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European Sustainable Electricity

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Most Optimal Solution for Electricity Provision

Final Report for WP 5-2

Report on evaluation simulation models and existing scenarios

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1 Introduction

The main focus of this work package is to analyze already available studies to provide an overview of scenarios regarding structural energy market development in the European Union. The organisation of the work package, the studies analyzed and the methodology is presented in the following.

Organisation of Work package 5.2

The main objective is to compare and evaluate existing scenarios for electricity provision in Europe as well as the energy models used to provide impact to the design of the scenarios in work package 5.3 and to identify appropriate models to perform the scenario runs. For comparing and evaluating the scenarios and the energy models, which focus on the development for electricity provision in Europe up to the year 2030, five studies will be analyzed.

1. World Energy, technology and climate policy outlook – WETO
2. World Energy Outlook – WEO
3. European energy and transport – Trends to 2030
4. Assessing Climate Response Options: POLIcy Simulations – ACROPOLIS
5. System Analysis for Progress and Innovation in Energy Technologies – SAPIENT

The selected studies are supposed to be a good survey of scenario based analyses for the European energy systems. Taking Europe as one world region or focusing on different countries within Europe, one will get a broadly based overview of possible scenarios and adjunct probable outcomes of European energy policies.

To describe these studies with respect to selected scenarios, the evaluation of the main focuses and main assumptions of the studies as well the used energy models are analysed in a standardized way. The organisation structure of the analyses is as follows:

Part A: Scenario and Model Review

I. *Scenario Review*

The comparison and evaluation of the scenarios of each above mentioned study, should ad least address the following aspects and make the following information available.

1. Main Focus of the Study: What are the main focuses of the studies and which technology and policy oriented questions are addressed? Key questions could be:

    - Technological Developments in Electricity Generation
    - Security of Supply
    - Environmental Impact of Different Policy Scenarios

2. Key framework assumptions – Development of parameters over time for the years 2005, 2010, 2020 and 2030

    - Gross Domestic Product
    - Population
    - Households
    - Fuel Prices
    - Policy for Nuclear Electricity Supply
    - Regulatory Framework

3. Scenarios analysed within the different studies

    - Philosophy and Characterisation of the Analysed Scenarios
    - Description of the Main Scenario Assumptions

4. Main results of the different scenarios with special focus on the electricity provision. Results should be provided in form of a table (see Table 1 and the excel file) for the years 2005, 2010, 2020 and 2030.

Table 1: Reporting table for main results of the various scenarios

<table>
<tr><th>Scenario</th><th colspan="2">Indicator</th><th>Fuel</th><th>2005</th><th>2010</th><th>2020</th><th>2030</th></tr>
<tr><td rowspan="13">Baseline

Scenario (i)

..

Scenario (n)</td><td colspan="2">Cost of Electricity Generation [Euro Cent/kWh]</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="10">Installed Electricity Generation Capacity and Production in Europe by Fuel</td><td rowspan="5">Installed Capacity [GW_e]</td><td>Coal</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Gas</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Oil</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nuclear</td><td></td><td></td><td></td><td></td></tr>
<tr><td>RES</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Electricity Generation [TWh]</td><td>Coal</td><td></td><td></td><td></td><td></td></tr>
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<tr><td>RES</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">CO_2 Emissions by Electricity Generation</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Share of Domestic Primary Energy Supply [%]</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

II. *Model Review*

The analysis of the models used for computing the different scenarios within the selected studies could provide rationales for the deviating results. Taking a more differentiated look on the modelling and analytical framework, one might better understand the differences in the model results and might have a more comprehensive overview of the reasons for the observed deviations.

Reviewing the different approaches will be fruitful for analysing the specific strength of the models and the necessities regarding the regional and technological diversification of the models for providing sophisticated scenario results for the European Union. For describing the existing models with respect to the selected studies, the following aspects might provide an overview of the main differences in the used models.

- Type of model, e.g. optimization, simulation, applied general equilibrium, top-down, bottom-up
- Objective function, e.g. overall cost minimization with respect to energy or electricity, utility maximization
- Regulatory framework, e.g. assumptions on the European energy and electricity markets, respectively
- Modelling of dynamic behaviour within the model, e.g. perfect foresight or myopic expectation, i.e. intertemporal or recursive dynamics, respectively
- Regional diversification and degree of aggregation, e.g. EU15, EU25, individual countries

- Time horizon, e.g. 2020, 2030, 2050, 2100
- Segmentation with respect to
  - Time steps
  - Markets, e.g. energy, electricity, heat, emission rights
  - Sectors, e.g. industry, conversion, transport, households
- Environmental aspects which are taken into account

III. *Comparison of Various Scenarios and Models*

Comparing the various scenarios and models by using the standardized information and data is a basis for analysing the deviating results that could be found within the available studies. It provides good insights for policy makers to interpret model results and evaluate the analysed scenarios.

2 Study, scenario and model review

2.1 WETO: World Energy, technology and climate policy outlook

Denise Van Regemorter, CES KULeuven

Scenario and Model Review

Scenario Review

Main Focus of the Study: provide a reference scenario (business as usual) over the period 2000-2030 based on the POLES model. It was seen as a benchmark for the assessment of scenarios and as serving at identifying the problems linked to energy consumption and production which could arise under a BAU development. It could thus contribute to the design of EU energy policies. Special focus was put on the position of the EU gas market in a world perspective and on the GHG emissions in the reference scenario. Two issues were further explored because of the great uncertainty attached to them:

- the resources estimates of oil and gas
- the technological developments in electricity generation

Key framework

- Gross Domestic Product World outlook: it results from CEPII projections based on a simple growth model, slightly above 3%/year over the thirty years (3.5% in first decade, 3.1% in the second and finally 2.6%) with the share of the industrialised countries falling to 45% of World GDP in 2030 from 62% in 2000. The share of the developing countries increases with most of the gains in the Asia region.
- Population growth are taken from the United Nations demographic projections: 1%/year over 2000-2030, higher in Latin America, Africa and Middle East region and lower in EU and Japan and Pacific regions but no real change in the world population structure.
- US Geological survey is the source for oil and gas ultimate recoverable resources considering median estimates
- Technological development for electricity generation derived from analysis in EU DG Research project; technical progress in line with past improvement
- Energy and climate policies: the policies in place in 2000 (not Kyoto, neither the targeted share for renewables or the nuclear phase-out in some countries)

Therefore the evolution in the energy system depicted in the reference scenario is mainly driven by the fundamentals and not by policies.

The variants for exploring uncertainties

- Two variants around resource availability:
  1. a low gas and oil resources to evaluate the impact of higher gas and oil prices
  2. a high gas resources case to evaluate the impact of structurally lower gas prices than oil prices.
- Four variants around technological development in electricity generation: for each fuel a further development/breakthrough in technologies is considered.

The variant for policy issues

- A CO2 abatement scenario for 2030 through the implementation of a carbon value differentiated by region and by time horizon.

The Reference scenario

The World energy outlook in the reference scenario corresponds to an expanded view of the system in 2000 with however some shifts in the relative shares of the main world regions and of the primary energy sources. These shifts are driven by the differentials in regional growth, in the relative energy price evolution and in technological development.

There is a slowdown in the energy consumption growth in the industrialised countries and a sustained high growth in the developing countries. The share of the developing countries in the World gross inland consumption increases from 40% to 55% over the projection period. Fossil fuels represent 88% of world energy consumption in 2030. Oil represent still the largest share (34%) though coal and gas consumption growth is higher.

The energy prices as derived from the POLES model are given in Table 1.

Table 1 : International Energy prices (€1999/bbl)

	2000	2010	2020	2030
Oil price	26.5	23.8	28.7	34.9
Gas				
America		14		25
Europe/Africa		14		28
Asia		25		33
Coal		8	9	10

In Europe the energy consumption increases only by 0.4% a year, the impact of the growth in income being partly compensated by an improved energy efficiency (energy intensity of GDP is declining). There is an increased contribution of natural gas which represents 27% of total energy consumption in 2030 (39% for oil and 16% for coal and lignite).

The electricity demand in the industrialised countries follows the economic activity but in the developing countries it grows faster. In Western Europe the growth rate is 1.6%/year over the period 2000-2030 and 2.7% in the new member states and the former Soviet Union.

Half of the production in 2030 at World level is provided by technologies emerged in the nineties: gas combined cycle turbines, advanced coal technologies and renewables; conventional coal represent only 12% in 2030 (36% in 2000), 33% for advanced coal and gas 25% (16% in 2000), nuclear 10% (18% in 2000), large hydropower 13% (19% in 2000), other renewables 4% (2% in 2000) though increase of wind and solar power of 11% a year.

The same trend is observed in Western Europe as in the World. Coal remains an important input for power gebneration with advanced coal substituting conventional coal. Nuclear remains rather stable even without accounting for phase-out decisions. Regarding renewables, wind power, small hydro and biomass are increasing rapidly but still contribute only for 8% of total electricity production in 2030.

Table 2: Electricity generation and CO2 emissions

Indicator	Fuel	Baseyear	2010	2020	2030
Electricity Production in Western Europe by Fuel (TWh)	Coal	675	665	922	1218
	Gas	433	649	882	1021
	Oil				
	Nuclear	882	899	863	959
	RES	772	905	1040	1081
CO_2 Emissions by Electricity Generation [Mt]		1026	1013	1236	1429
Share of Domestic Primary Energy Supply [%]		65.1%	54.3%	44.0%	38.8%
Indicator	Fuel	Baseyear	2010	2020	2030
Electricity Production in CIS and CEEC by Fuel (TWh)	Coal	469	442	708	926
	Gas	457	700	1213	1758
	Oil				
	Nuclear	365	474	407	372
	RES	465	549	650	710
CO_2 Emissions by Electricity Generation [Mt]		997	929	1264	1495
Share of Domestic Primary Energy Supply [%]		117.2%	111.9%	116.2%	129.8%

The World CO2 emissions more than double from 1990 to 2030, with the share of the industrialised countries decreasing from 70% to 42%.

Oil and gas resources

With lower oil and gas resources, the oil price increases with 22% in 2030 (around 40€/bbl) the gas price with 22% on the Asian market, 28% on the European market and 57% on the American market. This induces a decrease of the demand for these fuels and a shift towards coal. The impact on CO2 emissions is less than on energy consumption as gas is partly replaced by coal.

With higher gas resources (and no change for the oil resources compared to the reference) the gas price decreases and reaches 16, 20 and 28 €/bl in 2030 on respectively the American, Euro-African and Asian market. The demand of natural gas is 20% higher in 2030 and replaces principally coal. Total energy demand is however only slightly affected (+1.5% at World level) and CO2 emissions are stable.

The scenarios around technological development

The different scenarios around technology development examine per fuel what are the implications of an accelerated technological development for the electricity generation technologies. The improvements in the technologies are implemented through a decrease of the investment cost and in the specific fixed operating cost and an improved efficiency.

The gas case

The gas technologies considered for improvement are: gas turbine combined cycle and gas turbine combined cycle for combined heat and power. It is associated with the high gas reserve case evaluated in the scenarios regarding oil and gas resources. With the improvement in gas technology and the lower gas price, gas increases its share from 22% in the reference to 28% world wide. It occurs at the expense of coal technologies and some nuclear. Renewables also see their share decrease. The global CO2 emissions are reduced with 1.6% in 2030 compared to the Reference.

Table 3: The gas technology

Technologies		**Baseyear**		**2010**		**2030**
			reference	**technology case**	**reference**	**technology case**
GTCC(gas turbine combined cycle)						
	Total Investment cost (€99/kW)	745	587	548	533	427
	Efficiency	53.5	57	57	59	63
	Electricity generation (TWh)	1311	5240	6111	8334	10409
Total						
	Electricity generation (TWh)	15639	20159	20175	36621	36720
	CO2 emissions (Gt)	6794	8184	8162	12562	12359
	CO2 emissions (Gt) from elec.generation	2318	2457	2412	4298	3990

The coal case

The technologies with improvement are advanced coal technologies: the supercritical coal power plant, the integrated coal gasification combined cycle (IGCC) and the direct coal fired combined cycle. The cost reduction induces a shift towards coal-fired plants substituting gas-fired plants even in regions where cheap gas is available and new nuclear design power plants. This case does not produce changes in the World CO2 emissions, the improved efficiency compensating for the larger use of coal power plants. There are however large regional differences (-1% in Asia but +1.4% in Western Europe). The international coal price increases with 5 to 7% but it is not sufficient to reduce the competitiveness of these technologies.

Table 4: The coal technologies

		Baseyear		2010		2030
			reference	technology case	reference	technology case
Super critical						
	Total Investment cost (€99/kW)	1970	1303	1181	1117	805
	Efficiency	44	46	47.7	49	55
	Electricity generation (TWh)	0.009	1391	1518	6989	8608
IGCC						
	Total Investment cost (€99/kW)	2631	1805	1637	1361	980
	Efficiency	43.5	49	49	49.8	54
	Electricity generation (TWh)	0.11	355	396	3101	3752
direct coal						
	Total Investment cost (€99/kW)		1733	1696	1252	969
	Efficiency		46.5	50	49.3	54
	Electricity generation (TWh)				1893	2140
Total						
	Electricity generation (TWh)	15639	20159	20167	36621	37006
	CO2 emissions (Gt)	6794	8184	8170	12562	12560
	CO2 emissions (Gt) from elec.generation	2318	2457	2443	4298	4309

The nuclear case

The technologies considered are the standard large Light Water Reactor (LWR) and the new evolutionary nuclear design. These power plants become competitive compared to the CCGT plant and the super critical coal power plants. Nuclear contribution increases from 9% to 15.5% worldwide (from 16% to 37% in OECD). The CO2 emissions are reduced with 2.8% in 2030 (4.6% in OECD). International coal and gas prices are reduced but oil prices are unaffected as oil plays a minor role in electricity production.

Table 5: Nuclear technologies

		Baseyear		2010		2030
			reference	technology case	reference	technology case
LWR						
	Total Investment cost (€99/kW)	3632	3574	3159	3639	2365
	Electricity generation (TWh)	2627	3155	3158	2832	4253
New evolutionary design						
	Total Investment cost (€99/kW)	n.a	6770	5980	2560	1663
	Electricity generation (TWh)	n.a	n.a	n.a	377	1443
Total						
	Electricity generation (TWh)	15639	20159	20225	36621	36849
	CO2 emissions (Gt)	8794	8184	8202	12562	12214
	CO2 emissions (Gt) from elec.generation	2318	2457	2473	4295	3984

Renewables

The technologies considered are all for electricity production: biomass gasification for electricity production, photovoltaic, molten salt tower solar plant, small hydro and on-shore wind turbines. The renewables case results in a 3% reduction in World CO_2 emissions in 2030 (3.2% in Asia and 2.4% in the EU) mostly resulting from a reduction in centrally produced electricity. Gas and coal prices are reduced (around 5%) inducing some increase in fuel consumption in the other sectors.

Table 6: Renewables technologies

		Baseyear		2010		2030
			reference	technology case	reference	technology case
Biomass gasification for electricity production						
	Total Investment cost (€99/kW)	2368	2198	1976	2087	1461
	Electricity generation (TWh)	0.11	255	218	169	371
Photovoltaics						
	Total Investment cost (€99/kW)	6457	4373	3936	31.46	2202
	Electricity generation (TWh)	0.02	0.26	0.33	0.88	2.04
onshore wind turbines						
	Total Investment cost (€99/kW)	996	911	820	816	571
	Electricity generation (TWh)	23.6	171	230	710	2016
Total						
	Electricity generation (TWh)	15639	20159	20225	36621	36849
	CO2 emissions (Gt)	8794	8184	8202	12562	12214
	CO2 emissions (Gt) from elec.generation	2318	2457	2473	4295	3984

Summary

The table hereafter gives a summary for the impact of the technology cases on electricity generation and CO2 emissions in the different technology cases.

Table 7: Summary of the impact of the technology cases (% changes compared to Reference in 2030)

	Electricity generation						Total
	based on						
	Gas	Coal	Nuclear	Renewables	Total generation	CO2 emissions	CO2 emissions
gas case	21.6%	-12.2%	-5.3%	-10.5%	0.3%	-7.2%	-1.6%
coal case	-16.0%	15.0%	-6.5%	-10.2%	1.1%	0.3%	0.0%
nuclear case	-7.1%	-8.1%	77.5%	-9.9%	0.6%	-7.3%	-2.8%
renewable case	-12.3%	-8.8%	-2.4%	132.0%	-2.2%	-8.9%	-3.0%

Climate policy scenarios

The Climate policy case is designed through the introduction a carbon value imposed on the CO2 emissions. In 2010 the value is differentiated by regions: 13.5€99/t CO2 for Western Europe and the New Member States and 5.5€/tCO2 for the other countries having accepted a commitment. No carbon value applies on the CIS as their emissions are below their target in the reference. Between 2010 and 2030 a 60€99/tCO2 is imposed in Western Europe and the New member states and 30€99/tCO2 in the other World regions. These values have been chosen as being compatible with a global stabilisation of the GHG concentration and the long term EU emission target.

The impact on the energy consumption and the CO2 emissions are given in the table hereafter.

Table 8: Energy demand and CO2 emissions in EU25

	1990	Ref 2030	CA 2030	%change CA-REF
CO2 emissions (GTCO2)	4.1	4.7	3.5	-26%
Total consumption (MTOE)	1608	2000	1759	-12%
Coal, lignite	449	387	151	-61%
Oil	626	727	635	-13%
Natural gas	262	546	527	-3%
Nuclear	198	238	322	35%
Renewable	64	122	191	56%

With the carbon value the electricity production decreases with 9% in EU 25 (10% at World level). There is also a substantial shift in the mix for electricity production. At World level the impact in relative terms is the highest for renewable sources (wind, solar and small hydro) and in absolute terms for nuclear and CHP. Thermal production decreases significantly with a shift away from advanced coal power plants towards gas and biomass power plants.

When an accelerated technology development is assumed (as in the scenarios on technology development) associated with a climate policy, the carbon value can be reduced to approximately one third reaching the same target. The nuclear scenario produces in the long run the lowest carbon value. The renewables scenario is also potentially interesting; in the medium term it offers even the cheapest opportunities. The coal and gas case have less impact on the carbon value, in case of coal because it is more costly to shift away from the new coal technologies and in the case of gas because gas is already used in the climate policy case and the lower gas price in the gas case induces a higher demand.

Model Review

The model used in the WETO project is the POLES model.

- Type of model: it is a simulation model covering the World energy demand and supply
- Modelling of dynamic behaviour within the model: time recursive structure with yearly path
  - Regional diversification: it identifies 38 world regions/countries of which the 15 EU countries and the largest countries (USA, Canada, Japan, China, India, Brazil, …) and degree of aggregation, e.g. EU15, EU25, individual countries
- Time horizon for this study is 2030
- Segmentation with respect to
  - Time step: yearly
  - Markets, e.g. energy, electricity, heat, emission rights
  - Sectors: 15 final energy demand sectors (main industrial sectors, the residential and service sector, the transport modes), 12 large scale power generation technologies and twelve new and renewable energy technologies.
  - Discovery process module for oil and gas supply, depending on the dynamics of drilling activity and discovering of new resources.
  - International energy market module which balances energy demand and supply; one world market for oil and 3 regional market for gas and coal (America, Europe/Africa and Asia) with energy prices determined endogenously in the model. The oil price depends in the short run on the capacity utilisation rate of the Gulf countries and in the long run on the world average Reserve on Production ratio. The gas price on each market depends partly on a gas to oil price factor and in the long run on the average Reserve on Production ratio of the main suppliers on that market. The regional coal price depends on the cost (mining and operating cost) of the key suppliers on that market
- Environmental aspects which are taken into account: CO2 emissions
- Future capacities of technologies determined by future electricity demand and relative cost of the technologies and potential for renewables

2.2 WEO: World Energy Outlook

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The World Energy Outlook has been the flagship publication of The International Energy Agency (IEA) since 1993. The publication is focusing on global trends in the energy markets as well as regional outlooks for the next two to three decades. Some issues have provided deeper insights to specific subjects, e.g. energy prices and subsidies for end users, energy supply for economic growth, energy investments and in the latest issue in 2005 the Middle East and North Africa with emphasis on the need for investment in the energy industry in this region

Long-term energy projections has been provided using a World Energy Model (WEM). This model has been further developed from issues to issue. For the WEO 2002 the WEM underwent a significant transformation and enhancements, and the time horizon was extended from 2020 to 2030.

This report contains a short survey of the six latest issues of WEO focusing on the shifting policy issues presented in these reports as well as a description of the projection method and latest projection results.

WEO 2000

The 2000 issue of World Energy Outlook contains global trends to 2020 as a reference scenario and alternative cases. These forecasts are made using the IEA World Energy Model. Regional Outlooks cover OECD North America, Europe and Pacific, plus Russia China and Brazil.

It is emphasised that fossil fuels will continue to dominate the world energy mix, and massive investment in oil production facilities will be needed as well as in electricity generation. Technology advances in combined-cycle gas turbines (CCGTs) have shifted the economics of power generation in favour of gas.

WEO 2000 includes an assessment of WEO projections since 1992, which was presented for the Energy Modelling Forum at Stanford University in June 2000. The oil price assumptions in this period largely overestimated the rise in oil prices, while the GDP assumptions largely underestimated economic growth over the past decade (1990s). It is shown that the assumptions IEA crude-oil import prices 2000 and 2005 had fallen from WEO93 to 17 $-1990 per barrel for both years in WEO98. Among 21 projections of crude-oil prices for 2010 in the period 1993-1998 only a single was higher than 35 $ (1990) (37 $ in the Global2100 projection from 1993).

In contrast, the forecasts of overall energy demand in 2000 showed a seeming accuracy, which disguised many changes in the fuel mix and in demand among different regions.

The assessment of past projections concludes that oil price projections have clearly much less influence on energy demand than GDP assumptions, which highlights a need for more careful attention to non-OECD demand, which are characterised by less mature economies with higher energy intensities and a lesser role for energy taxes.

WEO 2001

The subtitle is “Assessing Today’s Supplies to Fuel Tomorrow’s Growth”. The key message is that the worlds possesses abundant supplies of energy, but massive investment in energy infrastructure will be needed to exploit these reserves. The time-horizon of the study is 2020. Beyond 2020, new technologies such as hydrogen-based fuel cells and carbon sequestration, hold on the prospect of plentiful, clean energy supplies in a carbon-constrained world.

WEO 2002

Extends the project horizon to 2030. Highlights the rapidly expanding importance of China as a strategic buyer on world oil and gas markets.

In Reference Scenario the global energy market is projected to grow by two-thirds over the next three decades, equal to annual demand growth of 1.7% per year. The projected CO_2 emissions from OECD will increase from 11,000 Mt in 2000 to 14,000 in 2030. The study also includes an elaborate Alternatives Policy Scenario, in which the CO_2 emissions from OECD remains below 12,000 Mt during the whole period.

WEO 2003

Taking up the issue on massive investment from the WEO 2001, the title of this issue is World Energy Investment Outlook. This issue is characterised as a first-ever attempt to quantify global energy investments needs.

Although the investment requirement is large in absolute terms, it is modest relative to the size of the world economy. Following the Reference Scenario of WEO 2002, these investment amounts to only about 1 % of global GDP, but it differs significant among regions. Russia's investment requirement will amount to 5 % of GDP, Africa's to 4 %. Thus the requirement will be much lower than 1 % in OECD countries. Again it is emphasised that the world's energy resources are sufficient to meet projected demands.

Power generation, transmission and distribution require about 60% of the investment requirement, and additional 10 % is needed for fuel requirements to the electricity sector.

It is emphasised that a substantial proportion of all this energy investment is required simply to maintain the present level of supply.

Also financial resources are sufficient on a global level, but the regional distribution of investment requirements indicates that more of the capital needed will have to come from private and foreign sources than in the past.

Domestic savings has been the single most important source of capital for investment in infrastructure projects, but in some regions, energy-capital needs are very large relative to total savings.

The investment pattern will be influenced dramatically by environmental policies in the OECD and the development of new energy technologies.

The last section of the executive summary is devoted to the role of governments. Governments everywhere will have to pay attention to how the policy, legal and regulatory framework affects investment risks and how barriers to investment can be lowered.

The investment study contains three types of analysis: A short survey of Global Energy Investment Needs to 2030. A much longer discussion of Financing Global Energy

Investment, sectoral studies for fossil fuels and electricity, and a few new technologies suitable to include in the investment forecast till 2030.

Investment pattern

The projected world energy investment in all sectors will increase over the next three decades to an annual average in the period 2021-2030 about 50% above the level in year 2000.

New technologies for oil and gas extraction, long-distance pipelines, further advance in Combined Cycle Gas Turbines (CCGT) highly efficient small-scale plants for distributed generation, increased thermal efficiency of coal-fired plants and integrated gasification combined cycle (IGCC) plants. Technological advances and cost reduction for LNG, gas-to-liquid and coal-to-liquid production. The use of advanced coal-mining technology will continue to lower the capital and operating costs of coal extraction and preparation.

The capital costs of renewable energy technologies are expected to fall substantially, and hydrogen-based fuel cells, carbon sequestration and storage technologies, and advanced nuclear reactors could radically change the energy supply outlook and investment patterns in the longer term.

Financial issues

An important feature of energy investments is that the electricity sector is the most capital-intensive of all the major industrial sectors, measured by capital investment per unit of value added. On average the electricity sector requires two or three times as much investment as manufacturing industries, such as automobile manufacturing, in order to generate one dollar of added value. Oil and gas extraction, processing and refining are also relatively capital-intensive.

Among the various risks in energy investments environmental risks were emphasises as a type of regulatory risk. Thus investors may hesitate to provide funds to energy projects which operate to low environmental standards.

Oil

Compared to the regional distribution of oil reserves and oil production, the investments in the oil sector in OECD Europe is relatively high. Nearly 5 % of the global oil cumulative investment 2001-2030 for exploration and development and refining will be in Europe, while European investment in non-conventional oil will be negligible. The relatively large amount of investment in Europe is due to the high cost for exploration and development, $5-5.5 per barrel in EU-15 compared to less than $2 per barrel in the Middle East.

Gas

More than 10 % of the projected global natural gas cumulative investment 2001-2030 for exploration and development, transmission and storage, LNG, and distribution will be in OECD Europe. The European natural gas production is peaking in the period 2001-2010 and is projected to fall by some 10% between 2010 and 2030, while natural gas production in the rest of the world will more than double from 2001-2030.

Investment in gas supply infrastructure within Europe will decline over the next three decades, due to stagnating production and slower demand growth. Upstream investments will remain the largest component as costs rise with the depletion of reserves in the North Sea.

Financing might be a hurdle to investment in new large-scale cross-border pipeline and LNG projects, depending on cost development. Geopolitical factors and regulatory uncertainties.

Demand forecasts show a steady growth in natural gas consumption, so import must increase significantly, mainly from the two current suppliers, Russia and Algeria. The rest will probably come from a mixture of piped gas and LNG from elsewhere.

Coal

Global coal production is projected to increase by about 50% from 2000 to 2030 and world coal trade will increase more, but remain a small proportion (some 15% of global coal production).

In contrast to other regions coal production in OECD Europe is expected to decline.

The key uncertainty facing future coal demand and investment is environmental policy. This uncertainty is discouraging investment. In the OECD Alternatives Policy Scenario, new environmental policies cut global coal investment by some 6 % compared to the Reference Scenario, and coal imports to OECD Europe and Japan is 20-30 % lower than in the Reference Scenario.

According to the WEO-2002 Reference Scenario coal's share in electricity generation declines in the period until 2020, but recovers slightly thereafter. Coal remains the largest source of electricity generation throughout the projection period.

Electricity

There are two key reasons that explain why the electricity sector will continue to need large investments: First the electricity sector is very capital intensive, although capital intensity was lower in the 1990s compared to earlier decades. This can be explained to a large extent by the greater use of gas-fired technologies and inadequate investment in networks. Second, the world will continue to shift from primary fuels to electricity, and demand for electricity increases as incomes increases.

For the OECD countries the new investment framework in liberalized markets has created many new challenges and uncertainties. Concerns exist about the adequacy of investment as markets adapts to the new conditions, particularly with regard to peak load. The risks to investors for building peaking capacity are high compared to baseload plant. Liberalised markets also require increased levels of investment in transmission to accommodate greater volumes of electricity trade. Higher investments in transmission will also be required because of increased use of intermittent renewables.

The OECD Alternatives Policy Scenario illustrates how government policies to address environmental concerns and to increased energy efficiency may affect investment over the next thirty years. Investment in renewables in the Alternatives Policy Scenario will amount to half the investment needed in total new capacity. Given the fact that other generation options are less expensive, investors in renewable energy projects will seek a guarantied market for their electricity.

Advanced technologies

The final short chapter summarise a few advanced technologies, which are considered for the investment projection until 2030. These are CO_2 capture, fuel cells for power generation and vehicles, and advanced nuclear reactors.

In the WEO 2002 fuel cells emerge as a new source for electricity generation around 2020. The fuel cells that are expected to achieve commercial viability first will involve the reforming of natural gas. Almost all the fuel cells in use for electricity generation by 2030 will be for distributed power generation. Fuel cells are expected to become competitive in distributes generation when capital costs fall below $ 1,000 per kW, just over a quarter of current costs (compared to $ 400 per kW for large-scale CCGT), and their efficiency approaches 60 %. In the Alternatives Policy Scenario fuel cells start increasing their market share around 2015.

The scenarios developed in the WEO 2002 show a limited role for nuclear power in the next thirty years as a result of unfavourable economics and government policies which constrain use in response to public opinion. Many argue that entirely new nuclear reactor designs are needed if there is to be a major nuclear expansion. Ten countries have pooled their efforts to develop candidate systems for a four generation of nuclear reactors. A table summarise six technologies with best deployment days from 2015 to 2025, e.g. Very-High-Temperature Reactors.

Outside the power sector, hydrogen fuel cell vehicles, where proton exchange membrane (PEM) fuel cells are widely considered the technology of choice for passenger cars.

Some technologies are characterised as speculative and unlikely to become practical before 2050. These include photoelectrochemical water splitting and algal systems for water production.

Tables and methodology

An Annex contains regional tables (world and selected regions, e.g. EU15) that describe cumulative investments in energy supply and infrastructure for each of the next three decades and energy demand and supply forecasts until 2030. The methodology used is demand driven based on the Reference Scenario for WEO 2002. For some technologies experience curves have been used to estimate the evolution of unit costs. **Table 9** shows an extract of energy investments in EU 15. The total cumulative investment in EU15 in the three decades are $ 1.6 trillion out of the world total at $ 16 trillion in year 2000 price level.

Table 9: Reference Scenario. Investment in EU15. $bn.

	2001-2010	2011-2020	2021-2030	2001-2030
Oil	53	37	27	117
Gas	137	123	105	365
Coal	5	3	3	10
Electricity	302	401	408	1110
Total Regional Investment	496	564	542	1603

WEO 2004

The headline of the Executive Summary is “Energy Security in a Dangerous World”.

A central message in this Outlook is that short-term risks to energy security will grow.

A truly sustainable energy system will call for technological breakthroughs that radically alter how we produce and use energy.

Oil prices have broken $50 a barrel. Soaring Chinese demand is rocking energy markets.

“We assume in our Reference Scenario that the prices reached in mid-2004 are unsustainable and that market fundamentals will drive them down in the next two years. (…) But a continuing surge in demand and underinvestment in production capacity combined with a large and sustained supply disruption could still result in a new price hike.”

The Outlook contains updated sectoral projections for the oil, natural gas, coal and electricity markets, a short survey of regional outlooks, and an in-depth study of Russia, emphasising Russia as an energy supplier. A special chapter is devoted to energy and development with an appendix containing electrification tables. Finally the Reference Scenario is confronted with an Alternative Policy Scenario.

An annex compares past projections and latest estimates as well as a comparison with forecast from other institutions, such as USDOE, OPEC, a Japanese institute of energy economics, the European Commission and others.

The IEA oil price projections for 2010 and 2020 are similar to the US and Japanese forecasts, higher than the OPEC forecasts and significantly lower than the forecasts of the European Commission. The IEA forecast for 2030 is 29 $-2000 per barrel compared with the EC forecast at 40.3 $/bbl. The IEA forecast for global oil demand is similar to the other organisations. However, forecasts from the Center for Global energy Studies (CGES) and Shell are significantly lower (IEA 106 mb/d by 2020, CGES “high price” scenario 90 mb/d). Shell’s forecast for 2020 at 95 is much lower than most others, largely because its “Dynamics as Usual” scenario projects a high share of new technologies in place in 2020. All studies foresee the growth in oil demand to be led by the transpoirt sector in developing countries.

In the WEO 2004, the IEA took the unusual step of raising the issue on “The precarious state of energy”.

WEO 2005

The title is “Middle East and North Africa Insigths”. The overall focus is the countries in the Middle East and North Africa (MENA), emphasising the need for investment in oil production and oil supply infrastructure. The traditional Reference Scenario is very detailed concerning these countries. In addition to the usual World Alternative Policy Scenario, this issue contains a Deferred Investment Scenario, which analyses how global energy markets might evolve if investments in the upstream oil and gas industry of MENA countries were to be substantially lower than implicitly assumed in the Reference Scenario. This scenario is reported in details for each of the MENA countries.

World Energy Model

Since 1993, the IEA has provided long-term energy projections using a World Energy Model (WEM). For the WEO 2002 the WEM has undergone a significant transformation and enhancements. Specifically the time horizon has been extended to 2030. The main features of the model are:

- 18 separately modelled countries and regions, e.g. the European Union (EU15) and other OECD Europe.

- For the OECD regions a detailed sectoral representation of the industrial sector and projections of demand by end-use or mode in the transport, residential and service sectors
- A world refinery model that analyses the regional implications of growing oil product demand and product trade.
- A technology-rich power sector model
- A resource-based model on fossil fuel supply.
- Regional energy balances.

The parameters of each module's equations are estimated econometrically, usually with data for the period 1971-2000.

New features are added to the model to address the topics in each issue of WEO. In the WEO 2003 the methodology adopted for calculated the investment required in each supply chain involved, for each fuel and region, the following steps:

- New-build capacity needs were calculated on the basis of projected supply trends, estimated rates of retirement of existing supply infrastructure and decline rates for oil and gas production.
- Unit cost estimates were compiled for each component in the supply chain. These costs were adjusted for each year of the projection period.

WEO 2004 Projection of electricity generation

The latest projection of electricity generation in details suitable for reporting as shown in **Table 10** is from WEO 2004. The European Union with 25 Member States from 1 May 2004 is reported in full details for the Reference Scenario. Neither the Alternatives Policy Scenario nor the update in WEO 2005 are reported in the same details. The contents of **Table 10** is an extract of the published table in WEO 2004.

Table 10: Reporting table for the WEO 2004 Reference Scenario for the European Union (EU25)

Indicator		Fuel	Baseyear	2010	2020	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			**n.a**	n.a	n.a.	n.a
Installed Electricity Generation Capacity and Production in Europe by Fuel	**GW$_e$**	**Coal**	**187**	180	181	183
		Gas	**119**	165	269	399
		Oil	**78**	81	67	32
		Nuclear	**133**	124	93	71
		RES	**164**	221	308	376
	TWh	**Coal**	**920**	969	1099	1076
		Gas	**521**	715	1071	1458
		Oil	**182**	143	107	59
		Nuclear	**961**	964	728	560
		RES	**401**	626	890	1118
CO_2 Emissions by Electricity Generation [Mt]			**1308**	1466	1650	1669
Share of Domestic Primary Energy Supply [%]			**35.06%**	**36.01%**	**37.51%**	**37.19%**

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2.3 PRIMES: European Energy and Transport – Trends to 2030

ICCS/NTUA

The study and scenario review for European Energy and Transport – Trends to 2030 has been made available in form of numerical result sheets.

Study:	TRENDS TO 2030 - SCENARIOS ON KEY DRIVERS
Scenario:	Baseline
Country / Region:	EU-25
Baseyear:	2000
Models:	PRIMES
Institution:	ICCS/NTUA
Name of author:	L. Mantzos and P. Capros
Date:	2004

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Gross Electricity Consumption TWh			2898	3135	3419	3690	3949	4173	4397
Cost of Electricity Generation [$Euro_{2000}$/MWh]			52.8	54.4	55.3	54.3	50.4	52.7	54.3
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Nuclear	140.3	138.9	129.8	123.7	108.0	106.6	107.8
		Large Hydro (pumping excluded)	94.1	95.3	95.8	95.8	95.9	96.2	96.3
		Small hydro	2.1	5.6	8.9	11.7	13.4	15.2	15.9
		Wind	12.8	27.7	72.7	91.1	103.5	122.8	134.9
		Other renewables	0.2	0.3	0.5	0.6	0.6	2.4	14.2
		Thermal plants	406.7	448.1	476.3	539.9	625.3	691.1	749.0
		of which cogeneration plants	103.4	115.2	129.7	149.8	168.1	184.2	198.7
		Open cycle units (incl. biomass-waste)	335.6	324.0	270.6	210.3	175.3	151.9	147.4
		Clean Coal and Lignite	0.0	0.0	0.5	1.1	1.9	4.7	6.5
		Supercritical Polyvalent Units	0.0	0.0	0.5	12.0	64.7	99.7	143.4
		Gas Turbines Combined Cycle	47.4	95.9	169.6	263.9	318.8	365.8	384.6
		Small Gas Turbines	22.8	27.0	33.9	51.3	63.3	67.5	65.8
		Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Geothermal	1.0	1.2	1.2	1.2	1.3	1.3	1.4
		TOTAL	656.2	716.0	783.9	862.8	946.7	1034.3	1118.2
	TWh	Nuclear	921.2	983.6	952.5	930.9	833.5	781.4	766.5
		Large Hydro (pumping excluded)	326.9	315.8	318.4	319.3	321.2	321.5	321.0
		Small hydro	10.2	20.4	32.0	41.5	46.8	51.7	53.9
		Wind	22.4	61.8	161.8	199.9	233.6	278.1	311.9
		Other renewables	0.0	0.3	0.5	0.7	0.8	3.4	18.7
		Thermal plants	1617.2	1752.7	1954.0	2197.3	2512.7	2736.7	2925.1
		Hard coal	636.4	492.5	453.0	448.5	610.6	760.6	976.5
		Lignite and other solids	275.3	262.0	242.8	201.2	219.0	197.4	199.1
		Diesel oil	11.4	13.2	12.3	12.2	10.5	11.8	11.7
		Fuel oil and other liquids (excl. refinery gas)	163.7	113.7	83.9	69.2	44.1	29.7	26.4
		Natural gas, derived gasses, refinery gas	467.1	791.8	1073.1	1373.2	1535.2	1644.9	1617.2
		Biomass	27.3	33.5	37.8	40.1	40.2	42.5	44.0
		Waste	31.0	40.2	45.2	46.8	46.8	43.1	43.4
		Hydrogen - Methanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Geothermal heat	5.2	5.8	5.9	6.1	6.3	6.6	6.9
		TOTAL	2897.9	3134.7	3419.1	3689.7	3948.7	4172.9	4397.2
CO_2 Emissions by Electricity Generation [Mt]			1249.0	1211.4	1218.7	1252.2	1393.6	1486.1	1605.0
Share of Domestic Primary Energy Supply [%]			54.4	51.8	48.2	43.6	39.2	36.0	33.7

Study:	TRENDS TO 2030 - SCENARIOS ON KEY DRIVERS
Scenario:	Full policy options scenario
Country / Region:	EU-25
Baseyear:	2000
Models:	PRIMES
Institution:	ICCS/NTUA
Name of author:	L. Mantzos and P. Capros
Date:	2004

% Change from baseline

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Gross Electricity Consumption TWh			2898	3042	3170	3336	3509	3589	3703	-7.3	-9.6	-11.1	-14.0	-15.8
Cost of Electricity Generation [$Euro_{2000}$/MWh]			52.8	54.2	59.1	57.4	52.7	53.6	54.0	6.8	5.9	4.5	1.8	-0.5
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Nuclear	140.3	138.9	129.8	140.0	140.6	155.2	174.1	0.0	13.2	30.1	45.6	61.5
		Large Hydro (pumping excluded)	94.1	95.3	96.6	96.8	96.9	97.1	97.1	0.9	1.0	1.1	0.8	0.9
		Small hydro	2.1	4.6	12.2	15.9	19.1	21.1	22.0	37.5	36.0	42.2	39.4	38.5
		Wind	12.8	23.8	77.7	105.6	135.5	166.7	177.5	6.9	15.9	30.9	35.8	31.5
		Other renewables	0.2	0.3	0.5	1.1	1.8	5.5	19.5	0.0	86.6	230.9	125.2	36.7
		Thermal plants	406.7	440.1	446.5	453.7	489.0	504.8	517.2	-6.2	-16.0	-21.8	-27.0	-30.9
		of which cogeneration plants	103.4	116.8	161.7	188.2	206.4	212.6	220.7	24.7	25.6	22.8	15.4	11.1
		Open cycle units (incl. biomass-waste)	335.6	321.6	283.1	216.6	175.3	143.3	128.8	4.6	3.0	0.0	-5.6	-12.6
		Clean Coal and Lignite	0.0	0.0	3.6	4.5	5.7	6.7	8.8	600.7	307.6	194.0	41.7	35.5
		Supercritical Polyvalent Units	0.0	0.0	0.0	0.0	7.1	8.6	10.2	-100.0	-99.7	-89.0	-91.4	-92.9
		Gas Turbines Combined Cycle	47.4	91.3	133.3	199.6	239.6	252.8	234.3	-21.4	-24.4	-24.8	-30.9	-39.1
		Small Gas Turbines	22.8	26.1	25.2	31.6	44.4	49.3	44.8	-25.6	-38.4	-30.0	-27.0	-31.9
		Fuel Cells	0.0	0.0	0.0	0.0	15.4	42.4	88.6					
		Geothermal	1.0	1.2	1.3	1.4	1.5	1.6	1.8	8.5	12.8	16.7	20.2	24.9
		TOTAL	656.2	703.1	763.4	813.1	882.9	950.4	1007.4	-2.6	-5.8	-6.7	-8.1	-9.9
	TWh	Nuclear	921.2	978.2	865.1	936.4	960.9	968.4	1049.9	-9.2	0.6	15.3	23.9	37.0
		Large Hydro (pumping excluded)	326.9	312.4	316.3	316.8	314.4	323.8	322.0	-0.7	-0.8	-2.1	0.7	0.3
		Small hydro	10.2	17.1	40.1	51.3	63.3	69.5	72.6	25.3	23.5	35.2	34.4	34.6
		Wind	22.4	51.9	178.4	235.9	313.4	396.9	439.3	10.3	18.0	34.2	42.7	40.9
		Other renewables	0.0	0.3	0.5	1.3	2.6	10.0	29.2	0.0	93.9	241.1	193.5	56.4
		Thermal plants	1617.2	1682.4	1770.0	1794.6	1853.8	1820.9	1790.0	-9.4	-18.3	-26.2	-33.5	-38.8
		Hard coal	636.4	470.4	330.4	229.5	155.2	102.2	91.3	-27.1	-48.8	-74.6	-86.6	-90.6
		Lignite and other solids	275.3	266.3	211.4	138.8	102.5	66.9	64.1	-12.9	-31.0	-53.2	-66.1	-67.8
		Diesel oil	11.4	11.5	11.5	11.3	11.6	12.1	10.5	-6.7	-7.4	10.0	2.3	-10.0
		Fuel oil and other liquids (excl. refinery gas)	163.7	101.1	31.9	23.8	19.8	15.6	14.5	-62.0	-65.6	-55.2	-47.4	-45.2
		Natural gas, derived gasses, refinery gas	467.1	757.4	888.4	1080.4	1226.9	1251.2	1237.0	-17.2	-21.3	-20.1	-23.9	-23.5
		Biomass	27.3	31.2	251.6	273.8	302.3	335.0	335.6	566.0	583.5	651.7	687.9	662.0
		Waste	31.0	38.7	38.4	30.3	28.9	30.8	28.5					
		Hydrogen - Methanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
		Geothermal heat	5.2	5.8	6.4	6.8	6.6	7.0	8.5	8.1	12.3	4.5	7.0	24.0
		TOTAL	2897.9	3042.4	3170.3	3336.3	3508.5	3589.5	3703.1	-7.3	-9.6	-11.1	-14.0	-15.8
CO_2 Emissions by Electricity Generation [Mt]			1249.0	1145.7	919.8	799.8	716.0	622.6	586.9	-24.5	-36.1	-48.6	-58.1	-63.4
Share of Domestic Primary Energy Supply [%]			54.4	53.0	54.0	51.8	48.6	47.3	46.5	12.0	18.9	24.0	31.4	38.0

Scenario:	"High oil and gas prices" scenario
Country / Region:	EU-25
Baseyear:	2000
Models:	PRIMES
Institution:	ICCS/NTUA
Name of author:	L. Mantzos and P. Capros
Date:	2004

% Change from baseline

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Gross Electricity Consumption TWh			2898	3132	3423	3709	3974	4209	4453	0.1	0.5	0.7	0.9	1.3
Cost of Electricity Generation [$Euro_{2000}$/MWh]			52.8	54.4	55.7	55.6	52.1	55.2	57.3	0.7	2.4	3.4	4.8	5.5
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Nuclear	140.3	138.9	129.8	124.0	108.5	106.9	109.6	0.0	0.2	0.4	0.3	1.6
		Large Hydro (pumping excluded)	94.1	95.3	95.8	95.9	96.3	96.3	96.4	0.0	0.0	0.4	0.0	0.2
		Small hydro	2.1	5.5	8.8	11.7	14.2	15.8	17.0	-0.7	0.7	5.7	4.2	7.0
		Wind	12.8	27.9	74.3	94.8	108.8	138.0	150.9	2.2	4.0	5.1	12.4	11.9
		Other renewables	0.2	0.3	0.5	0.6	0.6	4.1	17.9	0.0	0.0	3.0	68.8	25.4
		Thermal plants	406.7	448.1	478.3	543.4	628.7	692.9	752.4	0.4	0.7	0.5	0.3	0.5
		of which cogeneration plants	103.4	115.4	132.2	151.9	169.1	183.0	201.1	2.0	1.4	0.6	-0.7	1.2
		Open cycle units (incl. biomass-waste)	335.6	324.0	270.5	216.1	177.1	156.7	153.4	0.0	2.8	1.0	3.2	4.1
		Clean Coal and Lignite	0.0	0.0	0.6	1.5	2.4	6.7	9.3	10.0	33.4	21.9	41.5	42.5
		Supercritical Polyvalent Units	0.0	0.0	0.9	19.4	86.1	147.0	210.5	94.8	60.8	33.0	47.4	46.8
		Gas Turbines Combined Cycle	47.4	95.8	171.8	252.6	298.5	311.5	309.5	1.3	-4.3	-6.4	-14.9	-19.5
		Small Gas Turbines	22.8	27.0	33.2	52.6	63.4	69.6	68.3	-2.0	2.6	0.1	3.1	3.9
		Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
		Geothermal	1.0	1.2	1.2	1.3	1.3	1.4	1.5	2.2	2.4	2.4	3.3	4.2
		TOTAL	656.2	716.0	787.5	870.4	957.0	1054.0	1144.2	0.5	0.9	1.1	1.9	2.3
	TWh	Nuclear	921.2	983.6	952.4	933.6	843.8	787.6	790.4	0.0	0.3	1.2	0.8	3.1
		Large Hydro (pumping excluded)	326.9	315.7	318.7	319.9	322.7	327.6	326.7	0.1	0.2	0.5	1.9	1.8
		Small hydro	10.2	20.1	31.8	41.7	49.3	54.3	57.8	-0.7	0.3	5.2	5.0	7.1
		Wind	22.4	62.1	165.9	212.0	253.3	333.3	370.8	2.6	6.0	8.4	19.8	18.9
		Other renewables	0.0	0.3	0.5	0.7	0.8	5.7	23.7	0.0	0.0	3.5	65.7	27.1
		Thermal plants	1617.2	1750.5	1954.0	2200.8	2504.6	2700.4	2883.7	0.0	0.2	-0.3	-1.3	-1.4
		Hard coal	636.4	491.5	457.1	493.0	706.1	956.6	1263.8	0.9	9.9	15.6	25.8	29.4
		Lignite and other solids	275.3	262.2	244.2	216.4	228.9	234.6	216.9	0.6	7.5	4.5	18.9	8.9
		Diesel oil	11.4	13.0	12.0	12.2	10.4	10.1	10.7	-2.8	-0.3	-0.8	-14.1	-7.9
		Fuel oil and other liquids (excl. refinery gas)	163.7	113.3	78.2	64.9	42.1	27.5	26.7	-6.8	-6.1	-4.5	-7.7	1.1
		Natural gas, derived gasses, refinery gas	467.1	790.9	1072.3	1309.5	1410.7	1356.7	1234.9	-0.1	-4.6	-8.1	-17.5	-23.6
		Biomass	27.3	33.4	38.6	49.5	51.6	59.5	76.4	2.3	23.7	28.4	40.0	73.5
		Waste	31.0	40.5	45.6	49.0	48.2	48.5	47.0					
		Hydrogen - Methanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
		Geothermal heat	5.2	5.8	6.0	6.2	6.5	6.8	7.2	2.1	2.3	2.3	3.2	4.1
		TOTAL	2897.9	3132.4	3423.3	3708.7	3974.4	4208.9	4453.0	0.1	0.5	0.7	0.9	1.3
CO_2 Emissions by Electricity Generation [Mt]			1249.0	1209.6	1218.6	1274.1	1424.3	1547.2	1675.2	0.0	1.7	2.2	4.1	4.4
Share of Domestic Primary Energy Supply [%]			54.4	52.5	50.1	46.3	41.7	38.7	36.9	4.0	6.3	6.2	7.6	9.4

Study:	TRENDS TO 2030 - SCENARIOS ON KEY DRIVERS
Scenario:	Gothenburg type targets with domestic action scenario
Country / Region:	EU-25
Baseyear:	2000
Models:	PRIMES
Institution:	ICCS/NTUA
Name of author:	L. Mantzos and P. Capros
Date:	2004

Indicator	Unit	Fuel	2000	2005	2010	2015	2020	2025	2030	% Change from baseline 2010	2015	2020	2025	2030
Gross Electricity Consumption TWh			2898	3121	3395	3625	3828	3920	4049	-0.7	-1.8	-3.1	-6.1	-7.9
Cost of Electricity Generation [$Euro_{2000}$/MWh]			52.8	56.6	59.5	61.3	64.0	70.2	78.2	7.5	12.9	26.9	33.3	44.0
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Nuclear	140.3	138.9	129.8	124.5	115.5	126.7	137.4	0.0	0.6	7.0	18.9	27.5
		Large Hydro (pumping excluded)	94.1	95.3	95.9	96.3	96.4	96.8	96.9	0.1	0.5	0.6	0.6	0.7
		Small hydro	2.1	6.0	9.6	13.5	18.0	19.8	22.0	8.0	15.9	33.9	30.6	38.2
		Wind	12.8	35.2	79.8	107.8	144.8	178.5	213.5	9.7	18.3	39.9	45.4	58.2
		Other renewables	0.2	0.3	0.5	0.6	1.9	13.4	31.5	0.0	0.0	240.3	449.9	121.2
		Thermal plants	406.7	448.4	475.4	525.1	595.5	607.9	636.2	-0.2	-2.7	-4.8	-12.0	-15.1
		of which cogeneration plants	103.4	115.1	132.7	156.3	177.9	200.5	212.3	2.3	4.3	5.8	8.8	6.8
		Open cycle units (incl. biomass-waste)	335.6	322.4	265.1	204.1	174.8	146.5	137.2	-2.0	-3.0	-0.3	-3.6	-6.9
		Clean Coal and Lignite	0.0	0.0	0.3	0.7	3.3	7.1	12.3	-33.3	-39.6	71.5	49.1	89.5
		Supercritical Polyvalent Units	0.0	0.0	2.9	7.9	15.2	17.4	19.6	525.8	-34.1	-76.4	-82.6	-86.3
		Gas Turbines Combined Cycle	47.4	98.2	175.1	268.8	351.6	382.4	383.6	3.3	1.9	10.3	4.5	-0.3
		Small Gas Turbines	22.8	26.6	30.8	42.2	48.8	48.9	47.0	-9.3	-17.7	-22.9	-27.6	-28.5
		Fuel Cells	0.0	0.0	0.0	0.0	0.0	3.8	34.3					
		Geothermal	1.0	1.2	1.2	1.4	1.6	1.9	2.1	2.7	15.3	25.7	42.0	50.6
		TOTAL	656.2	724.1	790.8	867.8	972.1	1043.2	1137.5	0.9	0.6	2.7	0.9	1.7
	TWh	Nuclear	921.2	983.7	952.5	931.2	824.0	853.1	883.9	0.0	0.0	-1.1	9.2	15.3
		Large Hydro (pumping excluded)	326.9	315.3	318.5	317.8	311.2	309.9	313.0	0.0	-0.5	-3.1	-3.6	-2.5
		Small hydro	10.2	22.2	34.1	47.7	61.3	66.1	74.3	6.6	14.9	30.9	27.8	37.7
		Wind	22.4	79.1	177.4	238.9	320.8	413.4	517.6	9.7	19.5	37.3	48.6	66.0
		Other renewables	0.0	0.3	0.5	0.7	2.7	21.0	47.7	0.0	0.0	254.9	513.1	155.7
		Thermal plants	1617.2	1720.1	1912.1	2088.5	2307.8	2256.9	2212.4	-2.1	-5.0	-8.2	-17.5	-24.4
		Hard coal	636.4	466.3	397.1	274.1	128.1	53.7	17.9	-12.3	-38.9	-79.0	-92.9	-98.2
		Lignite and other solids	275.3	242.0	196.0	127.4	90.2	71.5	59.5	-19.3	-36.7	-58.8	-63.8	-70.1
		Diesel oil	11.4	13.2	11.5	12.5	13.2	12.6	12.7	-6.7	2.6	25.7	7.0	9.0
		Fuel oil and other liquids (excl. refinery gas)	163.7	108.5	68.7	57.7	21.7	16.4	15.8	-18.1	-16.6	-50.7	-44.8	-40.1
		Natural gas, derived gasses, refinery gas	467.1	805.4	1121.9	1438.7	1766.7	1769.7	1710.1	4.5	4.8	15.1	7.6	5.7
		Biomass	27.3	34.7	55.4	105.6	207.4	249.4	308.9	46.8	163.5	415.7	486.6	601.4
		Waste	31.0	44.1	55.3	65.5	73.3	75.4	78.6					
		Hydrogen - Methanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
		Geothermal heat	5.2	5.8	6.1	7.0	7.1	8.1	8.8	2.7	14.8	12.9	23.4	28.8
		TOTAL	2897.9	3120.7	3395.1	3624.8	3827.8	3920.3	4048.9	-0.7	-1.8	-3.1	-6.1	-7.9
CO_2 Emissions by Electricity Generation [Mt]			1249.0	1159.9	1109.2	1010.7	900.2	807.5	735.6	-9.0	-19.3	-35.4	-45.7	-54.2
Share of Domestic Primary Energy Supply [%]			54.4	52.0	48.8	44.8	41.4	40.9	41.3	1.2	2.8	5.6	13.7	22.5

Study:	TRENDS TO 2030 - SCENARIOS ON KEY DRIVERS
Scenario:	New nuclear technology accepted with strong support for renewables scenario
Country / Region:	EU-25
Baseyear:	2000
Models:	PRIMES
Institution:	ICCS/NTUA
Name of author:	L. Mantzos and P. Capros
Date:	2004

Indicator	Unit	Fuel	2000	2005	2010	2015	2020	2025	2030	% Change from baseline 2010	2015	2020	2025	2030
Gross Electricity Consumption TWh			2898	3135	3388	3687	3953	4176	4399	-0.9	-0.1	0.1	0.1	0.0
Cost of Electricity Generation [$Euro_{2000}$/MWh]			52.8	54.4	56.4	54.9	51.0	53.3	54.8	1.8	1.2	1.1	1.1	0.9
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Nuclear	140.3	138.9	129.8	135.3	145.8	172.1	200.8	0.0	9.3	35.0	61.4	86.2
		Large Hydro (pumping excluded)	94.1	95.3	96.7	96.8	97.0	97.2	97.2	1.0	1.0	1.2	1.0	1.0
		Small hydro	2.1	5.6	12.3	15.5	18.3	20.2	21.0	38.3	32.9	35.9	33.1	32.0
		Wind	12.8	27.6	84.8	105.8	124.3	146.8	166.6	16.6	16.1	20.0	19.6	23.5
		Other renewables	0.2	0.3	0.8	1.2	2.1	4.4	18.5	74.7	101.5	280.1	81.6	29.9
		Thermal plants	406.7	448.2	470.9	521.2	584.9	629.6	663.8	-1.1	-3.5	-6.5	-8.9	-11.4
		of which cogeneration plants	103.4	115.1	146.1	164.9	190.9	209.0	230.6	12.7	10.0	13.5	13.5	16.1
		Open cycle units (incl. biomass-waste)	335.6	324.3	279.9	221.9	194.0	168.1	165.0	3.4	5.5	10.7	10.7	12.0
		Clean Coal and Lignite	0.0	0.0	3.5	4.7	5.6	6.3	10.1	579.2	323.6	189.7	32.5	55.0
		Supercritical Polyvalent Units	0.0	0.0	0.0	5.3	25.6	54.7	84.5	-100.0	-56.2	-60.4	-45.1	-41.1
		Gas Turbines Combined Cycle	47.4	95.5	155.6	239.8	292.6	326.5	330.8	-8.3	-9.1	-8.2	-10.7	-14.0
		Small Gas Turbines	22.8	27.2	30.6	48.1	65.5	72.4	71.7	-9.8	-6.2	3.4	7.2	9.0
		Fuel Cells	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
		Geothermal	1.0	1.2	1.3	1.4	1.5	1.6	1.7	11.3	15.4	16.8	18.7	21.4
		TOTAL	656.2	715.9	795.2	875.8	972.4	1070.3	1167.9	1.4	1.5	2.7	3.5	4.4
	TWh	Nuclear	921.2	983.2	901.3	973.8	1015.7	1083.8	1207.9	-5.4	4.6	21.9	38.7	57.6
		Large Hydro (pumping excluded)	326.9	315.5	319.5	315.2	317.2	323.7	321.5	0.3	-1.3	-1.3	0.7	0.1
		Small hydro	10.2	20.4	40.2	51.3	61.5	67.3	69.8	25.5	23.5	31.4	30.1	29.4
		Wind	22.4	61.6	189.3	235.4	284.6	338.3	405.3	17.0	17.7	21.8	21.6	30.0
		Other renewables	0.0	0.3	0.9	1.3	3.0	6.2	24.5	86.3	92.1	292.2	80.1	31.5
		Thermal plants	1617.2	1753.5	1936.4	2110.0	2271.1	2357.2	2369.7	-0.9	-4.0	-9.6	-13.9	-19.0
		Hard coal	636.4	492.6	413.3	387.7	429.6	513.5	624.5	-8.8	-13.6	-29.6	-32.5	-36.0
		Lignite and other solids	275.3	261.6	234.8	168.7	156.3	129.1	142.1	-3.3	-16.1	-28.6	-34.6	-28.6
		Diesel oil	11.4	13.3	14.4	12.5	13.2	14.2	13.1	16.6	2.5	25.0	20.6	12.2
		Fuel oil and other liquids (excl. refinery gas)	163.7	113.9	76.8	65.2	41.9	28.2	27.2	-8.5	-5.8	-4.9	-5.1	2.8
		Natural gas, derived gasses, refinery gas	467.1	790.7	992.5	1263.3	1403.8	1436.5	1324.4	-7.5	-8.0	-8.6	-12.7	-18.1
		Biomass	27.3	32.6	158.5	181.0	198.7	212.6	215.3	319.5	351.9	394.0	400.0	389.0
		Waste	31.0	43.1	39.8	24.7	20.3	15.3	14.7					
		Hydrogen - Methanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
		Geothermal heat	5.2	5.8	6.6	7.0	7.3	7.7	8.3	11.0	14.9	16.1	17.8	20.6
		TOTAL	2897.9	3134.6	3387.6	3687.0	3953.1	4176.4	4398.7	-0.9	-0.1	0.1	0.1	0.0
CO_2 Emissions by Electricity Generation [Mt]			1249.0	1210.8	1144.7	1125.9	1177.7	1190.4	1230.0	-6.1	-10.1	-15.5	-19.9	-23.4
Share of Domestic Primary Energy Supply [%]			54.4	52.2	51.4	47.8	44.7	43.0	42.6	6.6	9.8	13.9	19.5	26.4

2.4 ACROPOLIS: Assessing Climate Response Options: POLIcy Simulations – insights from using national and international models

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The ACROPOLIS project applies and compares energy models to assess the impact of energy technologies and policy measures on greenhouse gases (GHG) emissions and on sustainability in a global systems analysis perspective. It was aimed to overcome the difficulties linked to the harmonisation of results from different energy models. The modeling consortium involves 7 EU and 5 non-EU organizations, applying five global models, three regional models and five national models. The project objectives are to i) bridge the communication gap between modelers and policy-makers, ii) address policy questions that are currently relevant to the main stakeholders, i.e. policy-makers and heir advisors, both at the regional or country level and at global level and iii) investigate the role of different policies and measures in reducing GHG emissions and fostering deployment of more advanced and climate-friendly energy technologies. Time horizon of the study is 2020/2030, whereas some of the applied models cover a time horizon to 2100.

I. Scenario Review

1. Main Focus of the Study: What are the main focuses of the studies and which technology and policy oriented questions are addressed?

- Examination of policy instruments for GHG mitigation
- Analyses of the effects of experience curves in energy models

The main focus of the Study was to examine a set of policy instruments for GHG emission control as well as to address a few relevant methodological issues, related to i) the implementation of experience curves in energy models and ii) the handling of uncertainties in the technological parameters within the models. The analysis of policy measures or instruments for emission control has been implemented based on a business as usual and four contrasting scenarios.

Using various energy system and energy economic models, a wide range of result parameters has been analysed, due to the differences in territorial and sectoral coverage, assumptions on technologies and options for GHG mitigation.

Within the study only gross domestic product (GDP), population and energy prices had been applied as harmonized key assumptions to provide enough flexibility to the different models.

2. Key framework assumptions – Development of parameters over time for the years 2005, 2010, 2020 and 2030

- Gross Domestic Product: Between 1995 and 2030 the compounded average annual growth rate (CAGR) is assumed to be 2.86 % per year.
- Population: Between 1995 and 2030 the compounded average annual growth rate (CAGR) is assumed to be 1.13 % per year.
- Fuel Prices: Prices for natural gas has been differentiated for the American market, the European market and the Asian market. For oil and coal one global price path has been adopted.

Table 1: Assumption on regional energy prices between 1990 and 2030

Euro1995/GJ	1990	2010	2020	2030
Gas (American market)	1.69	2.79	2.87	2.54
Gas (European market)	2.38	2.38	3.11	3.58
Gas (Asian market)	3.23	3.44	3.66	3.95
Oil	3.73	2.65	3.15	3.61
Coal	1.57	1.40	1.51	1.60

The assumptions on the development of the Gross Domestic Product (GDP) have been based on the B2 marker scenario of the IPCC Special Report on Emission Scenarios. From 1995 to 2030 a global compounded average growth rate for GDP has been assumed to be 2.86 % per annum. Modelers were free to assume country and region specific growth rates for their specific model, depending on the territorial coverage.

As the assumptions made on GDP growth rates, the development of global population has been adopted on basis of the IPCC B2 market scenario. The global compounded average growth rate for GDP has been assumed to be 1.13 % per annum. The modellers have been free to assume country and region specific growth rates here also.

Regarding the energy price development, region specific price paths have been adopted based on the POLES model simulation for the reference scenario in the Shared analysis Project. The baseline scenario includes the energy-environment related policies adopted till June 30th, 2001. A general discount rate of 5 % per annum has been assumed, approving definition of sector specific discount rates to the modellers. Prices and costs had to be reported in Euro1995.

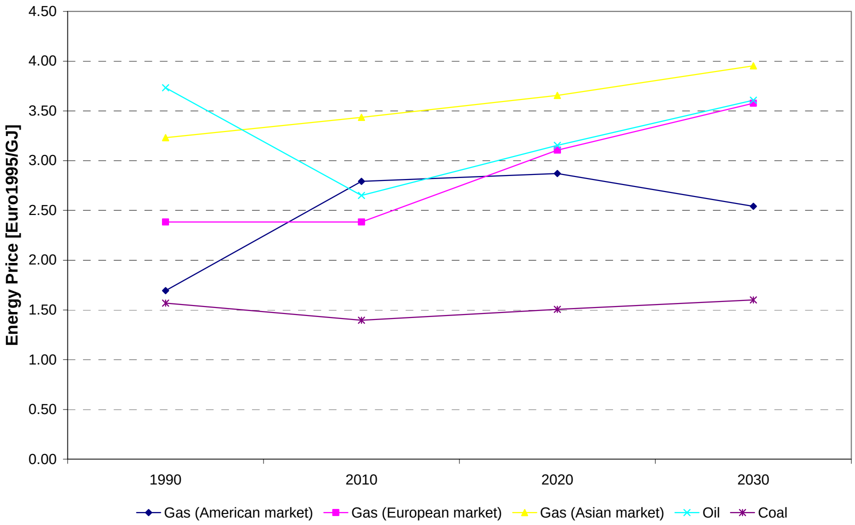

Figure 1: Development of region specific energy prices between 1990 and 2030

Assumptions on technological parameters, i.e. harmonized definition of specific technology specification like e.g. power plant efficiency, generation costs, fuel flexibility, future technological options for electricity provision and its evolution, life time of power plants, RES potentials, etc. It has been decided not to harmonize these assumptions within the ACROPOLIS project, due to the variety of energy models, regarding its territorial, sectoral and technological differences. Some of the results that have been found are due to the lack especially of harmonization of technological parameters.

3. Scenarios analysed within the different studies

- Business as usual scenario: Reference development for comparing four contrary scenarios on GHG control
- Renewable portfolio scheme and green certificates
- Internal flexible mechanisms
- Efficiency standards
- Internalisation of external costs

The business as usual scenario has been based on the energy-environment related policy measures and instruments adopted till June 30th, 2001. The key parameters as described above have been adopted for all five scenarios.

Table 2: Minimum share [%] of renewables for electricity generation by model

Model	Case	Geographical coverage	1990	2000	2010	2020	2030	2040	2050
MESSAGE	Base	World	20.0	23.1	25.8	28.0	29.98	34.97	37.8
MESSAGE	550 ppmv /Case1	World	20.0	23.7	28.6	34.6	36.3	40.2	44.4
DNE21	Base	World		18.5	20.1	21.3	21.5	18.9	19.2
DNE21	550 ppmv	World		18.5	20.8	22.4	24.4	26.5	35.7
DNE21	Case 1	World		18.5	22.5	26.9	28.3	31.3	34.6
GMM	Base	World	20	20.65	17.5	17.7	16.9	19.8	24.0
GMM	Case 1	World	20	22.5	32.4	35.1	40.3	45.7	49.3
MARKAL-MATTER	Base	Western Europe	20.6	20.0	25.4	25.0	25.5	26.7	27.3
MARKAL-MATTER	Case 1	Western Europe	20.6	20.1	31.0	34.0	42.0	50.0	58.0
Primes	Base	EU-15	14	14.0	14.0	15.0	17.0	Na	na
Primes	Case 1	EU-15	14	14.0	22.0	31.0	39.0	na	na
MARKAL-Nor	Base	Nordic		63.0	58.0	60.0	60.0	na	na
MARKAL-Nor	Case 1	Nordic		63.0	67.0	72.0	73.0*		
NEMS	Base	USA		10.0	10.0	9.0	na	Na	Na
NEMS	Case 1	USA		10.0	18.0	27.0	na	na	Na
NEO-MS	Base	Netherlands		3.0	7.0	6.0	na	na	na
NEO-MS	Case 1	Netherlands			9.0	15.0	na	na	na
TIMES	Base	Germany			8.0	9.0	11.0	14.0	17.0
TIMES	Case 1	Germany			11.5	20.8	28.7	35.6	41.3

Within the renewable portfolio scheme and green certificate scenario, a share of 22 % of electricity generation in 2010 has been used as a first step for the European Union countries, whereas the United States a target of 27 % of renewables of electricity generation by 2020 has been adopted. The minimum targets of the other countries and regions as well as rest of the world have been based figures of renewable electricity generation in the 550 ppmv scenario by IIASA. On the technological level, large hydro was treated as renewable, whereas municipal waste was excluded. Minimum share of renewables have been defined for various models within the renewable scenario.

For the international flexible mechanism scenario, the target for GHG emissions reduction has been defined in a soft landing scenario. In this scenario, CO_2 concentrations are stabilized in the long-term at about 550 ppmv and all countries participate in the emissions reductions. The global emissions and resulting atmospheric concentrations are similar to the WRE 550 scenario (see figure 2).

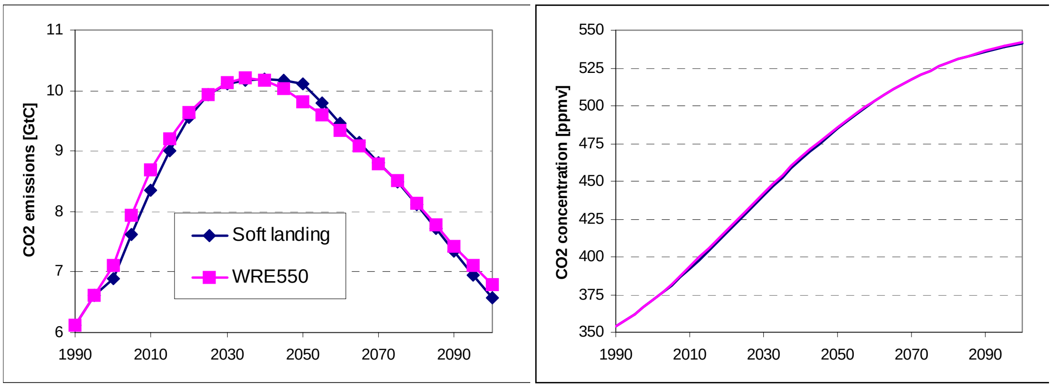

Figure 2: Global CO2 emission targets and resulting atmospheric concentration of the soft landing scenario compared with the WRE 550 scenario

Allocations of emission entitlements up to 2030 is based on the hypothesis of stabilization of CO2 concentrations at 550 ppmv by 2150. To achieve this, IPCC describes a trajectory in which emissions would reach a maximum of 12 Gt of Carbon by around 2030 and would decline subsequently. If about 2 GtC of emissions from the agriculture sector are taken out, energy-related CO2 emissions are limited to 10 GtC. The timing of participation in reduction varies among countries, beginning with the Annex B countries, the US joins in 2010 and all countries are participating by 2050. The United States are supposed to implement only domestic policies up to 2010. The Annex B countries continue their reduction effort after the first commitment period. For USA, the target is based on 2010 emissions as projected by EIA.

For non-Annex B countries, targets are based on each country's 2010 emissions, the GDP per capita and the population projections. Soft landing carbon emissions targets are adjusted to the specific regional breakdown of each model. For the non-Annex B countries, the constraint of stabilization of overall emissions by around 2030 means that at this date the increase in their emissions must be at most equal to the reduction of the Annex B countries. Furthermore, since world emissions should ultimately decline so as to achieve a stabilization of concentration of these countries must in the longer term, stabilize and then decline. The policy option investigated in this case study uses emissions trading between the parties. It is, however, assumed that Russia and other eastern European countries will sell only 50% of their emission permits stemming from hot air by 2010. No banking is allowed. There is no use of the Clean Development Mechanism.

Within the Efficiency standards scenario, seven cases have been formulated. Five of them address respectively measures for road transport, residential sector, service sector, power sector. The sixth considers combined measures for all sectors, whereas the seventh adopts the CO2 emissions calculated in the sixth scenario as a target. Based on the available information, modellers have to adopt the sector-wise efficiency targets given in Table 3. For power sector, the improvement is applied to the average efficiency of the all fossil power plants together including CHP. For industry sector, it is the improvement in the average energy intensity. Similarly, for residential and service sectors, it is the average end-use efficiency improvement. However, for the transport sector, efficiency improvement is targeted for passenger car only.

Table 3: Assumptions on improvement [%] of energy efficiency/intensity against the baseline

Sector/Region	2010	2020	2030	2040	2050
Power Sector					
Western Europe	3.75	7.50	11.25	15.00	18.75
N.America	3.44	6.88	10.32	13.76	17.20
Japan	1.25	2.50	3.75	5.00	6.25
EEFSU and ROW	2.50	5.00	7.50	10.00	12.50
Industry sector					
OECD & EEFSU	2.50	5.00	7.50	10.00	12.50
Developing World	3.75	7.50	11.25	15.00	18.75
Service & Residential					
OECD & EEFSU	5.00	10.00	15.00	20.00	25.00
Developing World	3.25	6.50	9.75	13.00	16.25
Transport - Road transport (car)					
Western Europe	2.50	5.00	7.50	10.00	12.50
N.America	5.00	10.00	15.00	20.00	25.00
Japan	1.40	2.80	4.20	5.60	7.00
EEFSU and ROW	2.95	5.90	8.85	11.80	14.75

The fourth scenario that has been analyzed within the ACROPOLIS study focuses on the implementation and coverage of external costs of energy provision and use. Beside the private costs like capital, fuel, labour, etc. environmental damage costs are tried to be addressed within the model analysis. Quantifying these costs and including them into the overall energy cost would allow to evaluate the favourable option both from an economic as well as an environmental point of view.

The external costs had been quantified for internalization based on the EsternE project. Due to the limitation within the ExternE project on external cost calculation for different fuels and existing technologies for the electricity sector in Europe only, a methodology had been developed within ACROPOLIS to apply the ExternE results in the energy models used.

The national implementation projects of ExternE dealt with the evaluation of externalities of power plants on different sites in different European countries. A scaling method is applied to adjust the external cost to different sites and countries. The main factor here is the population density, as it means higher exposure of the population to the negative effects. Hence, the higher the population density the higher the external cost will be.

Another important adjustment was made by scaling the results according to the efficiencies of the fossil fuel power plant used. Future power plants with high efficiencies should not be penalised by applying an external cost number derived from an existing conventional plant with considerably lower efficiency. The adjustment is made proportionally comparing the efficiency of the power plant in question with the reference efficiency. Specific external costs were derived for different configurations of power plants. Environmental technologies (DeSox, DeNox, dedust) can be taken into account. An overview of external cost numbers used in this case study as well as the adjustment factors are given in the Tables 4 to 7.

Table 4: Assumptions on external cost per t of pollutant

External cost per t of pollutant					
		NO_X	SO_X	particulates	CO_2
average cost	€/t	**7000**	**8000**	**14000**	**19**

Table 5: Adjustment factor for population density External

Adjustment factor for population density			
	NOX	SOX	particulates
high (Germany, Netherlands, Japan, India, China)	**1.5**	**1.5**	**1.5**
Medium	**1**	**1**	**1**
low (Scandinavia, Africa)	**0.75**	**0.75**	**0.5**

Table 6: Assumptions on power plant efficiency

Reference Power plant efficiency		
coal	41	%
oil	40	%
gas	55	%

Table 7: External cost for electricity generation (medium population density)

	DESOX (%)	DENOX (%)	Dedust (%)	External costs (Eurocents/kWh)
Coal				
type 1	0	0	0	16.6
type 2	0	50	80	5.3
type 3	90	50	99.5	2.1
type 4	99	75	99.5	1.9
Gas				
boiler	-	0	0	2.8
combined cycle	-	90	90	0.3
Biomass	n.a.	n.a.	n.a.	0.3
Nuclear	-	-	-	0.5
Wind	-	-	-	0.1
Solar	-	-	-	0.1

The external cost based on ExternE and adjusted as sketched above are internalised in all regions. There is no consideration of phased introduction according to economic development of the regions. Only the externalities of electricity generation had been considered due to the scarcity of data. For comparison two scenarios were analysed: one of them considering also the impact of electricity generation on climate change. The external cost of climate change is taken from ExternE as well and presents the median value.

3. Main results of the different scenarios with special focus on the electricity provision

Regarding the analyzed scenarios within the ACROPOLIS project, two contrary exemplary scenarios, i.e. the business as usual and the renewable scheme and green certificates scenario are described.

Business as usual scenario

Within the baseline scenario certain variations can be observed across the model results. They are partly caused by the differences in assumptions on resource availability, variations in techno-economic parameters and different timing in technology penetration which influence the technology and fuel choice. Differences in the model type and structure are responsible too.

Most of the models project global final energy demand for 2030 with in the range of 500 to 517 EJ. The models show an increasing share of electricity in final energy demand, although, share varies to some extent from model to model. Oil continues to have the largest share, in the range of 36 to 50% in 2030. Total electricity generation for the year 2030, is more or less comparable for most of the models. Due to the implementation of technology learning which inducing faster cost reduction for the technologies, one model projected a higher electricity generation than the other models in 2050. The other models show variations in electricity generation within the range of 10-12%.

Nearly all models projected coal to have a dominant share in the power generation (see Figure 3). All models project increasing share of natural gas and falling share of hydro in power generation. Three models project relatively rapid increase in renewable share, whereas all models project declining or even disappearing share of oil for power generation. Projections on nuclear electricity generation vary significantly among models.

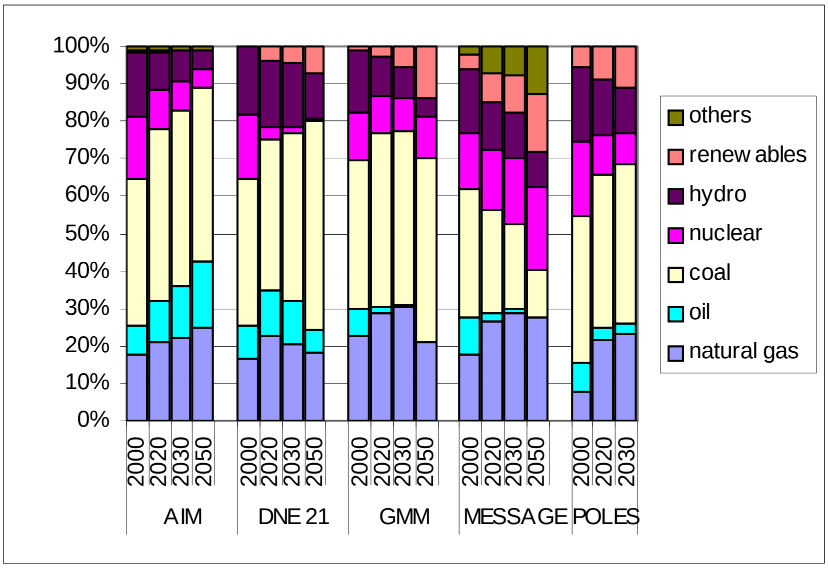

Figure 3: Global baseline power generation mix for various models

Again, detailed model results with respect to electricity provision on the global level are presented in Tables 8 and 9. For the global models, exemplary model results by GMM and POLES show only small differences regarding installed electricity generation capacity and generation, respectively. None of the global models provide either data concerning cost of electricity generation nor CO2 emissions by electricity production.

Table 8: Model results by GMM for baseline scenario, World

Indicator		Fuel	Baseyear	2000	2010	2020	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]				n.a.	n.a.	n.a.	n.a.
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Coal		988.25	1454.47	1972.35	2539.54
		Gas		483.12	590.39	1024.7	1711.98
		Oil		240.1	164.53	94.09	64.12
		Nuclear		307.07	313.3	401.05	471.91
		RES		755.59	847.57	1082	1607.43
	TWh	Coal		6246.5	9220.2	12947.2	17545.5
		Gas		3552.8	4950.1	8093.2	11657.4
		Oil		1121.0	823.6	473.1	213.2
		Nuclear		1998.8	2090.1	2797.7	3437.5
		RES		2731.0	3031.0	3706.9	5213.0
CO_2 Emissions by Electricity Generation [Mt]				n.a.	n.a.	n.a.	n.a.
Share of Domestic Primary Energy Supply [%]				100.00	100.00	100.00	100.00

Table 9: Model results by POLES for baseline scenario, World

Indicator		Fuel	Baseyear	2000	2010	2020	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]				n.a.	n.a.	n.a.	n.a.
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Coal		1095.40	1273.83	1750.35	2479.81
		Gas		595.14	1249.62	2098.21	2898.13
		Oil		386.14	399.06	417.03	421.60
		Nuclear		391.37	402.01	408.70	420.59
		RES		955.05	1336.24	1626.61	2080.37
	TWh	Coal		5433.3	7323.0	10972.6	15552.9
		Gas		1089.9	3082.0	5834.0	8533.2
		Oil		999.0	953.1	923.5	824.7
		Nuclear		2670.5	2811.3	2857.0	2940.7
		RES		3522.6	4930.6	6372.4	8498.4
CO_2 Emissions by Electricity Generation [Mt]				n.a.	n.a.	n.a.	n.a.
Share of Domestic Primary Energy Supply [%]				100.00	100.00	100.00	100.00

Regarding the analyses for Europe, three different models, covering three different regions had been applied. MARKAL-Matters covers OECD Western Europe of 1990, whereas PRIMES represents EU-15. MARKAL-Nordic on the other hand covers the Nordic countries. By comparing exemplary model results for MARKAL-Matters and PRIMES, some deviating developments can be observed. Again, it has to be noticed that both territorial coverage and assumptions on energy technologies had not been harmonized. Figure 3 presents the development of electricity generation in Europe by MARKAL-Matters and PRIMES.

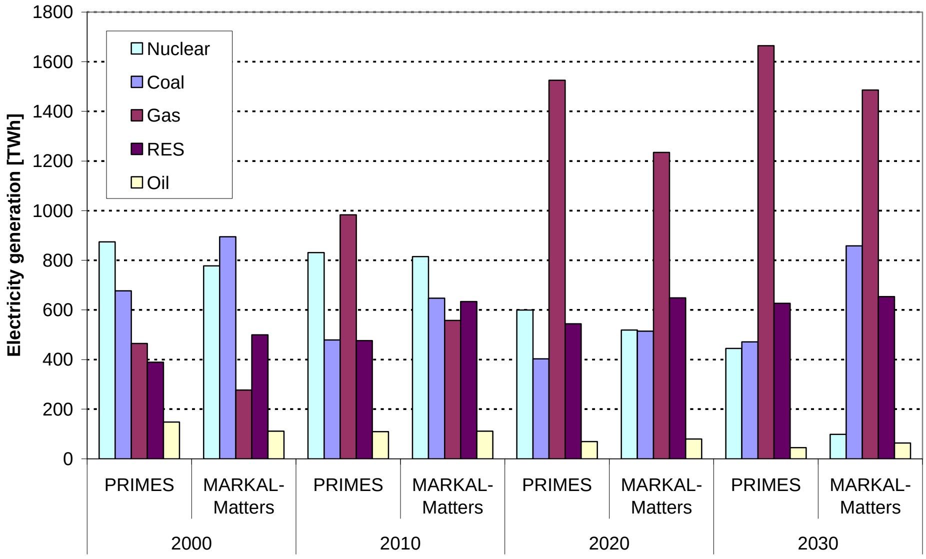

Figure 3: Electricity generation in Europe by MARKAL-Matters and PRIMES

The main differences can be seen in the ratio of electricity generation by nuclear and coal. Whereas PRIMES and MAARKAL-Matters show a nearly constant share of nuclear electricity generation between 2000 and 2010, nuclear is decreasing much faster between 2020 and 2030 in MARKAL-Matters than in PRIMES. The phase-out of nuclear capacities are mainly replaced by coal fired power plants. Tables 10 and 11 present detailed baseline results for MARKAL-Matters and PRIMES.

Table 10: Model results by MARKAL-Matters for baseline scenario, OECD90 - WEU

Indicator		Fuel	Baseyear	2000	2010	2020	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]			28.04	21.70	37.47	42.02	41.25
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Coal	43.26	34.18	21.01	5.84	0.4
		Gas	26.45	45.92	37.13	41.76	31.64
		Oil	67.33	46.87	25.38	12.08	12.08
		Nuclear	118.41	126.66	124.03	78.99	15.09
		RES	168.86	186.19	215.49	218.58	220.44
	TWh	Coal	762.2	894.7	647.2	514.4	857.8
		Gas	118.6	277.0	557.6	1234.8	1486.1
		Oil	180.6	111.1	111.2	79.4	63.5
		Nuclear	701.9	777.8	814.9	519.0	98.8
		RES	455.4	499.2	633.5	648.4	653.4
CO_2 Emissions by Electricity Generation [Mt]			n.a	n.a	n.a	n.a	n.a
Share of Domestic Primary Energy Supply [%]			55.8150	58.1477	50.4807	35.6193	32.0416

Table 11: Model results by PRIMES for baseline scenario, EU-15

Indicator		Fuel	Baseyear	2000	2010	2020	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]			n.a.	56.7	55.5	50.4	54.4
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Coal	n.a.	n.a.	n.a.	n.a.	n.a.
		Gas	n.a.	n.a.	n.a.	n.a.	n.a.
		Oil	n.a.	n.a.	n.a.	n.a.	n.a.
		Nuclear	n.a.	130.1	118.3	88.6	68.3
		RES	n.a.	102.7	131.8	170.2	200.2
	TWh	Coal	696.7	677.1	478.7	403.0	471.4
		Gas	261.5	464.8	982.9	1525.2	1664.4
		Oil	197.2	148.2	109.5	69.6	44.6
		Nuclear	810.1	874.1	831.2	599.4	444.9
		RES	342.7	389.6	476.5	544.0	626.2
CO_2 Emissions by Electricity Generation [Mt]			n.a.	920	942	1002	1027
Share of Domestic Primary Energy Supply [%]			0.5585	0.5382	0.4710	0.3907	0.3496

Renewable portfolio scheme and green certificate scenario

Results from three global models MESSAGE, DNE21 and GMM are compared. Similar to the baseline results, certain variations across the model results are observed which can be explained by the same reasons as listed for the baseline.

The increase in renewables for electricity generation compared to the baseline scenario in the year 2030 is more or less comparable for DNE 21 and MESSAGE (see Figure 4). Assumptions on higher share of renewables together with the endogenous technology learning resulted in faster cost reduction, and therefore much higher penetration of renewables for GMM. Although assumptions on fuel prices are the same (exceptions are MESSAGE and DNE 21), due to the variations in techno-economic parameters, different timing of technology penetration and the availability constraints of renewable resources, patterns of the substitution by additional renewables electricity generation vary at some extent from model to model. DNE21 with its nuclear free future electricity sector, replaces primarily coal by renewables. In case of MESSAGE, substitution by renewables is equally distributed to all conventional sources, natural gas, oil, coal and nuclear.

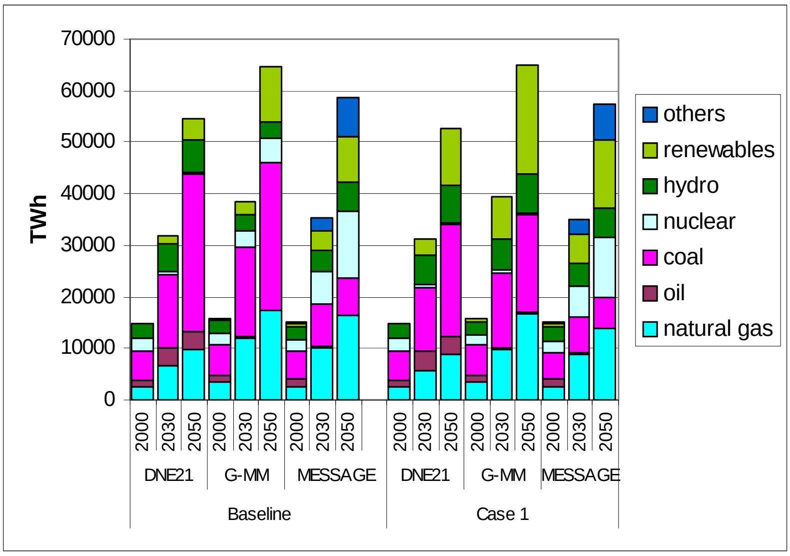

Figure 4: Global electricity generation mix by DNE21, GMM and MESSAGE

The technology mix of renewable sources contributing to the additional generation differs across the models. For DNE 21 and MESSAGE, which have already high hydro contribution in the baseline scenario, there is not much potential left for increasing its share any further. For GMM, large hydro contributes to 34% and 27% respectively, of the incremental generation in 2030 and 2050. All models project large increase in generation from bio energy. DNE 21 which has a low wind baseline generation, projects a large increase in wind generation especially in 2050. DNE21 keeps solar out from electricity generation in both the baseline as well as the renewable scenario. GMM projects a large increase of solar, whereas the use of solar is low in the baseline. A large increase in geothermal is only projected by GMM, while the other models project only a low contribution to power generation.

Focusing on Europe, the results of MARKAL-Matters and PRIMES show similar results for the renewables scenario, due to its similar territorial coverage. Both models show reduction in coal based generation over the baseline development about 8 to 10% in 2020 and about 17 to 20% in 2030. They showed large impact on gas based generation, reduction is about 25% in 2020 and in the range of 27 to 32% in 2030. While MARKAL-MATTER does not show any impact on nuclear, PRIMES projects a reduction in nuclear respectively by 8% and 28% over the baseline in 2020 and 2030. Figure presents the development of electricity generation by energy source for PRIMES and MARKAL-Matters in the renewable scenario.

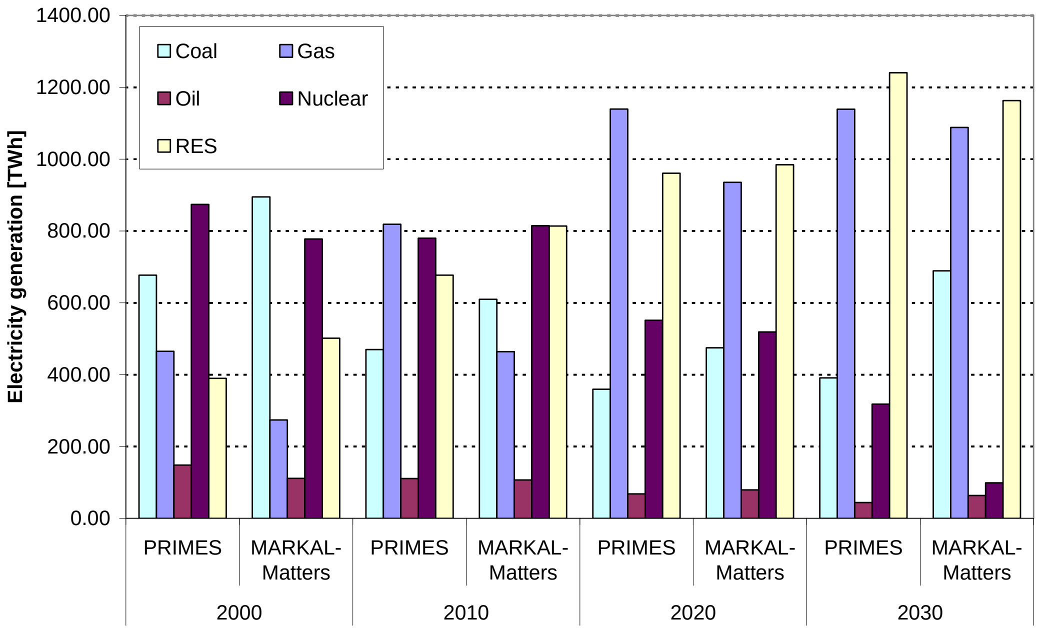

Figure 5: Electricity generation in Europe by MARKAL-Matters and PRIMES in the renewable scenario

Tables 12 and 13 present detailed model results for MARKAL-Matters and PRIMES regarding cost of electricity generation, development of installed generation capacity and generation by source, CO2 emissions of electricity production as well as the share of domestic primary energy supply. Considering the differences in territorial coverage and technological assumption, main deviations can be observed for cost of electricity generation, where MARKAL-Matters calculates only 42.39 Euro/MWh, whereas PRIMES calculates 58 Euro/MWh in the year 2030. Among other things, these differences are induced by differences in the electricity generation mix. As MARKAL-Matters shows a electricity generation of approximately 690 TWh by coal and 64 TWh by oil, PRIMES projects only 390 TWh by coal and 44 TWh by gas in 2030. Nuclear generation is projected to be approximately 99 TWh, whereas gas is projected to contribute 1090 TWh within the generation mix in MARKAL-Matters for the year 2030. PRIMES projects 918 TWh of nuclear and 1140 TWh of gas based electricity generation. The electricity generation by renewable energy sources in 2030 shows only small differences with approximately 1160 TWh for MARKAL-Matters and 1240 TWh for PRIMES.

Table 12: Model results by MARKAL-Matters for renewables scenario, OECD90 - WEU

Indicator		Fuel	Baseyear	2000	2010	2020	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]			28.04	21.66	33.50	34.32	42.39
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Coal	43.26	34.18	21.01	5.84	0.4
		Gas	26.45	45.92	35.87	70.13	64.98
		Oil	67.33	46.87	25.38	12.08	12.08
		Nuclear	118.41	126.66	124.03	78.99	15.09
		RES	168.86	187.19	280.42	334.31	400
	TWh	Coal	763.98	895.04	609.81	474.91	689.36
		Gas	118.59	273.91	464.24	935.52	1088.23
		Oil	180.56	111.11	106.84	79.39	63.53
		Nuclear	701.94	777.78	814.88	518.96	98.78
		RES	701.94	501.46	814.08	984.37	1163.06
CO_2 Emissions by Electricity Generation [Mt]			n.a	n.a	n.a	n.a	n.a
Share of Domestic Primary Energy Supply [%]			55.82	58.21	52.20	39.56	38.03

Table 13: Model results by PRIMES for renewables scenario, EU-15

Indicator		Fuel	Baseyear	2000	2010	2020	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]			n.a.	56.7	56.6	53	58.7
Installed Electricity Generation Capacity and Production in Europe by Fuel	GW_e	Coal	n.a.	n.a.	n.a.	n.a.	n.a.
		Gas	n.a.	n.a.	n.a.	n.a.	n.a.
		Oil	n.a.	n.a.	n.a.	n.a.	n.a.
		Nuclear	n.a.	130.1	118.3	86.6	50.1
		RES	n.a.	102.7	201.1	276.9	348.6
	TWh	Coal	696.74	677.10	469.84	359.74	391.33
		Gas	261.47	464.84	818.83	1139.38	1139.00
		Oil	197.24	148.21	111.04	68.18	44.17
		Nuclear	810.12	874.10	780.19	551.33	318.16
		RES	342.70	389.60	676.96	961.10	1240.75
CO_2 Emissions by Electricity Generation [Mt]				920	880	837	806
Share of Domestic Primary Energy Supply [%]			0.5585	0.5382	0.4882	0.4336	0.4081

II. Model Review

Within the ACROPOLIS study fifteen energy models, both bottom-up as well as top-down models had been applied. Due to the modeling approach, the bottom-up models focus mainly on energy systems covering a wide range of current and future energy technologies. In top-down models usually abstract from specific technological options, focusing mainly on feedbacks within the economy, e.g. policy induced income and GDP changes as well as impact of price changes on welfare.

Most of the various models cover different countries, regions or even one world region. The specific representation of the energy system, regarding specification of energy technologies differs from model to model, thus making the comparison of model results more difficult. Table 14 presents the characteristics of the models. The time horizon covered is at least 2020/2030, some of the models have looked beyond that time frame up to 2100.

Table 14: Model characteristics

Type	Model	Geographical coverage	Regions	Type	Institution
Global	AIM	World	21	CGE	NIES, Japan
	DNE 21	World	10	IAM	RITE, Japan
	GEM-E3	World	21	CGE	NTUA, Greece
	GMM	World	5	LP-MACRO	PSI, Switzerland
	MESSAGE	World	5	LP-MACRO	IIASA, Austria
	NEWAGE	World	13	CGE	IER, Germany
	POLES	World	38	Simulation	IPTS, Spain
Regional	MARKAL-MATTER	Western Europe	1	LP	ECN, Netherlands
	MARKAL-Nordic	Nordic region	4	LP	EST, Sweden
	PRIMES	EU countries	15	Market equilibrium	NTUA, Greece
National	MARKAL-MACRO-IT	Italy	1	LP-MACRO	ENEA, Italy
	MARKAL-Canada	Canada	1	LP	GERAD, Canada
	NEMS	USA	5-32	Simulation	EIA, USA
	TIMES	Germany	2	LP	IER, Germany
	NEV	Netherlands	1	Simulation	ECN, Netherlands

The Asian-Pacific Integrated Model (AIM) is a large-scale computer simulation model developed by the National Institute for Environmental Studies in collaboration with Kyoto University. The AIM model assesses policy options for reducing greenhouse gas emissions and avoiding impacts of climate change, particularly in the Asia-Pacific region. It can also be used for analysis at the global level. The period of analysis can be medium-term (up to 30 years) to long-term (up to 100 years). The original AIM is an integrated 'top-down and bottom-up' model and comprises an emission model, a climate model and an impact model. The emission model consists of a module on energy efficiency improvement, a module on energy service and a technology selection module for regional models. For the global emission model AIM uses mainly a general equilibrium model with higher sectoral aggregation while regional models, which are applied only for Asia, have detailed representation of energy service and technology. The climate model is developed to link emission and impact models. The impact model contains a spatial water balance model, an ecological model and a health impact model. It is used to estimate the increased risks of droughts, floods, vegetation changes and malaria.

Dynamic New Earth 21 (DNE21) model is a 10-region world model of optimization type, into which Energy Systems, Macro-economic and Climate Change modules are integrated, and its time horizon is 2000 to 2100.

GEM-E3World is an applied general equilibrium model, covering the world (separated in 21 regions), which provides details on the macro-economy and its interaction with the environment and the energy system. It is an empirical, large-scale model, written entirely in structural form. The model computes the equilibrium prices of goods, services, labour and capital that simultaneously clear all markets under the Walras law. In brief, the model can be characterised as follows:

1 GEM-E3 is a multi-country model, treating separately each region and linking them through endogenous trade of goods and services.
2 GEM-E3 includes multiple industrial sectors and economic agents, allowing the consistent evaluation of distributional effects of policies.
3 GEM-E3 is a multi-period model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and backward looking expectations.

In addition, the model covers the major aspects of public finance including all substantial taxes, social policy subsidies, public expenditures and deficit financing, as well as policy instruments specific for the environment/energy system.

The model determines the optimum balance of energy demand and supply, atmospheric emissions and pollutant abatement, simultaneously with the optimising behaviour of agents and the fulfilment of the overall equilibrium conditions. In this sense, the model analyses the interactions between the economy, the energy and the environment systems.

The results of GEM-E3 include projections of full input-output tables by country, national accounts, employment, and capital flows, balance of payments, public finance and revenues, household consumption, energy use and supply, and atmospheric emissions. The computation of equilibrium is simultaneous for all domestic markets of all 21 regions and foreign trade links.

A major aim of GEM-E3 in supporting policy analysis, is the consistent evaluation of distributional effects, across countries, economic sectors and agents. The burden sharing aspects of energy supply and environmental protection are fully analysed, while ensuring that the World economy remains at a general equilibrium condition.

The *Global MARKAL Model (GMM)* is a multi-regional, partial equilibrium "bottom-up" engineering model of the energy system that incorporates endogenous technological learning with spillovers across technologies and world regions. GMM includes sufficient technological details for being able to address the question of how policies can foster the development of new technologies and their subsequent deployment.

GMM considers five world regions: Two regions represent the industrialized countries: North America (NAM) and the rest of the countries belonging to the OECD in 1990 (OOECD). OOECD comprises Western Europe and the so-called Pacific OECD region (which includes Japan, Australia and New Zealand). One region represents the economies-in-transition, putting together the Former Soviet Union and Eastern Europe (EEFSU). The developing world is grouped in two additional regions. Developing countries in Asia are included in the ASIA region. ASIA comprises centrally planned Asia, South East Asia and Pacific Asia. The rest of the world is covered in the LAFM region, which includes Latin America, Africa and the Middle East.

There are six end-use demand sectors in the GMM model. Industrial and residential & commercial sectors are divided into thermal and electric uses. The transportation sector merges together passenger and freight transport means. Finally, the non-commercial use of biomass and non-energy feedstock is represented. In each of the demand sector, a set of generic end-use devices is defined. Assumptions concerning energy intensity and energy demand projection per region and demand category are trend extrapolation of the past performance on autonomous declining energy intensity together with a consideration of regional income and price elasticises. The demand projections and potentials for fossil fuel and renewable resources correspond to those of the characterization of the SRES-B2 storyline. The model horizon is 1990-2050 while a discount rate of 5% is applied to all calculations.

The supply sector is represented with some detail. Technologies for the production of electricity, heat and a variety of final fuels (oil products, alcohol, hydrogen, natural gas) from several fossil and non-fossil sources are included, as well as the corresponding transmission and distribution (T&D) chains. Investment, fixed O&M and variable O&M costs are considered for all the different supply technologies.

GMM is addressing technology dynamics in energy-systems models focusing on technological learning, a key driving force of technological progress. A typical learning curve describes the specific cost of a given technology as a function of the cumulative capacity, a proxy for the accumulated experience. Thus, it reflects the fact that some technologies may experience declining costs due to learning-by-doing. Endogenisation of the technological learning (ETL) enables the modeller to analyse how the specific investment cost of a “learning” technology declines with accumulated installed capacity of the respective technology.

The GMM model version used for this analysis applies the ETL option in combination with a partial equilibrium algorithm that adjusts demands for energy services to the increased marginal cost of services due to the imposition of a policy constraint. The energy end-use demands are not fixed, but they are elastic to their own prices, endogenously computed by the model in the Baseline, and self-adjusted if modified scenario conditions affect the prices. Each time an alternative set of policy assumptions is simulated, the model clears the energy markets by maximizing the producers and consumers surplus.

Additionally, the GMM model allows simulation of the global trade of selected energy or environmental commodities (e.g. fuels, electricity, emission permits), and defines a shadow price of the commodity globally traded among regions.

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) is a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development. The model provides a framework for representing an energy system with all its interdependencies from resource extraction, imports and exports, conversion, transport, and distribution, to the provision of energy end-use services such as light, space conditioning, industrial production processes, and transportation. The model’s current version, MESSAGE IV, has full global coverage, spatially disaggregated into eleven macro regions. The model provides information on the utilization of domestic resources, energy imports and exports and trade-related monetary flows, investment requirements, the types of production or conversion technologies selected (technology substitution), pollutant emissions, inter-fuel substitution processes, as well as temporal trajectories for primary, secondary, final, and useful energy. MESSAGE can be coupled with a macroeconomic model (MACRO) to assess GDP losses of policies.

NEWAGE-World (National European Worldwide Applied General Equilibrium) is a global CGE-Model separated in thirteen regions. The economic structure of each region consists of four production sectors, one non-energy sector and three fossil fuel sectors traded internationally for coal, gas and oil.

A country-specific price for coal and natural gas is defined by supply and demand in every region, but world supply and world demand determine the world price of oil. The energy prices of each country include taxes and subsidies. One carbon free backstop energy carrier is treated as a perfect substitute for the three fossil fuels. It is available in infinite supply at one price. This price is assumed to be a multiple of the world oil price in the benchmark year. So it establishes an upper bound on the world oil price.

The composite energy good is produced by fossil fuels (coal, gas and oil) through a nested CES technology. The input of the backstop resource is mapped by a Leontief production function. The production of the aggregated non-energy macro good is represented by a nested CES production technology. Inputs are labor, capital and the composite energy good. A CES transformation function determines the division of the macro good either for domestic use or for export.

There is a distinction between the energy good, which is produced for the industry and the one, which meets the demand of the households. A representative agent performs final demand. This is composed of a consumption good – an aggregate between imports and domestically produced goods – and the energy good. Households purchase final demand by their endowments of labor, capital, energy specific resources and revenues from taxes or the sale of emission permits.

International trade is based on the assumption of an Armington structure: Imports are not perfect substitutes for the domestically produced good. International trade is admitted for energy as well as for the composite non-energy good. In the model the regions buy and sell one homogenous oil good in the world market. International capital flows reflect borrowing and lending at a world interest rate. They are determined endogenously subject to an intertemporal balance of payments considering no changes in net indebtedness over the entire model horizon.

NEWAGE-W covers a time perspective till 2030. It describes a Ramsey dynamic structure. For each region a perfect foresight possessing representative agent maximizes the discounted utility over the entire time horizon and the investment behavior is fully forward-looking. The return on investment is balanced against the cost of capital. Primary factor inputs such as capital and energy yield the output of period t. Output is used for the consumption and investment. Investment augments the capital stock in the next period. Primary factors provide incomes, which can either be spend for the consumption or saving. Saving equals investment according to the identity, which is assumed generally in economic theory.

The *POLES* model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation up to the year 2030 and a partial equilibrium framework. Developed under EU research programmes, the model is fully operational since 1997.

The POLES model structure corresponds to a hierarchical system of inter-connected modules and involves three levels of analysis: (i) International energy markets; (ii) Regional energy balances; (iii.) National/regional models (currently 38) on energy demand, new technologies and renewable energy, power generation, primary energy supply and CO2 emissions.

The dynamics of the model is based upon a recursive simulation process, in which energy demand and supply in each national or regional module respond with different lag structures to international prices variations in the preceding periods. In each module, behavioural equations take into account the combination of price effects, technico-economic constraints and trends.

There are fifteen final energy demand sectors (covering the main industrial branches, transport modes, the residential and service sectors), twelve large-scale power generation technologies and twelve new and renewable energy technologies.

Oil and gas supply profiles in the largest world producing countries are dealt with a discovery process model in which oil and gas production depends on the dynamics of the drilling activity and discovery of new reserves, given the existing resources and the cumulative production. Coal supply is essentially demand driven.

The integration of import demand and export capacities of the different regions are ensured in the international energy market module, which balances the international energy flows. One world market is considered for oil (the ‘one great pool’ concept), while three regional markets (America, Europe/Africa, and Asia) are identified for gas and coal so as to account for regional differences in cost and market structures. The changes in international prices of oil, gas and coal are determined endogenously in this module.

The *MARKAL-MATTER* is a linear programming optimisation model that identifies the least-cost combinations of technological processes and improvement options that satisfy a specified level of demand for goods and services under certain policy constraints, notably the achievement of certain specified GHG reduction objectives, in a way that the overall system costs are minimised over all the time periods simultaneously. This is done for a part of the economy, whereby certain parameters have to be provided from outside the model.

In MARKAL-MATTER, both the energy and materials flows of an economic system are covered by including information on the physical production processes, economic costs and other characteristics – such as waste volumes or GHG emissions – of all major energy carriers, materials and end-use products. As the energy and materials systems are intricately interwoven, such an integrated approach offers the advantage that the interdependencies between these systems can be analysed comprehensively by means of a formalised model, thereby reducing analytical shortcomings and misguided policy choices. Moreover, by adding materials flows to the model, the number of technological (improvement) options is expanded strongly, thereby enlarging the scope of policy options to reach objectives such as GHG mitigation more cost-effectively.

The *MARKAL_Nordic* model covers Denmark, Finland, Norway and Sweden. The model is a bottom-up model with cost being the objective function. Both price of energy and the energy demand are given exogenously, while the final energy demand is a model output. The driver of the model is useful energy which depends on assumptions regarding GDP, population growth and energy intensity.

In the model, electricity may be traded freely between the countries. The transport sector is only represented through electricity demand from railways. The load curve for electricity is divided into three seasons, each with day and night, while the load curve for district heat is only divided into three seasons without diurnal representation. Other energy carriers are not affected by seasonal cost variations. In Finland, in contrast to Sweden, investment in new nuclear capacity is allowed.

The *PRIMES* energy system model has been developed in the context and with the financial assistance of a series of research programmes of the European Commission. The model has been successfully peer reviewed in the framework of the European Commission in 1997. From the very beginning, in 1993-1994, the PRIMES energy model was designed to focus on market-related mechanisms influencing the evolution of energy demand and supply and the context for technology penetration in the market. The PRIMES model also was designed to serve as an energy policy analysis tool including the relationships between energy policy and technology assessment.

The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply matches the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships.

The model is behavioural but it also represents in an explicit and detailed way the available energy demand and supply technologies and pollution abatement technologies. The system reflects considerations about market economics, industry structure, energy/environmental policies and regulation. These are conceived so as to influence market behaviour of energy system agents. The modular structure of PRIMES reflects a distribution of decision making among agents that decide individually about their supply, demand, combined supply and demand, and prices. Then the market integrating part of PRIMES simulates market clearing.
The PRIMES model is a general-purpose model. It is conceived for forecasting, scenario construction and policy impact analysis. It covers a medium to long-term horizon. It is modular and allows either for a unified model use or for partial use of modules to support specific energy studies.

The applied version of PRIMES (Version 2) here is fully operational and calibrated on 2000 dataset for all European Union Member States. Since March 2003 the model has also been developed and is fully operational and calibrated on a 2000 dataset for EU candidate countries, Norway and Switzerland.

The *MARKAL Italy* technical - economic model of the energy system covers the four main sectors of the energy system (agriculture, industry, transport, commercial and households), each subdivided in several sub sectors, mainly based on their energy or material dependency and importance. For instance, the industrial sector is split in the following sub-sectors: Paper, Chemical, Building, Mechanical, Iron and steel, Textile and others. Some sub-sector is split by branch or main energy consumption services. The MARKAL-Italy model has a very detailed Reference Energy system: there are over 70 independent demand for energy services, about 250 flows of energy goods and services, about 250 real or dummy flows of materials, about 1000 real or dummy technologies (including 50 power plants).

Emissions of NOx, SO2, VOC are bounded (by sector and as total), CO2 emissions are accounted for and may become an objective function. The model represents the domestic energy system and its main environment emissions from 1990 to 2030, evaluates energy consumption and the potential for emissions reduction of CO2, NOx , SOx and VOC and related costs. In recent years it has been used to set up reference scenarios for the National Conference on Energy and Environment (1998), to assess effectiveness and impact of different carbon tax schemes, to verify the mitigation scenarios of the third national communication to UNFCCC, to prepare scenarios to be used by the RAINS model at IIASA.

The update version includes actual power plants by type and size, actual fuel levies and presently available renewable supply, end use efficiency and mitigation technologies, prescribes mandatory EC sulphur levels of fossil fuels, domestic and European sulphur and nitrogen emission limits to 2010, green and white certificates instruments.

The MARKAL-MACRO model used in these scenario calculations is a combination of the energy system model MARKAL and a long-term macroeconomic growth model MACRO. MARKAL-MACRO is a dynamic, neoclassical, applied general equilibrium model. The linkage between MARKAL and MACRO is based upon the concept of an economy-wide production function. The integrated model, which simultaneously solves for energy and economic components using non-linear optimisation, is able to analyse separately price-induced energy conservation and autonomous energy efficiency improvements.

Contrary to several bottom-up programming economic equilibrium models, the MARKAL-MACRO-Italy model reproduces the statistical values in three time periods. Therefore the results appear quite robust in the near term (2010) and make interesting the comparison with scenarios coming out of comparable exercises.

The *National Energy Modeling System (NEMS)* was used to assess the impact of technology policies on U.S. energy markets. The primary purpose of NEMS is to analyze the energy-related consequences to the United States of alternative energy policies or pertinent economic or energy market influences. The policy questions of interest have determined the level of detail required within the structure of NEMS. For example, environmental issues relating to energy production and consumption have taken on a new importance with the implementation of the Clean Air Act Amendments (CAAA) of 1990 and the proposed Kyoto agreement of December 1997 on greenhouse gases. Accordingly, NEMS is designed to measure seven emissions (oxides of sulfur, oxides of nitrogen, carbon, carbon monoxide, carbon dioxide, volatile organic compounds and mercury) released in the use of energy products to generate electricity and, in the case of carbon (or carbon dioxide), constrain national emissions using a pricing mechanism. The technology representation in NEMS is particularly helpful in the analysis of national carbon mitigation policies and utility sector SOx, NOx, and mercury mitigation policies because of its explicit representation of vintaged (time-dependent) energy equipment and structures (e.g., building shells) and the careful tracking of vintaged capital stock turn-over rates. For similar reasons, NEMS contains sufficient detail in the transportation sector to project the use of alternative or reformulated fuels like compressed natural gas, ethanol, methanol, electric, etc. In addition to environmental concerns, NEMS is designed to account for existing and emerging government regulations (e.g., electricity restructuring), the potential for the development and use of new energy-related technologies, the increased use of renewable sources of energy (especially intermittent technologies), and the potential for demand side management, conservation, and increases in the efficiency of energy use. These topics reflect the expected scope of present and future government policy.

The NEMS representation of energy markets focuses on four important interrelationships: (a) interactions among the energy supply, conversion and consumption sectors, (b) interactions between the domestic energy system and the general domestic economy, (c) interactions between the U.S. energy system and world energy markets, and (d) the interaction between current production and consumption decisions and expectations about the future.

NEMS incorporates a market-based approach to energy analysis. It balances the supply of and demand for energy for each fuel and consuming sector, taking into account the economic competition between energy sources.

NEMS is partitioned into a modular system, which is solved by applying the Gauss-Seidel convergence method with successive over-relaxation. The modules of NEMS represent each of the fuel supply markets, conversion sectors, and end-use consumption sectors, and also include interactive macroeconomic and international modules. The primary flows between these modules are the delivered prices of energy and the energy quantities consumed by product, region, and sector, but include other information such as economic activity and technology characteristics. The delivered prices of fuels incorporate all the activities necessary to produce, import, and transport fuels to the end user.

The integrating methodology controls the independent execution of the component modules. The modules are executed from the integrating module, and, to facilitate modularity, the components do not pass information to each other directly but communicate through a central data file. This modular design provides the capability to execute modules individually or to substitute alternative modules, thus allowing decentralized development of the system and independent analysis and testing of individual modules. Furthermore, this modularity allows the flexibility to use the methodology and level of detail that is most appropriate to represent each energy sector.

A solution is achieved by equilibrating on the delivered prices and quantities of energy demanded, thus assuring an economic equilibrium of supply and demand in the consuming sectors. Each fuel supply, conversion, or end-use demand module is called in sequence by the integrating module and solved, assuming that all other variables in the other energy markets are fixed. For example, when solving for the quantities of fuels demanded in the residential sector for an input set of energy product prices, all other sectors of the economy are held fixed. The modules are iteratively called until successive end-use prices and quantities remain constant within a specified tolerance. This equilibration is achieved annually through the midterm period to 2020 [for AEO2002] and 2025 [AEO2003]. The NEMS system reflects market economics, industry structure, and energy policies and regulations that influence market behaviour.

NEMS consists of four supply modules (oil and gas, natural gas transmission and distribution, coal, and renewable fuels), two conversion modules (electricity and petroleum refineries), four demand modules (residential, commercial, transportation and industrial sectors), one module to simulate energy/economy interactions (macroeconomic activity), one to simulate world energy/domestic energy interactions (international energy activity), and one model to provide the mechanism to achieve a general market equilibrium among all the modules (the integrating module). The interested reader is referred to the model documentation reports for their descriptions on the EIA internet site.

TIMES (The Integrated Markal Efom System) is a new mathematical modelling scheme for representing, optimizing and analyzing energy systems on local, regional, national and global scales. It follows a so-called bottom-up system engineering approach, which allows a detailed technical description of the energy system by equalities and inequalities. TIMES has been developed over the last two years by a working group including IER under the auspices of the International Energy Agency (IEA) within the Energy Technology Systems Analysis Programme (ETSAP).

TIMES is based on the concept of Reference Energy System (RES). The RES describes the energy system as a network of processes and commodities being interconnected by flows of commodities. One characteristic aspect of a RES of a country or a region is that in most cases a process does not depict a single plant, but rather an entire technology type being available in the energy system. Another typical feature of a RES is that it may contain technologies that are not yet utilized in the real-world system.

TIMES establishes out of the RES abstraction, a core of mathematical formulas considering the following relationships:

1 Mass or energy balances for the commodities.

2 Transformation equations for a process relate the input to the output flows. The possibility of specifying fuel and process dependent efficiencies enables a flexible process description avoiding the need for dummy processes as used in MARKAL.

3 Capacity-activity relationships limit activities of processes by their available capacities.

4 A generic equation framework allows the generation of non-standard, user-defined equations; e.g. a dynamic constraint limits the investment in a new technology for the current period to a percentage of the existing capacity of the previous period.

5 Bounds can be set on variables of process input and output flow.

The design of TIMES is based on the “reference technology” concept, where costs and emission factors from different technologies are used in the modelling process. Thus, the cost of abatement can be estimated as a function of a movement between technologies from older, less expensive but more polluting technologies towards newer, cleaner, more expensive technologies. These abatement costs feed into the modelling process for energy supply and energy demand.

The German energy system model is demand driven and technology-intensive. GDP, population, heated living space requirement per person, freight kilometre demand etc. are the basic driving forces to determine the energy demand by sectors. Given a set of technological options to meet supply and demand along with assumptions on energy prices and resource availabilities, model optimises the total energy system costs to meet the sectoral energy demand (partial equilibrium modelling approach). Demand sector consists of industry, commercial, household and transport sectors, where as the sectors are further divided in sub-sectors. Supply side of the model considers all energy conversion levels i.e. the technologies of electricity and heat production. Conversion technologies are further divided in type of generation technology, plant size and operation time.

Year 2000 is assumed as base year and model horizon is up to 2050 with five years taken as each model period. Discount rate of 5% has taken in this model for calculation of economic parameters. Substantial basis for the base scenario development till 2020 is the scenario of Prognos for the Energy Report III of the Federal Ministry of Economics (BMWi). Total population approximately remains same in the year 2010 as base year. Population growth rate follows decline in trend after period 2010 onwards. It declines approximately 1.46% in 2020 and 17.32% in the year 2050 of the base year. GDP/capita increases from the year 2000 to 2050 and is highest in the year 2050 i.e. 150% increase of base year.

Additionally, attempt has been made to include existing obstacles or supporting measures as far as possible in base scenario calculation. The German government has adopted a few regulations for climate protection and energy supply security. The following ones are considered in the baseline scenario. The production of nuclear energy will be phased out during the following decades. The use of domestic steam coal for electricity production will decline considerably in future and the use of domestic lignite also. Electricity production from renewable energy sources and CHP plants will be subsidised by a specified reimbursement program. Efficiency improvement programmes for buildings will be carried out for old buildings. A self commitment of the German and the European car industry to reduce specific fuel consumption will be considered.

2.5 SAPIENT: System Analysis for Progress and Innovation in Energy Technologies

ICCS/NTUA

The study and scenario review for SAPIENT has been made available in form of numerical result sheets.

Study:	SAPIENTIA baseline scenario
Scenario:	
Country / Region:	EUROPE 15 + Norway + Switzerland
Baseyear:	2002
Models:	PROMETHEUS
Institution:	ICCS/NTUA
Name of author:	
Date:	

Indicator		Fuel		Baseyear	2030	2050
Industrial consumer electricity price [$Euro_{2000}$/MWh]						
	Mean			65.68	68.49	70.75
	Median			-	67.48	68.94
	Standard Deviation			-	12.12	15.47
	Value to be exceeded with 95% probability			-	50.55	49.24
	Value to be exceeded with 5% probability			-	88.97	98.29
Installed Electricity Generation Capacity and Production in Europe by Fuel	**GW_e**	**Coal (including CO2 capture and seq.)**				
			Mean	133.76	146.40	157.79
			Median	-	136.65	146.48
			Standard Deviation	-	49.52	62.96
			Value to be exceeded with 95% probability	-	82.10	74.19
			Value to be exceeded with 5% probability	-	240.39	277.70
		Gas (including CO2 capture and seq.)				
			Mean	128.83	187.51	130.75
			Median	-	180.39	118.47
			Standard Deviation	-	48.31	45.96
			Value to be exceeded with 95% probability	-	124.88	83.06
			Value to be exceeded with 5% probability	-	270.65	223.54
		Oil				
			Mean	60.30	18.51	7.56
			Median	-	17.54	6.94
			Standard Deviation	-	3.67	2.44
			Value to be exceeded with 95% probability	-	15.43	5.72
			Value to be exceeded with 5% probability	-	24.59	11.16
		Nuclear				
			Mean	125.94	114.00	145.08
			Median	-	98.30	118.80
			Standard Deviation	-	44.45	84.45
			Value to be exceeded with 95% probability	-	75.05	61.06
			Value to be exceeded with 5% probability	-	205.23	303.82
		RES (including large hydro)				
			Mean	198.90	497.52	770.37
			Median	-	475.84	718.30
			Standard Deviation	-	165.24	294.55
			Value to be exceeded with 95% probability	-	273.17	401.42
			Value to be exceeded with 5% probability	-	810.68	1333.85
	TWh	**Coal**				
			Mean	641.26	970.42	1125.74
			Median	-	907.91	1044.10
			Standard Deviation	-	364.59	466.12
			Value to be exceeded with 95% probability	-	501.70	511.62
			Value to be exceeded with 5% probability	-	1662.39	2011.43
		Gas				
			Mean	524.75	835.72	569.95
			Median	-	790.82	519.27
			Standard Deviation	-	228.82	185.80
			Value to be exceeded with 95% probability	-	548.67	382.18
			Value to be exceeded with 5% probability	-	1216.84	940.29
		Oil				
			Mean	211.38	64.81	26.48
			Median	-	61.44	24.29
			Standard Deviation	-	12.81	8.53
			Value to be exceeded with 95% probability	-	54.06	20.05
			Value to be exceeded with 5% probability	-	86.03	39.03
		Nuclear				
			Mean	925.34	837.37	1053.16
			Median	-	722.02	861.88
			Standard Deviation	-	326.53	606.45
			Value to be exceeded with 95% probability	-	551.23	447.70
			Value to be exceeded with 5% probability	-	1507.87	2202.65
		RES				
			Mean	605.41	1275.70	1747.32
			Median	-	1245.93	1669.03
			Standard Deviation	-	320.59	547.82
			Value to be exceeded with 95% probability	-	802.79	1018.15
			Value to be exceeded with 5% probability	-	1866.27	2775.74
CO_2 Emissions by Electricity Generation [Mt] (substracting CO2 captured)						
			Mean	988.23	1040.51	908.03
			Median	-	995.04	861.94
			Standard Deviation	-	260.41	344.49
			Value to be exceeded with 95% probability	-	690.43	432.13
			Value to be exceeded with 5% probability	-	1555.11	1540.29
CO_2 Emissions captured in Electricity Generation [Mt]						
			Mean	0.00	62.94	155.27
			Median	-	43.64	118.74
			Standard Deviation	-	60.63	129.56
			Value to be exceeded with 95% probability	-	6.39	21.65
			Value to be exceeded with 5% probability	-	183.87	409.77
Carbon value in Euro2000 per tn of CO2						
			Mean	0.00	34.54	58.42
			Median	-	30.34	47.69
			Standard Deviation	-	29.40	51.13
			Value to be exceeded with 95% probability	-	0.00	0.00
			Value to be exceeded with 5% probability	-	89.63	156.80
Share of Domestic Primary Energy Supply [%]				-	-	-

Study:	SAPIENTIA "High R&D" scenario (doubling government and bussiness energy R&D from 2006 to 2025)
Scenario:	
Country / Region:	EUROPE 15 + Norway + Switzerland
Baseyear:	2002
Models:	PROMETHEUS
Institution:	ICCS/NTUA
Name of author:	
Date:	

Indicator	Fuel	Baseyear	2030	2050
Industrial consumer electricity price [$Euro_{2000}$/MWh]				
Mean		65.68	65.54	67.82
Median		-	64.38	66.40
Standard Deviation		-	11.59	15.19
Value to be exceeded with 95% probability		-	48.19	46.70
Value to be exceeded with 5% probability		-	85.54	94.39
Installed Electricity Generation Capacity and Production in Europe by Fuel – **GW_e**	**Coal (including CO2 capture and seq.)**			
	Mean	133.76	146.15	151.10
	Median	-	136.65	139.77
	Standard Deviation	-	49.64	61.18
	Value to be exceeded with 95% probability	-	81.46	71.27
	Value to be exceeded with 5% probability	-	237.78	268.19
	Gas (including CO2 capture and seq.)			
	Mean	128.83	187.68	127.35
	Median	-	179.78	115.87
	Standard Deviation	-	48.81	43.51
	Value to be exceeded with 95% probability	-	124.90	82.69
	Value to be exceeded with 5% probability	-	269.44	214.77
	Oil			
	Mean	60.30	18.41	7.49
	Median	-	17.46	6.89
	Standard Deviation	-	3.58	2.31
	Value to be exceeded with 95% probability	-	15.40	5.70
	Value to be exceeded with 5% probability	-	24.41	11.13
	Nuclear			
	Mean	125.94	113.39	153.88
	Median	-	99.01	127.09
	Standard Deviation	-	42.72	92.82
	Value to be exceeded with 95% probability	-	75.54	62.56
	Value to be exceeded with 5% probability	-	201.94	327.18
	RES (including large hydro)			
	Mean	198.90	537.70	822.23
	Median	-	516.44	769.46
	Standard Deviation	-	175.07	313.27
	Value to be exceeded with 95% probability	-	299.56	426.11
	Value to be exceeded with 5% probability	-	871.43	1426.86
Installed Electricity Generation Capacity and Production in Europe by Fuel – **TWh**	**Coal**			
	Mean	641.26	970.13	1077.53
	Median	-	903.84	995.51
	Standard Deviation	-	366.11	453.34
	Value to be exceeded with 95% probability	-	501.14	489.01
	Value to be exceeded with 5% probability	-	1659.19	1944.55
	Gas			
	Mean	524.75	837.98	557.46
	Median	-	793.14	511.02
	Standard Deviation	-	232.64	176.52
	Value to be exceeded with 95% probability	-	550.50	381.40
	Value to be exceeded with 5% probability	-	1220.95	904.62
	Oil			
	Mean	211.38	64.48	26.21
	Median	-	61.16	24.12
	Standard Deviation	-	12.48	8.05
	Value to be exceeded with 95% probability	-	53.98	19.97
	Value to be exceeded with 5% probability	-	85.42	38.91
	Nuclear			
	Mean	925.34	832.58	1113.10
	Median	-	727.17	923.27
	Standard Deviation	-	313.53	661.34
	Value to be exceeded with 95% probability	-	554.87	457.65
	Value to be exceeded with 5% probability	-	1483.35	2337.06
	RES			
	Mean	605.41	1336.19	1771.82
	Median	-	1308.62	1694.95
	Standard Deviation	-	331.21	550.48
	Value to be exceeded with 95% probability	-	849.75	1036.11
	Value to be exceeded with 5% probability	-	1946.81	2770.12
CO_2 Emissions by Electricity Generation [Mt] (substracting CO2 captured)				
	Mean	988.23	1020.59	867.06
	Median	-	976.62	820.62
	Standard Deviation	-	257.24	334.40
	Value to be exceeded with 95% probability	-	674.85	405.62
	Value to be exceeded with 5% probability	-	1523.94	1498.75
CO_2 Emissions captured in Electricity Generation [Mt]				
	Mean	0.00	64.66	152.03
	Median	-	45.98	118.07
	Standard Deviation	-	60.84	126.73
	Value to be exceeded with 95% probability	-	7.06	21.91
	Value to be exceeded with 5% probability	-	190.64	407.60
Carbon value in Euro2000 per tn of CO2				
	Mean	0.00	34.47	57.72
	Median	-	30.24	46.96
	Standard Deviation	-	29.37	50.80
	Value to be exceeded with 95% probability	-	0.00	0.00
	Value to be exceeded with 5% probability	-	89.53	156.14
Share of Domestic Primary Energy Supply [%]		-		

Study:	SAPIENTIA "Zero R&D" scenario (no government energy R&D from 2006 to 2050)
Scenario:	
Country / Region:	EUROPE 15 + Norway + Switzerland
Baseyear:	2002
Models:	PROMETHEUS
Institution:	ICCS/NTUA
Name of author:	
Date:	

Indicator	Fuel	Baseyear	2030	2050
Industrial consumer electricity price [$Euro_{2000}$/MWh]				
Mean		65.68	70.65	76.77
Median		-	69.42	75.25
Standard Deviation		-	12.47	16.17
Value to be exceeded with 95% probability		-	52.37	53.45
Value to be exceeded with 5% probability		-	91.70	106.77
Installed Electricity Generation Capacity and Production in Europe by Fuel — **GW_e**	**Coal (including CO2 capture and seq.)**			
	Mean	133.76	143.32	158.52
	Median	-	134.10	148.54
	Standard Deviation	-	48.22	62.14
	Value to be exceeded with 95% probability	-	80.71	75.38
	Value to be exceeded with 5% probability	-	235.08	273.10
	Gas (including CO2 capture and seq.)			
	Mean	128.83	190.61	138.59
	Median	-	183.25	125.63
	Standard Deviation	-	48.95	49.51
	Value to be exceeded with 95% probability	-	127.20	85.44
	Value to be exceeded with 5% probability	-	275.19	233.79
	Oil			
	Mean	60.30	18.65	7.81
	Median	-	17.65	7.13
	Standard Deviation	-	3.82	2.76
	Value to be exceeded with 95% probability	-	15.46	5.78
	Value to be exceeded with 5% probability	-	25.11	11.68
	Nuclear			
	Mean	125.94	112.61	116.44
	Median	-	96.11	92.82
	Standard Deviation	-	44.96	67.89
	Value to be exceeded with 95% probability	-	74.33	55.78
	Value to be exceeded with 5% probability	-	203.44	257.01
	RES (including large hydro)			
	Mean	198.90	486.94	800.94
	Median	-	465.60	751.77
	Standard Deviation	-	161.60	306.13
	Value to be exceeded with 95% probability	-	266.34	407.18
	Value to be exceeded with 5% probability	-	797.10	1375.33
TWh	**Coal**			
	Mean	641.26	946.18	1128.44
	Median	-	882.70	1052.87
	Standard Deviation	-	354.24	459.22
	Value to be exceeded with 95% probability	-	491.78	519.57
	Value to be exceeded with 5% probability	-	1620.04	1981.54
	Gas			
	Mean	524.75	848.68	599.31
	Median	-	804.68	545.88
	Standard Deviation	-	231.39	199.46
	Value to be exceeded with 95% probability	-	556.68	390.34
	Value to be exceeded with 5% probability	-	1230.34	999.36
	Oil			
	Mean	211.38	65.32	27.35
	Median	-	61.83	24.95
	Standard Deviation	-	13.32	9.62
	Value to be exceeded with 95% probability	-	54.17	20.27
	Value to be exceeded with 5% probability	-	87.86	40.86
	Nuclear			
	Mean	925.34	827.26	854.13
	Median	-	706.14	679.99
	Standard Deviation	-	330.33	498.03
	Value to be exceeded with 95% probability	-	546.09	409.61
	Value to be exceeded with 5% probability	-	1494.69	1888.14
	RES			
	Mean	605.41	1257.39	1830.33
	Median	-	1221.94	1759.33
	Standard Deviation	-	316.79	579.65
	Value to be exceeded with 95% probability	-	782.12	1032.58
	Value to be exceeded with 5% probability	-	1850.82	2911.29
CO_2 Emissions by Electricity Generation [Mt] (substracting CO2 captured)				
	Mean	988.23	1046.99	944.41
	Median	-	1003.41	896.70
	Standard Deviation	-	258.36	346.40
	Value to be exceeded with 95% probability	-	697.97	469.33
	Value to be exceeded with 5% probability	-	1553.71	1563.42
CO_2 Emissions captured in Electricity Generation [Mt]				
	Mean	0.00	60.78	160.46
	Median	-	41.56	124.93
	Standard Deviation	-	59.51	133.01
	Value to be exceeded with 95% probability	-	5.84	21.46
	Value to be exceeded with 5% probability	-	177.33	425.55
Carbon value in Euro2000 per tn of CO2				
	Mean	0.00	34.55	58.75
	Median	-	30.35	48.30
	Standard Deviation	-	29.40	51.28
	Value to be exceeded with 95% probability	-	0.00	0.00
	Value to be exceeded with 5% probability	-	89.64	156.94
Share of Domestic Primary Energy Supply [%]		-		

3 Summary and comparison of studies and scenarios

The following overview provides a summary which contrasts the distinct studies analysed in WP 5.2. The summary's objective is to highlight the major study results and its conclusions.

3.1 World energy, technology and climate policy outlook (WETO 2030)

Main Focus

Main objective of the WETO project was to establish a well-founded baseline of the development of energy supply and demand for energy related policy analysis.

Model

POLES is a simulation model with inter-connected modules that cover world energy demand and supply by accounting for international energy markets, regional energy balances, and national models on energy demand, technologies, power generation, primary energy supply and CO_2-emissions. Demand is disaggregated into 15 sectors. Supply is generated from a so called discovery process model or it may be demand driven as well. Trade on international and regional energy markets is modelled. For this study, regional coverage focuses on Western Europe and the economies in transition. The time horizon ranges from 2000 up to 2030.

Scenarios

The basic reference scenario, which builds upon various fundamental exogenous assumptions, is accompanied by seven variant developments. The variants are not to be thought of as counterfactual policy evaluations but rather present alternative sensitivity developments in the reference case driven by changes in fundamental variables or by a climate change policy. Regarding fundamental variables, the variants can be distinguished with respect to the uncertainty they represent. The first group is uncertainty in gas and oil resource availability. Here there are two variations, namely high gas and oil resources with resulting low prices, and high gas resources but low oil resources with resulting asymmetric prices. The second group builds upon uncertainties with respect to technology development. It considers four variants with accelerated technological development for generation technologies for each fuel. Acceleration is implemented by decrease in investment costs, decrease in fixed operating costs and improvement in efficiency. The cases are gas case, coal case, nuclear case, renewable case. In each case, competitiveness in the specific technology is enhanced as strong as is necessary to substitute other technologies, even amidst possibly induced increases in relevant fuel prices. The policy variant consists of a single policy issue, namely CO_2 abatement through implementation of carbon value differentiated by region and time horizon. This variant is applied to the reference case and to the four technology variants.

Scenario Overview

- Reference
- Resource uncertainty
    - high gas and oil resources
    - high gas resources
- Technology scenarios
    - gas technologies associated with high gas resource scenario
    - coal technologies
    - nuclear case
    - renewable case
- Carbon value policy scenario

Results

Results are comprehensive and concern energy demand, energy prices, generation mix, share of domestic primary energy supply, and CO_2 emissions. Here, the report table covers electricity generation, CO_2 emissions by electricity generation and share of domestic energy supply.

3.2 World Energy Outlook 2004 (WEO)

Main Focus

Main focus is to provide a business as usual scenario and a critical assessment on possible global long-term energy system development that is likely to evolve under the current framework.

Model

The WEO analysis is based on the World Energy Model (WEM). WEM has six main modules that capture energy demand by industry sector, power sector technologies, refinery and other transformation, resource based fossil fuel supply, CO_2 emissions and investment. Regional energy balances are taken into account. Model parameters are estimated econometrically based on time series from 1971-2001. The model covers 18 countries or regions, focusing on OECD. The model is constantly under development and applied each year in the course of the WEO.[1] The study at hand (cf. chapter 2.2, Grohnheit, RISOE) considers the WEO2004 projection for electricity generation. Regional coverage for that projection is EU-25. Alternative scenarios exists but are not reported by Grohnheit, RISOE due to lack in detail. Base year is 2002. From the model versions of the WEO 2002 onwards, the WEM time horizon for scenario analysis is 2030.

Scenarios

The reference scenario of WEO 2004 is presented.

Scenario Overview

- Reference scenario

Results

Results from WEO2004 are given in the reporting table for the reference case.

3.3 Trends to 2030, PRIMES

Main Focus

The main focus is to assess the likely long-term economic, energy, transport and CO_2-trends for Europe, especially including new EU accession and candidate states.

Model

PRIMES is a price driven partial equilibrium MCP energy system model for energy-environment analysis within the context of market driven behaviour. It serves as a modelling system that simulates a market equilibrium solution for energy supply and demand in a multi regional framework. Although behavioural and price driven, PRIMES simulates in detail the technology choice in energy demand and energy production. PRIMES is organised around a modular design representing in a different manner fuel supply, energy conversion and end-use of demand sectors, where an important feature is the technology richness in each of these modules.[2] Here, regional coverage is EU-25. Time horizon ranges from the base year 2000 up to 2030.

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[1] Source next to Gronheit (2006): http://www.worldenergyoutlook.org/model.asp

[2] Source: http://www.e3mlab.ntua.gr/manuals/PRIMsd.pdf

Scenarios

For the comparative study at hand the PRIMES model is applied to five scenario cases. Although subsumed under the title *Trends to 2030* the scenarios differ from what has been documented and published by PRIMES under that title. Here, as commonly there is a business as usual development that serves as a reference case. There are four alternative scenarios. The first scenario allows for full policy options. The second scenario assumes high oil and gas prices. In the third scenario EU member states are obliged to cap emissions as given in the Gothenburg protocol. Relevant emissions caps of the Gothenburg protocol are for 2010 and concern sulphur, NOx, VOCs and ammonia emissions. However, reported PRIMES results strongly suggest that CO_2 emissions are capped as well in the Gothenburg type scenario, as CO_2 emissions from electricity generation fall from 1245 Mt CO_2 in the base year down to 736 Mt CO_2 in 2030. This indicates that the Gothenburg type scenario might possibly be considered a type of carbon value scenario. The fourth scenario assumes that new nuclear technology is accepted while at the same time renewable energy sources are supported.

Scenario Overview

- Reference
- Full policy options
- High oil and high gas prices
- Gothenburg caps
- Nuclear and RES

Results

Results are comprehensive. Comparison in the report at hand focuses on the reference case and the renewable scenario. It must be noted that PRIMES represents results in technological detail. However, the distinction in technology type made for installed capacity and generation itself differ, which hampers comparison. For installed capacity, it is impossible to aggregate the data by technology type into the fuel based presentation required for comparison in the report at hand. For generation, technology rich information is aggregated into five fuel types. Thus, here only generation is considered in fuel detail.

3.4 ACROPOLIS

Main Focus

The ACROPOLIS project applies and compares energy models to assess the impact of energy technologies and policy measures on greenhouse gases (GHG) emissions and on sustainability in a global systems analysis perspective. It was aimed to overcome the difficulties linked to the harmonisation of results from different energy models.

Models

There is a variety of very distinctive top-down and bottom-up models applied in the Acropolis project. Amongst these are MESSAGE, DNE21, GMM, MARKAL-MATTER, PRIMES, MARKAL-NORDIC, NEMS, NEO-MS, and TIMES. Most of these models either provide regionally respectively nationally limited results or they are world models (e.g. POLES, GMM). Because the report at hand focuses on the EU, it only considers MARKAL-MATTER and PRIMES as relevant for comparison. MARKAL-MATTER extends the Western European MARKAL-model towards an integrated energy and materials system model. MARKAL-MATTER covers OECD Western Europe of 1990 (OECD90-WEU), with a time horizon from 1995 to 2030. PRIMES is described in the section above. For the Acropolis project, PRIMES captures EU-15 with a time horizon from 1990 to 2030.

Scenarios

A reference development is compared to four contrary scenarios on GHG control strategies. First, enhancement of renewable energy application is considered. Second flexible mechanisms under a soft landing scenario are assumed such that CO_2 concentrations are stabilized in the long-term at about 550 ppmv and all countries participate in the emissions reductions. Third, assumptions of energy efficiency standards provide seven further cases for analysis. The fourth scenario introduces external costs as measured by ExternE and internalizes them as a cost factor.

Scenario Overview

- Reference scenario
- Renewable portfolio scheme and green certificates
- Internal flexible mechanisms
- Efficiency standards
- Internalisation of external costs

Main Assumptions

Key framework assumptions – Development of parameters over time for the years 2005, 2010, 2020 and 2030

- *Gross Domestic Product*: Between 1995 and 2030 the compounded average annual growth rate (CAGR) is assumed to be 2.86 %.
- *Population*: Between 1995 and 2030 the compounded average annual growth rate (CAGR) is assumed to be 1.13 %.
- *Fuel Prices*: Prices for natural gas has been differentiated for the American market, the European market and the Asian market. For oil and coal one global price path has been adopted.

Results

Comparison focuses on the reference case and the renewable case. Regarding the requirements of the reporting table, MARKAL-MATTER does not provide information on emissions by electricity generation.

3.5 SAPIENT

Main Focus

The objective is to analysis the impact of energy related technological improvement especially through R&D in the future development of the energy system.

Model[3]

PROMETHEUS covers, albeit in a rather aggregate way all the major aspects of the world energy system together with key global environmental issues (global temperature change). The model recognises three main sources of uncertainty, namely uncertainty regarding assumptions and the evolution of exogenous variables, variation in variables that are not explicitly modelled since they are considered relatively unimportant but could cumulatively cause deviations, uncertainties arising from imperfect knowledge of the system and notably the parameters included in the model. PROMETHEUS deals with these uncertainties as a self-contained energy model consisting of a set of stochastic equations and identities (in total over 2100 equations). All exogenous variables, parameters and error terms in the model are

[3] Source: Sapienta Final Report.

stochastic and there is explicit representation of their distribution including terms of co-variance. As a result all endogenous variables are also stochastic. It also contains stochastic relations describing technology improvement dynamics (both learning by research and experience). Regional coverage is EU15 plus Norway and Switzerland. Base year is 2002. The time horizon may be extended up to 2050.

Scenarios

First, the model is applied for a reference case description. Second, a scenario with no R&D, where all public R&D expenditures are set to zero from 2006 to 2050 is carried out. The second counterfactual scenario assumes high private and public R&D expenditures, namely a doubling from 2006 to 2050. In all scenarios CO_2 emissions are accounted for as a cost factor, i.e. there is a carbon value.

Scenario Overview

- Reference
- no R&D
- high R&D

Results

Results show mean average, medians, deviations and confidence values for most of the indicators required for the reporting table. Comparison with other models' results is done applying the mean.

3.6 Study Result Comparison

Based on the presented summary, in the following the study results are compared and contrasted. Comparison is only carried out for the reference case (baseline) and only up to the extent that data is provided. Concerning the baseline development, it has to be considered that the assumption of some key parameters differ amongst the studies. Nonetheless the following graphs and tables give a valuable insight into differences in model results.

Electricity production

The two models providing results for electricity production in the EU-25 are PRIMES and WEM of the WEO 2004. Base year differ but the development can be compared quite well. Overall generation increases from around 2900 TWh (PRIMES) and 2950 TWh (WEO) in the base year up to 4400 TWh (PRIMES) and 4270 TWh (WEO) in 2030 respectively. Hence, the WEO reference scenario expects a smaller growth than PRIMES, even more so considering the different base years. The model results also differ with respect to the energy carrier mix. PRIMES results project a much higher share of gas fired generation. WEO has a higher growth in RES combined with a stronger decrease in nuclear power generation. In the PRIMES results there is a striking decline in coal fired generation in 2010 compared to 2000. This drop cannot be explained without having insight into detailed scenario assumptions. It must be considered that the difference may result from different policy assumptions but may also be due to different specific energy carriers subsumed under each of the five fuel types presented in figure 1 and table 1.

Table 2 contrasts the percentage share of domestic primary energy supply for PRIMES and WEM. Hereto, two things are worth mentioning. First, it is striking that in the base year albeit considering 2000 and 2002 respectively, the documented domestic share differs by more than 19 percentage points. This deviation cannot be explained without gaining more detailed insight into the model assumption and the base year data generation. Second, the model PRIMES on the one side and WEM on the other side project two contrary developments. In WEM domestic share increases, whereas in PRIMES domestic share decreases. This is coherent to the different energy mixes shown in figure 1. For instance, with a higher growth in gas fired generation as is the case in PRIMES, import of energy carriers must increase. With a relatively higher share of RES in WEM, the domestic share will tend to rise.

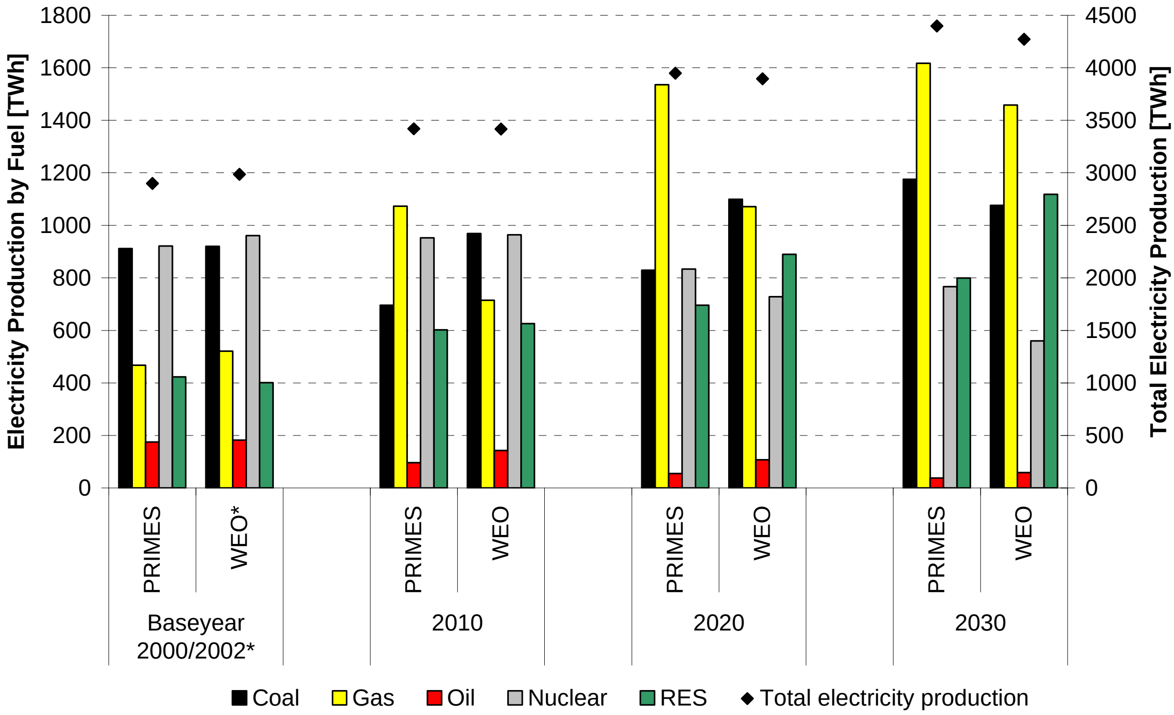

Figure 1: Electricity production in the EU-25

Table 1: Production by fuel [TWh]

	Baseyear 2000/2002*		2010		2020		2030	
	PRIMES	WEO*	PRIMES	WEO	PRIMES	WEO	PRIMES	WEO
Coal	912	920	696	969	830	1099	1176	1076
Gas	467	521	1073	715	1535	1071	1617	1458
Oil	175	182	96	143	55	107	38	59
Nuclear	921	961	953	964	834	728	767	560
RES	423	401	602	626	696	890	800	1118
Total	2898	2985	3419	3417	3949	3895	4397	4271

Table 2: Share of domestic primary energy supply [%]

	2000/2002*	2010	2020	2030
PRIMES (EU-25)	54.4	48.2	39.2	33.7
WEO* (EU-25)	35.1	36.0	37.5	37.2

There are four models providing results for electricity production in the EU-15, namely PRIMES EU-15, MARKAL, POLES, and PROMETHEUS. All model results except POLES (WETO) are taken from the ACROPOIS study. The regional mapping WEU in the case of POLES includes the EU-15, Cyprus, Malta, Norway, Switzerland, and Turkey. The regional mapping WEU in the case of PROMETHEUS includes the EU-15 plus Norway and Switzerland. These facts somewhat makes a comparison of model results more complicated and leads to a higher production in POLES and PROMETHEUS in the base year 2000 than in the case of PRIMES and MARKAL. The data from PROMETHEUS displayed in figure 2 are the mean average values. Next to base year, PROMETHEUS only generates results for 2030 and 2050.

As indicated in figure 2 and table 3, PRIMES and MARKAL provide similar results throughout the model periods even though overall production is higher in PRIMES (3250 TWh in 2030) than in MARKAL (in 3160 TWh 2030). Different to these two models, PROMETHEUS with its broader regional mapping suggests a higher production growth (3920 TWh in 2030) as does POLES WEU (4280 TWh in 2030). This means, that overall generation in POLES for the WEU is considered as high as in WEO for EU-25 in the year 2030. The fuel mix contains more coal in the case of MARKAL and PROMETHEUS than it does in the case of PRIMES. Hence, in both studies for the EU-15 as well as for the EU-25, the PRIMES baseline scenario projects higher growth in production and a higher gas share in production than other models. PRIMES EU-15 more over exhibits a very considerable coal gas shift from 2000 to 2010. POLES does not report any generation from oil.

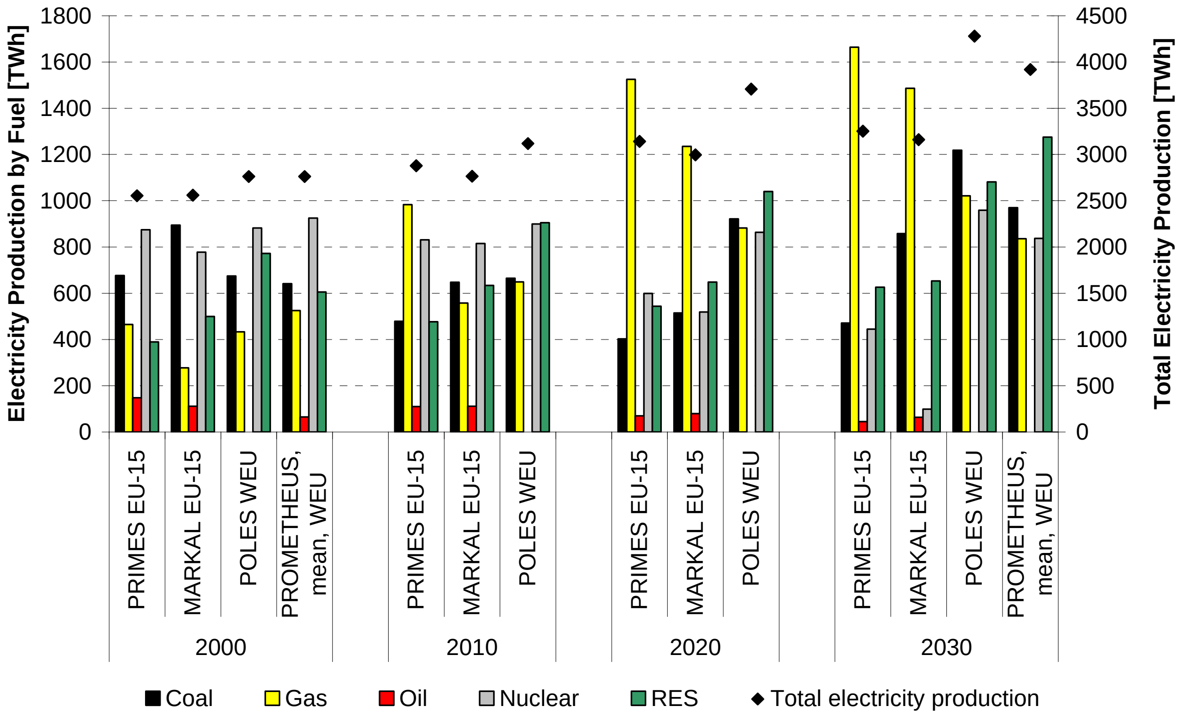

Figure 2: Electricity production in the EU-15[4]

[4] Regional mapping WEU in the model PROMETHEUS includes EU-15, Norway, and Switzerland. Regional mapping WEU in the model POLES includes the EU-15, Cyprus, Malta, Norway, Switzerland, and Turkey.

Table 3: Production by fuel [TWh]

	2000				2010		
	PRIMES EU-15	MARKAL EU-15	POLES WEU	PROMETH. mean, WEU	PRIMES EU-15	MARKAL EU-15	POLES WEU
Coal	677.10	894.65	675.00	641.26	478.71	647.20	665.00
Gas	464.84	276.99	433.00	524.75	982.86	557.64	649.00
Oil	148.21	111.11	0.00	64.81	109.50	111.23	0.00
Nuclear	874.10	777.78	882.00	925.34	831.18	814.88	899.00
RES	389.60	499.22	772.00	605.41	476.48	633.54	905.00
Total	2553.85	2559.75	2762.00	2761.57	2878.73	2764.48	3118.00

	2020				2030		
	PRIMES EU-15	MARKAL EU-15	POLES WEU	PRIMES EU-15	MARKAL EU-15	POLES WEU	PROMETH. mean, WEU
Coal	402.98	514.44	922.00	471.44	857.80	1218.00	970.42
Gas	1525.20	1234.82	882.00	1664.44	1486.09	1021.00	835.72
Oil	69.65	79.40	0.00	44.56	63.53	0.00	0.00
Nuclear	599.38	518.96	863.00	444.90	98.78	959.00	837.37
RES	543.96	648.40	1040.00	626.23	653.43	1081.00	1275.70
Total	3141.17	2996.02	3707.00	3251.57	3159.63	4279.00	3919.21

CO_2 emissions from electricity generation

Information on the development of CO_2 emission from electricity generation is provided by POLES for the region WEU, by the WEM in the WEO for the EU-25, by PRIMES for both the EU-25 and the EU-15, and by PROMETHEUS for the WEU.

All studies project increasing emission in the electricity sector in the long run. Only PRIMES EU-25 shows a short decline in 2010 compared to 2000 which mirrors to the drop in coal fired generation and the increase in gas fired generation shown in figure 1. Also, WEO has higher CO_2 emissions than PRIMES for the EU-25. This is despite an overall production which is lower and a RES based generation which is higher in WEO than in PRIMES. Comparing the development of emissions from the WETO model POLES for EU-15 to the results from PRIMES for the EU-15 shows that in POLES results diverge from 2020 on.

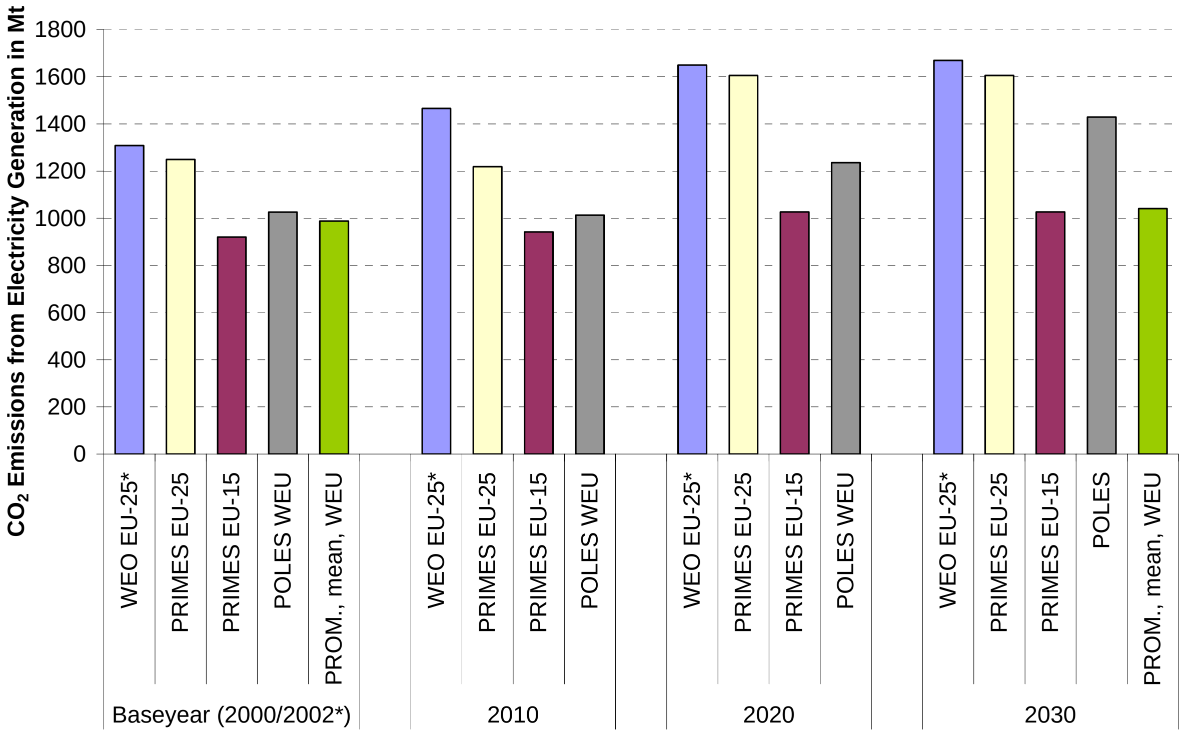

Figure 3: CO_2 emissions in different models[5]

Table 4: CO_2 emission by electricity generation [Mt]

	Base Year (2000/2002*)	2010	2020	2030
WEO EU-25*	1308	1466	1650	1669
PRIMES EU-25	1249	1219	1605	1605
PRIMES EU-15	920	942	1027	1027
POLES WEU	1026	1013	1236	1429
PROMETHEUS, mean, WEU	988	n.a.	n.a.	1041

Conclusion

Contrasting the results most of all reveals major similarities. However, there are also some remarkable differences between the studies, due to differences in basic model assumptions and assumptions on policy measures within the baseline scenario. Therefore, the results of this comparison have to be interpreted very carefully. As shown in the study summary and in the result comparison, objective, philosophy, concept and detail of the models differ as do their regional scope and the studies' assumptions.

[5] Regional mapping WEU in the model PROMETHEUS includes EU-15, Norway, and Switzerland. Regional mapping WEU in the model POLES includes the EU-15, Cyprus, Malta, Norway, Switzerland, and Turkey.