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Ref. № 430.102.3

Working paper

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Input Assumptions for Long-Term Energy Scenario Studies with PLANELEC-Pro Model

Abstract

This paper performs a general review of available energy sector statistics and selected long-term energy scenario studies with the objective to assess generic technical and economical parameters of existing and future power generations technologies and to define other data inputs that could be further used for prospective studies with PLANELEC-Pro model.

February 2006

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1. Definition of World Regions

The following world regions are distinguished in the paper : North America; Latin America and the Caribbean; Sub-Saharan Africa; Middle East and North Africa; Western Europe; Central and Eastern Europe; Russia and other CIS countries; Centrally Planned Asia; South Asia; Pacific OECD; and Other Pacific Asia. *Table 1* presents exhaustive list of countries and their regional groupings.

TABLE 1. LIST OF REGIONS AND COUNTRIES

Code	Region	Countries
NAM	**North America**	Canada, Guam, Puerto Rico, United States of America, Virgin Islands
LAM	**Latin America and the Caribbean**	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines, Suriname, Trinidad-Tobago, Uruguay, Venezuela
WEU	**Western Europe**	Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom
CEE	**Central and Eastern Europe**	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, The former Yugoslav Republic of Macedonia, Poland, Romania, Serbia and Montenegro, Slovakia, Slovenia
CIS	**Commonwealth of Independent States**	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
MEA	**Middle East and North Africa**	Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, United Arab Emirates, Yemen
AFR	**Sub-Saharan Africa**	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Congo (DR), Côte d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe
SAS	**South Asia**	Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
PAO	**Pacific OECD**	Australia, Japan, New Zealand, Republic of Korea
CPA	**Centrally Planned Asia**	Cambodia, China, Korea (DPR), Lao (PDR), Mongolia, Viet Nam
PAS	**Other Pacific Asia**	Brunei, Fiji, French Polynesia, Indonesia, Kiribati, Malaysia, Myanmar, New Caledonia, Papua-New-Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Tonga, Vanuatu.

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2. Current Electricity Generation Structure

Table 2 and *Table 3* represent respectively the structure of installed electricity generating capacities and net electricity production in 2000 for each world region according to US DoE Energy Information Administration data [1]. The regional statistics of gross and net electricity production can be found also in IEA "Electricity Information" publication [2] which provides additional data regarding the structure of thermal power generation (*Figure 1*) and electricity production from renewable sources (*Figure 2*). The historical data on the installed power generation capacities in IEA publication [2] are available only for OECD countries (NAM, WEU, PAO regions). For other world regions some approximations have to be made in order to build a consistent database of the existing capacities which could be further used for simulations with PLANELEC-Pro model.

TABLE 2. INSTALLED ELECTRICITY GENERATING CAPACITIES BY TYPE, JANUARY 1, 2000 (GW)

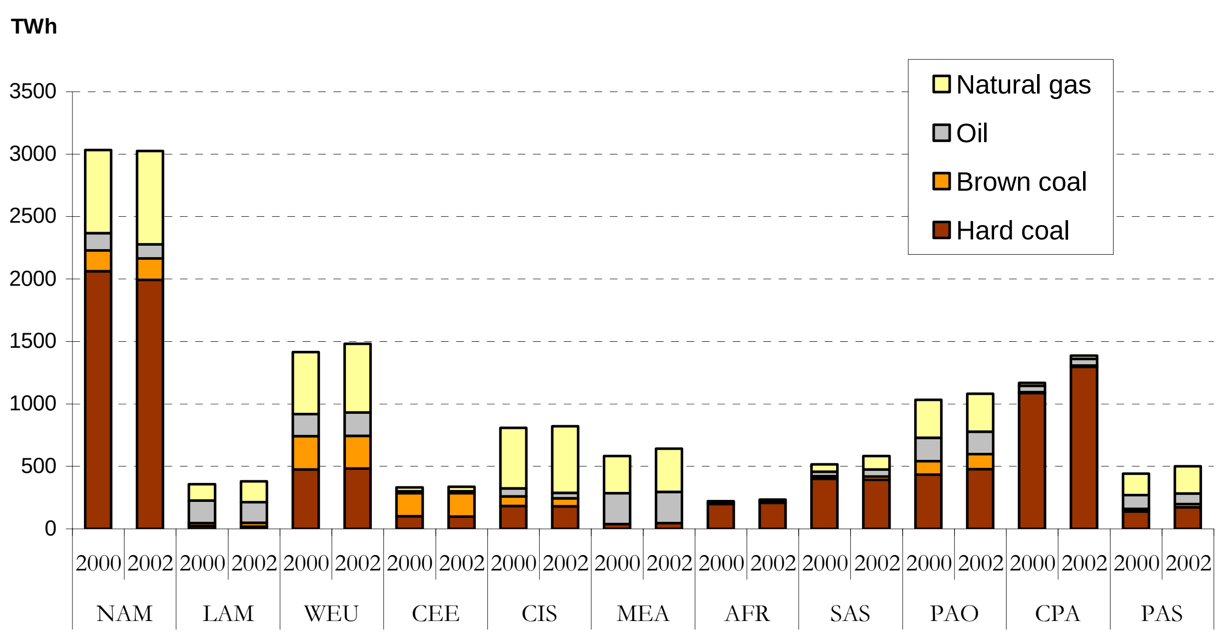
Region	Nuclear	Hydropower	Conventional Thermal	Renewables	Total
NAM	108.47	146.40	636.15	17.34	908.36
LAM	3.04	121.62	85.32	3.69	213.66
WEU	127.83	134.46	335.78	15.33	613.40
CEE	13.93	22.72	90.62	0.02	127.29
CIS	34.50	64.41	220.61	0.03	319.55
MEA	0.00	9.48	123.29	0.08	132.85
AFR	1.84	15.44	47.27	0.05	64.60
SAS	2.36	31.58	97.10	1.08	132.12
PAO	58.96	34.61	235.14	2.09	330.81
CPA	2.17	81.26	243.32	0.00	326.75
PAS	5.14	16.62	80.60	2.28	104.64
World	**358.25**	**678.61**	**2195.20**	**41.97**	**3274.03**

Source: EIA [1]

TABLE 3. NET ELECTRICITY GENERATION IN 2000 (TWh)

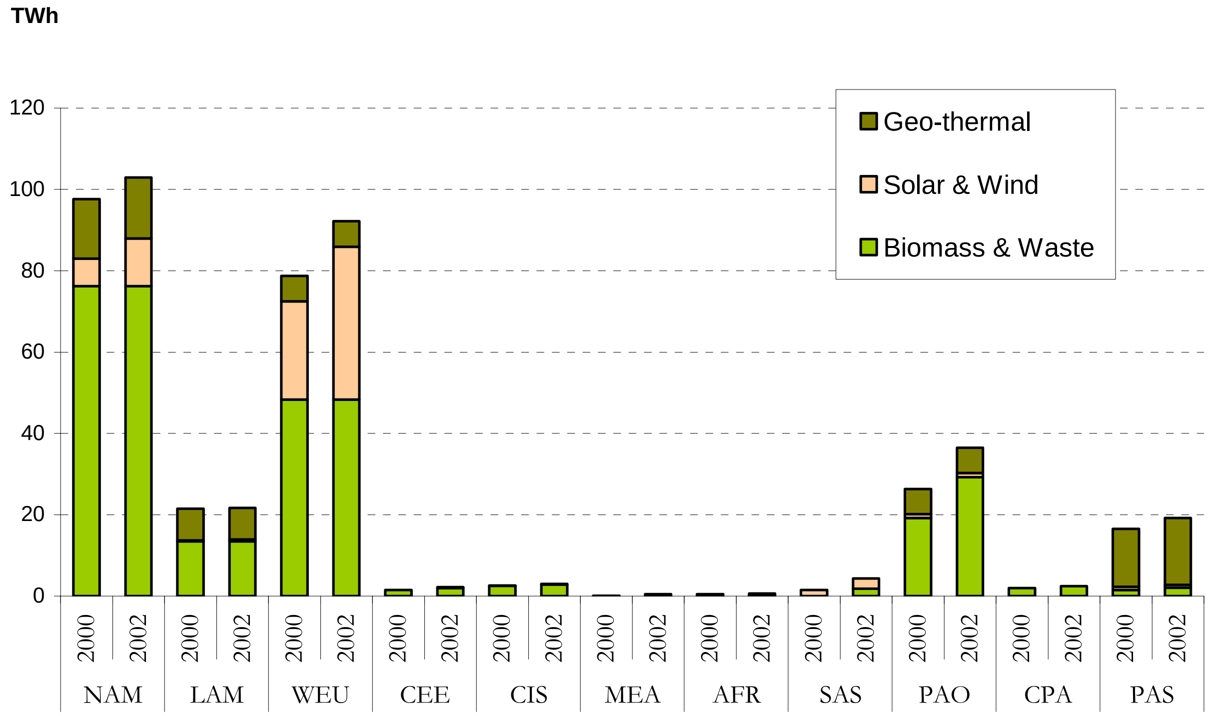
Region	Nuclear	Hydropower	Conventional Thermal	Renewables	Total
NAM	823.1	630.4	2870.6	93.2	4417.3
LAM	18.7	578.7	333.2	23.4	954.1
WEU	845.8	527.2	1332.4	74.9	2780.3
CEE	77.5	61.2	311.5	1.4	451.7
CIS	195.4	224.5	760.4	2.5	1182.8
MEA	0.0	30.2	542.0	0.2	572.4
AFR	13.0	57.9	209.6	0.7	281.3
SAS	14.4	98.6	501.6	2.9	617.6
PAO	409.5	131.1	922.7	30.7	1494.0
CPA	15.9	268.8	1095.2	2.3	1382.2
PAS	37.0	43.1	382.2	17.1	479.4
World	**2450.3**	**2651.8**	**9261.4**	**249.5**	**14612.9**

Source: EIA [1]



Source: IEA [2]

Figure 1. Structure of Thermal Power Generation in 2000 - 2002



Source: IEA [2]

Figure 2. Structure of Electricity Production from Renewable Sources and Wastes in 2000 - 2002

3. Near-term Prospects

The near term prospects for development of regional power generation systems were analysed basing on IEA publication "World Energy Outlook 2004" (WEO) [3]. The main data corresponding to the "Reference Scenario" of IEA WEO-2004 are summarised in *Table 4*.

TABLE 4. STRUCTURE OF POWER GENERATION CAPACITIES AND ELECTRICITY GENERATION IN IEA WEO-2004 (REFERENCE SCENARIO)

North America [1] (NAM)								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	332	329	380	441	2165	2410	2621	2861
Oil	64	64	62	28	113	97	107	53
Natural Gas	305	382	452	538	747	1056	1413	1664
Nuclear	109	115	117	109	880	930	950	885
Hydro	166	169	173	179	584	636	655	679
Renewables	19	32	64	137	106	157	254	457
Total	**995**	**1091**	**1248**	**1432**	**4595**	**5286**	**6000**	**6599**

Latin America (LAM)								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	10	12	17	27	55	66	90	135
Oil	50	55	55	49	161	179	201	186
Natural Gas	47	97	187	318	182	350	684	1179
Nuclear	4	4	5	5	31	32	39	39
Hydro	125	154	189	219	566	721	885	1025
Renewables	6	10	17	30	29	55	86	140
Total	**242**	**332**	**470**	**648**	**1024**	**1403**	**1985**	**2704**

OECD Europe [2]								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	192	186	194	197	945	1000	1160	1138
Oil	74	77	68	34	185	139	109	65
Natural Gas	127	170	273	399	569	748	1117	1490
Nuclear	133	127	95	73	972	987	752	580
Hydro	182	202	208	222	496	585	604	649
Renewables	35	88	169	234	104	284	530	752
Total	**743**	**850**	**1007**	**1159**	**3271**	**3743**	**4272**	**4674**

[1] Includes only Canada and USA
[2] Includes countries of Western Europe (WEU) region + Czech Republic, Hungary, Poland, Slovak Republic

TABLE 4 (continued)

Transition Economies [3]								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	111	108	93	87	324	381	409	394
Oil	38	39	38	31	57	69	65	61
Natural Gas	130	149	236	332	556	652	976	1324
Nuclear	40	41	43	38	264	292	305	272
Hydro	91	104	109	114	281	338	355	373
Renewables	1	4	7	13	3	13	24	44
Total	**411**	**445**	**526**	**615**	**1485**	**1745**	**2134**	**2468**

Middle East [4]								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	5	6	9	11	29	33	48	60
Oil	55	63	79	96	207	216	264	315
Natural Gas	73	89	132	176	259	392	580	775
Nuclear	0	1	1	1	0	6	6	6
Hydro	6	10	12	14	17	28	35	40
Renewables	0	1	2	6	0	3	6	18
Total	**139**	**170**	**235**	**304**	**512**	**678**	**939**	**1214**

Africa [5]								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	39	45	59	76	225	271	361	462
Oil	23	32	47	67	60	76	101	140
Natural Gas	24	47	94	165	105	220	458	825
Nuclear	2	2	2	2	11	13	13	13
Hydro	22	25	26	35	74	86	86	118
Renewables	1	2	3	8	4	6	9	25
Total	**111**	**153**	**231**	**353**	**479**	**672**	**1028**	**1583**

South Asia [6]								
	Capacity (GW)				**Electricity Generation (TWh)**			
	2002	***2010***	***2020***	***2030***	***2002***	***2010***	***2020***	***2030***
Coal	69	85	129	200	425	546	839	1302
Oil	12	20	28	34	51	73	97	109
Natural Gas	24	42	81	125	106	184	353	525
Nuclear	3	7	11	16	22	54	80	123
Hydro	32	46	65	77	95	171	239	284
Renewables	2	5	7	13	5	19	26	51
Total	**142**	**205**	**321**	**465**	**704**	**1047**	**1634**	**2394**

[3] Includes countries of CIS and CEE regions except Czech Republic, Hungary, Poland and Slovak Republic
[4] Includes countries of MEA region except North Africa (Algeria, Egypt, Libya, Morocco, Sudan and Tunisia)
[5] Includes all countries of African continent
[6] Includes countries of SAS region except Afghanistan, Bhutan and Maldives

TABLE 4 (continued)

OECD Pacific (PAO)								
	Capacity (GW)				Electricity Generation (TWh)			
	2002	*2010*	*2020*	*2030*	*2002*	*2010*	*2020*	*2030*
Coal	92	102	116	119	597	642	718	702
Oil	81	84	72	45	180	141	112	61
Natural Gas	91	122	165	225	323	464	598	700
Nuclear	59	70	77	87	414	534	588	662
Hydro	63	69	73	77	126	138	147	154
Renewables	6	13	26	42	37	59	89	136
Total	**392**	**460**	**529**	**595**	**1677**	**1978**	**2252**	**2415**

China								
	Capacity (GW)				Electricity Generation (TWh)			
	2002	*2010*	*2020*	*2030*	*2002*	*2010*	*2020*	*2030*
Coal	247	394	560	776	1293	2030	2910	4035
Oil	17	20	21	17	50	59	65	53
Natural Gas	8	23	67	111	17	55	196	315
Nuclear	4	10	22	35	25	82	180	280
Hydro	82	109	165	210	288	383	578	734
Renewables	2	10	20	38	2	44	89	156
Total	**360**	**566**	**855**	**1187**	**1675**	**2653**	**4018**	**5573**

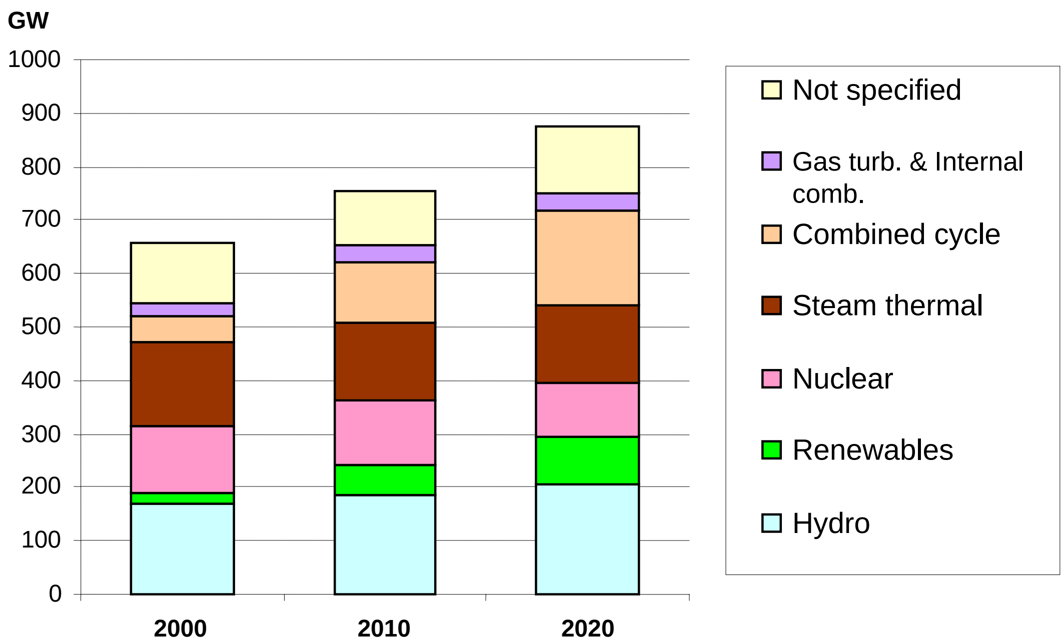
East Asia [7]								
	Capacity (GW)				Electricity Generation (TWh)			
	2002	*2010*	*2020*	*2030*	*2002*	*2010*	*2020*	*2030*
Coal	38	70	134	221	183	313	610	1002
Oil	40	46	52	50	117	138	153	139
Natural Gas	64	90	137	175	206	306	452	532
Nuclear	5	8	9	9	35	55	62	69
Hydro	32	46	57	71	83	126	155	193
Renewables	5	7	11	19	28	42	58	98
Total	**184**	**267**	**400**	**545**	**652**	**980**	**1490**	**2033**

World Total								
	Capacity (GW)				Electricity Generation (TWh)			
	2002	*2010*	*2020*	*2030*	*2002*	*2010*	*2020*	*2030*
Coal	1135	1337	1691	2155	6241	7692	9766	12091
Oil	454	500	522	451	1181	1187	1274	1182
Natural Gas	893	1211	1824	2564	3070	4427	6827	9329
Nuclear	359	385	382	375	2654	2985	2975	2929
Hydro	801	934	1077	1218	2610	3212	3739	4249
Renewables	77	172	326	540	318	682	1171	1877
Total	**3719**	**4539**	**5822**	**7303**	**16074**	**20185**	**25752**	**31657**

Source: IEA [3]

[7] Includes countries of PAS region + Afghanistan, Bhutan, Maldives, Korea (DPR) and Vietnam

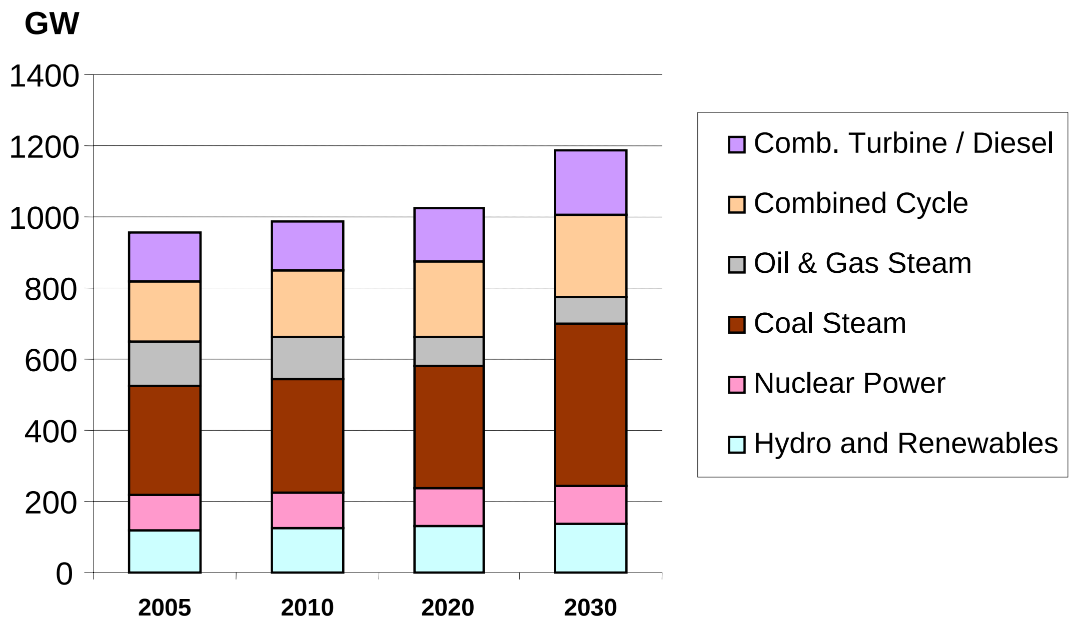
The present day structure of installed power generating capacities by fuel and technology type and the near-term prospects (up to 2020) for its development in Western Europe were analysed basing on "EURPROG" report [4] published by the Union of Electricity Industry (EURELECTRIC). This annually updated publication is a reference source of detailed information on the structure, programs and prospects of the European electricity sector. *Figure 3* represents the projected technological structure of electricity generating capacities in WEU region for the period 2000 – 2010 – 2020. It clearly shows the growing importance in electricity mix of the power plants based on natural gas combined cycle and renewable energy technologies, while the relative shares of oil-fired, coal-fired and nuclear power plants are projected to decline over twenty years period.



Source: EURPROG [4]

Figure 3. Projected Structure of Electricity Generating Capacities by Technology Type in Western Europe in 2000 - 2020

The near term projections (up to 2030) of the evolution of power generating capacities in USA were taken from DoE / EIA publication "Annual Energy Outlook" (AEO) [5]. *Figure 4* represents the structure of electricity capacities in repartition by main technology types for the period 2005 – 2030 in "Reference case" of latest AEO 2006 edition. Contrary to the case of Western Europe, the share and total capacity of coal-fired power generation are expected to increase in USA over 25-years period, while the capacity of nuclear power plants would remain relatively stable, the share and capacity of conventional thermal oil and natural gas – fired power generation would decline and the capacity of combined cycle power plants would grow. The increase in total capacity of power generating technologies using renewable energy sources is projected to be much more moderate than in WEU region.



Source: EIA [5]

Figure 4. Projected Structure of Electricity Generating Capacities by Technology Type in USA in 2005 - 2030

4. Long-term Electricity Demand and Supply Scenarios

The main objective pursued while developing electricity demand & supply scenarios is to evaluate the upper range of future electricity supply to be assured by the existing power generating capacities together with the additions of power plants of prospective technologies. Another objective is to determine the possible development paths of power generation systems in each world region and to estimate the respective share in total installed capacities and maximum electricity supply of each technology / fuel type, including advanced energy technologies, such as Thermonuclear Fusion.

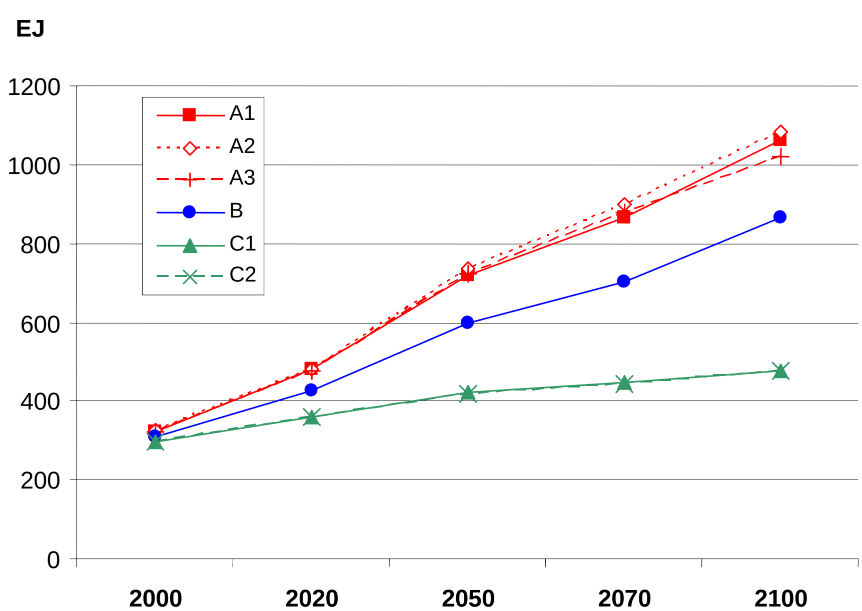
The scenarios analysed herein include those developed in renowned international studies such as IIASA / WEC "Global Energy Perspectives" [6] and IPCC "Special Report on Emission Scenarios" [7]. All these studies develop their own sets of scenarios, which differentiate essentially on the underlying assumptions regarding future population, economic growth, availability of primary energy resources, technology development patterns and other factors. As a result, the future levels of energy consumption and electricity production significantly differ across various studies and scenarios. Main details of selected scenarios are given bellow.

The IIASA / WEC study describes three alternative cases that diverge into six scenarios of future economic development and energy consumption trends, and quantifies their implications for 11 world regions. The key parameters of all three cases are given in *Table 5*. The projected level of world final energy consumption for the time horizon 2100 is shown in *Figure 5*. Case "A" is characterised by remarkable technological improvements which entail rapid economic growth resulting in a highest energy demand. Case "B" is considered as less ambitious, though perhaps more realistic, with a moderate pace of technology improvements, and consequently slower economic growth and lower energy consumption. Case "C" corresponds to the projection of an ecologically driven future. It allows for significant technological progress, especially as concerns non-fossil energy technologies, and favours extensive international cooperation centred on environmental protection and equitable economic growth. The projected energy consumption in case "C" is the lowest one among all scenarios.

Table 5. Key Characteristics of IIASA / WEC Scenario Cases

Case	**A** *High growth*	**B** *Middle course*	**C** *Ecologically driven*
Number of scenarios			
	3	*1*	*2*
Primary energy demand, EJ			
1990	*379*	*379*	*379*
2050	*1048*	*837*	*601*
2100	*1895*	*1464*	*880*
Resource availability			
Fossil	*High*	*Medium*	*Low*
Non-fossil	*High*	*Medium*	*High*
Technology costs			
Fossil	*Low*	*Medium*	*High*
Non-fossil	*Low*	*Medium*	*Low*
Technology dynamics			
Fossil	*High*	*Medium*	*Medium*
Non-fossil	*High*	*Medium*	*High*
Net carbon emissions, GtC			
1990	*6*	*6*	*6*
2050	*9-15*	*10*	*5*
2100	*6-20*	*11*	*2*

Source: IIASA / WEC [6]



Source: IIASA / WEC [6]

Figure 5. World Final Energy Consumption in IIASA / WEC Study "Global Energy Perspectives"

The IPCC "Special Report on Emission Scenarios" (SRES) has a larger number of scenarios and, hence, a broader range of energy demand projections, because several models developed by different research institutions were applied in the analysis. The SRES scenarios are built on the basis of four general storylines, which can be characterised by the following excerpt from Nakicenovic et al. [7] :

- The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.

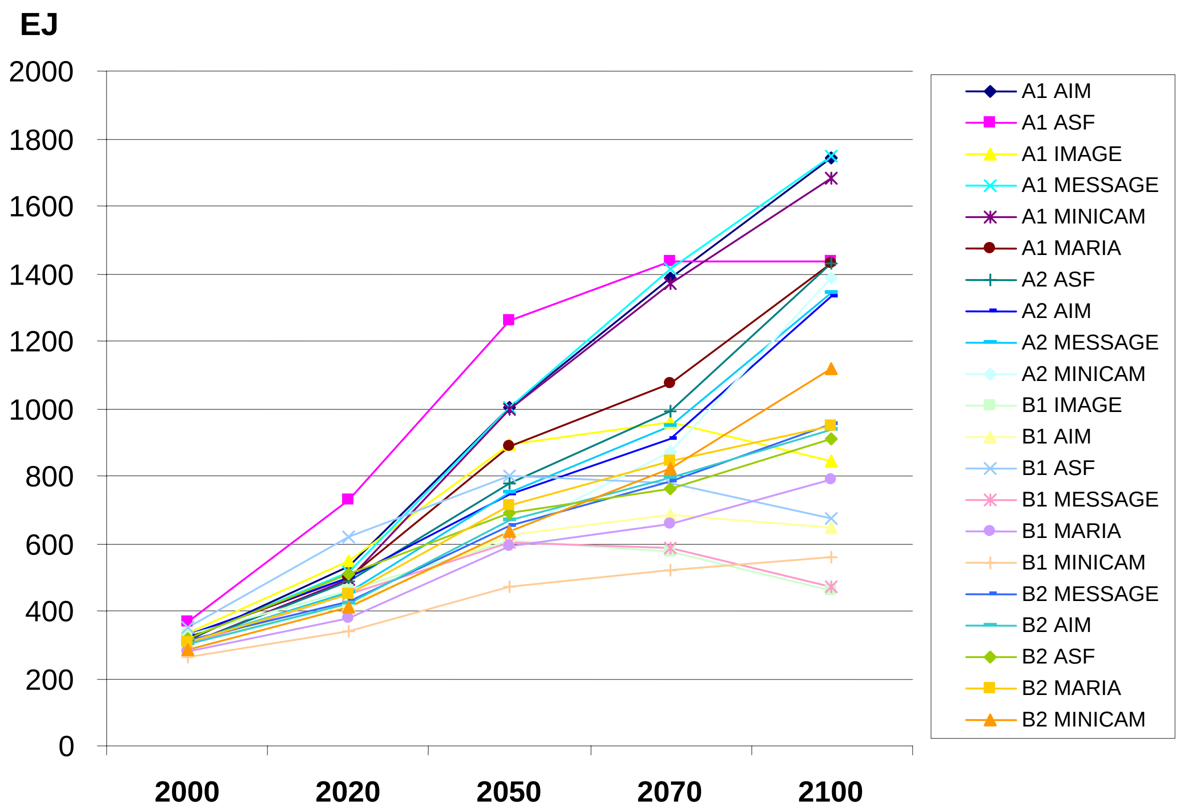
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

- The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

The possible evolution of world final energy consumption according to different scenarios, as projected by the models applied in SRES studies, is shown in *Figure 6*. It was observed that IIASA /

WEC projections fall into the range of SRES estimates, and that the IIASA / WEC case "B" scenario of future energy consumption is very close to SRES "B2" storyline scenarios. Therefore, the final energy demand projection of IIASA / WEC "middle-course" scenario "B" was chosen in as the baseline for further elaboration of long-term multi-regional electricity demand and supply scenarios using PLANELEC-Pro model.

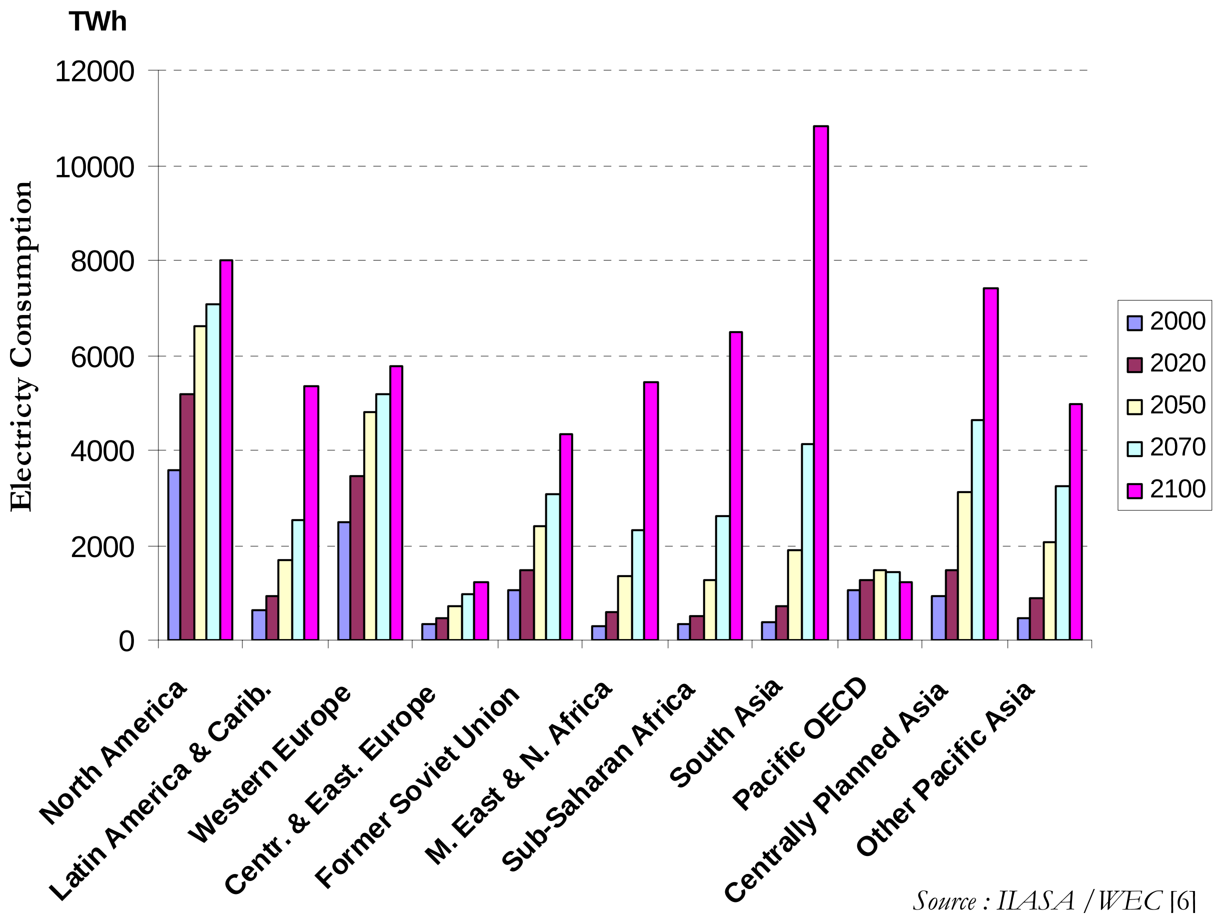


Source: IPCC [7]

Figure 6. World Final Energy Consumption in IPCC SRES Studies

According to IIASA / WEC [6], the additional characteristics of this scenario are described as follows: compared to other cases, scenario "B" incorporates intermediate estimates of economic growth and technological development. It makes provision for downfall of trade barriers and for expansion of new arrangements facilitating international trade. Scenario "B" also manages to fulfil the development aspirations of the South, but less uniformly and at a slower pace than in other cases. The world total final energy consumption, in this scenario, equals to 309 EJ in 2000, and increases gradually up to 596 EJ in 2050 and up to 864 EJ in 2100.

Next, the existing regional scenarios of future final energy and electricity consumption were analysed. The evolution of future electricity consumption in regional perspective [8] according to the IIASA / WEC scenario "B" projection is shown in *Figure 7*. Assuming that electricity consumption represents a portion of the total final energy consumption, the total demand for electricity can be estimated as the sum of electricity production needed to satisfy the end-use demand and the additional production to meet specific requirements of the electricity system, including the own use of power plants, electricity use by heat pumps, electric boilers and pumping storage, as well as the transmission and distribution network losses.



Source : IIASA / WEC [6]

Figure 7. Regional Electricity Consumption (IIASA / WEC – Scenario "B")

According to IIASA/WEC scenario "B", the total final energy consumption in the industrialised countries increases moderately in the first half of the century, and then it is expected to steadily go down. In Central & Eastern Europe and Former Soviet Union, the final energy consumption is projected to rise until the time horizon 2070, and then it may slightly decrease. The greatest increase

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[8] The regional groupings in IIASA/WEC "Global Energy Perspectives" slightly differ from regions definition adopted in the present paper. So, Estonia, Latvia and Lithuania are included in our study in CEE region while in IIASA/WEC study they belong to FSU region; the Republic of Korea is included in "Other Pacific Asia" (PAS) region in IIASA/WEC study while it belongs to "Pacific OECD" (PAO) region in the present study

in final energy consumption with an impressive pace is supposed to occur in developing Asian and African countries. Moreover, it is expected that by the end of the century final energy consumption in these developing countries will be more than three times higher compared to industrialised OECD and Former Soviet Union countries.

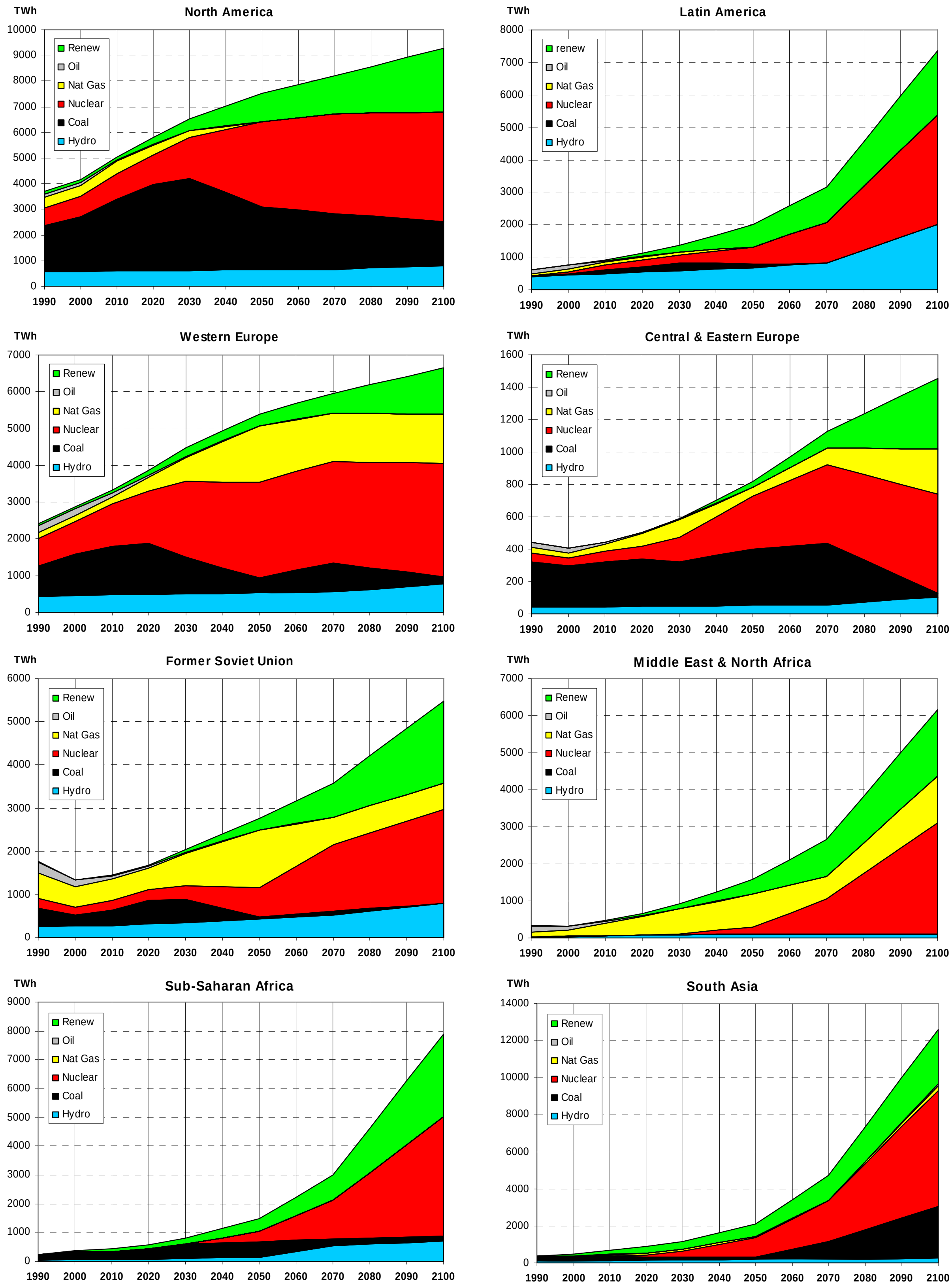
The share of electricity in world total final energy consumption in IIASA / WEC scenario "B" is expected to increase from actual 13.3% up to 16.2% in 2050 and up to 24.2% in 2100. Meanwhile, there is a significant deviation from world average figures across the regional data. As it is specified in *Table 6*, the industrialised countries actually record higher values of electricity share in final energy consumption than developing and transitional economy countries. The prospects for the end of the century indicate that this difference is likely to remain. This fact can be explained by a remarkable increase of the electricity share in final energy consumption in industrialised countries (up to 45%), while the countries of MEA, AFR and CPA regions are expected to stay considerably bellow the world average values.

TABLE 6. ELECTRICITY SHARE (%) IN TOTAL FINAL ENERGY CONSUMPTION
(IIASA / WEC – SCENARIO "B")

	2000	2020	2050	2070	2100
North America	*18.4*	*23.8*	*30.7*	*36.0*	*45.6*
Latin America & Caribbean	*9.2*	*9.1*	*11.1*	*13.8*	*24.9*
Western Europe	*19.0*	*24.2*	*33.5*	*38.1*	*45.8*
Central & Eastern Europe	*13.3*	*14.8*	*17.2*	*20.4*	*28.5*
Former Soviet Union	*12.3*	*12.2*	*14.0*	*16.5*	*24.3*
Middle East & North Africa	*7.5*	*7.9*	*8.7*	*10.6*	*17.3*
Sub-Saharan Africa	*9.4*	*7.9*	*10.3*	*12.1*	*17.4*
South Asia	*6.3*	*7.6*	*10.8*	*15.9*	*23.1*
Pacific OECD	*22.2*	*25.8*	*33.2*	*36.9*	*39.0*
Centrally Planned Asia	*7.2*	*7.2*	*9.6*	*12.5*	*17.7*
Other Pacific Asia	*8.7*	*10.2*	*14.4*	*19.8*	*28.4*
World average	***13.3***	***14.3***	***16.2***	***18.5***	***24.2***

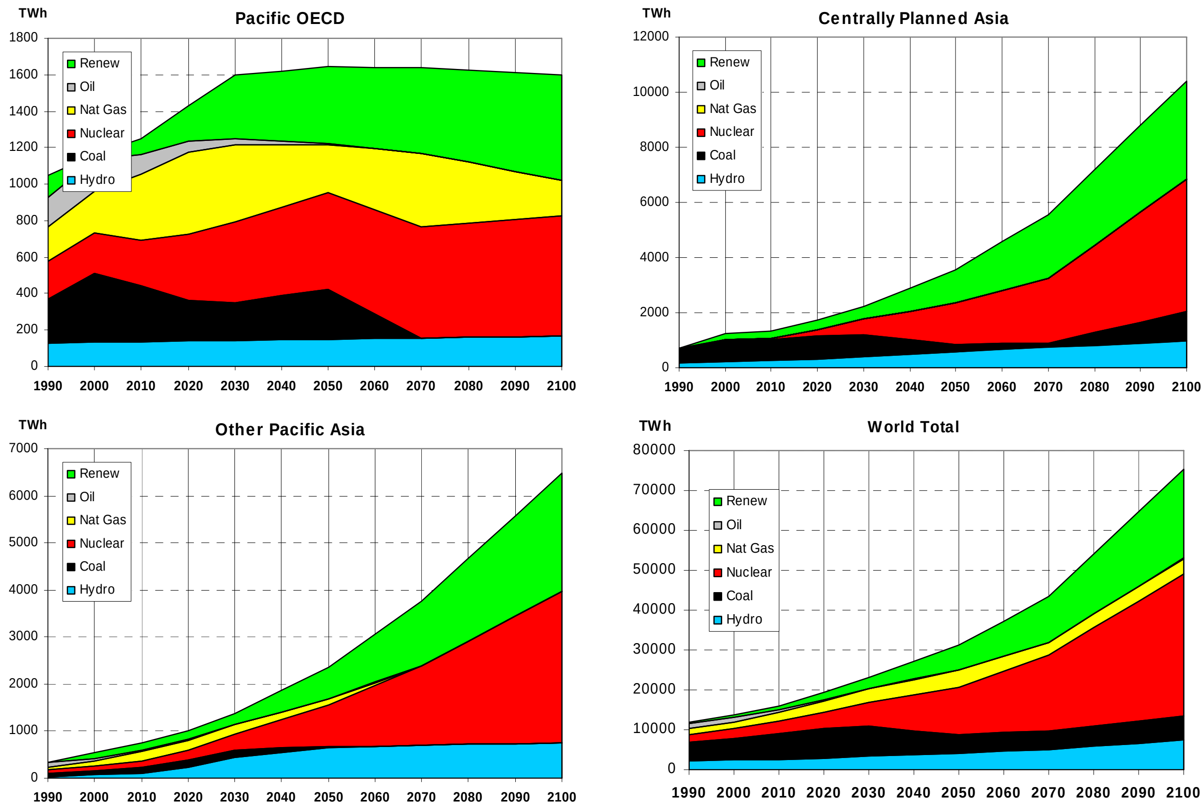
Source: IIASA / WEC [6]

Basing on the estimation of final energy consumption in global and regional perspective, the projected share of electricity in total energy consumption, the availability of primary energy fuels and other factors, the multi-regional scenarios of future electricity supply by fuel and technology type were elaborated. For that purpose, first, the electricity generation structure in case of IIASA/WEC scenario "B" was analysed for each world region (*Figure 8-a, 8-b)* .



Source: IIASA / WEC **[6]**

Figure 8-a. Electricity Generation Structure by Fuel Type in IIASA / WEC – Scenario "B"



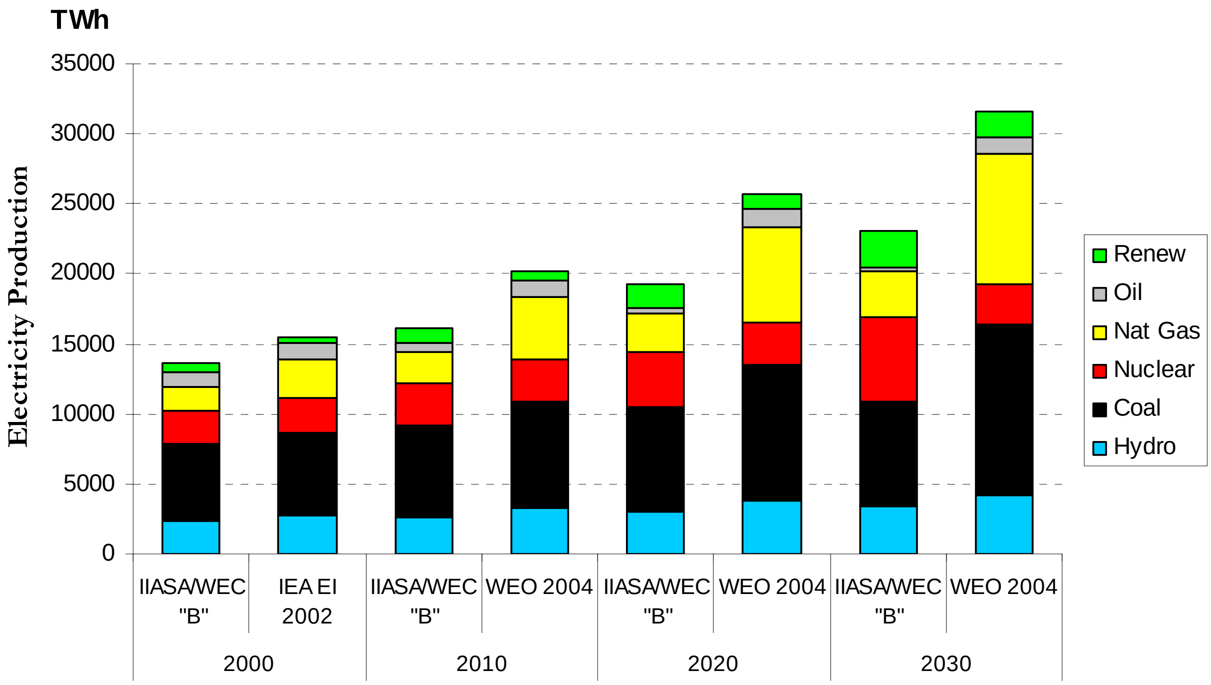
Source: IIASA / WEC [6]

Figure 8-b. Electricity Generation Structure by Fuel Type in IIASA / WEC – Scenario "B"

As it is shown in *Figure 9*, the IIASA/WEC scenario "B" projections for initial period (2000 – 2030) noticeably differ from actual data regarding the electricity generation structure in 2000 (IEA "Electricity Information" [2]) and the numerical projections for years 2010 – 2030 of the IEA WEO – 2004. So, the estimation of the total world electricity production in IIASA /WEC scenario "B" is significantly lower than in IEA actual data and projections.

The share and total amount of electricity produced from natural gas appear to be considerably underestimated in IIASA /WEC scenario "B" accounting only for 1690 TWh in 2000 and 3279 TWh in 2030. Meanwhile, according to IEA the world natural gas – based electricity generation has reached 3070 TWh in 2000 [2] and it is expected to steadily grow up to 9329 TWh in 2030 in WEO – 2004 "Reference scenario" [3].

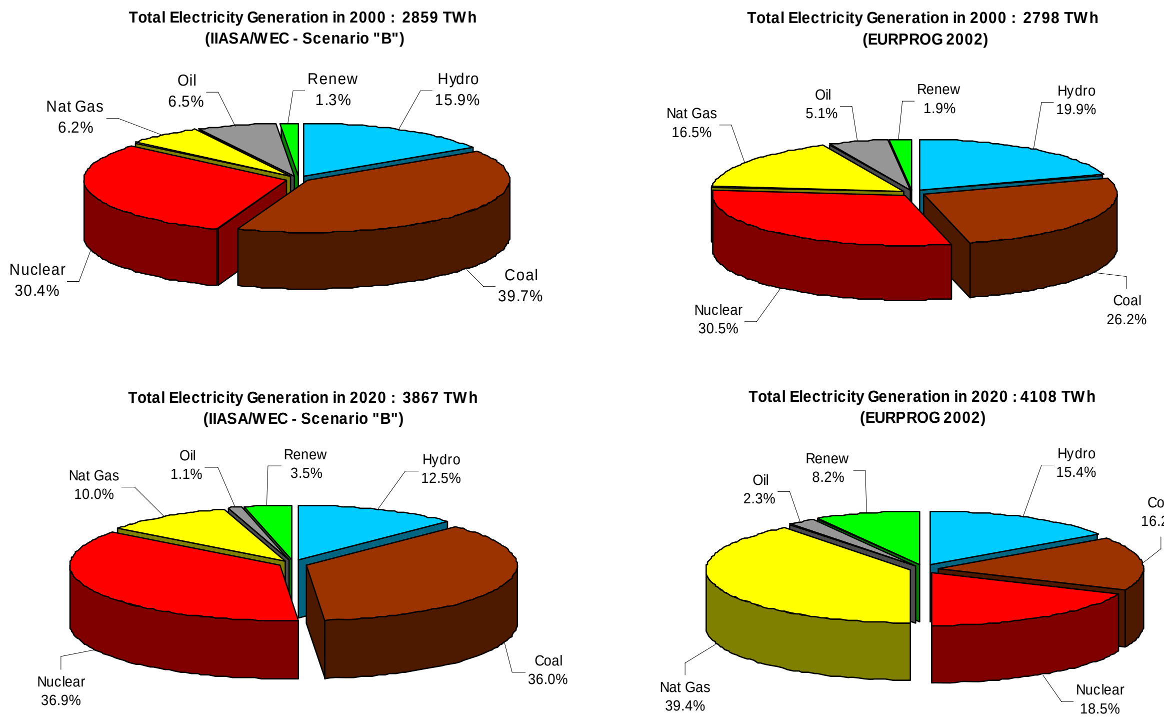
The same conclusion refers to the electricity production by coal and oil-fired power plants. The IEA statistics and projections of the coal and oil – based electricity generation record higher values then IIASA/WEC scenario "B". Contrary to that, the renewable energy technologies and nuclear power plants in IIASA/WEC scenario "B" are expected to produce more electricity in 2030 than in IEA WEO – 2004 "Reference scenario".



Source: IIASA / WEC [4] *and IEA* [6,7]

Figure 9. World Electricity Production in IIASA / WEC – Scenario "B" vs. IEA "Electricity Information 2002" and "World Energy Outlook 2004"

The situation is slightly different in the case of Western Europe. While the total amount of electricity to be produced in WEU region in 2020 also appears to be underestimated in IIASA / WEC scenario "B" compared to near-term projections of IEA WEO-2004 and EURPROG report [4], at the same time the share and total amount of coal-based electricity generation in IIASA / WEC scenario "B" are much higher in both 2000 and 2020, and the projected share and amount of electricity generation from renewable sources, except hydro, in 2020 are significantly lower. As it is shown in *Figure 10*, the expected share of natural gas according to EURPROG is considerably higher (16.5% in 2000 and 39.4% in 2020) compared to IIASA / WEC scenario "B" projection (6.2% in 2000 and 10.0% in 2020), and the share of nuclear power will be much lower in 2020 (18.5 %) compared to IIASA / WEC scenario "B" (36.9%).



Source: IIASA / WEC [6] *and EURPROG* [4]

Figure 10. Projected Structure of Electricity Production in Western Europe in IIASA / WEC – Scenario "B" and EUROPROG Report

Basing on the review of available energy statistics, the data from global / regional prospective studies (up to 2030) and the global energy scenarios (up to 2100), it was decided to preserve in the regional long-term electricity supply scenarios for the period 2000 – 2030 the actual and anticipated structure of power generating capacities and production in accordance with near term prospects from IEA WEO-2004, EURPROG and US DoE AEO-2006, and to adjust the regional electricity production growth rates during the period 2030 – 2100 in such a way that the projections of the IIASA / WEC scenario "B" could be replicated in the second half of the 21st century.

5. Regional Electricity Demand and Load Assumptions in PLANELEC Model

Before proceeding to the formulation of regional electricity supply scenarios, several assumptions have to be made regarding the electrical load parameters, such as total electricity demand, system load factors and load duration curves, maximum and minimum load to be assured by the regional electricity systems.

The evolution of regional electricity demand in near-term perspective (up to 2030) was assessed basing on the available statistics of electricity sector and the prospective data from IEA WEO-2004 and EURPROG publications. The assumptions of IIASA / WEC scenario "B" were used for the year 2100. The projections of electricity demand for the period 2031-2099 were obtained by interpolation except NAM, WEU, CIS and AFR regions, where reference values for years 2050 and 2070 of IIASA / WEC scenario "B" were applied. The resulting estimates of future electricity demand for each world region are shown in *Figure 11*.

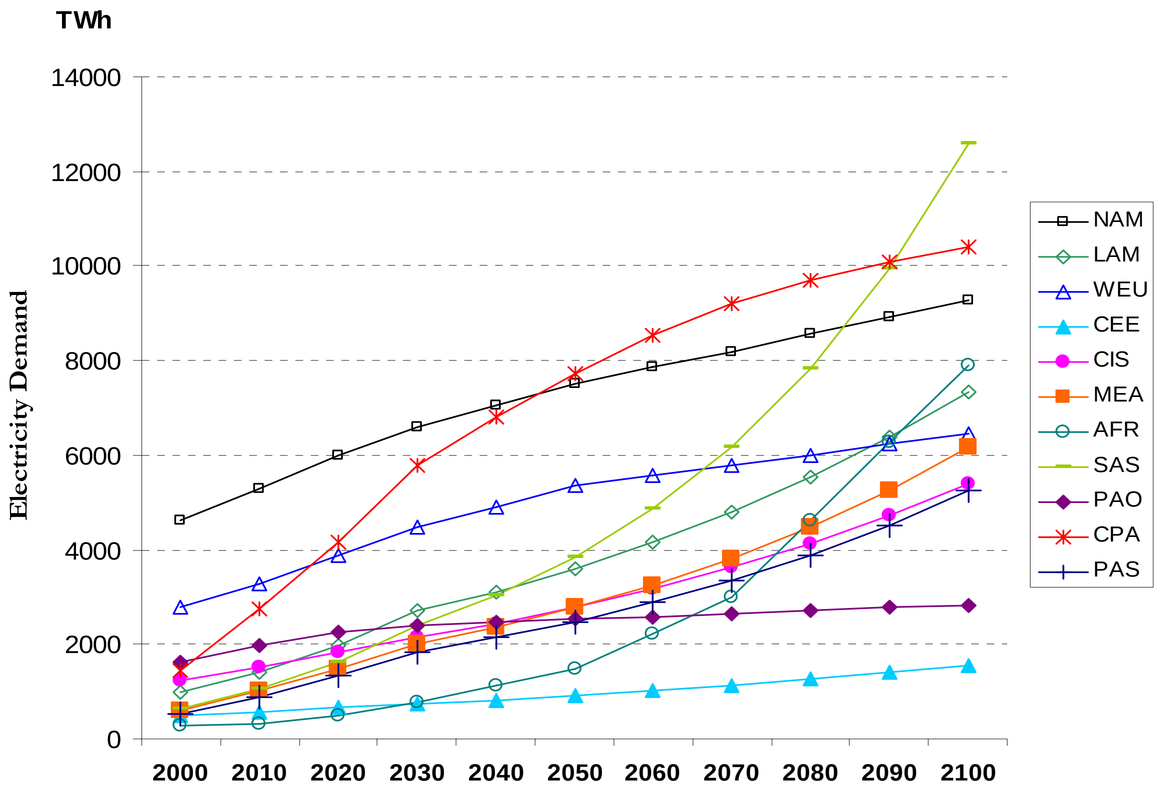


Figure 11. Evolution of Regional Electricity Demand

The assumptions on system load factors (*Table 7*) were made basing on actual IEA data, available only for OECD countries [2], and taking into account general considerations regarding the anticipated regional structure of electricity consumption by main economic sectors.

TABLE 7. YEARLY LOAD FACTORS FOR REGIONAL POWER GENERATION SYSTEMS

	2000	*2020*	*2040*	*2060*	*2080*	*2100*
North America	*0.71*	*0.71*	*0.71*	*0.70*	*0.70*	*0.69*
Latin America & Caribbean	*0.68*	*0.67*	*0.67*	*0.63*	*0.63*	*0.62*
Western Europe	*0.72*	*0.72*	*0.68*	*0.67*	*0.67*	*0.66*
Central & Eastern Europe	*0.69*	*0.70*	*0.69*	*0.66*	*0.65*	*0.65*
Former Soviet Union (CIS)	*0.71*	*0.71*	*0.71*	*0.68*	*0.67*	*0.67*
Middle East & North Africa	*0.62*	*0.62*	*0.62*	*0.60*	*0.60*	*0.60*
Sub-Saharan Africa	*0.69*	*0.67*	*0.66*	*0.63*	*0.62*	*0.62*
South Asia	*0.68*	*0.65*	*0.64*	*0.61*	*0.60*	*0.60*
Pacific OECD	*0.58*	*0.58*	*0.62*	*0.67*	*0.69*	*0.69*
Centrally Planned Asia	*0.73*	*0.70*	*0.69*	*0.66*	*0.65*	*0.65*
Other Pacific Asia	*0.69*	*0.67*	*0.67*	*0.63*	*0.63*	*0.63*

Source: Authors estimation

Given the projected electricity demand and load factors, the load duration curves (LDC) were defined for each world region. It was assumed that future power generation systems would be entirely interconnected, at least at regional level, as discussed in Biberacher et al. [8]. Accordingly, the regional electricity consumption patterns could be represented by single load duration curves. However, each year's and each region's LDC will be different depending on the projected regional electricity demand of a given year. The example of a normalised load duration curve of WEU region in 2000 is given in *Figure 12*.

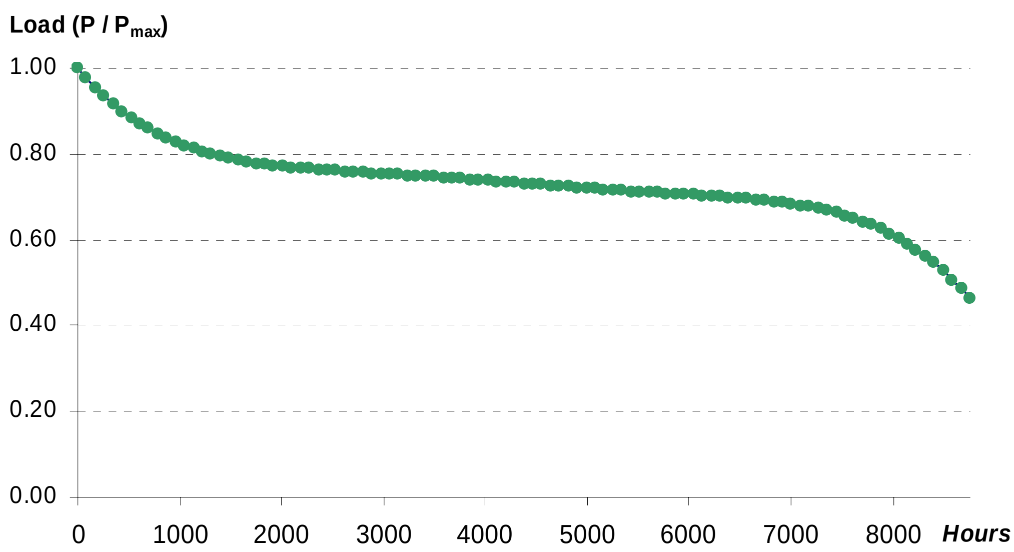


Figure 12. Normalised Load Duration Curve of Western Europe Region in 2000

Finally, the regional estimations of minimum and maximum electrical load (*Table 8*) were made basing on the projected electricity demand, the assumed system load factors and the load duration curves of each year.

TABLE 8. ASSUMED VALUES OF MAXIMUM AND MINIMUM ELECTRICAL LOAD (GW)

		2000	**2020**	**2040**	**2060**	**2080**	**2100**
North America	*max*	747	966	1139	1277	1400	1528
	min	312	404	472	516	554	590
Latin America & Caribbean	*max*	166	338	534	750	1005	1347
	min	59	115	178	198	255	331
Western Europe	*max*	433	669	849	964	1039	1118
	min	199	215	273	310	334	359
Central & Eastern Europe	*max*	79	109	136	178	221	275
	min	30	43	53	56	67	81
Former Soviet Union (CIS)	*max*	201	295	391	536	703	922
	min	84	127	166	188	239	306
Middle East & North Africa	*max*	113	270	437	625	853	1164
	min	27	64	104	119	171	245
Sub-Saharan Africa	*max*	48	86	196	409	849	1454
	min	18	29	61	102	209	349
South Asia	*max*	106	285	539	914	1481	2398
	min	39	88	154	199	311	480
Pacific OECD	*max*	321	445	455	443	447	471
	min	53	69	108	148	171	176
Centrally Planned Asia	*max*	225	674	1120	1483	1696	1832
	min	105	276	432	466	516	542
Other Pacific Asia	*max*	90	228	364	519	706	961
	min	34	79	123	139	184	309

Source: Authors estimation

6. Potential Electricity Supply by Main Technological Options

In order to determine the upper bounds for market penetration of different types of power generating technologies, the long-term electricity supply potentials in repartition by main types of primary energy were analysed basing on the available data. *Table 9* summarises the assumed values of maximum electricity supply potentials for advanced nuclear fission, thermonuclear fusion and renewable energy technologies, including hydropower. It is assumed that the existing reserves and resources of fossil fuels (coal, natural gas, oil) will largely suffice to cover electricity generation needs in the 21st century, and hence the market deployment of respective technologies will be subject to economical and environmental considerations.

TABLE 9. ELECTRICITY SUPPLY POTENTIALS BY MAIN TECHNOLOGICAL OPTIONS

	Maximum Global Electricity Supply in 2100 (TWh/yr)
Advanced Nuclear Fission	*40000*
Thermonuclear Fusion	*7000*
Hydro	*10000*
Wind	*10000*
Photovoltaic	*15000*
Biomass	*5000*
Geothermal	*800*

Source: Authors estimation

The subsequent sections provide the main assumptions regarding electricity supply potentials for each type of power generating technologies considered in this paper.

6.1. Coal

The current estimates of coal reserves-to-production ratio fall in to the range of 164 – 190 years (BP [9], WEC [10]). Furthermore, the available estimates of global coal resources show more than 5-fold excess of the presently technologically and economically recoverable reserves (BGR [11]). That makes of coal the power generation fuel of primary choice, especially for less developed countries, because of its abundance, more or less uniform distribution across world regions, relatively stable price and the accumulated experience in handling coal-fired electricity generation technology. The major factors, which limit further expansion of coal power generation, relate to the release in to atmosphere of pollutants (such as SO_x, NO_x and particulate matters) that mostly exercise a local impact, and the emission of greenhouse gases blamed for their contribution to the global climate change.

The local pollution can be reduced through adopting several practically proved measures, such as retrofitting of power plants with special equipment (electrostatic precipitators, filters, scrubbers etc.) and the pre-treatment of coal fuel. The possible solutions for curbing greenhouse gases emissions from coal combustion consists in increasing the efficiency of coal-fired power plants by applying innovative thermodynamic cycles, such as integrated coal gasification – combined cycle technology etc., and equipping the power plants with CO_2 capture functionality allowing for its further sequestration in earth crust and/or deep ocean. While the former solution allows for reducing CO_2 emissions by several percentage points (6 to 8 % of power plants emissions according to different estimates) without significant increase of the electricity cost, the later type of technology, which is still in demonstration phase, potentially may allow for substantial CO_2 emission abatement (up to 90%), however at the expense of nearly doubled electricity production cost. Furthermore, the most affordable sites for geological sequestration of CO_2 will be used first, and that will alleviate the potential for electricity cost reduction due to technological learning.

6.2. Natural Gas and Fuel Oil

The current prospects for oil and natural gas fuels are less promising than those for coal. The ranges of reserves and reserves-to-production estimates in WEC and BP statistics are: 148 – 162 Gt / 40.5 – 41.2 years for oil and 171 – 179 tcm / 59.8 – 66.7 years for natural gas [9], [10]. These figures can be criticised as too pessimistic, since they don't account for so-called "non-conventional" resources which may be extracted at higher cost. On the other hand, they can give an idea, when the peak in production of conventional oil and gas will be reached giving place to massive exploitation of more costly non-conventional resources.

A recent IEA study [12] draws a more comprehensive picture of global conventional and non-conventional resources of oil and natural gas that can be summarised as follows:

Oil

- ***Some 7 to 8 $\times 10^{12}$ barrels of conventional oil.*** *Of these, 3.3 $\times 10^{12}$ barrels are considered technically (or ultimately) recoverable; 1.0 $\times 10^{12}$ have already been produced.*
- ***7 $\times 10^{12}$ barrels of non-conventional oil*** *(heavy oil, bitumen, oil sands, and oil shales). Estimated technically recoverable quantities vary from 1 to 3 $\times 10^{12}$ barrels.*

Natural Gas

- ***450 $\times 10^{12}$ cubic metres of technically recoverable conventional gas****, or 2.8 $\times 10^{12}$ barrels of oil equivalent (boe), of which about 80 $\times 10^{12}$ cubic metres have already been produced (0.5 $\times 10^{12}$ boe).*
- ***At least 250 $\times 10^{12}$ cubic metres of non-conventional gas****, or 1.5 $\times 10^{12}$ boe (coal bed methane, tight gas, gas shales), although there is no reliable estimate world wide and there could be two or three times more.*
- ***Between 1 000 and 10 000 000 $\times 10^{12}$ cubic metres of gas locked in the form of hydrates*** *at seabed level or in permafrost (between 6 and 60 000 $\times 10^{12}$ boe). The recoverability status of these resources is unknown.*

Given the above figures it can be assumed that the existing oil and natural gas resources may largely suffice to cover electricity generation needs. Hence, the major factor limiting the deployment of oil and natural gas – fired power generation will be the future price of these fuels.

6.3. Hydropower

The hydropower potential was assessed basing on WEC data [13]. *Table 10* summarises the regional estimations of gross theoretical, technical and economical capabilities for exploitation of hydropower resources in different world regions. It was observed that the value of total world economically exploitable hydropower potential falls into the range of estimates given in IPCC Third Assessment Report: 6964 – 8708 TWh / yr [14]. In IIASA/WEC scenario "B" projection the total world hydropower production in 2100 attains 7421 MWh. In the present study the maximum potential for hydropower production in 2100 was fixed at 10000 MWh/yr assuming that economical potential can be fully exploited and additional 2000 TWh/yr of technically exploitable potential can become economically viable.

TABLE 10. HYDROPOWER EXPLOITATION CAPABILITY (TWH/YR)

	Gross theoretical capability	Technically exploitable capability	Economically exploitable capability
North America	*6244*	*1494*	*899*
Latin America & Caribbean	*7465*	*2966*	*1565*
Western Europe	*2653*	*1068*	*773*
Central & Eastern Europe	*357*	*180*	*117*
Former Soviet Union (CIS)	*4 024*	*2 247*	*1282*
Middle East & North Africa	*886*	*297*	*175*
Sub-Saharan Africa	*3 678*	*1 809*	*1056*
South Asia	*3 854*	*1 028*	*340*
Pacific OECD	*1 186*	*269*	*203*
Centrally Planned Asia	*6 820*	*2 202*	*1418*
Other Pacific Asia	*3 537*	*819*	*113*
World Total	***40 704***	***14 379***	***7 941***

Source: WEC [13]

6.4. Renewable Energy

The global potentials for electricity production by renewable energy technologies, other than hydropower, were assessed basing on the data provided in IPCC Third Assessment Report [14]. So, the worldwide potential for wind power generation is estimated at 20000 TWh/yr which is about 2.5 times lower than other estimates that can be found in the literature [9]. The range of estimates of solar energy potential is 1575 to 49837 EJ/yr. Assuming the conversion efficiency of PV modules equal to 15%, that gives the electricity production potential of $\approx$ 65000 – 2000000 TWh/yr which will largely suffice to cover total world electricity demand projected in IIASA WEC Scenarios. The total technical potential for energy production from biomass crops is estimated at 396 EJ/yr in 2050, that assuming 40% efficiency of biomass - fired power plants gives the total electricity production potential of $\approx$ 44000 TWh/yr. The global long-term potential for geo-thermal energy according to IPCC SRES can be estimated at 20 EJ/yr corresponding to $\approx$ 800 TWh/yr with 15% conversion efficiency. The marine energy can also represent a significant potential, but it was cumbersome to find any reliable estimates of available resources and technology itself, and hence it was omitted.

[9] The assessment of Grubb and Meyer (1993) citied in IPCC TAR corresponds to 53000 TWh/yr

While renewable energy resources appear to be immense and practically inexhaustible, several factors hinder their utilisation for electricity generation needs. As regards wind and solar power, the main limiting factors are related to their low energy density, uneven geographical distribution and intermittent character. In order to overcome these problems and to exploit fully this type of energy resources, the installation of a global interconnected electricity grid has to be envisaged, as discussed in Biberacher et al. [8]. Another major problem is higher economic cost compared to other electricity supply options, especially in the case of photovoltaic technology. This problem can be dealt with through intensification of R&D efforts and proliferation of public policy measures supporting the deployment of renewable energy technologies that should lead to gradual reduction of their costs through exploitation of learning-by-searching and learning-by-doing opportunities. The main problem with biomass energy arises from the competition for arable land with food and feedstock production required to meet world alimentary needs. This problem is expected to become more and more acute in the second half of the 21st century, especially in developing countries, given the projected pace of world population growth.

Considering these issues, some reasonable limits on the global renewable energy supply potentials had to be imposed. The resulting estimates of maximum worldwide electricity production potentials by main types of renewable energy technologies are given in *Table 9* in the beginning of Section 6.

6.5. Nuclear Fission

The power generation based on nuclear fission technology is seen in IIASA-WEC scenario "B" as the main source of future electricity supply. Its share in total world electricity production is assumed to increase steadily from 17% in 2000 to 38% in 2050 and reaching substantial 47.2 % (35605 TWh) in 2100. Meanwhile, the analysis of recent trends and near-term prospects for development of regional power generation systems may lead to revision of these estimates. So, in "Reference scenario" of IEA WEO-2004 the share of nuclear power in world electricity production is expected to decrease from 16.5% (2654 TWh) in 2002 to 9.3% (2929 TWh) in 2030. These values roughly correspond to the "low estimate" given in IAEA projections [15].

As regards the longer term prospects for development of nuclear power (from 2030 up to 2100) the following issues have to be taken into account. First, the extensive growth of nuclear power capacities based on open fuel cycle, such as thermal light water reactors, will face the problems of exhaustion of uranium resources and handling of spent nuclear fuel. As discussed in Gagarinskii et al. [16] these problems can be solved through the closure of the fuel cycle with separation of plutonium from thermal reactors and using of this plutonium in fast reactors with expanded breeding. It will allow for increasing the nuclear power capacity in 2100 to about 5000 GW without exceeding the limits of supply of natural uranium. This solution, however, will be confronted with the problem of proliferation of radioactive materials and general public acceptance. Another possibility for expanding fuel base of nuclear power consists in using thorium.

Another issue affecting nuclear power concerns the need for curbing the greenhouse gases emissions. In the presence of environmental constraints nuclear power plants demonstrate a relatively good economic performance compared to other base-load electricity generation options using fossil fuels. This can play in favour of expanding nuclear power capacities. Considering these facts, the maximum global potential for deployment of nuclear power in 2100 was assumed to not exceed 40000 TWh/yr that is in line with assumptions of Gagarinskii et al. [16] and the findings of Bennett & Zaleski [17] in case of "Ecologically Driven / Basic Option" scenario.

6.6. Thermonuclear Fusion

The controlled thermonuclear fusion is broadly recognised as one of the most prominent technological options for centralised power generation expected to become available by the mid - 21st century [18], [19]. Assuming that technological feasibility of fusion is proved during the demonstration / prototype stage, the industrial scale deployment of fusion power plants can start during the period 2050 - 2060 in the countries / regions participating in ITER and further fusion R&D initiatives.

One of the main factors that drives the research & development of fusion technology is the availability of practically inexhaustible and universally accessible fuel resources, namely deuterium and tritium. In fact, deuterium is found naturally in sea water in abundant amounts (1 part in 6000) and tritium may be bred from the vast deposits of lithium which exist in the earth's crust and the oceans [20], [21]. A more comprehensive assessment of the resources required for construction and operation of fusion energy facilities is given in Tokimatsu et al. [22] confirming the idea that there are no major limitations for fusion at least for several thousand years.

As regards the total capacity of fusion power that can be deployed over the century and beyond, it will depend mainly on the pace of technological progress and the resulting economic performance of fusion power plants. The evaluation given in Cook et al. [23] assumes that under favourable conditions fusion power generation can tap 20% of the market that can be translated into electricity production of ≈ 15000 TWh in 2100 and ≈ 2000 GW of installed fusion power generating capacities in case of IIASA / WEC scenario "B" global projection. In the study of Tokimatsu et al. [24] the range of estimates of global fusion capacities in 2100 corresponds to ≈ 1700 GW in IIC case (with Initial Introduction Constraints) and ≈ 3500 GW in MCS case (assuming Maximum Construction Speed for fusion).

Basing on the existing studies and experts' recommendations the following figures were chosen to describe the maximum regional potentials for deployment of fusion power plants:

- ***Western Europe***

  Lako et al. [25] in their study of long term energy scenarios for Western Europe estimate the maximum capacity of fusion power that can be installed in 2100 under tight CO_2 emission constraints (450 - 500 ppm) at 157.5 GW. In the present study maximum capacity of fusion power plants to be deployed in WEU region in most optimistic scenario is assumed to not exceed 10 GW in 2060, 60 GW in 2080 and 200 GW in 2100 [10].

- ***North America***

  In the paper of Schmidt et al. [26] two fusion implementation scenarios have been developed assuming growth rates of 1 and 2 % per year starting from 2070, normalised to the total North American electricity production. These growth rates translate in to annual construction of about 10 and 20 GW of fusion capacity. Accordingly, the total installed capacity of fusion power plants in 2100 can achieve 300 GW in the first scenario and 600 GW in the second scenario. In order to preserve coherence with the assumptions made for the case of Western Europe and considering the projected electricity demand and the size of power generation system in NAM region, which are roughly 1.5 times bigger than in WEU region, the first "more moderate" scenario was chosen for estimating the potential of fusion deployment. The resulting maximum values of fusion power generating capacities to be installed in North America are: 15 GW in 2060, 100 GW in 2080 and 300 GW in 2100.

- ***Japan***

  According to the paper of Tokimatsu et al. [27] the construction of fusion power plants can start in Japan simultaneously with Western Europe, North America and Former Soviet Union, i.e. in 2050, reaching the total capacity of approx. 100 GW in 2100. Considering that this estimate

[10] according to the recommendations of EFDA SERF programme experts; see conclusions from the discussion meeting held in Garching, EFDA/CSU, October 13, 2003

corresponds to the optimistic projection of world total installed fusion power generation capacity of ≈ 3500 GW in 2100, and that the more realistic scenario presumes nearly half of that figure [24], it was decided to set up the maximum potential for deployment of fusion in Japan equal to 3 GW in 2060, 20 GW in 2080 and 60 GW in 2100.

- ***China, India***

  The projection of maximum capacities of fusion power plants that can be installed in developing countries, such as China and India, are based on the report of Hamacher & Sheffield [28]. In case of China the national target is to have 10% of electricity production from fusion by 2100. Assuming that the deployment of fusion will begin in China starting from 2070 and considering the electricity demand projection of IIASA-WEC scenario "B" (≈ 10000 TWh in 2100), the maximum potential for construction of fusion power plants was estimated at 30 GW in 2080 and 140 GW in 2100. The projection for deployment of fusion power in India assumes the maximum capacity of 67 GW (7% of total capacity) in 2100 and 99 GW for the whole SAS region.

- ***Other regions / countries***

  It was further assumed that in other countries / regions the potential for deployment of fusion power could reach ≈ 200 GW in 2100. Accordingly the maximum worldwide electricity supply potential of fusion power plants in 2100 could attain in most optimistic case ≈ 1000 GW (≈ 7000 TWh/yr) that roughly corresponds to 9.4 % of the world electricity market.

7. Technology Assumptions

The existing power plants were classified according to the following main types of electricity generation technologies and fuels:

- Open cycle gas turbine
- Gas turbine operated in combined cycle with steam turbine
- Natural gas fired thermal power plant
- Diesel engine
- Fuel oil fired thermal power plant
- Multifuel thermal power plant (coal, fuel oil, natural gas)
- Nuclear power plant

- Anthracite coal fired thermal power plant
- Lignite coal fired thermal power plant
- Municipal wastes and biomass residues incinerator equipped with steam turbine
- Run-of-the-river hydro power plant
- Reservoir accumulation hydro power plant
- Pumping and storage hydro power plant
- On-shore / off-shore wind power plant

The detailed assumptions on each power generating technology of the existing system are given in Annex I. The reference values, presented there, are based on the case of Western Europe. According to the assumptions of "Energy Technology Perspectives" (ETP) model applied in recent IEA studies the following region specific cost multipliers were derived in order to define generic economic parameters of the power plants in other world regions.

TABLE 11. REGIONAL MULTIPLIERS FOR COSTS OF POWER GENERATING TECHNOLOGIES, %

	Investment cost	Fixed O&M costs	Variable O&M costs
North America	*91*	*100*	*105*
Latin America & Caribbean	*114*	*90*	*89*
Western Europe	***100***	***100***	***100***
Central & Eastern Europe	*91*	*90*	*89*
Former Soviet Union (CIS)	*114*	*90*	*89*
Middle East & North Africa	*114*	*90*	*89*
Sub-Saharan Africa	*114*	*90*	*89*
South Asia	*82*	*80*	*84*
Pacific OECD	*118*	*95*	*100*
Centrally Planned Asia	*82*	*80*	*84*
Other Pacific Asia	*114*	*80*	*84*

Source: Authors calculation based on IEA data [29]

The candidate electricity generation technologies include the following options:

Natural Gas - based Technologies

Four different types of natural gas fuelled technologies are considered as potential candidates for expansion of the existing electricity generation systems. They include: [1] open cycle gas turbine (GT); [2] gas turbine equipped with heat recovery steam generator and operated in combined cycle with steam turbine (NGCC); [3] combined cycle gas turbine with the possibility of capture and storage of CO_2 (NGCC-CCS); [4] fuel cell. The main technical and economical characteristics of natural gas - fuelled power plants expected to be put in operation during the respective periods are given in Annex II. The data describing economical parameters refer to the case of Western Europe, while for other world regions the region-specific cost multipliers given in *Table 11* have to be applied.

Fuel Oil Technologies

Two types of fuel oil fired power generation technologies include: [1] advanced thermal power plant (only for the period 2000 – 2020) and [2] fuel oil gasification combined cycle power plant. Detailed assumptions on technical and economical characteristics of these technologies (case of WEU region) are presented in Annex II.

Coal – based Technologies

The coal – fuelled power generation technologies are divided in the PLANELEC-Pro model into two main categories depending on the type of coal used: anthracite or lignite. The technologies considered in this paper include: [1] anthracite-fuelled advanced thermal power plant based on pulverised coal (PC) combustion; [2] lignite-fuelled advanced thermal power plant based on coal fluidised bed combustion; [3] anthracite and lignite - fuelled integrated coal gasification power plant based on combined cycle technology (IGCC); [4] anthracite-fuelled IGCC power plant equipped with CO_2 capture and storage functionality; [5] anthracite-fuelled integrated coal gasification power plant based on fuel cell technology and operated in combined cycle with steam turbine (IGFCCC); [6] anthracite-fuelled IGFCCC power plant with CO_2 capture and storage functionality. Explicit technical-economical characteristics of coal-based technologies of both types (anthracite and lignite) are given in Annex II.

Nuclear Power Technologies

The candidate nuclear fission and fusion power generation technologies considered in the study include: [1] conventional light water nuclear fission reactor (only for the period 2000 – 2040), [2] advanced fission reactor of generic concept as envisaged by Generation IV initiative, including those allowing for "breeding" of nuclear fuel and using thorium (for the period 2040 – 2100), [3] thermonuclear fusion reactor based on magnetic confinement concept (from 2050 onwards). Selected technical and economical parameters of nuclear power plants defined in PLANELEC –Pro model are given in Annex II.

Renewable Energy, Hydropower and Waste Incineration Technologies

The power generation technologies based on renewable energy sources include: [1] biomass – fired thermal power plant; [2] geothermal power plant; [3] solar energy plant based on photovoltaic technology; [4] on-shore and [5] off-shore wind power plant (farm). The hydropower technologies considered as potential candidates in PLANELEC model include: [6] run-of-the-river hydropower plant; [7] accumulation hydro plant with reservoir and [8] pumping and storage hydropower plant. The power plants based on incineration of municipal wastes [9] are also considered as separate type of electricity generation technology. Selected characteristics of renewable, hydro and wastes energy technologies are given in Annex II.

The main data sources basing on which the technology assumptions presented in *Annex I and II* were elaborated include: EFDA report "Socio-Economic Research on Fusion / Summary of EU Research 1997 – 2000" [30], ECN report "Characterisation of Power Generation Options for the 21st Century" [31], MIT study "The Future of Nuclear Power" [32], ORNL study "An Assessment of the Economics of Future Electric Power Generation Options and the Implications for Fusion" [33], EFDA report on the European Fusion Power Plant Conceptual Study (PPCS) [34], ECN studies "Coal-fired Power Technologies" [35] and "Potentials and Costs for Renewable Electricity Generation" [36], IEA study "Prospects for CO_2 Capture and Storage" [29], IEA/NEA publication "Projected Costs of Generating Electricity" [37], US DoE publication "Assumptions to the Annual Energy Outlook" [38], etc.

All economical indicators are given in € 2004. The discount rate applied in the calculation of annuity payments on capital investment is 5%. The learning factors which normally explain the reduction of capital and O&M costs of new technologies subject to the total capacity installed were defined exogenously basing on the assumptions made in similar studies (see e.g. IEA [39], Eherer & Baumann [40], Hamacher & Bradshaw [41]). It was further assumed that the costs related to electricity grid connection and grid extension in the future regionally, or even globally, interconnected systems would not have a decisive impact on the choice of candidate power generation technologies, and hence they could be omitted.

8. Assumptions on Fuel Prices

The availability and prices of power generation fuels are among the main drivers of future development paths of regional electricity systems. The prospects for different types of energy sources have been discussed above in Chapter 6. The availability issue can be treated further through the adoption of different scenarios regarding the shares of specific technologies/fuels in total electricity production/capacities installed.

Meanwhile, several assumptions on the evolution of fuel prices have to be made to allow further analyses with PLANELEC-Pro model For that purpose, the historical and actual prices of main power generation fuels (fuel oil, natural gas and steam coal) were analysed basing on IEA statistical data [2], [42], [43], [44]. The estimates of future prices of main hydrocarbon fuels were made basing on the "Reference scenario" assumptions of IEA WEO-2005 [45] and the long-term projections of marginal costs (shadow prices) calculated by IIASA - MESSAGE model, as presented in a recent review of IPCC SRES scenarios [46]. The price of lignite is assumed to be in the range 78 – 83 % of the price of anthracite grade coal due to its lower calorific value.

The estimation of fuel cost for nuclear fission reactors was made basing on the actual data from *UxC* [47] with the provision of nearly two-fold cost increase in long term perspective considering the use of breeding technologies and thorium, and taking into account the cost of nuclear wastes management in accordance with *WISE Uranium Project* data [48]. The cost of fuel for thermonuclear fusion was assessed basing on the publications of Varandas [49] and Hamacher & Bradshaw [41]. Finally, the future price of biomass fuel was estimated on the basis of actual data from EUBIONET [50] and assuming a relatively moderate cost increase with the annual rate of 0.4 – 0.8 %. *Table 12* indicates the resulting global projections of average fuels prices for each of the 20-years sub-periods.

TABLE 12. ASSUMPTIONS ON FUEL PRICES IN PLANELEC MODEL (€ 2004 / GJ)

	Hard Coal	**Lignite**	**Fuel oil**	**Natural gas**	**Biomass**	**Nuclear fission**	**Fusion (DT + Li)**
2000 - 2020	*1.26*	*0.98*	*5.04*	*3.88*	*2.60*	*1.06*	-
2021 - 2040	*1.38*	*1.14*	*7.46*	*4.90*	*2.85*	*1.16*	-
2041 - 2060	*1.68*	*1.39*	*10.48*	*5.91*	*3.18*	*1.35*	*0.004*
2061 - 2080	*2.16*	*1.79*	*14.91*	*7.77*	*3.62*	*1.67*	*0.005*
2081 - 2100	*2.51*	*2.08*	*20.96*	*10.13*	*4.21*	*1.98*	*0.005*

Considering the increasing tendency towards globalisation of international energy markets, the uncertainty in prediction of future energy prices and a very-long time horizon of the study, it was assumed that single fuel prices could be applied for all world regions to perform scenario analyses, although it is a very rough approximation.

Bibliographic References

[1] Energy Information Administration, "International Energy Annual 2003", *Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington DC,* Posted: May-July 2005, Available on-line http://www.eia.doe.gov/iea/

[2] International Energy Agency, "Electricity Information" (2002 - 2005 Editions), *OECD/IEA*, 2002 - 2005

[3] International Energy Agency, "World Energy Outlook 2004", *OECD/IEA*, 2004

[4] EURPROG Network of Experts, "Statistics and Prospects for the European Electricity Sector (1980-1990, 2000-2020)", EURPROG 2002 - 2005, *Union of the Electricity Industry* (Eurelectric), 2002 - 2005

[5] Energy Information Administration, "Annual Energy Outlook 2006 with Projections to 2030", *EIA, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington DC,* Release date: February 2006, Available on-line http://www.eia.doe.gov/oiaf/aeo/index.html

[6] N. Nakicenovic, A. Grübler, A. McDonald (eds.), "Global Energy Perspectives", IIASA / WEC, *Cambridge University Press*, 1998

[7] N. Nakicenovic, R. Swart (eds.), "Special Report on Emissions Scenarios: a Special Report of Working Group III of the Intergovernmental Panel on Climate Change", IPCC, *Cambridge University Press*, 2000

[8] M. Biberacher, T. Hamacher, R.P. Shukla, "Fusion as a New Supply Option in Long-term Energy Studies", *Proceedings of 19th World Energy Congress*, Sydney, Australia, Sept 5-9, 2004

[9] BP, "Statistical Review of World Energy", June 2005. Available from www.bp.com

[10] World Energy Council, "Survey of Energy Resources", 20th Edition, London, 2004. Available from http://www.worldenergy.org/wec-geis/publications/reports/ser04/overview.asp

[11] BGR - Federal Institute for Geosciences and Natural Resources - Germany, "Reserves, Resources and Availability of Energy Resources 2005", Annual report, Available from http://www.bgr.bund.de/cln_029/nn_468312/EN/Themen/Energie/energie__node__en.html__nnn=true

[12] International Energy Agency, "Resources to Reserves: Oil & Gas Technologies for the Energy Markets of the Future", *OECD / IEA*, 2005

[13] World Energy Council, "Survey of Energy Resources: Hydropower", London, 2001. Available from http://www.worldenergy.org/wec-geis/publications/reports/ser/hydro/hydro.asp

[14] B. Metz, O. Davidson, R. Swart, J. Pan (Eds.), "Climate Change 2001: Mitigation" *Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, UK

[15] International Atomic Energy Agency, "Energy, Electricity and Nuclear Power Estimates for the Period up to 2030", *Reference data series No.1*, July 2005 Edition, IAEA, Vienna

[16] A.Y. Gagarinskii, V.V. Igntaiev, N.N. Ponomarev-Stepnoi, S.A. Subbotin, V.F. Tsibulskii, "Role of Nuclear Power in World Energy Production in the 21st Century", *Atomic Energy*, Vol. 99, No. 5, 2005

[17] L.L. Bennett, C.P. Zaleski, "Nuclear Energy in the 21st Century", in B. Kursunoglu, S.L. Mintz, A. Perlmutter "Global Warming and Energy Policy", *Kluwer Academic/Plenum Publishers*, 2001

[18] International Energy Agency, "Technology Options: Fusion Power", *IEA Energy Technology Policy* & *Collaboration (ETPC)* Paper No. 01/2003

[19] D. J. Ward, N. P.Taylor, I. Cook, "Economically Acceptable Fusion Stations with Safety and Environmental Advantages", *Fusion Engineering and Design* 58-59 (2001) 1033-1036

[20] International Fusion Research Council, "Status Report on Fusion Research", *Nuclear Fusion* 45 (2005) A1 – A28

[21] D. Fasel, M. Tran "Availability of lithium in the context of future D–T fusion reactors", *Fusion Engineering and Design*, 75-79 (2005) 1163-116

[22] K. Tokimatsu, J. Fujino, S. Konichi, Y. Ogawa, K. Yamaji, "Role of Nuclear Fusion in Future Energy Systems and the Environment under Future Uncertainties", *Energy Policy* 31 (2003) 775 - 797

[23] I. Cook, D. Ward, N. Taylor, "Accelerated Development of Fusion, and Its Economic Value", *presentation at IEA Workshop on Socio-Economics Aspects of Fusion Power*, Culham Science Centre, 25-27 April 200, Available on-line http://fusion.org.uk/socioecon/

[24] K. Tokimatsu, Y. Asaoka, S. Konichi, J. Fujino, Y. Ogawa, K. Okano, S. Nishio, T. Yoshida, R. Hiwatari, K. Yamaji, "Studies of Breakeven Prices and Electricity Supply Potentials of Nuclear Fusion by a Long-term World Energy and Environment Model", *Nuclear Fusion* 42 (2002) 1289-1298

[25] P. Lako, J.R. Ybema, A.J. Seebregts, P.V. Gilli, R. Kurz, G. Kolb, P. E. Morthorst, J. Lemming, B. Villeneuve, "Long Term Scenarios and the Role of Fusion Power: Synopsis of SE0 Studies, Conclusions and Recommendations", *ECN-C--98-095*, February 1999

[26] J. A. Schmidt, S. Larson, M. Pueyo, P.H. Rutherford, D.L. Jassby, "U.S. Fusion Energy Future", *Proceedings of 14th Topical Meeting on the Technology of Fusion Energy*, Park City, Utah, Oct. 15-19, 2000, Available from http://energystudies.pppl.gov/

[27] K.Tokimatsu, J.Fujino, Y.Asaoka, Y.Ogawa, K.Okano, T.Yoshida, R.Hiwatari, S.Konishi, S.Nishio, K.Yamaji, Y.Kaya, "Studies of Nuclear Fusion Energy Potential Based on a Long-term World Energy and Environment Model", *Proceedings of 18th Fusion Energy Conference*, October 4 - 10, 2000, Sorrento, Italy

[28] T. Hamacher, J. Sheffield, "Development of Fusion Power: What Role Could Fusion Power Play in Transitional and Developing Countries", *IPP Garching (with support from EFDA) and Joint Institute for Energy* & *Environment*, Report Number: JIEE 2004-04, Sept. 2004

[29] International Energy Agency, "Prospects for CO_2 Capture and Storage", *OECD/IEA*, 2004

[30] G. Borrelli, I. Cook, T. Hamacher, K. Lackner, P. Lako, R. Saez, G.C. Tosato, D.J. Ward, "Socio-Economic Research on Fusion / Summary of EU Research 1997 – 2000", *EFDA-RE-RE-1*, July, 2001.

[31] P. Lako, A.J. Seebregts "Characterisation of Power Generation Options for the 21st Century", *SERF programme, Report on behalf of Macro task E1*, ECN-C--98-085, December 1998

[32] S. Ansolabehere, E. S. Beckjord, J. Deutch, M. Driscoll, P.E. Gray, J.P. Holdren, P.L. Joskow, R.K. Lester, E.J. Moniz, N.E. Todreas, "The Future of Nuclear Power", An Interdisciplinary MIT Study, *Massachusetts Institute of Technology*, 2003

[33] J.G. Delene, J. Sheffield, K.A. Williams, R. L. Reid, S. Hadley, "An Assessment of the Economics of Future Electric Power Generation Options and the Implications for Fusion", *Oak Ridge National Laboratory*, Report # ORNL/TM-1999/243/R1

[34] D. Maisonier, I. Cook, P. Sardain, R. Andreani, L. Di Pace, R. Forest, L. Giancarli, S. Hermsmeyer, R. Norajitra, N. Taylor, D. Ward, "A Conceptual Study of Commercial Fusion Power Plants", *Final Report of the European Fusion Power Plant Conceptual Study (PPCS)*, European Fusion Development Agreement, EFDA-RP-RE-5.0, April 2005

[35] P. Lako, "Coal-fired Power Technologies: Coal-fired Power Options on the Brink of Climate Policies", ECN-C--04-076, October 2004

[36] M. de Noord, L.W.M. Beurskens, H.J. de Vries, "Potentials and Costs for Renewable Electricity Generation: a Data Overview", ECN-C--03-006, February 2004

[37] Nuclear Energy Agency / International Energy Agency, "Projected Costs of Generating Electricity", 2005 Update, *OECD/IEA*, 2005

[38] Energy Information Administration, "Assumptions to the Annual Energy Outlook 2005", *EIA, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington DC,* Available on-line http://www.eia.doe.gov/oiaf/aeo/assumption/index.html

[39] International Energy Agency, "Experience Curves for Energy Technology Policy", *OECD / IEA*, 2000

[40] Ch. G. Eherer, M. Baumann, "Long-term Technology Based Modelling with TIMES", Final Report on the Research Project, *EFDA/SERF sub task: TW3-TWE-FESA/A*, Technische Universitat Graz, January 2005

[41] T. Hamacher, A. M. Bradshaw, "Fusion as a Future Power Source: Recent Achievements and Prospects", *Max-Planck-Institut für Plasmaphysik*, Proceedings of 18th World Energy Congress.

[42] International Energy Agency, "Coal Information 2004" with 2003 data, *OECD/IEA*, 2004

[43] International Energy Agency, "Oil Information 2004" with 2003 data, *OECD/IEA*, 2004

[44] International Energy Agency, "Natural Gas Information 2004" with 2003 data, *OECD/IEA*, 2004

[45] International Energy Agency, "World Energy Outlook 2005", *OECD/IEA*, 2005

[46] N. Nakicenovic, K. Riahi, "An Assessment of Technological Change Across Selected Energy Scenarios", RR-02-005, *IIASA*, Laxenburg, Austria, May 2002

[47] UXC, "Ux Weekly Spot Prices", The Ux Consulting Company, LLC, Available from http://www.uxc.com/review/uxc_prices.html

[48] World Information Service on Energy, Uranium project, *Nuclear Fuel Cost Calculator*, Available from http://www.antenna.nl/wise/uranium/nfcc.html.

[49] C.A.F. Varandas, "Fusion: a Safe, Clean and Sustainable Energy for the Future", *Associação EURATOM/IST, Centro de Fusão Nuclear, Instituto Superior Técnico*, 1049-001 Lisboa, Portugal

[50] EUBIONET, "Fuel prices in Europe 2002 / 2003". *European bioenergy networks, Innovative solutions for solid, gaseous and liquid biomass production and use,* Juväskylä, March 2003.

Annex I

Table A1. Assumed Technical & Economical Parameters of Existing Power Generation Technologies

	Efficiency	O&M fixed	O&M variable	Investment cost	Lifetime	Forced outage	Scheduled maintenance
	%	€/kW *month	€/MWh	€ / kW	yrs	%	days
NGCC	*50*	*2.2*	*0.66*	*750*	*25*	*10*	*36*
GT	*33*	*1.1*	*0.70*	*550*	*25*	*10*	*146*
NG Thermal	*38*	*2.5*	*1.10*	*900*	*30*	*8*	*44*
Diesel engine	*37*	*2.0*	*0.50*	*600*	*30*	*6*	*160*
Fuel Oil Thermal	*37*	*2.2*	*1.10*	*950*	*30*	*8*	*44*
Multifuel Thermal	*37*	*2.7*	*1.40*	*1050*	*30*	*8*	*44*
Nuclear Fission	*34*	*4.3*	*0.40*	*2000*	*40*	*5*	*36*
Anthracite Thermal	*42*	*2.9*	*2.10*	*1200*	*30*	*6*	*50*
Lignite Thermal	*40*	*2.9*	*2.60*	*1250*	*30*	*6*	*50*
Waste+Biomass Thermal	*30*	*6.9*	*4.70*	*1800*	*30*	*10*	*73*
Hydro-Run-of-the-River	-	*1.4*	*0.20*	*2400*	*50*	-	-
Hydro-Accumulation	-	*1.1*	*0.20*	*2600*	*50*	-	-
Hydro-Pumping & Storage	-	*1.8*	*1.40*	*3200*	*50*	-	-
Wind Turbine	-	*2.1*	-	*1000*	*20*	-	-

All costs in € 2004

Annex II

Table A2-1. ***Assumed Technical & Economical Parameters of Candidate Power Generation Technologies*** *(Average Values for the Period 2000 – 2020)*

	Efficiency	**O&M fixed**	**O&M variable**	**Investment cost**	**Lifetime**	**Forced outage**	**Scheduled maintenance**
	%	€/kW *month	€/MWh	€ / kW	yrs	%	days
NGCC	*56*	*2.08*	*0.61*	*550*	*25*	*5*	*36*
NGCC-CCS	*48*	*3.06*	*8.61*	*942*	*25*	*8*	*44*
GT	*38*	*1.10*	*0.64*	*392*	*25*	*5*	*164*
NG Fuel Cell	*64*	*0.34*	*34.83*	*3483*	*25*	*10*	*36*
Adv. Oil Thermal	*45*	*2.10*	*1.06*	*939*	*30*	*5*	*36*
Oil IGCC	*46*	*2.30*	*0.63*	*1422*	*25*	*10*	*36*
Nuclear Fission LWR	*37*	*4.27*	*0.36*	*1872*	*40*	*5*	*30*
Anthracite Thermal Adv.	*46*	*2.70*	*1.87*	*1132*	*30*	*6*	*40*
Anthracite IGCC	*51*	*4.06*	*2.12*	*1293*	*25*	*10*	*40*
Anthracite IGCC-CCS	*42*	*4.32*	*18.71*	*1715*	*25*	*10*	*55*
Lignite FBC	*40*	*2.80*	*2.40*	*1205*	*30*	*6*	*40*
Lignite IGCC	*49*	*4.50*	*2.60*	*1343*	*25*	*10*	*40*
Waste Thermal	*24*	*6.92*	*4.50*	*6478*	*30*	*10*	*55*
Biomass Thermal	*36*	*3.30*	*3.65*	*1590*	*30*	*10*	*36*
Geothermal	*15*	*6.54*	*0.40*	*1819*	*30*	*5*	*36*
Hydro-Run-of-the-River	-	*1.40*	*0.20*	*1800*	*50*	-	-
Hydro-Accumulation	-	*1.10*	*0.20*	*2400*	*50*	-	-
Hydro-Pumping & Storage	-	*1.80*	*1.20*	*2600*	*50*	-	-
Wind on-shore	-	*1.86*	-	*921*	*30*	-	-
Wind off-shore	-	*4.22*	-	*1679*	*40*	-	-
Solar PV	-	*1.60*	-	*4354*	*30*	-	-

All costs in € 2004

***TABLE A2-2. ASSUMED TECHNICAL & ECONOMICAL PARAMETERS OF CANDIDATE POWER GENERATION TECHNOLOGIES** (AVERAGE VALUES FOR THE PERIOD 2020 – 2040)*

	Efficiency	O&M fixed	O&M variable	Investment cost	Lifetime	Forced outage	Scheduled maintenance
	%	€/kW *month	€/MWh	€ / kW	yrs	%	days
NGCC	*59*	*1.92*	*0.56*	*468*	*25*	*5*	*32*
NGCC-CCS	*51*	*2.82*	*7.37*	*861*	*25*	*8*	*42*
GT	*40*	*1.08*	*0.63*	*362*	*25*	*5*	*164*
NG Fuel Cell	*65*	*0.30*	*30.87*	*2846*	*25*	*8*	*32*
Oil IGCC	*49*	*2.12*	*0.58*	*1261*	*25*	*8*	*36*
Nuc. Fission "Gen. IV"	*39*	*4.11*	*0.34*	*1799*	*40*	*4*	*30*
Anthracite Thermal Adv.	*49*	*2.49*	*1.73*	*1024*	*30*	*5*	*35*
Anthracite IGCC	*54*	*3.60*	*1.88*	*1146*	*25*	*8*	*35*
Anthracite IGCC-CCS	*46*	*3.99*	*15.73*	*1599*	*25*	*9*	*50*
Anthracite IGFCCC	*56*	*4.45*	*3.45*	*1782*	*25*	*10*	*55*
Anthracite IGFCCC-CCS	*44*	*5.30*	*17.87*	*2134*	*25*	*10*	*60*
Lignite FBC	*43*	*2.53*	*2.17*	*1090*	*30*	*5*	*35*
Lignite IGCC	*52*	*3.99*	*2.31*	*1191*	*25*	*8*	*35*
Waste Thermal	*26*	*6.26*	*4.07*	*5860*	*30*	*10*	*55*
Biomass	*40*	*2.92*	*3.23*	*1410*	*30*	*9*	*34*
Geothermal	*15*	*5.92*	*0.36*	*1612*	*30*	*4*	*32*
Hydro-Run-of-the-River	-	*1.40*	*0.20*	*1800*	*50*	-	-
Hydro-Accumulation	-	*1.10*	*0.20*	*2400*	*50*	-	-
Hydro-Pumping & Storage	-	*1.80*	*1.20*	*2600*	*50*	-	-
Wind on-shore	-	*1.68*	-	*753*	*30*	-	-
Wind off-shore	-	*3.74*	-	*1216*	*40*	-	-
Solar PV	-	*1.07*	-	*2907*	*30*	-	-

All costs in € 2004

Table A2-3. Assumed Technical & Economical Parameters of Candidate Power Generation Technologies *(Average Values for the Period 2040 – 2060)*

	Efficiency	O&M fixed	O&M variable	Investment cost	Lifetime	Forced outage	Scheduled maintenance
	%	€/kW *month	€/MWh	€ / kW	yrs	%	days
NGCC	*62*	*1.81*	*0.53*	*415*	*25*	*5*	*28*
NGCC-CCS	*54*	*2.50*	*6.24*	*748*	*25*	*7*	*40*
GT	*42*	*1.06*	*0.61*	*341*	*25*	*5*	*164*
NG Fuel Cell	*66*	*0.25*	*25.25*	*1979*	*25*	*6*	*28*
Oil IGCC	*52*	*2.00*	*0.55*	*1141*	*25*	*6*	*36*
Nuc. Fission "Gen. IV"	*42*	*3.95*	*0.33*	*1728*	*40*	*3*	*30*
Fusion	*46*	*25.54*	*0.36*	*6765*	*40*	*4*	*71*
Anthracite Thermal Adv.	*51*	*2.35*	*1.63*	*945*	*30*	*5*	*30*
Anthracite IGCC	*56*	*3.32*	*1.73*	*1037*	*25*	*7*	*30*
Anthracite IGCC-CCS	*50*	*3.53*	*13.09*	*1417*	*25*	*8*	*45*
Anthracite IGFCCC	*60*	*3.79*	*2.94*	*1487*	*25*	*9*	*50*
Anthracite IGFCCC-CCS	*50*	*4.33*	*14.16*	*1745*	*25*	*10*	*55*
Lignite FBC	*46*	*2.34*	*2.00*	*1006*	*30*	*5*	*30*
Lignite IGCC	*55*	*3.68*	*2.13*	*1077*	*25*	*7*	*30*
Waste Thermal	*28*	*5.78*	*3.76*	*5409*	*30*	*10*	*55*
Biomass	*44*	*2.65*	*2.93*	*1275*	*30*	*8*	*32*
Geothermal	*15*	*5.46*	*0.33*	*1459*	*30*	*3*	*28*
Hydro-Run-of-the-River	-	*1.40*	*0.20*	*1800*	*50*	-	-
Hydro-Accumulation	-	*1.10*	*0.20*	*2400*	*50*	-	-
Hydro-Pumping & Storage	-	*1.80*	*1.20*	*2600*	*50*	-	-
Wind on-shore	-	*1.55*	-	*642*	*30*	-	-
Wind off-shore	-	*3.38*	-	*955*	*40*	-	-
Solar PV	-	*0.79*	-	*2021*	*30*	-	-

All costs in € 2004

TABLE A2-4. ASSUMED TECHNICAL & ECONOMICAL PARAMETERS OF CANDIDATE POWER GENERATION TECHNOLOGIES (AVERAGE VALUES FOR THE PERIOD 2060 – 2080)

	Efficiency	**O&M fixed**	**O&M variable**	**Investment cost**	**Lifetime**	**Forced outage**	**Scheduled maintenance**
	%	€/kW *month	€/MWh	€ / kW	yrs	%	days
NGCC	*64*	*1.74*	*0.51*	*383*	*25*	*5*	*24*
NGCC-CCS	*56*	*2.31*	*5.33*	*676*	*25*	*6*	*38*
GT	*44*	*1.04*	*0.60*	*327*	*25*	*5*	*164*
NG Fuel Cell	*68*	*0.21*	*21.50*	*1433*	*25*	*4*	*24*
Oil IGCC	*54*	*1.92*	*0.53*	*1053*	*25*	*5*	*33*
Nuc. Fission "Gen. IV"	*45*	*3.79*	*0.31*	*1660*	*40*	*3*	*25*
Fusion	*48*	*17.97*	*0.30*	*5000*	*40*	*4*	*63*
Anthracite Thermal Adv.	*53*	*2.25*	*1.56*	*890*	*30*	*5*	*25*
Anthracite IGCC	*58*	*3.19*	*1.67*	*957*	*25*	*6*	*25*
Anthracite IGCC-CCS	*52*	*3.26*	*11.25*	*1282*	*25*	*7*	*40*
Anthracite IGFCCC	*63*	*3.43*	*2.66*	*1292*	*25*	*8*	*45*
Anthracite IGFCCC-CCS	*54*	*3.77*	*11.70*	*1486*	*25*	*9*	*50*
Lignite FBC	*48*	*2.20*	*1.89*	*947*	*30*	*5*	*25*
Lignite IGCC	*58*	*3.54*	*2.04*	*994*	*25*	*6*	*25*
Waste Thermal	*30*	*5.44*	*3.54*	*5093*	*30*	*10*	*55*
Biomass	*48*	*2.44*	*2.70*	*1177*	*30*	*7*	*30*
Geothermal	*15*	*5.14*	*0.31*	*1346*	*30*	*3*	*24*
Hydro-Run-of-the-River	-	*1.40*	*0.20*	*1800*	*50*	-	-
Hydro-Accumulation	-	*1.10*	*0.20*	*2400*	*50*	-	-
Hydro-Pumping & Storage	-	*1.80*	*1.20*	*2600*	*50*	-	-
Wind on-shore	-	*1.46*	-	*569*	*30*	-	-
Wind off-shore	-	*3.12*	-	*813*	*40*	-	-
Solar PV	-	*0.65*	-	*1464*	*30*	-	-

All costs in € 2004

Table A2-5. Assumed Technical & Economical Parameters of Candidate Power Generation Technologies *(Average Values for the Period 2080 – 2100)*

	Efficiency	**O&M fixed**	**O&M variable**	**Investment cost**	**Lifetime**	**Forced outage**	**Scheduled maintenance**
	%	€/kW *month	€/MWh	€ / kW	yrs	%	days
NGCC	*66*	*1.70*	*0.50*	*368*	*25*	*5*	*20*
NGCC-CCS	*58*	*2.22*	*4.52*	*637*	*25*	*5*	*36*
GT	*46*	*1.02*	*0.59*	*321*	*25*	*5*	*164*
NG Fuel Cell	*70*	*0.19*	*19.06*	*1081*	*25*	*3*	*20*
Oil IGCC	*56*	*1.88*	*0.52*	*991*	*25*	*5*	*30*
Nuc. Fission "Gen. IV"	*48*	*3.64*	*0.30*	*1595*	*40*	*3*	*20*
Fusion	*50*	*12.40*	*0.26*	*4089*	*40*	*4*	*54*
Fusion (Massive) [11]	*60*	*10.40*	*0.23*	*3100*	*40*	*4*	*54*
Anthracite Thermal Adv.	*55*	*2.21*	*1.53*	*855*	*30*	*4*	*20*
Anthracite IGCC	*60*	*3.13*	*1.63*	*920*	*25*	*5*	*20*
Anthracite IGCC-CCS	*54*	*3.13*	*9.65*	*1183*	*25*	*6*	*30*
Anthracite IGFCCC	*66*	*3.29*	*2.55*	*1169*	*25*	*7*	*40*
Anthracite IGFCCC-CCS	*58*	*3.48*	*9.77*	*1318*	*25*	*8*	*40*
Lignite FBC	*50*	*2.12*	*1.81*	*910*	*30*	*4*	*20*
Lignite IGCC	*60*	*3.47*	*2.00*	*936*	*25*	*5*	*20*
Waste Thermal	*32*	*5.23*	*3.40*	*4893*	*30*	*10*	*55*
Biomass	*52*	*2.30*	*2.54*	*1108*	*30*	*6*	*28*
Geothermal	*15*	*4.94*	*0.30*	*1268*	*30*	*3*	*20*
Hydro-Run-of-the-River	-	*1.40*	*0.20*	*1800*	*50*	-	-
Hydro-Accumulation	-	*1.10*	*0.20*	*2400*	*50*	-	-
Hydro-Pumping & Storage	-	*1.80*	*1.20*	*2600*	*50*	-	-
Wind on-shore	-	*1.40*	-	*525*	*30*	-	-
Wind off-shore	-	*2.94*	-	*751*	*40*	-	-
Solar PV	-	*0.58*	-	*1104*	*30*	-	-

All costs in € 2004

[11] Alternative assumptions on the costs and efficiency of fusion technology based on EFDA PPCS model "D" estimates [34] for the case of "massive deployment"