Energy Requirements for the Next Millennium

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Introduction

At the turn of the millennium, two billion people, a third of the world's population, have no access to modern energy services. World population is expected to double by the end of the 21st century. Economic development needs to continue, particularly in the South. This requires vast amounts of energy and vast amounts of money. During the 1990's, global energy capital expenditures have been over 200 billion USD per year. Interestingly enough, global annual government subsidies for conventional energy have constituted a similar amount (UNDP, 1997). One of the key issues to improve the standard of living of the poor is to make clean energy available to them at prices they can cope with. How can the energy requirements of the next century, not to mention the next millennium, be met?

The scarcity of energy resources forecasted in the 1970s did not occur. With technological and economic development, estimates of the ultimately available energy resource base continue to increase. It appears that economic development over the next century will not be constrained by geological resources. Environmental concerns, financing, and technological constrains appear more likely sources of future limits.

An attempt will be made in this paper to summarise the main findings of international commissions in recent years on how to meet the energy requirements of the next century. The main sources of information have been two books. Firstly, the report of the World Energy Council's Commission "Energy for Tomorrows World - the Realities, the Real Options and the Agenda for Achievement" published in 1993 (WEC, 1993), which followed the UN World Commission's Report on Environment and Development, "Our Common Future" (Brundtland, 1987). The second main source of information is a book entitled "Global Energy Perspectives" (Nakicenovic et al., 1998) presented at the World Energy Congress in 1998 and commissioned by the World Energy Council (WEC) and the International Institute for Applied Systems Analyses (IIASA). The book presents the results of a five year detailed study following in the footsteps of the "Energy for Tomorrows World"(WEC, 1993). Most of the data and figures in the present paper are obtained from the book of Nakicenovic et al. (1998).

The aim of the WEC Commissions report (WEC, 1993) was to "... identify a realistic framework for the solution of regional and global energy problems, whereby adequate, sustainable energy at acceptable costs can be supplied to meet the needs of all people whilst achieving socially acceptable care and protection of the environment. It is to identify the realities, the real options and the agenda for achievement".

Present Energy Situation

Since the dawn of humanity, man has used energy to make his life easier and more comfortable. Unfortunately, a third of the world's population are still at the level of using the fire only for cooking and for light. The majority, however, make use of different forms of energy to increase productivity, reduce the use of muscular power, for the ease of transport, and for the general well being of the people.

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Energy affects all aspects of modern life. There is a strong positive correlation between energy use per capita in a country and issues that we value highly such as productivity per capita in the country (Figure 1) and life expectancy (Figure 2). Similarly, there is an inverse correlation between energy use and issues such as infant mortality and illiteracy. It is of interest to note in Figure 2 that in the least developed countries a relatively small increment in energy use adds very significantly to the quality of life in the countries.

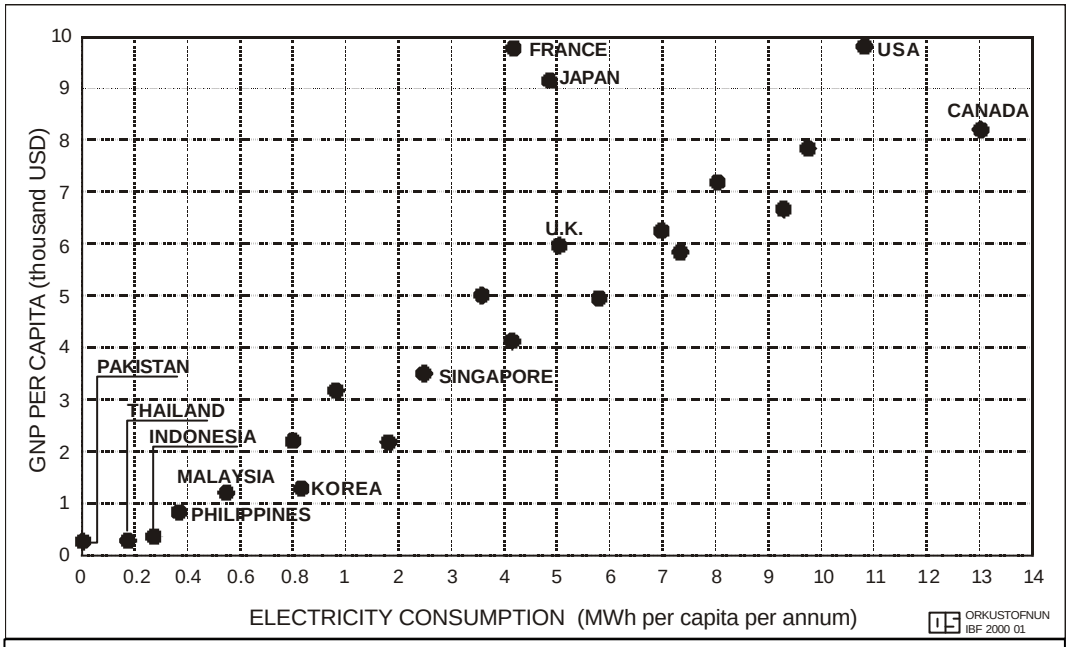

Figure 1: Electricity consumption and GNP per capita of selected countries in 1978

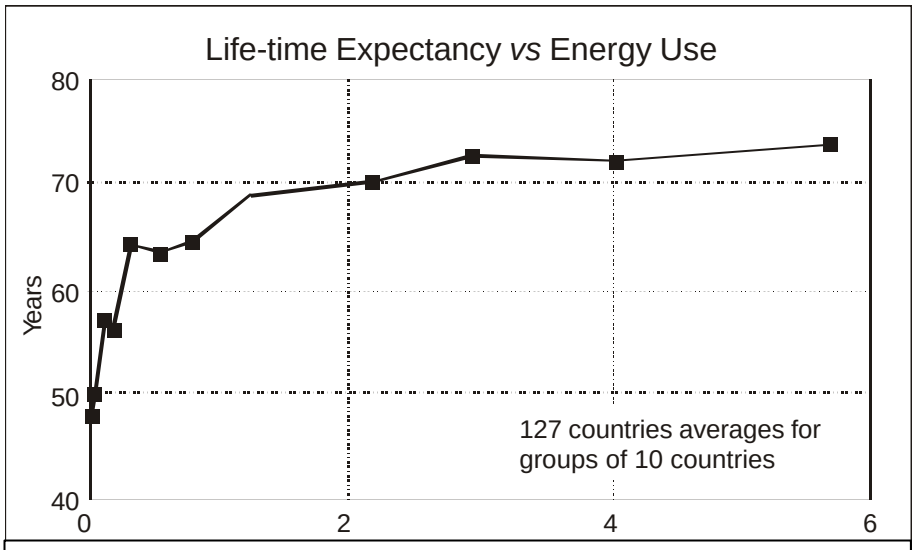

Figure 2: Life-time expectancy and energy use (from WEC, 1993)

From regional analyses of energy use (WEC, 1993) it was found, not unexpectedly, that the first priority for the majority of the world's population is access to sufficient affordable energy. Some 70% of the

world's population lives at per capita energy consumption level one-quarter of that of Western Europe, and one sixth of that of the United States (WEC, 1993). Table 1 (compiled from Chapter 7 of Nakicenovic et al., 1998) shows key data from 1990 for the 11 regions of the world as regards % of world population, % of the Gross World Product (GWP), % of global primary energy use, % of global energy-related net carbon emissions and the approximate Gross Domestic Product (GDP) per capita.

Table 1: Key energy data from 1990 for the 11 regions of the world as regards % of world population, % of the Gross World Product (GWP), % of global primary energy use, % of global energy-related net carbon emissions and the approximate Gross Domestic Product (GDP) per capita (compiled from Chapter 7 of Nakicenovic et al., 1998)

	% World Population	% GWP	% Global primary energy use	% Global energy related net carbon emission	GDP per capita USD (1990)
NAM	5	29	24	25	~23,000
LAM	8.3	5.2	6.8	4.7	2,500
AFR	9	1	3	2.3	540
MEA	5	3	4	5	2,120
WEU	8	34	16	16	~17,000
EEU	2.4	1.4	-	4.8	2,400
FSU	5	4	-	17	-
CPA	24	2.3	11	12	-
SAS	20	2	4.9	3.2	334
PAS	8	3	4.7	3.5	1,500
PAO	2.7	16	6	6.3	~23.000

NAM North America, LAM Latin America, AFR Sub-Saharan Africa, MEA Middle East and North Africa, WEU Western Europe, EEU Central and Eastern Europe, FSU Newly independent states of the former Soviet Union, CPA Centrally planned Asia and China, SAS South Asia, PAS Other Pacific Asia, PAO Pacific OECD.

It is notable that in 1990, with just 5% of the world's population, North America (Canada and USA) accounted for 29% of the GWP, 24% of global primary energy use, and 25% of global energy-related net carbon emissions. Sub-Saharan Africa with 9% of the world's population, accounted for 1% of the GWP, 3% of global primary energy use (2/3 from fuelwood), and 2% of global energy-related net carbon emissions. South Asia with 20% of the world's population, accounted for less than 2% of the GWP, 5% of global primary energy use, and 3% of global energy-related net carbon emissions.

The task to make energy available to the bulk of the people in the developing countries at prices they can cope with is certainly large. Still bigger is the task to provide **clean** energy to the developing countries as well as the industrialised countries and the countries of Central and Eastern Europe. And when we think of that the world population is expected to double by the end of the 21st century, the task at hand for the peoples of the world is certainly such that many wonder how it can be met.

Population Growth

Population growth is, of course, a central issue in studies of how to meet the energy requirements of the world. Figure 3 (reproduced from Nakicenovic et al., 1998) shows the historical development from 1850 to 1990 and World Bank projection to 2100 (Bos et al., 1992), (top) rural-urban and (bottom) by macroregion, in billion people. Urbanization trends are based on UN (1994) and Berry (1990).

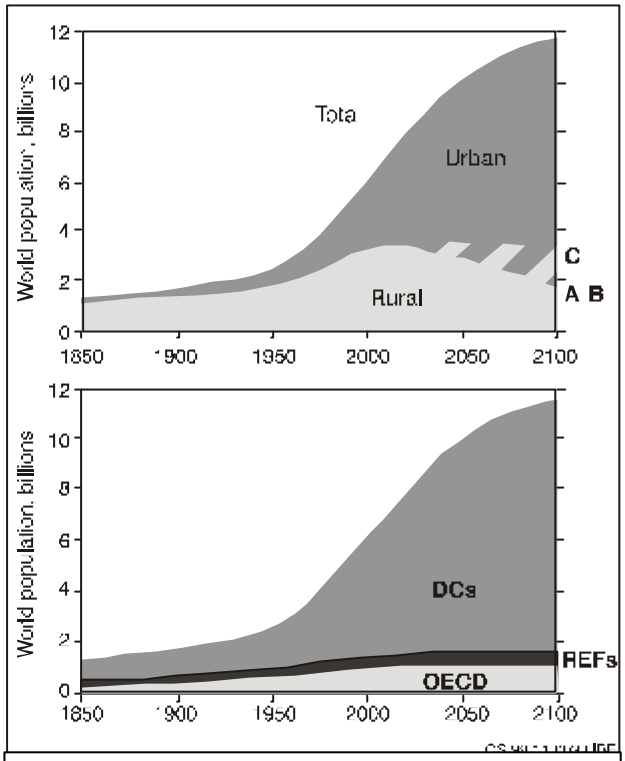

Figure 3: World population showing historical development from 1850-1990 and World Bank projection to 2100 (Bos et al. 1992), (top) rural-urban and (bottom) by macroregion, in billion people. Urbanization trends are based on UN (1994) and Berry (1990). The figure is reproduced from Nakicenovic et al. (1998).

As stated by Nakicenovic et al. (1998), the good news in the 1992 World Bank and other global projections is that population growth is slowing down. The next doubling of the world's population is expected to take much longer than the last one, which took only 40 years. The population is expected to rise from the present 6 billion to approximately 10.4 billion by 2100 according to the 1998 UN long-range projection. Virtually all of the population growth is expected in the South. By 2100, the population of the USA, Canada and the whole of Europe combined drops to less than 10% of the world total, according to central studies of the World Bank, IIASA and the UN.

By the year 2100, the presently categorised developing countries can be expected to account for about 80% of the global energy demand (WEC, 1993). Even then energy per capita availability in the developing countries is likely to be far less than in the rest of the world - perhaps only 50-60% of that in the OECD area by then. The WEC (1993) study suggests that by the end of next century close to three-quarters of the world's population is likely to be urbanised and the interim pressures on housing, sanitation, air and water quality, health care and congestion are likely to have been intense. Energy systems geared to providing the comforts, motive power and mobility that people seek from energy may have lead to some profound changes. The challenge to city transportation systems over that time frame is likely to have called forth some imaginative responses (WEC, 1993).

How to Meet Future Energy Requirements

The WEC (1993) study states that energy issues should be viewed in their total, global, social and institutional, as well as economic and environmental, perspective. In particular, what people demand is not energy as such but the services which energy can provide - heating, cooling, cooking, lighting, mobility and motive power. The WEC Commission developed three energy Cases, each representing different assumptions in terms of economic development, energy efficiencies, technology transfer and the financing of development around the world. These Cases were developed to illustrate future possibilities. The main horizon year adopted was 2020.

The IIASA-WEC study (Nakicenovic et al., 1998), from which most figures and data in the present paper are adopted, expanded the Cases of WEC (1993) into six alternative scenarios. The principal focus is on the period between 2020 and 2050, but some results are also presented out to 2100. Case A is basically a high-growth future in terms of income, energy, and technology. Case B has a more modest but perhaps more realistic growth. Case C presents a "rich and green" future. It includes both substantial technological progress and unprecedented international co-operation centred explicitly on environmental protection and international equity. The characteristics of the three cases for the world in 2050 compared with 1990 are shown in Table 2 (from Nakicenovic et al., 1998), showing the primary energy mix, energy sector investments, and emissions.

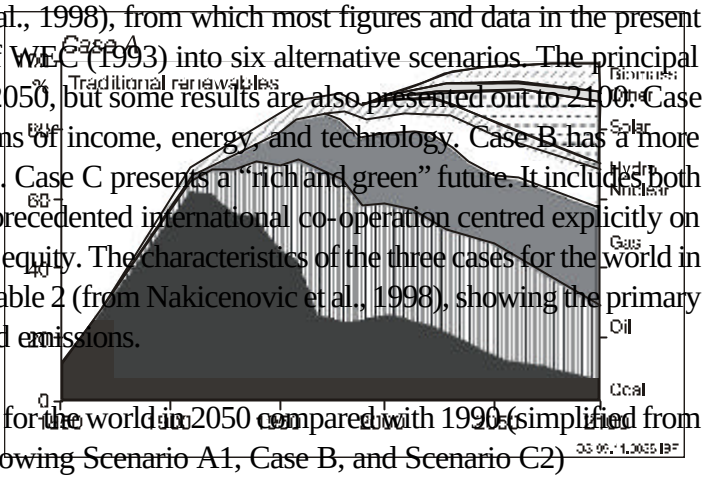

Table 2: Characteristics of the three cases for the world in 2050 compared with 1990 (simplified from Table 5.1 of Nakicenovic et al. (1998) showing Scenario A1, Case B, and Scenario C2)

	Base year 1990	**Case A**	**Case B**	**Case C**
Primary energy, Gtoe	9	25	20	14
Primary energy mix (%)				
Coal	24	15	21	10
Oil	34	32	20	18
Gas	19	19	23	23
Nuclear	5	12	14	12
Renewables	18	22	22	37
Energy investments trillion (USD)	0.2	0.8	0,8	0.5
As % of GWP	1.2	0.8	1.1	0.7
Final energy (Gtoe)	6	17	14	10
Emissions				
Sulphur (MtS)	59	54	55	22
Net carbon (GtC)	6	12	10	5

All three Cases provide for substantial social and economic development, particularly in the developing countries. They provide for improved energy efficiencies and environmental compatibility, and thus for associated growth in both the quantity and quality of energy services. To facilitate comparisons, all the Cases assume the same population growth with 10 billion people in 2050 and nearly 12 billion by 2100.

The IIASA-WEC study (Nakicenovic et al., 1998) states that all scenarios except Case C approach the doubling of pre-industrial CO2 concentrations that is the base for most climate calculations. In all scenarios except Case C, carbon concentrations continue to rise throughout the 21st century. Based on current knowledge, an increase of CO2 concentrations to 600 ppmv by the end of the 21st century could lead to an increase in the mean global temperature of about 2.5 ? C and a sea level rise of up to half a meter. The scientific uncertainties of such estimates are, however, substantial (IPCC, 1996).

Case C is certainly the most challenging for the international community. It is optimistic about technology and geopolitics, but unlike Case A, it assumes unprecedented progressive international co-operation

focussed explicitly on environmental protection and international equity (Nakicenovic et al., 1998). It assumes a broad portfolio of environmental control technologies and policies, including incentives to encourage energy producers and consumers to utilise energy more efficiently and carefully, "green taxes", international environmental and economic agreements, and extensive technology transfer. It incorporates policies to reduce carbon emissions in 2100 to 2 gigaton carbon (GtC) per year, which is one third of today's level. One option is a carbon tax that gradually increases well above USD 100 per ton of carbon in 2100 to a value comparable with average gasoline taxes in Western Europe at present.

In the IIASA-WEC study (Nakicenovic et al., 1998), Case A is divided into three scenarios, A1 (shown in Fig. 4) which assumes gas and oil to provide nearly 20% each of the primary energy in 2100, A2 which assumes coal to provide 40% of the primary energy, and A3 which assumes fossil fuels being reduced to 30% by 2100.

Similarly, Case C is divided into two scenarios, (C1) in which nuclear energy is phased out and 80% of the primary energy provided by renewables, and (C2) in which a new generation of safe nuclear reactors has been developed. Scenario C2 is shown in Figure 4.

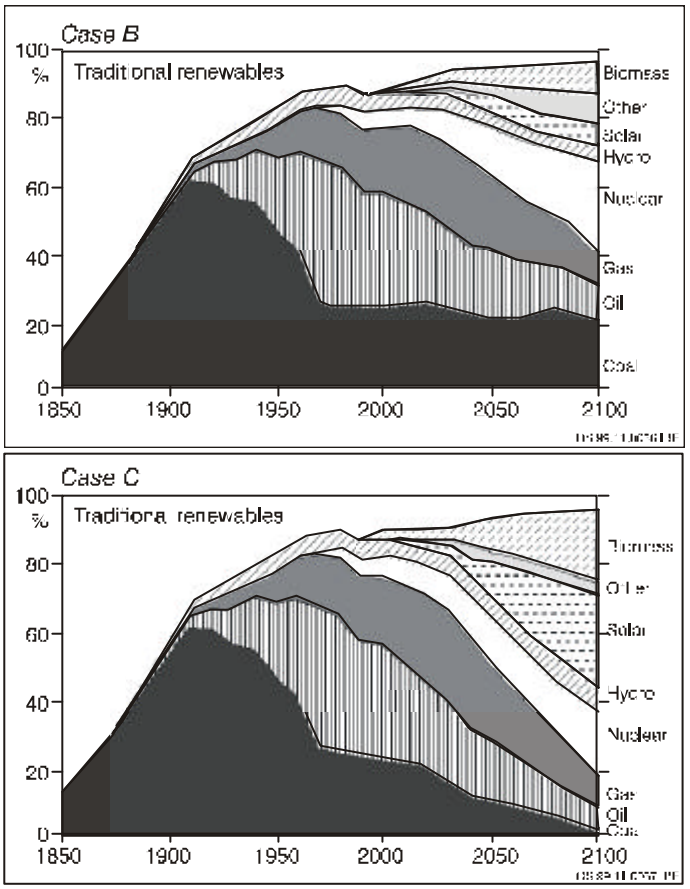

Figure 4: Evolution of primary energy shares, historical development from 1850 to 1990 and in scenarios to 2100. Case A, the oil and gas-intensive high economic growth case. Case B, the cautious economic growth case. Case C, the renewable and Abio-nuc.@ case. The figures are reproduced from Nakicenovic et al.(1998), and show Scenario A1, Case B, and Scenario C2 (see text)

The Kyoto protocol of 1997 specifies emission limits for the OECD countries and the countries in transition to market economies (regions NAM, WEU, EEU, FSU, and PAO in Table 2). The IIASA-WEC study compared the energy-related carbon emission limits of these regions and concluded that in Case C all the regions are well within their Kyoto limits already in 2010 and heading toward yet lower emissions thereafter. Case B and scenario A3 come close to being in compliance with the Kyoto protocol (Nakicenovic et al., 1998).

The Increased Role of Renewables

In all the scenarios, the peak of the fossil fuel era has passed (Nakicenovic et al., 1998). Fossil energy consumption grows more slowly than total primary energy needs. Oil and gas are important transitional sources of energy in all scenarios, but their percentage share in the total primary energy gradually declines throughout the next century. In absolute amounts, however, future oil and gas requirements are huge compared with current levels. By 2050 the highest scenarios imply increases in oil production of more than a factor of two and of gas production by close

to a factor of five compared with current production levels. The role of coal is variable from a revival in scenario A2 and Case B, to a decline in the other scenarios. In scenario A1 (shown in Fig.4) oil and gas maintain the highest market share of all scenarios and for the longest time. It may be worth recalling here, that in long term energy forecasts in the middle of the 20th century, nuclear energy was expected to provide a major share of the energy requirements by year 2000!

Considerable progress is expected in the development of clean fuels technology. The development of fuel cells and the use of hydrogen as an energy carrier for transportation are also very important fields of research. The pace of such development is, however, difficult to quantify.

In all scenarios there is a significant expansion of renewables. Traditional uses of renewables (fuel wood and animal waste) are expected to be gradually replaced by high-quality energy carriers, including those from "new" renewable sources (such as modern biomass, solar, wind, and geothermal energy). Hydro power and traditional biomass are already important factors in the world's energy mix, contributing about 18% of the total world energy requirements, whereas the "new" renewables contribute only about 2% of the world primary energy use (WEC, 1993).

The "new" renewables are at a variable stage of development as yet. The period until 2020 is considered a very important transitional period for renewables in the energy market, especially as one of the potentially largest single contributors of the "new" renewables, namely solar energy for electricity production, is still not commercially competitive with conventional energy sources.

"Modern" biomass, wind and geothermal energy are, however, making a relatively fast progress. A comprehensive description of the "new" renewables is given in the World Energy Council publication "New Renewable Energy Resources - A Guide to the Future" (WEC, 1994).

The WEC Commission (WEC, 1993) estimated that the "new" renewables might in 2020 contribute 3-4% of the total energy demand with minimum policy support and 8-12% of the world energy demand with major policy support. Different opinions have been stated on the WEC Commission's study on the potential role of the various renewable energy sources. An example will be given here regarding the role of hydropower and geothermal energy. Similar cases can probably be made for some of the other "new" renewables.

Björnsson et al. (1998) made a special study of the potential role of hydropower and geothermal energy in the world energy scenario in 2020. Table 3 (from Björnsson et al., 1998) is divided into three parts, the first two of which are taken directly from the WEC Commission's study (WEC, 1993). The figures in the third part for hydro and geothermal are supplied by Björnsson et al. (1998). For traditional renewables, no policy support is envisaged, and for hydro major policy support is envisaged for "small hydro" only, according to WEC (1993). The figures for hydro in Table 3, however, refer to both "small" and "large" hydro.

Table 3 shows that major policy support can be expected to increase energy production from renewables in 2020 from 117 to 151 EJ/a, or by 29%, according to WEC (1993) and that the emphasis on hydro and geothermal advocated in Björnsson et al. (1998) could increase them from 117 to 181 EJ/a, or by 54%. Production from geothermal would be increased by 276% and that from hydro by 47% over and above the "major policy support" figures in WEC (1993). This is in line with the view

expressed by Björnsson et al (1998) that hydro and geothermal were given inadequate attention in the WEC (1993) study.

Björnsson et al. (1998) concluded:

1) that by vigorously developing the hydro and geothermal resources of the world over the next few decades, global emissions of carbon dioxide in 2020 from energy production and use can be reduced by some 10% from the level estimated in Case B of the WEC 1993 Energy Study;
2) that there are ample undeveloped resources available for this;
3) that the environmental impacts of hydro and geothermal need not hinder their development;
4) that both energy sources possess a number of positive attributes from an operational point of view;
5) that they are generally cost-competitive and involve lower financial risk than many other energy sources; and
6) that, accordingly, financing of the necessary investment, largely by private capital, should not be a serious obstacle. Björnsson et al. (1998) conclude that hydro could contribute 61 EJ/a and geothermal 14 EJ/a, totalling 75 EJ/a, to the global primary energy supply in 2020, which is about 77% higher than envisaged in Case B of the WEC (1993) study.

Table 3: Assumed primary energy production from renewables in 2020
(From Björnsson et al. 1998)

Renewables	WEC[1)]				Björnsson et al. 1998	
	Minimum		Maximum[2)]			
	EJ/a	%	EJ/a	%	EJ/a	%
Traditional	55.6	47.6	55.6	36.9	55.6	30.8
Modern biomass	10.2	8.7	23.6	15.7	23.6	13.1
Solar	4.6	3.9	14.9	9.9	14.9	8.2
Wind	3.6	3.1	9.0	6.0	9.0	5.0
Oceanic	0.6	0.5	2.3	1.5	2.3	1.3
Geothermal	1.7	1.5	3.8	2.5	14.3	7.9
Hydro power	40.7	34.8	41.5	27.5	60.8	33.7
Total	117.0	100.0	150.7	100.0	180.5	100

1) WEC Commission: Energy for Tomorrow's World, St. Martin's Press 1993
2) With major policy support

The Role of UN Agencies

To meet the aim stated by the WEC Commission (WEC, 1993) to supply adequate, sustainable energy at acceptable costs to meet the needs of all people whilst achieving socially acceptable care and protection of the environment, requires a concerted effort of all governments, international agencies, the business as well as the academic communities around the world. The UN system has a tradition for dealing with many of the key issues.

There are many areas of conflict on the horizon which ever of the scenarios we choose to meet the future energy requirements of the world. Two energy sources, biomass and nuclear energy, will be taken as examples. All the scenarios described in previous chapters involve a significant increase of use of biomass for energy production. Both agricultural food production and biomass production for energy require land. The IIASA-WEC study (Nakicenovic et al., 1998) looked at the potential land-use conflict between agriculture and biomass energy. In Asia, for example, the land required for expanding agricultural production and achieving maximum biomass use would require the entire arable land by 2100. They conclude that the future of biomass will in all likelihood be constrained, particularly in densely populated regions such as Asia.

All but one of the energy scenarios involves a great increase in the use of nuclear energy. Problems associated with the safety of nuclear plants and the storage and disposal of nuclear waste are of much public concern internationally. This has lead many industrialized countries to stop building new nuclear plants. One of the world's most technologically developed country, Sweden, decided after a national referendum to phase out by 2010 the nuclear plants which have provided over 40% of the electricity since the mid 1980´s. In addition to nuclear safety and waste disposal problems, the international concern for the proliferation of weapon's-grade fissile materials will increase as more and more nations install and operate nuclear plants. That will create conflicts of a political nature but still be closely related to the energy debate.

United Nations agencies have played a major role in the development of the energy sector, in particular in the developing countries. UNDP projects have been key elements in the early stages of energy projects in a large number of countries in all continents, not least in the development of renewable energy sources such as hydropower and geothermal energy. The World Bank (through IDA, IBRD, and lately IFC) has been instrumental in financing and in conducting quality control on major energy projects around the world. But it is not least in the arena of international agreements on the sustainable use of energy resources that the UN agencies have a major role to play.

It is clear that no single energy source is going to take over from the polluting fossil fuels. The integration of local energy sources in individual countries and regions into grids that make use of the best local and imported energy is important if we are to find solutions to regional and global energy problems. In the developing countries in particular, the expansion of the energy sector must go hand in hand with infrastructure, social development and economic growth. High technology energy industry cannot thrive in countries characterised by the oxcarts.

Technology transfer from the industrialised to the developing countries is certainly of major importance. One of the main constraints of energy development in many countries is a shortage of skilled manpower with practical experience. The developing countries rely heavily on foreign consultants, but in many cases the consultants have to work for a considerable time in a given country to be able to adjust their expertise to the special characteristics of the energy resources and the infrastructure in that country. It is very important to secure that the experience obtained during the development and implementation of major energy projects be maintained within the country when the consultants depart. Assigning fully qualified local experts to work as counterparts with the foreign consultant's best does this. Many of the local experts need to receive a part of their training internationally. The energy sector can only work in true harmony with other sectors in a country when local competence has been secured in key functions

at national level.

We must not, however, forget the need to educate also the decision-makers that have to deal with the most complex matters in the international fora. United Nations agencies might consider increasing the opportunities for multidisciplinary training of young professionals who have been chosen by their nations and by the international agencies to deal with the complex issues at hand for mankind. To meet the energy requirements of the world in the future can only be done in harmony with meeting many other human requirements. The common goal is to improve the quality of life of the peoples. All nations, the united nations of the world, are involved.

Conclusions

At the turn of the millennium, two billion people, a third of the world's population, have no access to modern energy services. World population is expected to double by the end of the 21st century. Economic development needs to continue, particularly in the South. A key issue to improve the standard of living of the poor is to make clean energy available to them at prices they can cope with. Energy affects all aspects of modern life. There is a strong positive correlation between energy use per capita in a country and issues that we value highly such as productivity per capita in the country (Figure 1) and life expectancy (Figure 2). Similarly, there is an inverse correlation between energy use and issues such as infant mortality and illiteracy.

The scarcity of energy resources forecasted in the 1970s did not occur. With technological and economic development, estimates of the ultimately available energy resource base continue to increase. Economic development over the next century will apparently not be constrained by geological resources. Environmental concerns, financing, and technological constrains appear more likely sources of future limits.

Amongst the top priorities for the majority of the world's population is access to sufficient affordable energy. Some 70% of the world's population have a per capita energy consumption level one-quarter of that of W-Europe, and one sixth of that of the USA. The World Energy Council has presented several scenarios for meeting the future energy requirements with varying emphasis on economic growth rates, technological progress, environmental protection and international equity. All provide for substantial social and economic development, particularly in the developing countries. They provide for improved energy efficiencies and environmental compatibility. During 1990-2050, the primary energy consumption is expected to increase by some 50% according to the most environmentally conscious scenario and by some 275% according to the highest growth rate scenario. In the environmental scenario, the carbon emissions are expected to decrease slightly from 1990 levels. The high growth rate scenario is expected to lead to a doubling of the carbon emissions.

In all scenarios, the peak of the fossil fuel era has already passed. Oil and gas are expected to continue to be important sources of energy in all cases, but the role of renewable energy sources and nuclear energy vary highly in the scenarios and the level to which these energy sources replace coal. Hydro power and traditional biomass are already important factors in the world's energy mix, contributing about 18% of the total world energy requirements, whereas the "new" renewables contribute only about 2% of the world primary energy use (WEC, 1993). The potentially largest single contributor of the "new" renewables, namely solar energy for electricity production, is still not commercially competitive

with conventional energy sources. "Modern" biomass, wind and geothermal energy are commercially competitive and are making a relatively fast progress. Considerable progress is expected in the development of clean fuels technology. The development of fuel cells and the use of hydrogen as an energy carrier for transportation are also important fields of research.

It is clear that no single energy source is going to take over from the polluting fossil fuels. The integration of local energy sources in individual countries and regions into grids that make use of the best local and imported energy is important if we are to find solutions to regional and global energy problems. In the developing countries in particular, the expansion of the energy sector must go hand in hand with infrastructure, social development and economic growth. Technology transfer from the industrialised to the developing countries is certainly of major importance. Attention is drawn to the need also to educate the decision-makers. UN agencies should increase the opportunities for multi-disciplinary training of young professionals who have been chosen by their nations and by the international agencies to deal with the complex issues at hand for mankind.

To meet the energy requirements of the world in the future can only be done in harmony with meeting many other human requirements. The common goal is to improve the quality of life of the peoples. To supply adequate, sustainable energy at acceptable costs to meet the needs of all people whilst achieving socially acceptable care and protection of the environment requires a concerted effort of all governments, international agencies, the business as well as the academic communities around the world.

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