JRC Scientific and Technical Reports

Comparison of Long-Term World Energy Studies

Assumptions and results from four world energy models

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EUR 22938 EN - 2007

JRC EUROPEAN COMMISSION

Institute for Prospective Technological Studies

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JRC36387

EUR 22938 EN
ISBN 978-92-79-07078-5
ISSN 1018-5593
DOI: 10.2791/19003

Luxembourg: Office for Official Publications of the European Communities

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Printed in Spain

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1 SUMMARY

The POLES (Prospective Outlook for the Long-term Energy System) model is a global sectoral simulation model for the development of long-term energy supply and demand scenarios until 2050. The model is used to generate global energy scenarios, such as the World Energy, Technology and Climate Policy Outlook (WETO; EC, 2003) and the WETO-H_2 update (EC, 2006). In addition, dedicated greenhouse gas emission reduction scenarios are increasingly produced to support the assessment of climate change policies and measures.

For both purposes it is crucial that the baseline scenario calculated with the POLES model provides a consistent and reliable outlook. A comparison with the outcomes of global reference energy projections from other sources provides a sensible first step in "benchmarking" the model outcomes.

The following comparison of the POLES reference scenario (WETO-H_2 reference case; EC, 2006) with scenarios produced by the International Energy Agency (IEA reference scenario; IEA, 2006a), the U.S. Department of Energy (US-DoE reference case; US-DoE, 2006) and the World Energy Council (WEC-A2 scenario; WEC/IIASA, 1995 and 1998) indicates an overall high concordance among all scenarios.

It must be noted that, in order to improve the comparability among the studies, all data have been harmonised by applying the growth rates derived from each study to the initial 2001 values of the WETO study.

With regard to the most important basic input assumptions, very similar values for population trends are observed, particularly for the more recent studies from WETO, IEA and US-DoE. Assumptions regarding GDP growth are close for WETO and IEA, while the US-DoE study assumes a higher increase of GDP particularly for the decade 2020 to 2030. The projected oil price differs more between the studies, with the three more recent projections (WETO, US-DoE, IEA) showing substantially higher prices than the WEC. This may be the result of these more recent studies better reflecting the latest increase in oil prices.

The resulting projections of world energy consumption and CO_2 emissions reflect the similarities and differences between the key assumptions. Both indicators are well in line for the WETO, IEA and WEC studies, with slightly elevated values for the US-DoE study.

However, this resemblance in total energy consumption and CO_2 emissions conceals more important differences in the projections for individual energy sources. With respect to the development of different fuels, projections for oil demand are very similar among the more recent studies, but differ for coal and gas. This deviance is mainly driven by differences in the projected fuel mix used for electricity generation.

The US-DoE study projects significantly higher coal consumption throughout the scenario period until 2030 than the other studies. In the WETO study, the lower consumption of coal will be compensated mainly by the higher consumption of natural gas in the decade 2010 to 2020, and nuclear energy in the decade 2020 to 2030. As a result, the WETO study shows the highest consumption of natural gas in 2010 and 2020 (falling back to an average level in 2030) and has the most pronounced nuclear electricity production in 2030.

The projections for hydro electricity and biomass are quite similar for WETO and IEA, with the latter showing slightly higher values particularly for 2030. Although high growth rates for 'other renewables' are assumed in all scenarios, the contribution of 'other renewables' to overall world energy consumption remains at a low level, even in the most favourable case (WETO). In terms of the relative contribution of renewable sources to overall electricity generation, the three more recent studies are particularly well in line.

In conclusion, the comparison exercise carried out shows that important assumptions used in WETO (here: the WETO-H_2 reference case modelled with POLES) as well as the results obtained for the baseline projection on total energy consumption and carbon dioxide emissions are mostly in line with those of other reliable global energy studies, with important differences occurring mainly in the future development of nuclear power.

2 INTRODUCTION AND METHODOLOGY

The POLES model is a recursive simulation model at global level, breaking down the world in 47 regions. It works on a year by year basis until 2050. The model is organised in modules for the different countries/regions and energy consuming sectors, activities and technologies. As such it contains technologically-detailed sub-models for energy-intensive sectors, including power generation, iron and steel production, chemical production, non-metallic mineral industry as well as residential sectors and modal transportation sectors (including aviation).

The model is used for the following types of study:

- Development of energy demand, supply, fuel mix etc.;
- Different greenhouse gas emission scenarios, either for exploring pathways to reach a certain emission reduction target or to analyse the impact of different energy pathways on emissions. For this purpose, also non-energy climate-change related issues are included;
- Dedicated energy technology cases, e.g. the impact of supporting one specific technology.

The model has recently provided input to a number of Commission dossiers, including the development of a baseline and a 2 degree target scenario, which were used in the Communication on post-2012 climate change strategies “Limiting Global Climate Change to 2 degrees Celsius – The way ahead for 2020 and beyond” (EC, 2007), and the World Energy Technology Outlook until 2050 (WETO-H_2 2006) produced for DG RTD (EC, 2006).

This paper compares the WETO-H_2 2006 reference hypotheses and results with the projections provided by other world energy studies. Three institutions carry out forecasts with a scope comparable to WETO:

- The Energy Information Administration of the U.S. Department of Energy provides yearly updated energy forecasts to 2030 in its International Energy Outlook. For this comparison we used the US-DoE 2006 reference case projection (US-DoE, 2006).
- The International Energy Agency (IEA) produces a world energy outlook to 2030. We used the reference scenario for comparison (IEA, 2006). Besides the reference scenario, the 2006 report provides an analysis of alternative policies and their effects in terms of energy security and carbon dioxide emissions. Furthermore, the report looked in depth at nuclear power and biofuels and their contribution in reducing dependency from fossil fuels.
- IIASA has developed a set of scenario projections to the year 2100 for the World Energy Council. For this comparison, we use the WEC 1998-A2 scenario, which assumes an oil and gas resource availability that is comparable to the one used in the WETO Reference (WEC/IIASA, 1995 and 1998). Even if this is somewhat outdated, the IIASA WEC 1998 exercise is worth retaining the comparison exercise because this model (and the A2 scenario) was used as a reference in the UNFCCC negotiations that led to the ratification of the Kyoto Protocol. In addition, since the time horizon considered in this comparison is 2030, the relatively outdated starting point is acceptable.

The four studies compared here use database and conversion factors that may slightly differ from one model to the other. For example, the studies use divergent starting years (see Table 1). The projections in WETO-H_2, by the US-DoE, the IEA and the WEC start in the years 2001, 2002, 2004 and 2000, respectively. Furthermore, the historical values are based on distinct data sources, meaning that slight differences among historical values would remain even if all studies had a similar starting year.

Such variance in the initial value is likely to result in differences in the projected values even if two models predicted an identical development of the energy system. The present study, however, primarily aims at comparing the trends in energy supply and demand under business as usual conditions among different models, and does not focus on the comparability of different basic data sources.

In order to eliminate the effect of different starting years and resulting discrepancies, a harmonisation among the different projection data was conducted separately for each of the variables analysed (e.g. population, GDP, energy demand). The procedure of harmonisation among the studies is illustrated for the variable 'population' in the following:

1. The average annual growth rates of population are derived from each scenario for all decades.
2. For each of the scenarios, the respective average annual growth is applied to the starting year of the scenario in order to obtain a (virtual) value for the year 2001. For example, the US-DoE value for 2002 is divided by (1+growth rate of the first decade) to get the value of 2001.
3. The virtual value for the year 2001 is then adjusted to be identical to the 2001 value of the WETO scenario (see Table 2).
4. In the final step this correction factor is applied on the whole time series of population of US-DoE in a way that the values for the first year are identical.

Population (Mill. pers)	Average annual change per decade (%/year)			Original values						
	2001-10	2010-20	2020-30	2000	2001	2002	2004	2010	2020	2030
WETO	1.18	0.99	0.76		6113			6792	7496	8082
US-DOE	1.08	1.03	0.80			6280		6841	7576	8203
IEA	1.10	0.95	0.80				6400	6834	7512	8135
WEC	1.34	1.17	1.00	6168				7049	7919	8751

Table 1: Original values of population

Population (Mill. pers.)	Average annual change per decade (%/year)			Harmonised values						
	2001-10	2010-20	2020-30	2000	2001	2002	2004	2010	2020	2030
WETO	1.18	0.99	0.76		6113			6792	7496	8082
US-DOE	1.08	1.03	0.80		6113			6731	7454	8071
IEA	1.10	0.95	0.80		6113			6746	7414	8029
WEC	1.34	1.17	1.00		6113			6894	7744	8558

Table 2: Harmonised values of population

In Figure 1, the effect of the above harmonisation procedure is illustrated. If the original projections for population are compared, it seems that the scenario developed by the US-DoE assumes a slightly larger population in the year 2030 than the WETO scenario. After the harmonisation, both scenarios show very similar projections. This indicates that the slight discrepancy in the original values does not stem from the model but is rather due to different data sources used for the starting value, while the far more important growth rates are almost the same.

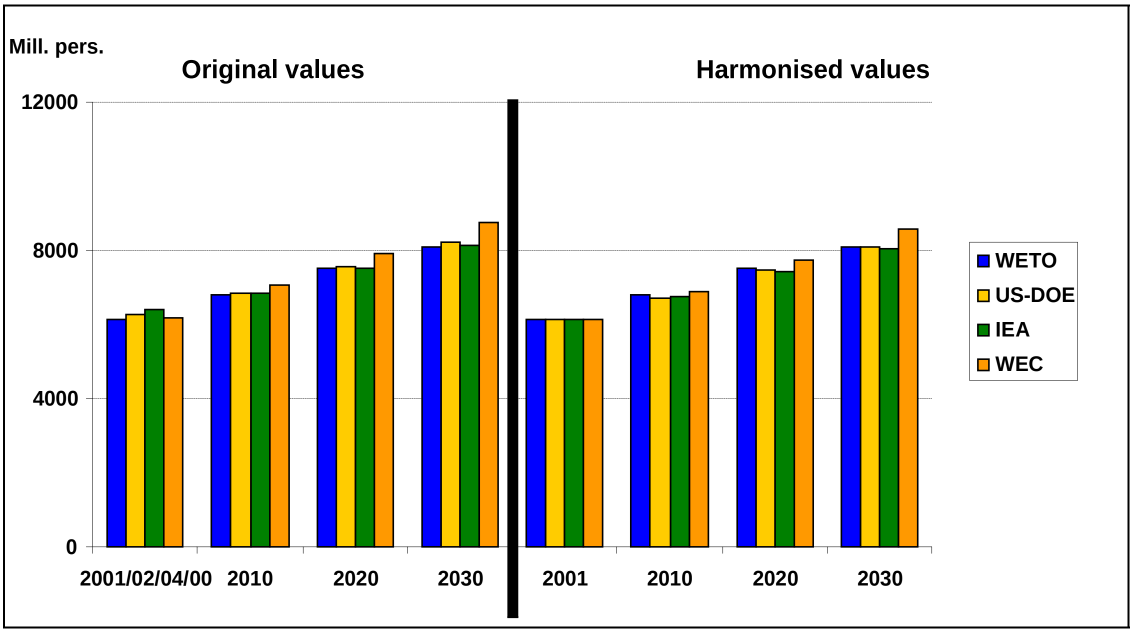


Figure 1: Original and harmonised values of population

In summary, the harmonisation procedure applied allows to have a clearer view and a better understanding of the common outcomes and divergences between the studies.

However, some potential caveats of this approach need to be mentioned. Applying the harmonisation implies that the absolute values presented in the following are not the values given by the respective studies (except for WETO), but the results of applying the different growth rates to a harmonised starting value for the WETO value in the year 2001.

Furthermore, applying the growth rate on the start year to calculate the year 2001 is based on the assumption that in the first decade the annual change is homogenous. For some of the variables this might be not the case. Especially the oil price fluctuated strongly between the year 2000 and the year 2004. Therefore, it was abstained from harmonising oil prices.

Besides different starting values, also the territorial disaggregation of the four energy models is very heterogeneous. The WETO study, developed with the POLES model, is the one having a higher degree of country/zone details (47 countries/zones individually represented[1]). The US-DoE study series is produced with the SAGE model, in which the world is split into 16 countries/zones[2]. The IEA world energy outlooks have been carried out since 1993 with the help of successive versions of the WEM model, whose latest release includes 21 regions/zones in detail[3]. The WEC/IIASA study was carried out with the MESSAGE model, which splits the world into 11 regions/zones[4].

[1] http://energy.jrc.es/Pages/Activities.htm#POLES
[2] http://www.eia.doe.gov/oiaf/ieo/pdf/appi.pdf
[3] http://www.worldenergyoutlook.org/annex_c.pdf
[4] http://www.iiasa.ac.at/cgi-bin/ecs/book_dyn/bookcnt.py

The heterogeneity in territorial treatment makes it extremely difficult to perform a sound comparison of the model results on a regional scale. This paper will therefore focus on the salient magnitudes reported at world level in the four studies considered.

In the following chapters, main exogenous assumptions and endogenous results will be compared among the four scenarios. Bearing in mind that differences in the latter are responsible to a great extent for the differences in the former, no further considerations related to the model structure and specifications are undertaken.

3 KEY ASSUMPTIONS

3.1 Population

With a world population of slightly less than 7 billion in 2010 and around 7.5 billion in 2020, all four studies reflect very similar population projections in this time horizon. For the 2030 projection, the downward revision of the World Population Prospects operated by the UN in recent years translates into the fact that the more recent studies (WETO, US-DoE and IEA) show significantly lower projections (around 8.1 billion) than the WEC study of 1998 (8.6 billion).

Population	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	1.18	0.99	0.76
US-DoE	1.08	1.03	0.80
IEA	1.10	0.95	0.80
WEC	1.34	1.17	1.00

Table 3: Annual change of world population

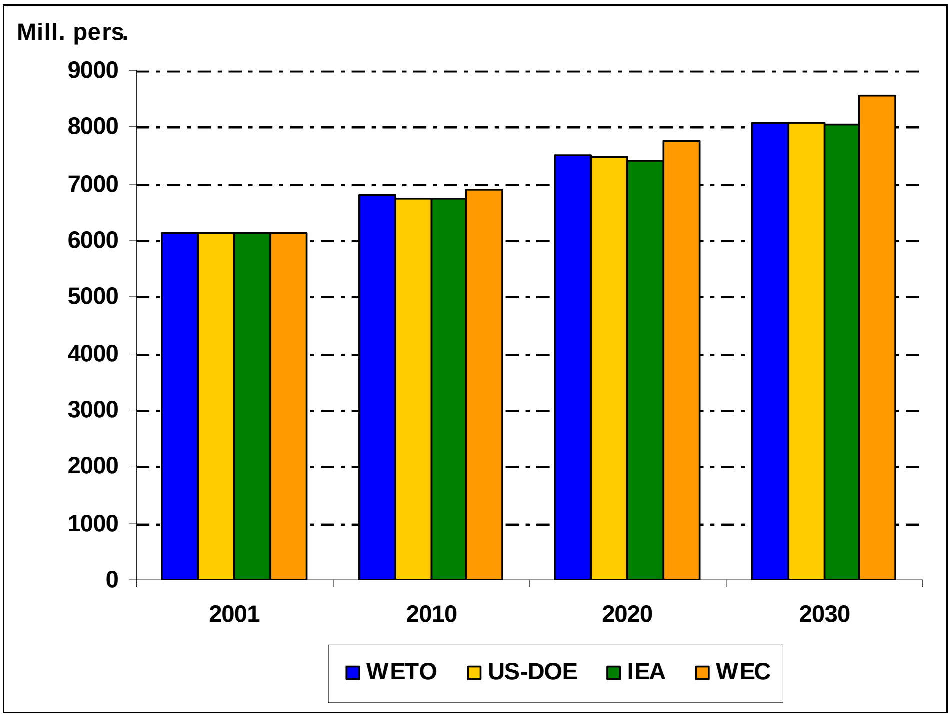


Figure 2: World population

3.2 Gross Domestic Product

The average annual rates of GDP growth differ among the four studies. WEC assumes the lowest average annual growth rates, with values in the range of 2.6 to 2.7%/year. On the other side, US-DoE uses an annual growth rate of 4.3% for first decade which decreases towards 3.6%/year in the last decade. Needless to say, this discrepancy on the future evolution of GDP entails a systematic divergence of crucial variables like primary energy demand, electricity demand and emissions as it will be illustrated in the following sections.

On the other hand, it should be noted that the assumptions made in WETO and IEA are very similar, and lie in between those of the other two studies. They start with an average growth rate of 3.9 - 4.0%/year until 2010, which is expected to decrease towards 2.7-2.9% in the last decade. As a consequence, GDP multiplies by a factor of 2.5 within nearly 30 years for WETO and IEA, and by a factor close to 3 in the case of the US-DoE study.

GDP*	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	3.89	3.20	2.65
US-DoE	4.30	3.75	3.56
IEA	4.00	3.45	2.90
WEC	2.74	2.59	2.67
*All monetary values use 2000 as the base year			

Table 4: Annual change of GDP

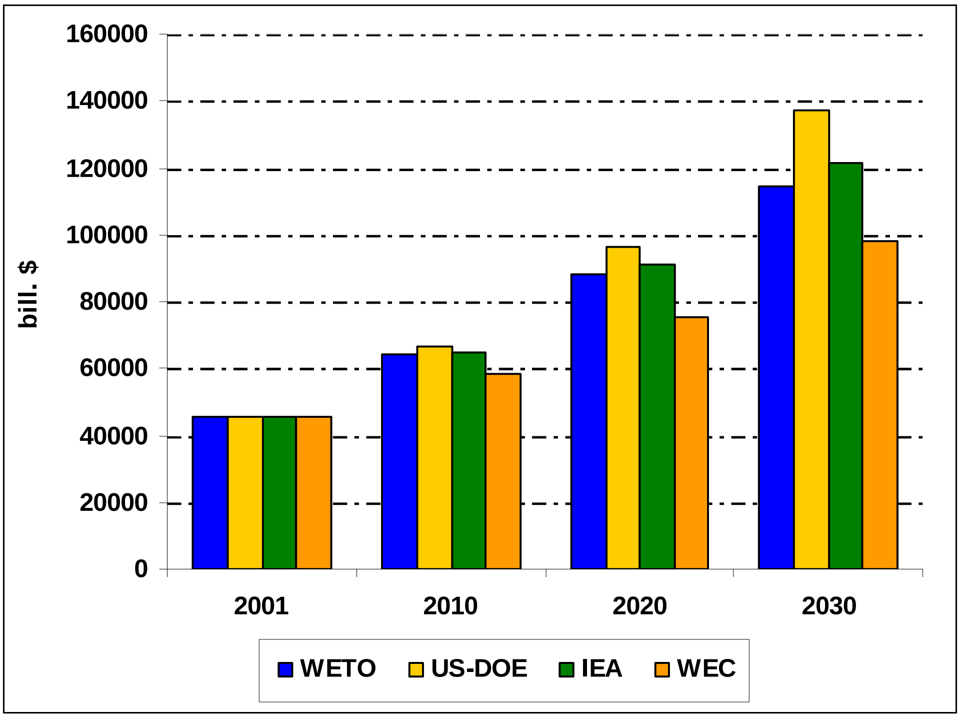


Figure 3: World GDP

3.3 Oil price

After a ten year period during which world oil prices remained below 20 $/bl, oil prices have been rising towards the range of 40-77 $/bl between 2004 and 2006. These price fluctuations were accompanied by an extremely high volatility, due to political uncertainties in many oil producing countries, the impact of weather extremes on production capacities and stockpiling trends.

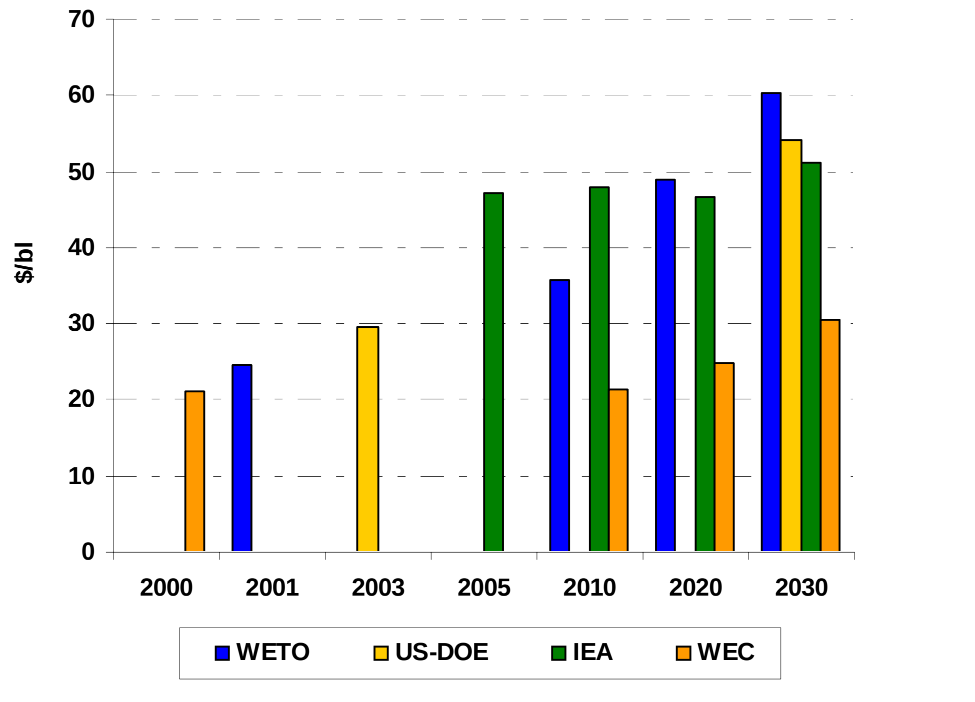
Most long-term energy models include a mechanism of endogenous price formation in the oil market, depending, in the long-term, on scarcity indicators (the reserve-to-production ratio), and in the short-term, on the spare production capacity of large oil producing countries.

However, the price volatility induced by short-term market expectations often distorts the long term evolution of prices. As a consequence, some models assume exogenously the evolution of oil price rather than estimating it. This is the case for the US-DoE study, which merely assumes the long-term value for the year 2030 to be 54 $/bl.

The three studies elaborating price projections point to a decline in oil prices between the presently observed levels and those in 2010, but nevertheless project an important increase compared to the starting values (except for the IEA projection with a high starting level for the year 2005). In 2020, two out of three studies show a similar level compared to 2004/5. By 2030, the WETO endogenous projection of oil prices reach the highest level, but the price differences to projections of the US-DoE and IEA are rather limited. Price levels in the order of 60 $/bl are deemed to be necessary – in the set of the WETO hypotheses and the modelling framework – to balance world demand and supply, including that of non-conventional oil resources.

Oil price	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	4.29	3.17	2.16
US-DoE	2.28 (between 2003-30)		
IEA	0.35	-0.28	0.94
WEC	0.20	1.46	2.11

Table 5: Annual change of the oil price



Note: The oil prices are not harmonised with regard to the start year due to a lack of data.
The base years of the scenarios differ and for these years the volatility of the oil price had been very high.

Figure 4: Oil price

4 KEY OUTCOMES

4.1 Energy consumption and energy intensity

The foreseen world total primary energy consumption levels, as they stem from the harmonisation process used here, show similar values for the four considered studies. The world primary energy consumption would increase to around 12 Gtoe in 2010, 14 Gtoe in 2020 and 16-17 Gtoe in 2030. Only US-DoE derives significantly higher values, i.e. 15 Gtoe in 2020 and 18 Gtoe in 2030 which are probably (at least partly) due to higher GDP assumptions. However, this resemblance in total energy forecasts[5] hides more important differences in the projections for individual energy sources, as analysed in Chapter 5.

Primary energy	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	2.29	1.64	1.50
US-DoE	2.75	1.86	1.64
IEA	2.09	1.70	1.31
WEC	1.84	1.81	1.82

Table 6: Annual change of primary energy

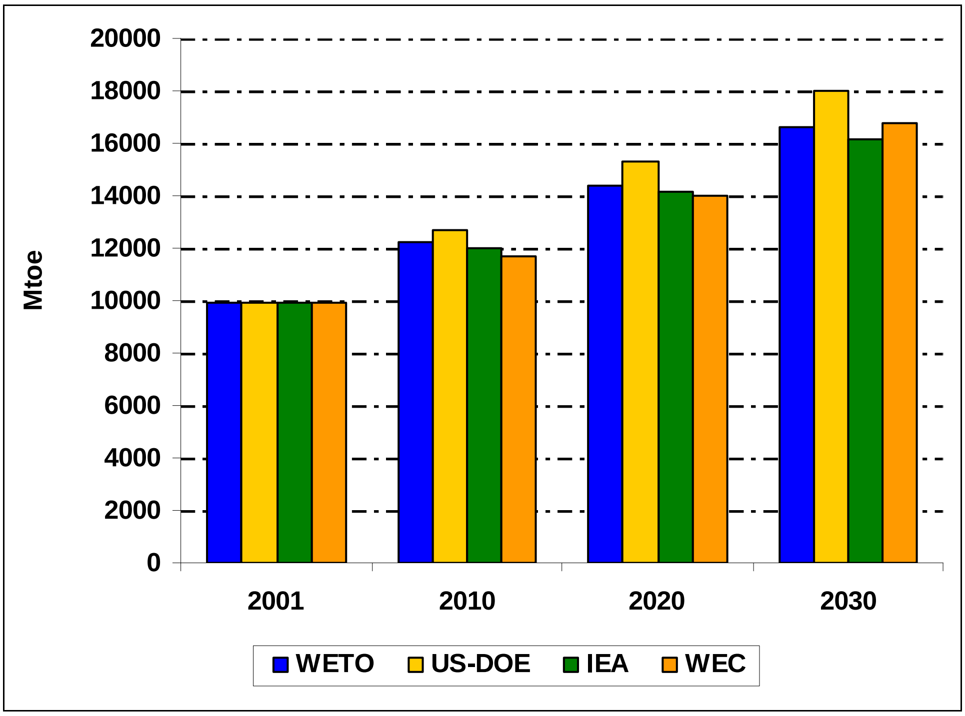


Figure 5: Primary energy

[5] It should be noted that minor discrepancies may occur due to the application of different assumed conversion factors when calculating back the nuclear and hydro-electricity generation into primary energy. The Eurostat/IEA convention suggests using a conversion factor for nuclear power of 33% for historic data. However, for example, WETO applies a moderately increasing efficiency over time in order to reflect the assumed development of technology.

The underlying developments in energy intensity (defined as the ratio between primary energy demand and GDP) provide an indication about the assumed decoupling between energy demand and economic growth. Reductions in energy intensity reflect improvements in technical energy efficiency as well as modifications in consumers' behaviour and structural changes of the economy, such as a shift away from energy-intensive industries towards services.

Energy intensity is expected to decrease by some 1.1-1.9%/year for WETO, US-DoE and IEA, while this decrease is much more limited in the WEC scenario. By 2030, differences of about 30% occur between the highest energy use per GDP (i.e. US-DoE) and the lowest (i.e. WEC). Focusing on the more recent studies, the WETO projections indicate a primary energy consumption per GDP that is about 10% higher than the values for US-DoE and IEA. The poorer energy intensity in the WETO scenario partially reflects the higher use of electricity compared to other scenarios (see Section 4.3). As the production of electricity involves important efficiency losses, this leads to higher energy intensity compared to scenarios with lower shares of electricity in the final energy demand.

Energy intensity (Energy per GDP)	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	-1.54	-1.51	-1.12
US-DoE	-1.49	-1.82	-1.85
IEA	-1.83	-1.69	-1.55
WEC	-0.87	-0.76	-0.83

Table 7: Annual change of energy intensity

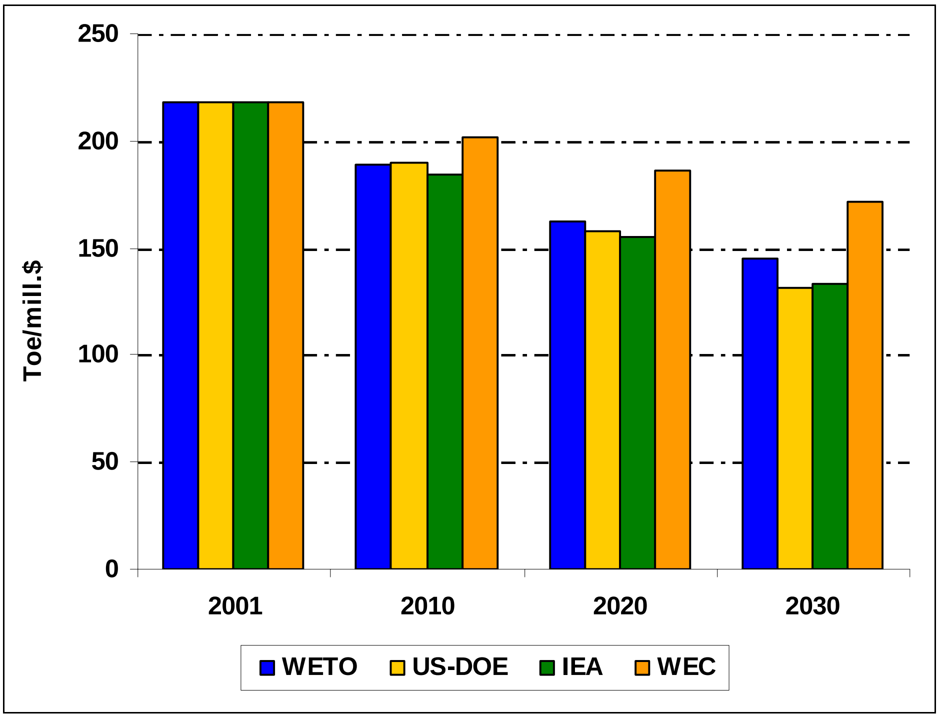


Figure 6: Energy intensity

4.2 CO_2 emissions

Even though the POLES model was extended to also cover non-CO_2 greenhouse gas emissions as well as emissions from non-energy use, the following comparison is restricted to energy-related CO_2 emissions as a common basis for all models.

The total projected CO_2 emissions from the combustion of fossil fuels show a reasonable similarity with about 28-29 Gt CO_2 in 2010, 33-34 Gt CO_2 in 2020 and 39 Gt CO_2 in 2030 in the WETO, IEA and WEC studies. This compares to 20.8 and 23.5 Gt in 1990 and 2000, respectively (IEA, 2006b). The results of the US-DoE are about 15% above those of the other scenarios, which is mainly due to the higher GDP assumptions and, consequently, the higher projections of energy consumption. In addition, it reflects a higher contribution of fossil energy sources - in particular coal - in US-DoE projections compared to the other studies.

CO_2 emissions	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	2.35	1.65	1.25
US-DoE	2.82	1.93	1.74
IEA	2.26	1.77	1.29
WEC	1.89	1.65	1.66

Table 8: Annual change of CO_2 emissions

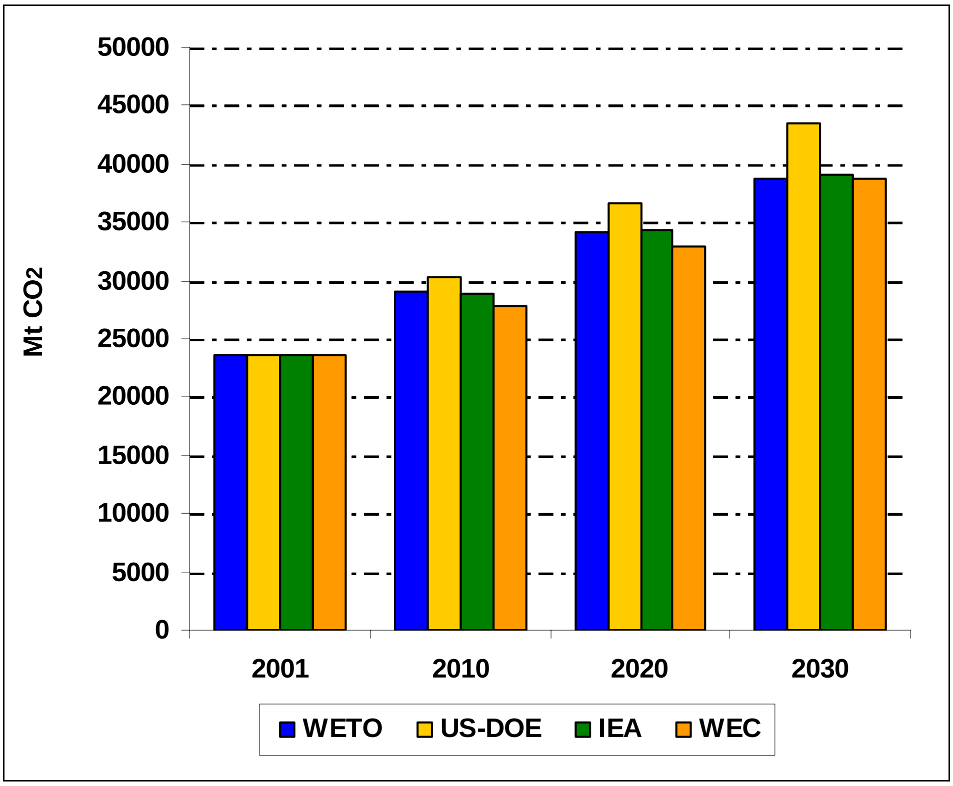


Figure 7: CO_2 emissions

4.3 Electricity consumption

For this comparison, the final electricity consumption was selected instead of electricity generation. Final electricity consumption covers electricity supplied to the final consumer's door for all energy uses and is thus an appropriate indicator of the projected final demand for electricity. The difference to total electricity generation consists in the exclusion of own use by electricity producers or transmission and distribution losses, which can make up some 17-18% of total generation.

Relatively large differences of up to 15 % are observed between the highest and the lowest projections by 2030. WETO projects the highest electricity consumption by 2030, influenced to some extent by optimistic assumptions on the technological development and, consequently, on the deployment of advanced power generation technologies. These differences are much less pronounced for the years 2010 and 2020, for which WETO and US-DoE projections are rather close.

Final electricity	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	3.53	2.84	2.64
US-DoE	3.65	2.50	2.14
IEA	3.29	2.70	2.12
WEC	2.49	2.45	2.38

Table 9: Annual change of final electricity consumption

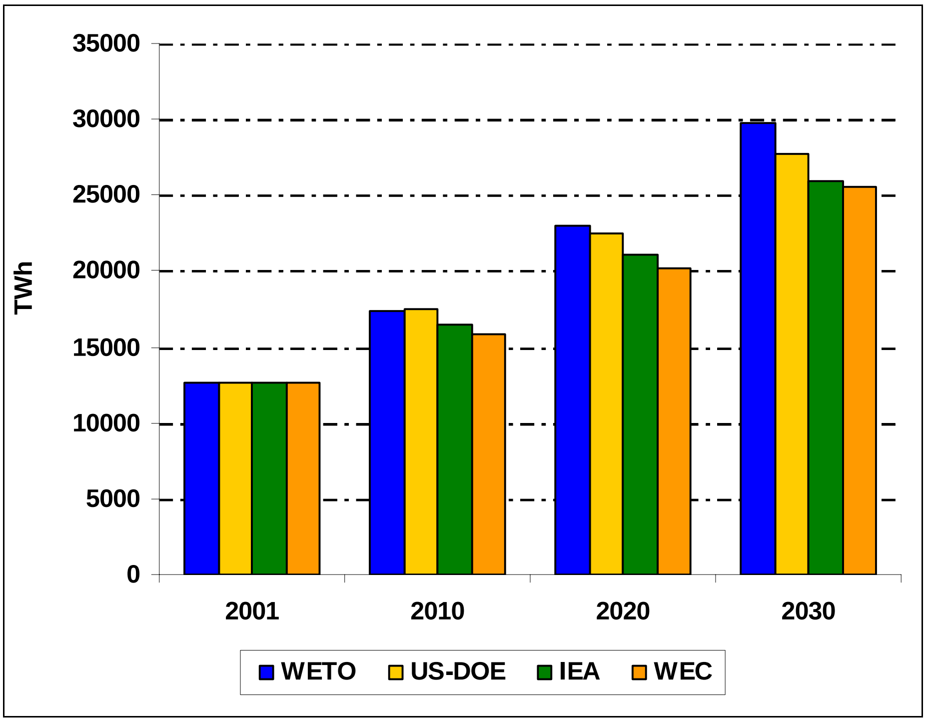


Figure 8: Final electricity consumption

5 DETAILED OUTCOMES BY ENERGY SOURCE

While total energy consumption and CO_2 emissions are rather well in line among the four scenarios compared, differences occur in the absolute consumption and the shares of individual fuels both in total energy consumption and electricity generation, as illustrated in the charts below. Important variances occur in particular in the projected share of coal production and nuclear electricity generation, while the share of oil in total energy consumption is projected to be more or less of a similar order (at least among the more recent studies).

These are, to a large extent, the results of different fuel mixes in electricity generation, which are due to disperse assumptions on technology characteristics and the price development of various fuels. In particular, the share of coal in electricity generation differs between WETO and US-DoE/IEA/WEC with the latter having larger shares. In WETO this is counterbalanced by a higher share of nuclear energy. Interestingly, the shares of renewables are rather similar among the three more recent studies with differences occurring in the composition between renewable energy sources.

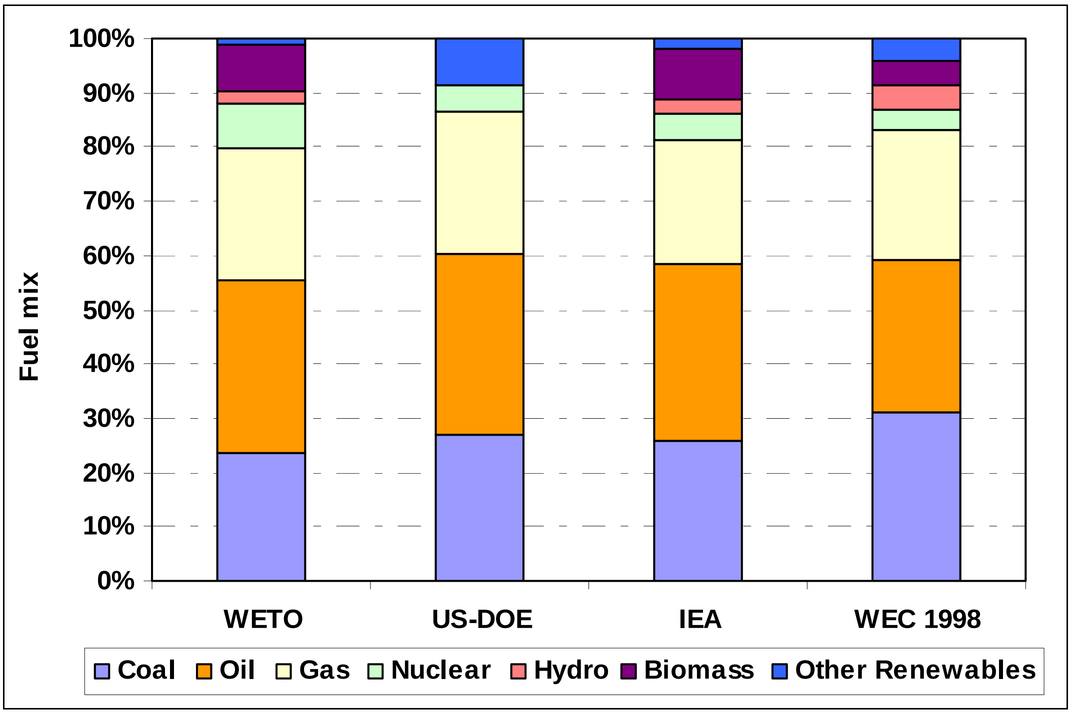


Figure 9: Fuel mix of total energy consumption by 2030

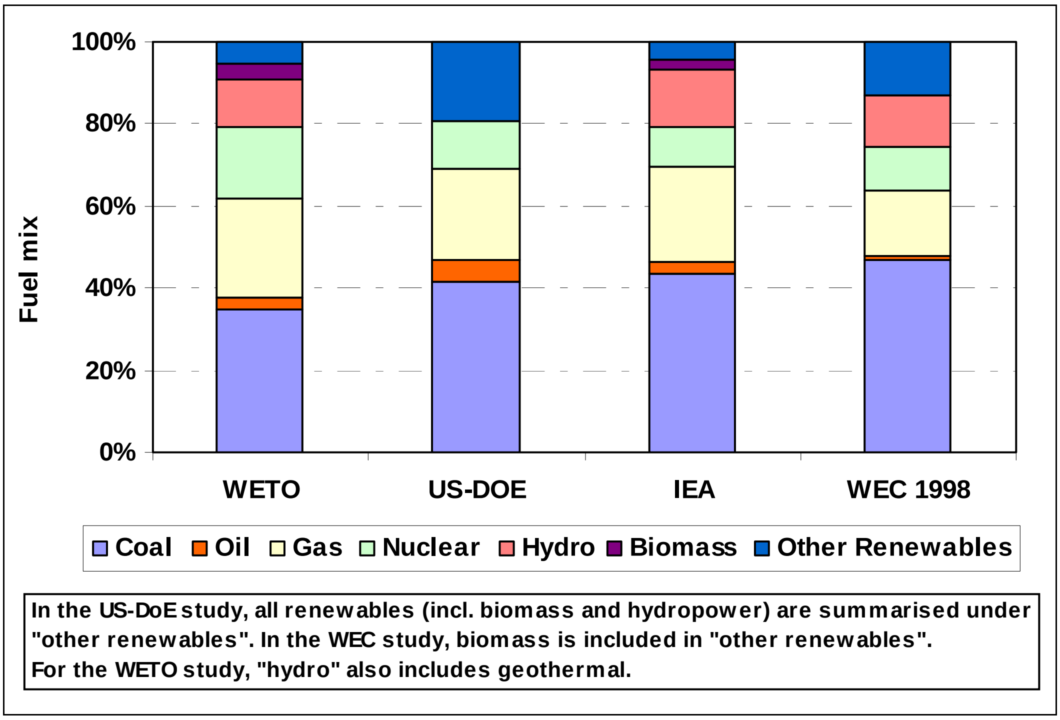


Figure 10: Fuel mix of electricity generation by 2030

Developments over time of the individual fuels are explained in more detail in the following sections. In order to minimise distortions that may occur as a result of applying different conversion factors when re-calculating the primary energy from electricity consumption (see footnote 1), electricity generation instead of primary energy is used as the basis for the scenario comparison in the case of nuclear and hydropower.

5.1 Oil production

World oil demand will reach 4 Gtoe in 2010 according to the four studies, and will exceed 5.3 Gtoe by 2030 in two of them. The corresponding growth rates remain, however, at a relatively low level, between 1 and 2 %/year. Only the WEC study shows lower levels of world oil demand in spite of the fact that this study also assumes the lowest oil price. This may be the result of a lower assumed growth in transport demand, which has increased in more recent studies to reflect the significant rise in recent years.

Oil production	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	1.40	1.90	1.22
US-DoE	1.98	1.28	1.27
IEA	1.71	1.39	1.07
WEC	1.44	0.97	0.81

Table 10: Annual change of oil production

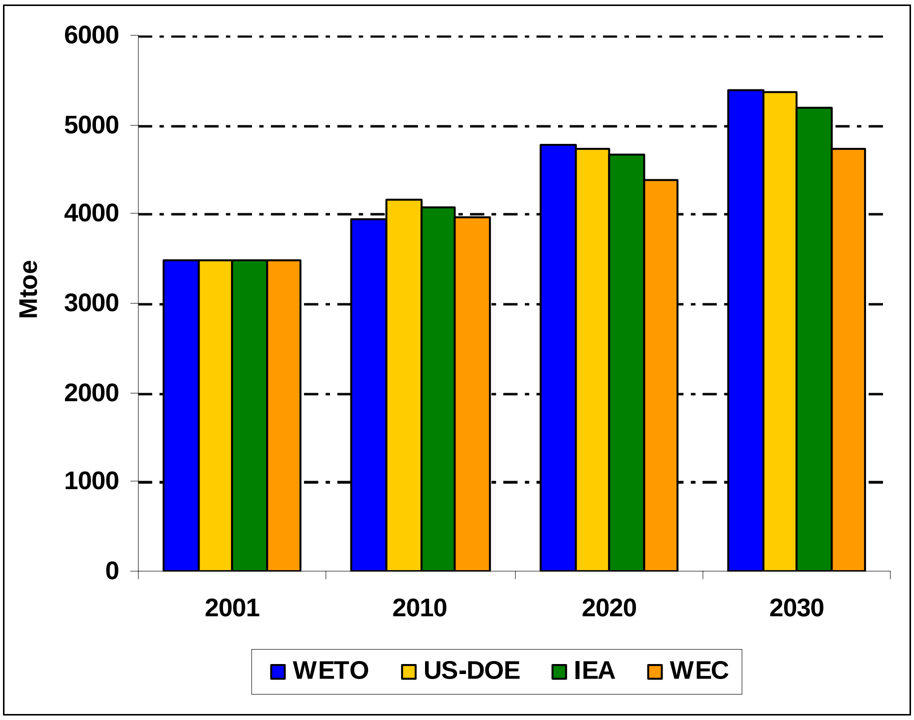


Figure 11: Oil production

5.2 Coal production

All studies point to an increase in world coal consumption over the next decades, reflecting a rise in the costs of natural gas and oil and a growing total energy demand. Total coal production is projected to reach around 3 Gtoe in 2010. In the longer term, particularly the US-DoE scenario, but also the WEC study, show structurally higher coal consumptions than the other two studies. In these studies, coal continues to rise with an average growth rate higher than 2%/year for the last two decades until 2030. In both cases, coal consumption reaches a level between 4.5 and 4.9 Gtoe in 2030, corresponding to a doubling from the current level.

On the other hand, for WETO and IEA the growth rates are in the range of 1.3 to 1.9%/year in the last two decades, which leads to a coal production of between 4.0 and 4.1 Gtoe in 2030. In the IEA scenario, this can to some extent be explained by the comparably lower final electricity consumption, as coal production is primarily driven by its use in power generation. In the WETO scenario with its relatively higher electricity generation, the use of coal for power generation is replaced by natural gas and nuclear power.

Coal production	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	2.50	1.39	1.66
US-DoE	3.63	2.20	2.02
IEA	2.57	1.93	1.29
WEC	2.13	2.31	2.22

Table 11: Annual change of coal production

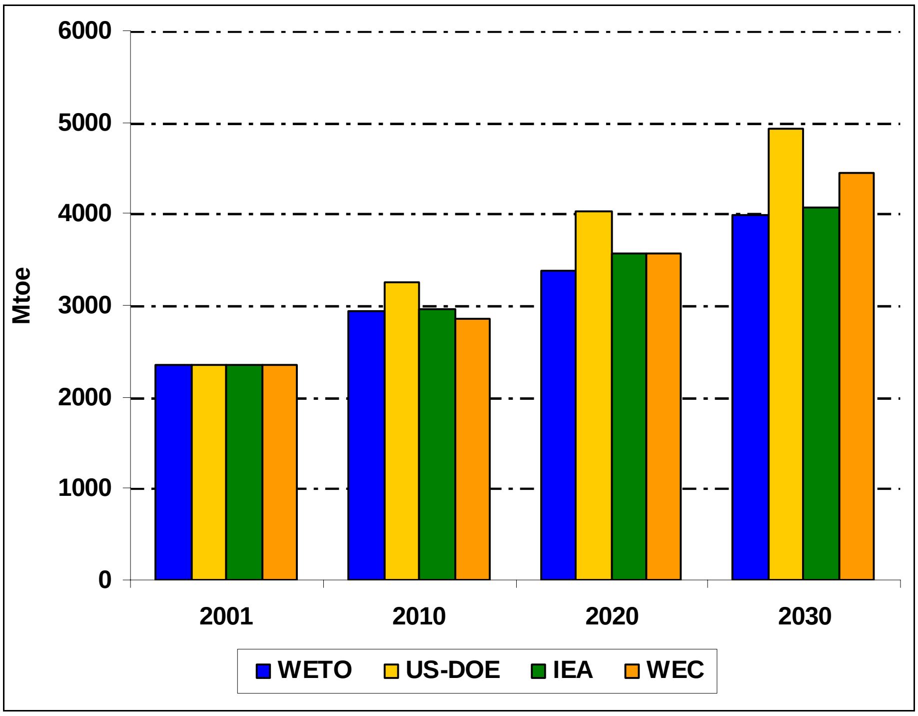


Figure 12: Coal production

5.3 Natural gas production

The four studies show an important increase in natural gas production, despite some differences in the absolute values. These differences are more pronounced in 2010 and 2020 than in 2030. Compared to oil production, the average growth rates are much higher with values of about 2%/year at least until 2020, leading towards gas production reaching some 3.8-4.2 Gtoe by 2030. This is a clear indication of the strong dynamics that have to be expected for natural gas in the next twenty years, following the trend in the past decade. However, in the long run, the annual increases slow down, reflecting increases in prices and concerns about supply security.

Differences can be identified in the intermediate time steps. Due to higher growth rates in the first decade, the WETO study anticipates 10% higher values in 2010 and 2020 compared to other studies. The higher gas consumption in the WETO study offsets the decrease in coal consumption compared to the US-DoE, until - in the decade 2020 - 2030 - nuclear power becomes more important.

Natural gas production	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	4.76	1.64	0.91
US-DoE	2.96	2.57	1.98
IEA	2.49	2.08	1.67
WEC	2.73	2.13	2.02

Table 12: Annual change of natural gas production

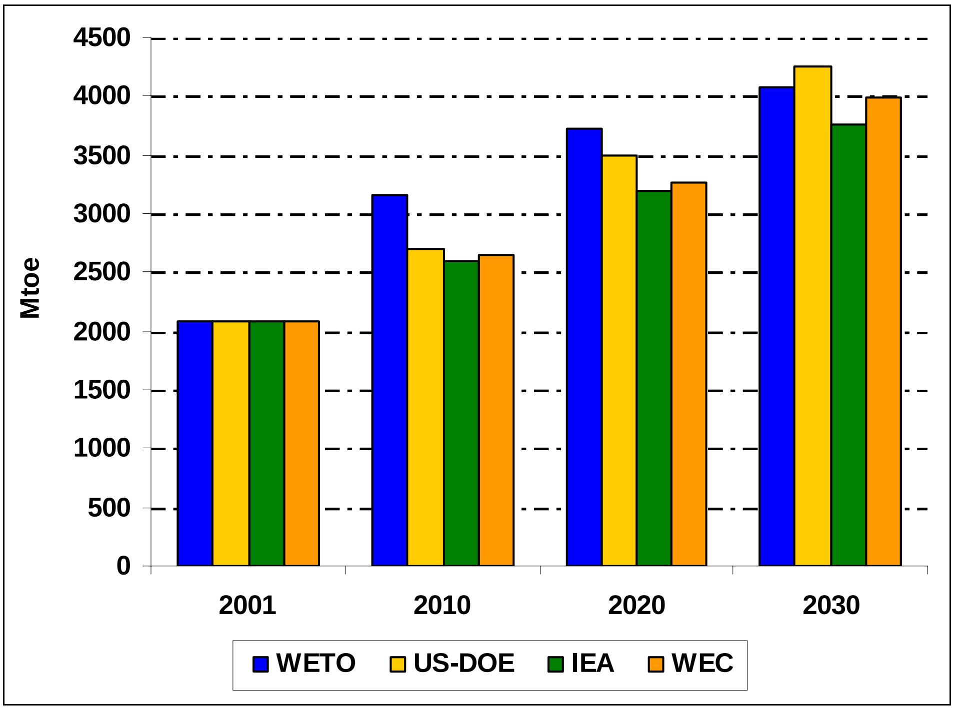


Figure 13: Natural gas production

5.4 Nuclear electricity generation

The prospects for nuclear electricity development in the next thirty years appear to be relatively limited until 2020 in all four studies. This is explained by the market slowdown in new plant orders since the 1980s. The WETO study, however, projects some increase in nuclear power production for the decade 2010-2020, due partly to the additions of new capacities and partly to improvements in management and load factors in existing plants.

After 2020, the WETO study significantly diverges from the other three studies, foreseeing more than 6300 TWh of nuclear power production at world level by 2030. This figure represents almost 100% more nuclear power production than the one foreseen by the other studies (which range from 3300 to 3600 Mtoe). In terms of growth rate, WETO anticipates an annual growth rate of 4.7% between 2020 and 2030.

The development of nuclear power is influenced to a large extent by assumptions of societal acceptability and others factors such as the availability of long-term safe storage facilities for highly radioactive waste. Furthermore, the economics of nuclear energy (and also the amount of waste produced) depend on whether the successful market introduction of a next generation of advanced reactors is assumed.

The WETO study assumes that economic and societal obstacles to nuclear can be overcome, which leads to an increase in nuclear power production. In particular, it assumes a rapid deployment of advanced light water reactors, accompanied by radical changes in the acceptability of the technology on a global scale.

On the other hand, the IEA outlook points for a rapid decommissioning of the so called “second generation” plants after 2010, while at the same time assuming a slower introduction of advanced nuclear technology. The IEA study thus configures the fastest nuclear phase-out scenario, reflecting the phase-out policies or -intentions of some OECD Member countries.

Nuclear electricity	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	1.56	2.76	4.68
US-DoE	0.92	1.32	0.55
IEA	1.15	0.78	0.41
WEC	0.51	1.02	1.70

Table 13: Annual change of nuclear electricity

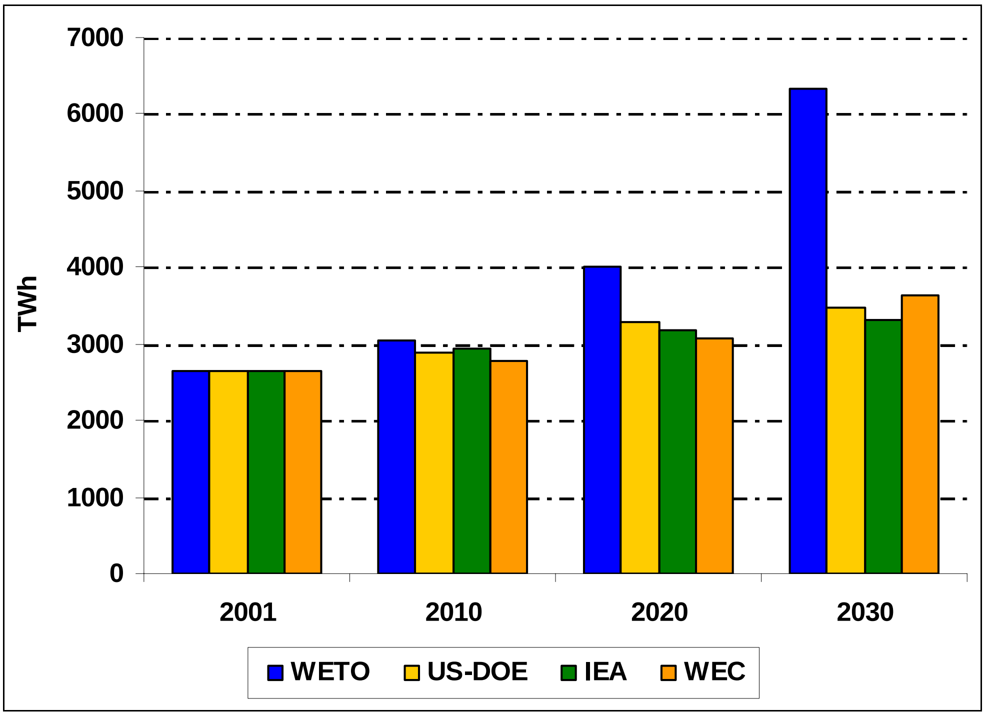


Figure 14: Nuclear electricity generation

5.5 Renewables

Renewables comprise hydropower, micro-hydro systems, biomass, modern biofuels as well as other renewables like photovoltaic and geothermal. Overall, they are expected to increase their share within the world energy supply. In all studies the annual average growth rates appear to be in the range of 1-2% in all decades with the exemption of US-DoE in the first and WEC in the last decade.

The annual average growth rates of renewables are in general a bit lower than those of natural gas and coal – due to lower gas and coal prices – and a bit higher than those of oil – due to the assumptions made on their availability. It needs to be noted that the assumed growth rates for the currently dominating renewable energy sources, i.e. biomass and hydropower, are relatively modest, while those for 'other renewables' such as wind or solar power reach some 5-10% annual growth. For this reason, these three renewables sub-categories will be assessed separately in the following sections.

Production of hydropower, biomass and 'other renewables'	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	1.68	1.12	1.36
US-DoE	4.33	1.62	1.63
IEA	1.91	1.83	1.72
WEC	1.11	1.72	2.34

Table 14: Annual change of the production of hydropower, biomass and 'other renewables'

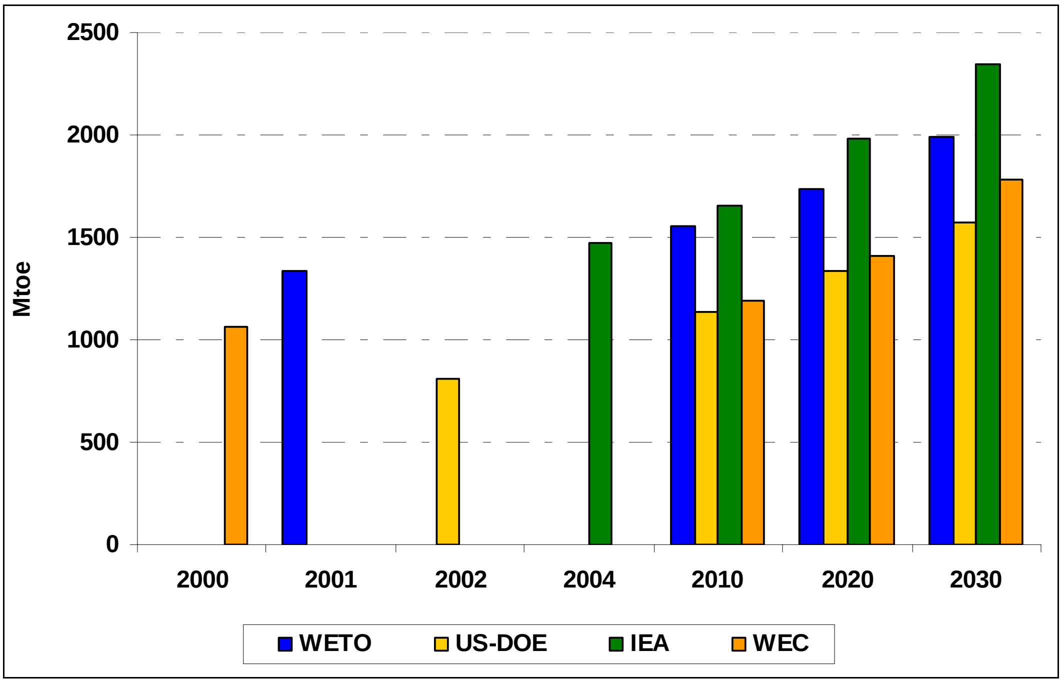


Figure 15: Production of hydropower, biomass and 'other renewables'

Total amounts of energy (see Figure 15) are not harmonised with regard to the different levels in the start year. In this case, a harmonisation would be misleading as the base years of the scenarios differ too much, especially for the US-DoE projections with values being some 30% below those of WETO and IEA.

Nevertheless, the harmonisation is applied on a more detailed level regarding the data on hydropower, biomass and other renewables separately as no data for US-DoE are available on this disaggregation.

5.5.1 Hydro electricity generation

World hydro electricity generation is expected to rise relatively regularly over the period, with average rates of 1.9 and 2.5 %/year between 2000 and 2010 and 1.5 and 2.1%/year between 2010 and 2020 for the WETO and the IEA studies. Throughout the time period considered, the projected hydro electricity generation is rather close in all scenarios.

Hydro electricity*	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	1.89	1.52	1.10
US-DoE	n.a.	n.a.	n.a.
IEA	2.49	2.10	1.71
WEC	1.24	1.31	1.36
* In WETO, 'hydro' also comprises geothermal.			

Table 15: Annual change of hydro electricity

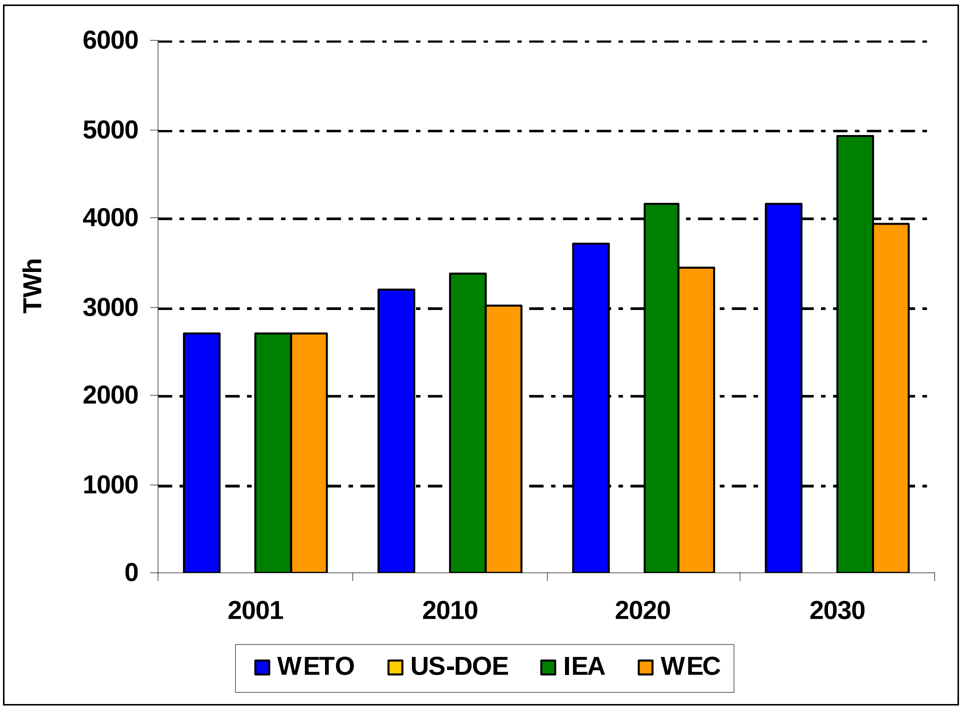


Figure 16: Hydro electricity generation

5.5.2 Biomass production

The three studies providing projections for bioenergy consumption show increases of between 0.7 and 1.9%. The average annual growth rates are the highest in the WEC, leading to biomass consumption being 16% above the WETO values by 2030.

The differences among the projections are partly due to the fact that the contribution of biomass to the world supply of energy is difficult to measure and is captured in the models differently. Biomass comprises both commercial bioenergy as well as the traditional use of bioenergy in developing countries (e.g. for cooking) with the latter having a broader ranger of uncertainty. It is therefore difficult to model the consumption of traditional bioenergy use as the proper dynamics of the corresponding energy sources as well as their links – in terms of substitution processes – with commercial fuels have hardly been explored.

Biomass production	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	1.52	0.70	0.79
US-DoE	n.a.	n.a.	n.a.
IEA	1.43	1.32	1.20
WEC	0.94	1.63	1.88

Table 16: Annual change of biomass production

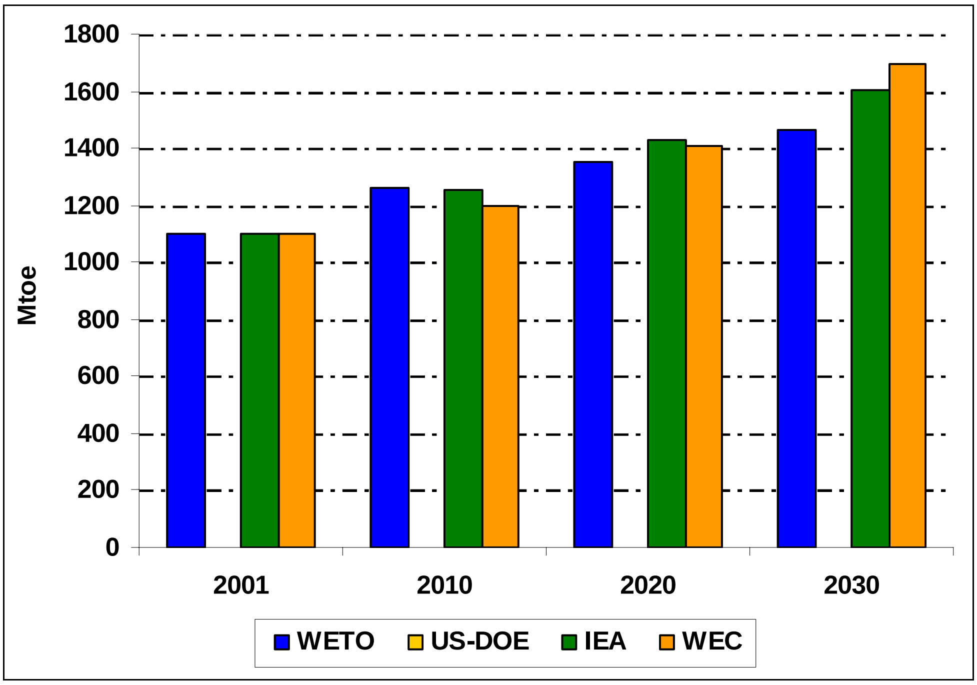


Figure 17: Biomass production

5.5.3 Production of 'other renewables'

The category of 'other renewables' used for this comparison includes different modern renewable energy sources like wind energy and photovoltaic power. Altogether, they represent not more than 7 Mtoe in 2001. However, their expected average growth rate is high, i.e. above 8 %/year for the first decade in all studies, and the bulk of this growth is expected to take place in renewable primary electricity.

For the period 2010-2030 the WETO study maintains a similar growth rate (13%/year in 2010-2020 and 10%/year in 2020-2030) considering e.g. offshore wind parks, whereas the IEA and WEC study anticipate some saturation effects. This discrepancy leads to a significantly different penetration of 'other renewables' into the world primary energy mix by 2030: 174 Mtoe in the WETO study, and 46 Mtoe and 66 Mtoe respectively in the IEA and WEC studies (Figure 18).

Other renewables	Average annual change per decade (%/year)		
	2001-10	2010-20	2020-30
WETO	12.98	12.63	9.69
US-DoE	n.a.	n.a.	n.a.
IEA	8.23	6.76	5.32
WEC	8.55	8.98	6.70

Table 17: Annual change of production of 'other renewables'

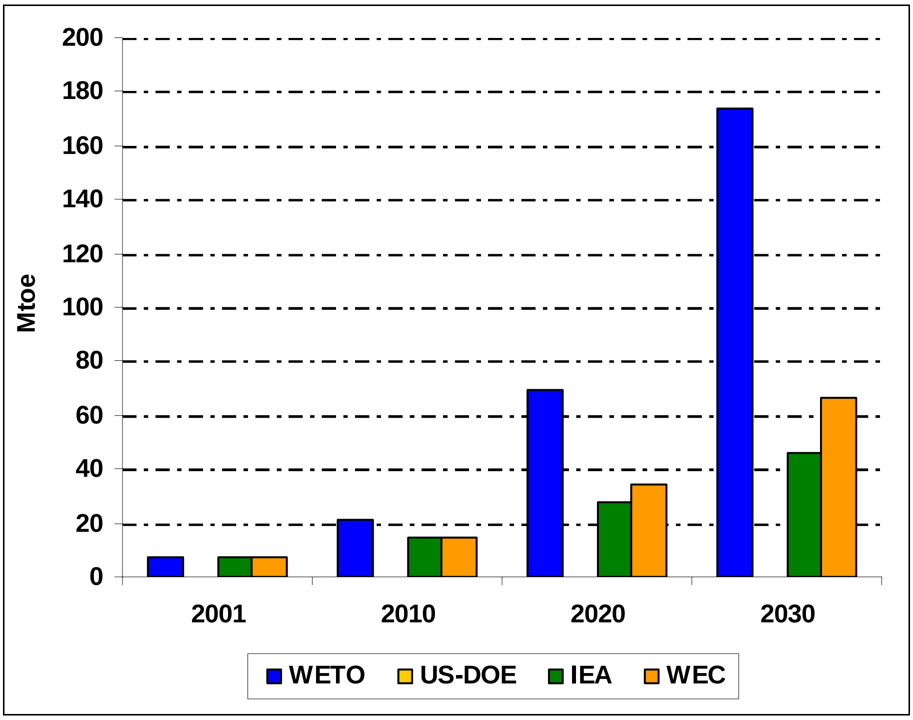


Figure 18: Production of 'other renewables'

6 CONCLUSIONS

The purpose of this paper was to compare the WETO-H_2 2006 reference assumptions and results with the projections provided by other world energy studies: the one produced by the US-DoE Energy Information Administration, the World Energy Outlook 2006 from the IEA and, for the sake of reference with the UNFCCC scenarios, the projections made in 1998 by the World Energy Council.

The comparison exercise indicates an overall high concordance between all scenarios.

Concerning the main exogenous hypothesis, rather similar assumptions were made in the demographic dynamics among the more recent studies (WETO-H_2, IEA and US-DoE). Regarding economic growth, the IEA World Energy Outlook and the WETO-study are well in line. The US-DoE study assumes a (moderately) higher increase of GDP particularly for the decade 2020 to 2030.

The baseline scenarios for global energy consumption and CO_2 emissions are well in line for the WETO, IEA and WEC studies, with slightly elevated values for the US-DoE study. These limited variances are basically due to the different assumptions made for GDP as well as the distinct model characteristics. The projected evolution of GDP energy intensity is nevertheless divergent: WEC foresees only a slight improvement of 21% by 2030, whereas IEA and US-DoE anticipate improvements of around 40% by the same date. WETO is closer to the latter, with a value of 33%.

Beyond this apparent broad agreement related to the totals of energy consumption and CO_2 emissions, more important variations in the projections for individual energy sources should be underlined. Concerning primary energy carriers, the prospects for coal and gas demands exhibit noticeable differences, mainly driven by the fuel mix in the power sector. Oil demand, on the other hand, remains similar among the scenarios.

The US-DoE forecasts considerably higher coal consumption than the other studies. In the WETO study, the lower consumption of coal is partially offset with a higher consumption of natural gas in the decade 2010 to 2020, and nuclear energy in the decade 2020 to 2030. As a consequence of this, WETO turns out to be the scenario with highest natural gas consumption in 2010 and 2020 (falling back to an average level in 2030) and the most pronounced nuclear electricity production in 2030.

The forecasts for hydro electricity and biomass are comparable between WETO and IEA, with the latter showing slightly higher values particularly for 2030. Although high growth rates for 'other renewables' are predicted in all scenarios, their contribution to overall world energy consumption remains at a low level, even in the most favourable case (WETO). For the share of renewable sources in total electricity generation, the three more recent studies are well in line.

To summarise, the comparison exercise carried out shows that important assumptions used in WETO (here: the WETO-H_2 reference case modelled with POLES), as well as the results obtained for the baseline projection on total energy consumption and carbon dioxide emissions are mostly in line with those of other reliable global energy studies, with important differences occurring mainly in the future development of nuclear power.

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European Commission

EUR 22938 EN – Joint Research Centre – Institute for Prospective Technological Studies
Title: Comparison of Long-term World Energy Studies
Authors: Burkhard Schade, Tobias Wiesenthal
Luxembourg: Office for Official Publications of the European Communities
2007
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-07078-5

Abstract

The POLES model is widely used to assess possible long term trends of energy supply and demand under various assumptions. For this purpose, policy-driven scenarios are compared to a reference (or baseline) development. Developing a reliable and consistent reference scenario is thus important. This report compares the POLES reference scenario published in the WETO-H_2 report with the outcome of reference projections from world energy models used by the International Energy Agency, the U.S. Department of Energy and the World Energy Council. Following the comparison of basic input parameters like population and GDP, the projections regarding oil price, greenhouse gas emissions and energy sources are analysed. On this basis, conclusions about the concordances and the discrepancies of the energy models are drawn.

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LF-NA-22938-EN-C

EUROPEAN COMMISSION

ISBN 978-92-79-07078-5

9 789279 070785

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