy. Even with the most gloomy prospects of the industry as envisioned in the WEC C scenarios, the cumulative requirement of coal in the period 1990-2050 will exceed the cumulative use up to date (1995).

unlike the WEC ecological scenarios, do not incorporate carbon taxes. The technological assumptions are based on combined production of hydrogen rich fuels (mainly methanol from coal) and biomass and sequestering of the hereby-separated CO_2 in saline aquifers or depleted natural gas fields.

The variant is offered as a possible way to incorporate coal on a significant scale in a GHG-constrained world. It seems however that the market structure envisioned in the variant would require innovative R&D in almost every area of energy production. If sequestering techniques and other fossil fuels cleaning devices are given massive focus the development of renewables would most likely happen at a slower pace. Conversely, a future with aggressive policies directed towards sustainability and a shift to renewables R&D funding seems unlikely to favour the technological innovation needed in the coal intensive variant.

In the reference cases the cost of energy services provided by coal is not projected significantly below that of renewables (Top-down model ERB [11]) and coal is therefore phased out being a generally dirtier fuel. Similar lacks of cost competitiveness due to technological progress in other areas are envisioned in the case C scenarios.

Oil and natural gas:
Oil and natural gas are not as abundant in their resource base (reserves and resources) as coal. According to estimates used by WEC the total resource base of oil and natural gas with unconventional and conventional occurrences included, add up to approximately 1700 Gtoe. This is a high figure and is based on a high estimate[6] of oil and gas resources (occurrences with less geological assurance or lack of economic feasibility). If only conventional occurrences are considered the estimate is approximately 700 Gtoe and with elimination of resources conventional reserves amount to 300 Gtoe.

The matter of resource scarcity has been heavily treated since new occurrences as well as technological progress has historically increased the reserve base despite growth in production [1]. The IPCC and WEC differ in their projections in this area. The latter projects a cumulative oil and gas use in the period 1990-2050 of 1.5 to 2 times the estimated conventional reserves depending on the scenario. The five LESS-variants all project a cumulative use at eighty percent of conventional oil and gas resources by the year 2100.

The matter of oil consumption illustrates a fundamental difference between the two studies. Especially the case A1 variant picture significant market shares (15-35%) for the oil industry until 2100, whereas the IPCC LESS-variants all envision a more swift transition away from oil with annual use decreasing from approximately 140 EJ/year in 1990 to 75 EJ/year by 2050 [4].

Though the scenarios differ in their projections the message of the ecological scenarios is a similar one. The use of oil and natural gas is decreased not as a direct result of resource scarcity, but rather indirectly due to their lack of ability to compete in costs. In the IPCC this would come about as a result of unfavorable environmental restrictions such as emission constraints etc. In the WEC-scenarios expensive conversion of resources into reserves or the use of unconventional reserves would also contribute to higher production costs in the oil industry.

6.3.2 Renewables

The renewable perspective is treated more thoroughly in section 7. This section treats the general outlook and the assumptions made in the scenarios considered providing an overall overview of the supply side.

[6] Upper range estimate Masters et al., 1994 [1 page 36].

Though at present only hydropower accounts for a significant amount of global energy production the positive outlook of renewables is more consistent among the scenarios than for any other source.

Traditionally renewables have been restricted to the direct burning of wood e.g. in cooking stoves. Entering the 21st century renewables cover a broad range of technologies capable of providing clean energy services with low CO_2-emissions. In the case of biomass, the distinction between traditional use and new forms involving the cultivation of crops for fueling biomass power plants or production of synthetic fuels is of importance. In all of the eleven scenarios considered renewables provide 20% or more of the primary energy demanded by the year 2050 opposed to approximately 17% in 1990 (Figure 6.3 provides the absolute values of renewables contribution to primary energy production in the scenarios.). The 17% however are made up primarily of traditional renewables (i.e. direct end use of biomass) whereas the envisioned 20% or more by 2050 is a portfolio of new renewables. This clarifies the consistent positive outlook for renewables characterizing the ecological as well as the business as usual scenarios.

Niche markets and small-scale applications are keywords when trying to create a denominator for the development of renewables in the scenarios.

Especially intermittent renewables, e.g. solar and wind, have been able to cut costs successfully through experiences gained with small-scale applications (i.e. photovoltaic devices for lighting or water pumping) in niche markets, a trend expected to continue.

The ability to produce electricity in areas where grid connections are not available is stressed as a vital parameter in both scenarios. Considering the expected economical growth in the developing countries rural areas without grid connection will form important markets in which renewables can further cut costs through learning by doing.

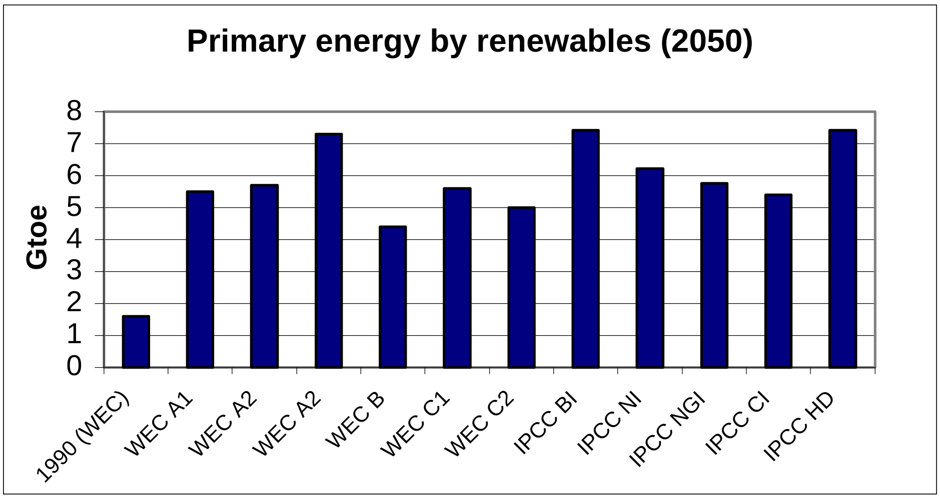

Figure 6.3: **Renewables (including hydro, biomass, intermittent renewables and geothermal energy) in global primary energy production [1,4].**

The renewables portfolio is pictured as one of diversification. Availability of resources and technology varies geographically and is mentioned in the WEC scenarios as the main source of this diversification.

State incentives providing subsidies for wind power mainly in Denmark and California have developed an industry and increased the cost competitiveness of wind power. Some degree of government interference in the form of subsidies or environmental legislation favoring renewables is expected in the scenarios of both the WEC and the IPCC. However, the focus of the two studies is different in terms of market structures and political measurements.

The WEC scenarios focus on technological transfer from north to south. Policy options are mentioned but are considered unlikely to bypass the process of slow diffusion through niche markets. The IPCC focus is concentrated on policy options such as government R&D and regulations/legislation.

To summarize, the scenarios focus on two main sources of renewables cost-competitiveness.

- In the ecological scenarios (WEC C and IPCC EE) political and industrial strategies favour renewables, and cost-effectiveness is achieved in energy markets of relatively moderate demand.

- In the high demand scenarios market penetration is eased for renewables because scarcity in recoverable cost-competitive fossil fuels occur.

6.3.3 Nuclear

As for the coal industry the expected future role of nuclear energy varies considerably across the scenarios. The contribution of nuclear energy in each of the scenarios is illustrated in Figure 6.4.

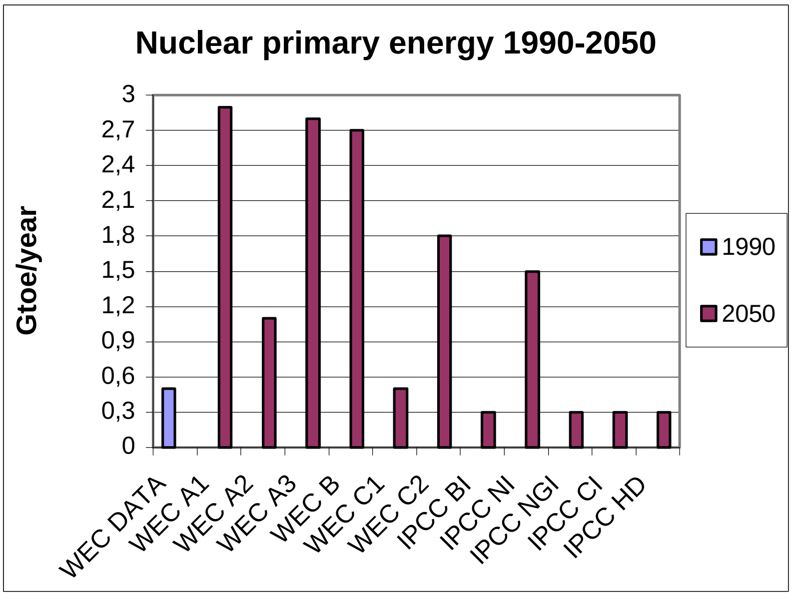

Figure 6.4: **Nuclear primary energy production 1990-2050 [1,4].**

The WEC scenarios are generally more positive in their projections of nuclear energy than the IPCC scenarios. However if only the ecological scenarios are considered the two studies provide two possible story lines with many similarities. The WEC case C2 and the NI-variant of the IPCC revive the nuclear industry opposed to the BI/NGI/CI-variants of IPCC and case C1 of WEC where the use of nuclear energy is phased out in the next century.

The decreasing trend in nuclear energy plant construction has to be turned around if the industry is to become a significant part of the future energy system. The need for increased public acceptance is a key issue stressed in both studies. The main areas of public concern are summarized in the following.

- Minimization of large-scale catastrophe risks.
- Disposal of high level radioactive waste.
- Prevention of fissile material proliferation.

The diverging market shares of nuclear energy in the scenarios are primarily a result of assumptions about the industry's ability to overcome the obstacle of these public concerns. With this as the main parameter in the different story lines a number of assumptions concerning technological developments is introduced.

The fact that a long-term future for fission based nuclear energy would have to be based on the introduction of improved nuclear technologies is realized in both studies. The WEC mentions improved fuel-cycles and burn-up rates or commercialized breeder reactors as ways of reducing the problems arising from shortage in uranium resources.

The two ecological scenarios visualizing the brightest future for the nuclear industry; the NI LESS variant and the WEC C2 scenario differ in their assumptions on technological developments and implementations. The NI LESS-variant adapts breeder reactors as the key technology, an option also used in the WEC cases A and B. In the C2 scenario the small-scale ideology of the renewable industry is pursued in the nuclear industry and a future of simple, small-scale (150-250 GW) plants is envisioned.

The high demand variants A1 and A3 of the WEC study as well as the case B scenario project accelerated growth in the nuclear industry. The levels of primary energy production in absolute terms are higher in these scenarios than the level projected in IPCC NI-variant. Because the level of total primary energy demand is proportionately higher in the WEC scenarios the net result is a similar market share for nuclear energy (approximately 10% in 2050) in these four somewhat nuclear positive scenarios.

Considering the various words of caution mentioned in the WEC study, breeder reactor technology development, public acceptance etc., it seems inadequate that only one scenario foresees a troublesome future for the nuclear fission industry. The overall impression is that with the exception of the C1 scenario nuclear fission energy is able to gain ground in spite of public concern, resource scarcities, and difficulties with breeder reactors.

6.3.4 Market shares in the electricity sector.

The following is based on the WEC study, and parallels to the IPCC reference variants are drawn.

On a global scale the portfolio of electricity suppliers is diversified. Coal, nuclear and renewable energy forms are the major players whereas oil practically disappears as a utility fuel within the next three decades. Especially the share of coal and nuclear in electricity production vary significantly across the scenarios.

- Coal based power generation follow the decreasing trend of fossil fuels in all scenarios except the coal intensive A2 scenarios where coal use continues to average high market shares in electricity production (58% in 2050). In the IPCC reference cases (BI & NI) global use follows a similar decreasing pattern declining 50% by 2050 and almost 100% by 2100.

- Nuclear energy use increases in all scenarios compared to the current level. The variation is however huge with high global market shares in C2, B, A1, A3 and low shares in C1 and A2. A similar variation is found in the LESS-variants. Here the nuclear intensive (NI) variant increases the share in electricity production provided by nuclear energy to 46% by 2100 (Figure 6.5), opposed to a contribution of only 3% in the biomass intensive (BI) variant (Figure 6.6).

- The role of renewables is more scenario-independent and even without hydropower the average level is approximately 20-40% by 2050 in all the WEC scenarios. Similar levels are found in the LESS-variants where renewables account for 30% of the electricity produced by 2050 in the BI variant and somewhat lower in the NI variant. By 2100 the BI variant assumes development of storage techniques making the possible contribution of renewables (including hydro, geothermal, intermittent renewables and biomass) as high as 93% (Figure 6.6).

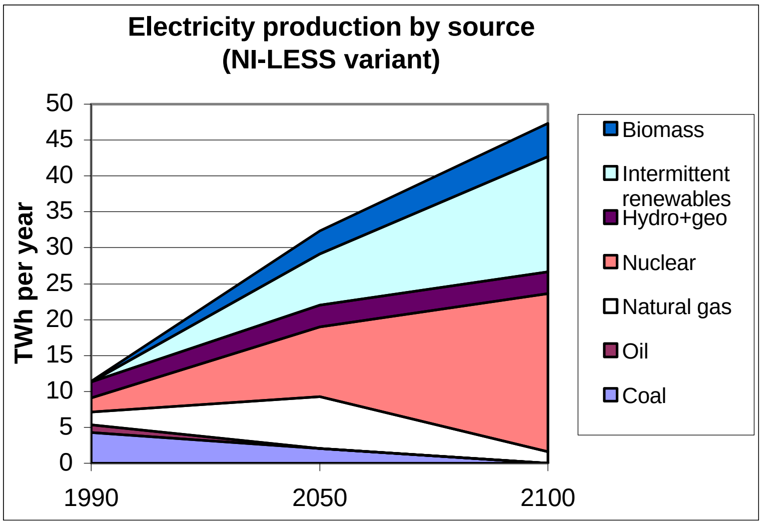

Figure 6.5: **Global electricity generation by source in fractions from 1990-2100 in the NI-variant [4].**

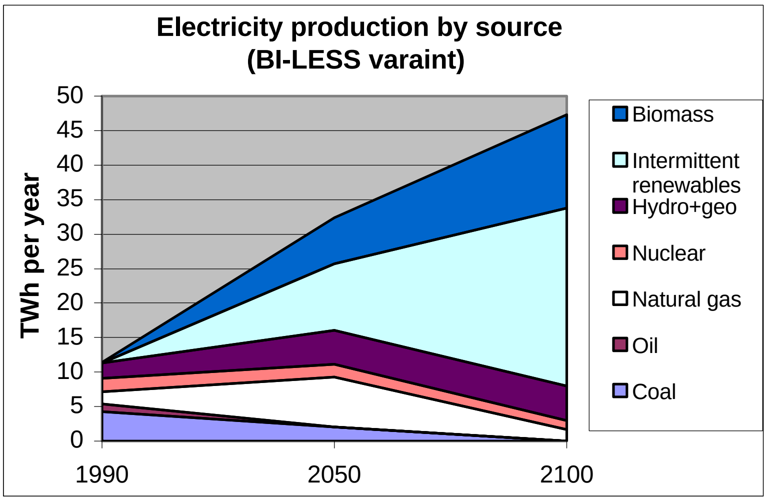

Figure 6.6: **Global electricity generation by source in fractions from 1990-2100 in the BI-variant [4]**

On the regional scale one or two fuels seem to dominate, depending on the scenario considered. By 2050 the fuels of choice are either nuclear gas or coal (A2) in the OECD region, whereas renewables are the fuel of choice in DC regions assisted by nuclear or coal depending on the scenario. The IPCC incorporates regional differences less scenario dependent than the WEC. Coal use is expected to increase 2.7 fold in Central, South and East Asia in the period 1990-2050 whereas the environmental WEC scenarios C1, C2 envision a practical phase out of coal in all regions by 2050. The dominance of certain fuels on a regional level indicates that the use of IPCC LESS-variants could perhaps be combined successfully with political and technological elements on a more specific regional level. The strength of the LESS-variants is their conduction of a thorough analysis of possibilities arising from different technological strategies. A structure incorporating a general frame of global (resembling the WEC-structure) and perhaps to some extent regional political demands and technological strategies could enhance the plausibility of future possibilities stated in the conclusions of the LESS-variants.

7. The Future Role of Renewables

In this section the future role of renewables is elaborated by treating the prospects of wind energy, solar energy and biomass separately.

7.1 Wind energy

The wind energy industry has developed steadily in terms of cost reductions over the past two decades. Optimisation of design and reliability has been essential factors [13,14,19] and further improvements are in both studies described as a critical premise for the reduction of production costs.

In "Global Energy perspectives to 2050 and Beyond" the specific assumptions concerning wind energy are not addressed, but in "Renewable Energy Resources" WEC [19], where the current policies scenario is described as similar to case B, a detailed description of wind energy prospects to 2020 is given . Many of the assumptions made in this study govern the outlook of the wind power industry as presented in the three WEC cases. Some of these are considered in the following.

The intermittent nature of wind energy means that at some level of market penetration restructuring of the additional energy system will be necessary. In [19] it is assumed that in energy supply systems made up by less than 10% wind power such restructuring has not yet begun. Since the penetration of intermittent renewables is projected levels of less than 20-25% in cases A and B throughout the century, and considering that 10% is taken as the most conservative from a range estimates[7], the effects seem significant only in the case C scenarios. The policy pull assumed in these variants would form the economic foundation for such a transition.

The study concludes that since the contribution of electricity from wind power by 2020 is only approximately 1.5% of total electricity consumption and only a few percent of the total wind potential, factors like resources, grid integration, financial constraints etc. will not pose major threats to further expansion of wind energy. A similar continuance is found in case B where wind energy expands in absolute terms towards 2050 but remains roughly constant in terms of share in the renewable portfolio. The development in case A and C is not radically different, the use of wind energy is higher in absolute terms due to the favourable learning curves but the share of wind in the renewable portfolio does not vary significantly among the cases.

In the WEC study wind power is projected significant especially in the OECD. In absolute terms the amount of energy from wind power is projected higher for the OECD than in DC's until the middle of the next century. In share of the total renewable portfolio the difference is more significant since the DC's total use of renewables is projected 3-4 times higher than the total use of the OECD.

Increased capacity and the introduction of new design factors such as variable speed and two bladed rotors are mentioned as possible areas of technological developments in the IPCC study. Further public acceptance concerning noise and visual impact is addressed. In the high demand variant it is assumed that all extra electricity compared the other LESS variants are provided by intermittent renewables. The development of storage techniques in the late half

[7] The estimates varied according to specific circumstances and characteristics of the utility system[19].

of the 21st century is a crucial necessity if intermittent renewables is to attain such significant market shares in the electricity sector.

The scenarios of Shell are similarly positive in their projections: Sustained Growth and Dematerialization [13] both envision a steady expansion of wind power and market shares are projected close to 10% of global energy consumption by 2100.

Though a detailed analysis on the development of wind power is not presented in the scenarios the overall picture is clear. Wind power will play a modest but significant role in a renewable portfolio that provides more than 20% of global primary energy by 2050 and 30% by 2100 in all of the scenarios considered.

7.2 Solar energy

At present solar photovoltaics are only cost-competitive in some, often isolated, rural areas. Average overall costs at 15-55 cents/kWh [16,18] depending on technology and location are somewhat higher than costs of wind power and biomass. Projections however are generally positive indicating overall costs coming down to levels of 5-10 cents/kWh by 2020 [18] and 3.5-5 cents/kWh by 2030 [16].

The modularity of photovoltaics is a unique quality within the renewable portfolio. Opposed to wind mills and biomass plantation photovoltaics can be deployed in rural areas where land availability is scarce (roof tops, parking lots etc. [19]).

In the WEC-study solar energy is projected an essential role in the renewable portfolio especially in the DC's. In the variants A3 and C1 solar energy constitutes 25-30% of total renewable use in the developing countries by the year 2050. The successful installation of small-scale stand-alone applications in remote rural areas seems to support the possibility of such developments.

The Shell-scenario Sustained Growth [13] incorporates cost reductions in solar photovoltaics averaging 6-8 % per year. At this rate solar energy would enter the market as a competitor around 2015. From this point solar energy increases steadily in market share and by 2060 it provides more than 10% of the global annual energy consumption, surpassing the levels projected for both biomass and wind power in the scenario.

Though photovoltaics at present has to pass some technological thresholds in order to become cost-competitive the outlook is generally a positive one. The very few disadvantages posed by photovoltaics are most likely the main reason.

7.3 Biomass

Unlike intermittent renewables (i.e. solar and wind power) biomass can be stored and used when required. Furthermore biomass can act as fuelstock for both electricity and synthetic liquid production. Combined with the CO_2-neutrality these qualities make biomass an interesting part of the renewable portfolio.

When addressing the economics of biomass for electricity production, focus tend to be on the following aspects:

- Technology
- Location
- Fuelstock

Since biomass is a term covering a vast variety of different fuelstocks, conversion technologies are many, differing in size and availability. When burning residue resources are limited but often cheap compared to projects of energy crop cultivation. The latter of course has the advantage that resource availability can be governed to some extent.

Biomass plays an important role especially in the high demand scenarios (i.e. HD-LESS and WEC A-scenarios) and the BI-LESS variant. The conflict of land-use for both agriculture and energy production is much debated and somewhat surprisingly the WEC case-A variants present estimates of available land that are much higher than those of the BI/HD-variants.

	2050	2100
IPCC LESS-variants (Mha)	100-385	300-570
WEC Case A scenarios (Mha)	390-610	690-1350

Table 6.1: Global land use for biomass in 10^6 ha (rounded up to nearest five) [1,4].

The most significant role for biomass is projected in the developing countries. Since population growth rates are projected high in these regions the matter of technology transfer seems to be extremely relevant. If conflict of land use is to be minimised optimisation of energy crop cultivation as well as agriculture in general seems a necessity.

There seems to be no obvious trend in the projections on future availability of suitable land and the matter remains one of the key issues when addressing the future role of biomass.

In the WEC-study biomass is the essential part of the renewable portfolio constituting close to 50% or more in the developing countries by 2050 in all scenarios. The transference of technology from the industrialised countries as mentioned above is noted as a key parameter and seems most likely in the ecological C-scenarios where the necessary strong assumptions on international trade and policies are made.

All the LESS-variants of the IPCC-study rely heavily on biomass as primary energy source of the future. The use of biomass exceeds the total use of intermittent renewables in all variants throughout the next century.

In both the IPPC and the WEC-study biomass will be the central source when it comes to fluid fuel production. Because of the variety of various other energy sources biomass is envisioned a less dominant role in electricity production (i.e. Figure 6.5/6.6).

In all scenarios biomass is an important part of the renewable portfolio in the 21st century. However, not unlike fossil fuels biomass is not abundant in its resource base and land use constraints will occur at some point if energy requirements continue to increase.

8. Conclusions

As described the two studies considered differ in their construction of the energy systems demand side. The three cases of the WEC study vary in their projections and together form a broad picture of possible developments. In the IPCC-study the demand-side parameters are incorporated as exogenous parameters and a bottom-up approach, where supply-side projections is to match the exogenous values of the demand side, is taken.

The primary goal of the IPCC-study is to show that deep reduction in CO_2-emmissions is possible through different supply side structures in the energy market. The supply side analysis in the five variants is valuable and provides an overview on possible developments of the different existing technologies. The descriptions are thorough and the idea of a future supply-side somewhere in between two or more of the variants seems very likely. However, the usage of only a single level of economic growth makes the conclusions of the study highly dependent on this parameter. Since estimates of economical growth vary significantly and the levels assumed for the LESS-variants are quite optimistic compared to various other studies the single estimate approach seems questionable.

A positive element of the WEC scenarios is the broad range of possible futures covered with a relatively modest number of scenarios. The use of a single population forecast and several economical growth variants helps accentuate the story lines in the scenarios and would be a relevant methodology for generation of scenarios including fusion energy. The WEC scenarios are overall more positive in nuclear fission projections than the IPCC LESS variants. However the ecological WEC scenarios and the LESS variants are comparable in this area both presenting phase-out and revival variants following similar patterns.

As described in Section 5.5.2 the general outlook of the electricity sector is a positive one. Being a clean and convenient end-use fuel, electricity will meet the demands set by the consumer of tomorrow and expand in share of global final energy use. Nuclear energy used only in electricity production expands in absolute terms in all the scenarios at a magnitude dependent on the industry's ability to overcome public concerns.

Fusion energy would possess obvious advantages when considering public concerns. The IPCC-study mentions that fusion energy could make prevention of proliferation easier. The ability to avoid the negative attention fission energy has received over the past decades seems just as important. If focus is on plant safety, minimal creation and safe disposal of radioactive waste, fusion energy would stand a better chance of public acceptance in the late half of the next century than fission energy, having to battle images of the past.

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