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EUSUSTEL

European Sustainable Electricity; Comprehensive Analysis of Future European Demand and Generation of European Electricity and its Security of Supply

Priority SSP-3
Policy Support and Anticipating Scientific and Technological Needs
Specific Support Action

D5.3
Report on 4 scenarios and 'most optimal solution'

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EUSUSTEL

European Sustainable Electricity

Contract no.: 006602

Most Optimal Solution for Electricity Provision

Final Report for WP 5-3

Scenario analyses with PRIMES and TIMES-EG

USTUTT and ICCS/NTUA

1 Introduction

The aim of the scenario analysis is to understand how the electricity generation system will develop under different policy assumptions, reflecting current energy, technology and environmental related measures and to evaluate the most optimal solution for electricity provision in the EU-25. For that purpose two of the most appropriate models have been used, the energy system model PRIMES of the ICCS/NTUA, Greece and the electricity and gas market model TIMES-EG of the IER/USTUTT, Germany.

Four contrasting scenarios have been designed to analyse the energy system development with a special emphasis on the electricity market. Starting point is a business as usual scenario, in which all current policy measures within the EU-25 countries are reflected. This Baseline scenario (BL) projects the development of energy demand and supply as well as the structural changes within the electricity generation sector given the technology and policy framework as it can be found in the various European countries.

The second scenario, called the Post Kyoto (PK) reflects the climate policy targets as agreed on the Kyoto protocol for the European Union extrapolating the targets to the year 2030. The third scenario, the Post Kyoto - All Technologies (PKAT) assumes the same climate protection policy as the Post Kyoto scenario but relaxes some of the constraints regarding nuclear generation which is currently under restriction in some of the European countries. The fourth scenario (LID) focuses on the issue of security of supply, seeking to reduce import dependence on fossil fuel by raising energy taxes on coal, oil and gas.

The modelling work has been performed as follows:

1. The PRIMES model has been used first to quantify a Baseline scenario. For analytical and comparison purposes this scenario has been designed so as to be as close as possible to the most recent Baseline scenario that PRIMES has prepared in late 2005 for the European Commission DG TREN.
2. Three main alternative scenarios have been qualitatively defined. The first two scenarios, namely PK and PKAT, which differ in terms of the scope of technological options that can be used in power generation, aim at limiting CO_2 emissions from energy in 2030 at the level of -16% from base year, i.e. 1990. The emissions cap has been considered as a constrained imposed on EU-25 taken as a whole.
3. The PRIMES model has been used to determine the optimal (in the sense of the overall energy market equilibrium) allocation of the target to the energy demand and

supply sectors of each country of Europe and also across countries. For this purpose, PRIMES has been running iteratively: the model determined the marginal cost value (termed as “carbon value”) of the overall emissions cap which influences the decision making in all sectors and countries by altering the relative competitiveness of the various energy forms. As a consequence of applying the carbon value, CO_2 emissions are abated up to the level needed to exactly match the emissions constraint. The carbon value is therefore the dual variable associated to the overall emissions cap. The carbon value is not a tax and does not entail direct costs to consumers and producers. By altering the relative competitiveness of the various energy forms, the carbon value drives restructuring of the energy system towards less carbon emission which entails costs to producers and consumers. The costs are higher than in baseline where the emission constraint is absent. So, indirect costs stem from the overall emissions cap. The model estimates different carbon values for the two alternative scenarios because the scenarios differ with respect to the technological options that are available for emission abatement. It is assumed that the two scenarios PK and PKAT meet the same overall emissions cap.

4. The fourth scenario, namely LID is assumed to take as given the carbon value as determined in the PK scenario. Since the carbon value in this scenario is not endogenous, the emissions are reduced but not necessarily at the same level as in the previous two scenarios. In addition, it is assumed that the LID scenario has to meet an additional constraint, namely to import 10% less fossil fuel energy than the PK scenario. It is further assumed that this constraint applies on EU-25 taken as a whole. To meet the import constraint, it is assumed that an energy excise tax is imposed uniformly on all uses of fossil fuels. The PRIMES model is used to determine what exactly level of energy tax is needed to meet the import limitation constraint. The determined level of tax applies on fossil fuel use (on coal, oil and gas but not on lignite) in a uniform manner on all sectors and countries of the EU. In the LID scenario, the effects of the energy tax add to the effects of the carbon value.
5. After the above mentioned PRIMES model runs, the TIMES model has been used. This model focus only on electricity and gas supply system. TIMES has been calibrated to PRIMES model runs as regards baseline assumptions, electricity demand, nuclear energy policy, minimum renewables development and others. Also the TIMES model has used the carbon values and the import energy tax as determined by the PRIMES model.

Details and numerical results of these model calculations are presented below.

2 Scenario characterization

2.1 General assumptions for all scenarios

To reflect the current socio-economic trends in the European Union 25, main macroeconomic and demographic assumptions have been agreed on to ensure that the two models PRIMES and TIMES-EG are calibrated to a consistent Baseline scenario. The assumptions made for the Gross Domestic Product (GDP) and population between 2005 and the year 2030 are presented in Table 1. The GDP is projected to increase by approximately 2.5% per year until 2015, beginning to slow down to approximately 2.0% yearly until 2015 and 1.5% per year until 2020, respectively. Population in EU-25 is projected to stabilize after 2015 at approximately 470 mil. inhabitants. These assumptions are in line with the baseline scenario developed with the PRIMES model for DGTREN in late 2005.

Table 1: Assumptions on Gross Domestic Product [000M€$_{2000}$] and Population [mil.] in EU-25

Indicator	2005	2010	2015	2020	2025	2030
GDP [000M€$_{2000}$]	9715.5	10946.8	12304.8	13656.3	14963.7	16051.4
Population [mil.]	458.842	464.054	467.306	469.270	470.057	469.365

Regarding price development of the imported fossil fuels, the recent price increases for oil, gas and coal are taken into account. For the period beyond 2006, it is assumed that prices show stabilisation or slight increase until 2015, but in the longer term prices are assumed to increase again in real terms. Oil prices start in 2005 from a level of 54 $ per toe and are projected to reach the same level in 2025 in constant dollars of 2005. Coal prices first stabilise and then start rising very smoothly. Gas prices are assumed to exhibit a continuous increase after 2005 mainly due to an increase in overall demand. The projected oil, gas and coal prices assumed for the scenario analysis are shown in Table 2a and 2b.

Table 2a: Assumption on fuel prices [$$_{2005}$/toe]

Energy Carrier	2005	2010	2015	2020	2025	2030
Oil	54.00	44.61	44.91	48.06	54.44	57.60
Gas	30.31	33.89	34.22	36.98	42.87	44.75
Coal	13.31	12.54	13.36	14.07	14.59	14.95

Table 2b: Assumption on fuel prices [$€_{2005}$/toe]

Energy Carrier	2005	2010	2015	2020	2025	2030
Oil	44.23	36.54	36.79	39.37	44.59	47.18
Gas	24.83	27.76	28.03	30.29	35.12	36.66
Coal	10.90	10.27	10.94	11.53	11.95	12.25

All other assumptions, for example about energy policies and measures and technological developments, are set exactly as for the Baseline Scenario which has been quantified by the PRIMES model in late 2005 and published by DG TREN ("European energy and transport: Trends to 2030 – Update 2005"). Within this context, it is assumed that support measures for renewables continue in baseline and progressively vanish in the long term. Policies aiming at rational use of energy and improved energy efficiency are also included in baseline, but far less than the extent suggested in the recent directives or other EC documents on energy efficiency.

The results of PRIMES for baseline scenario have been used by the TIMES model to calibrate the basic model run. As an example, Table 3 shows the projection of PRIMES about development of renewables which has taken as an assumption for the TIMES model (TIMES takes these data as minimum volume of RES electricity supply under a continuation of the present support schemes).

The assumptions about economic development and demographics in the European Union as well as the assumptions about world fossil fuel prices are kept unchanged in all scenarios.

Table 3: Assumptions of TIMES model on minimum RES electricity generation in the EU25 [GWh_{gross}], as resulted from the PRIMES model Baseline Scenario

	2000	2005	2010	2015	2020	2025	2030
EU-25 [amount]	427,664	489,974	624,596	761,433	941,053	1,135,246	1,208,429
EU-25 [%]	14.7	15.4	17.9	20.2	23.5	26.9	27.7

2.2 Baseline (BL)

„Business as usual development for the EU-25 until 2030 considering current European policies based on PRIMES Baseline“

It is assumed that the baseline scenario does not address Kyoto and post-Kyoto objectives. However, in this scenario it is assumed that the current ETS system continues to operate and that it balances at low prices of emission allowances. This reflects absence of further pursuing climate policy measures in the European Union 25. So, it is assumed that the ETS system induces a constant Carbon Value of 5€/tCO_2 which is applied as an opportunity cost on all uses of fossil fuels. This Carbon Value has been is not enough to meet the Kyoto CO_2 target of limiting emissions between 2008 and 2012 at a level of -8% from their level in base year, i.e. 1990.

For the Baseline scenario (BL) it is assumed that current policies regarding electricity generation from nuclear energy are maintained in the long term. This implies that the announced nuclear phase-out in Belgium, Germany and Sweden is implemented. Also, it is assumed that eleven other member-states do not develop nuclear energy, but the rest of member-states may invest in new nuclear plants. However, it is assumed that extension of lifetime of nuclear plants does not take place. Table 4 shows the restrictions on the development of nuclear energy as assumed for the baseline scenario.

Table 4: Assumptions on nuclear phase-out in Belgium, Germany and Sweden [GW_{gross}] and countries, which are assumed to not use nuclear power for electricity generation

Country	2000	2005	2010	2015	2020	2025	2030
Belgium	6.03	6.08	6.08	5.24	4.22	2.17	0.00
Germany	23.67	20.96	19.73	13.67	5.52	0.00	0.00
Sweden	9.82	9.82	9.82	6.93	4.97	0.61	0.00
			No nuclear power plants in:				
	Latvia	Cyprus	Malta	Austria	Luxembourg	Estonia	
	Greece	Denmark	Portugal	Italy	Ireland		
			No restrictions but not extension of life time				
	France	UK	Spain	Finland	Poland	Czech	
	Slovakia	Slovenia	Lithuania	Hungary	Romania	Bulgaria	

2.3 Post-Kyoto (PK)

„Emission reduction according to a Post-Kyoto target of -16 % CO_2-emissions until 2030 applying a trading scheme within the EU-25“

For the Post Kyoto scenario (PK) climate policy in the EU-25 is assumed to become a major driver of change. It is assumed that the EU25 has to reduce CO_2 emissions from energy so as in 2030 emissions do not exceed a level of -16% from their level in 1990 and a -8% in 2020. For 2010, it is assumed that reduction of emissions of other greenhouse gases and the use of flexibility measures provide for in the Kyoto protocol allows the energy system reducing CO_2 emissions from energy less than 8% in 2010. The Carbon Values which are needed to meet the restrictions on carbon dioxide emissions from energy are calculated by the PRIMES model. The Carbon Values are used to simulate EU-25 climate policy measures in the TIMES-EG model. Table 5 shows the Carbon Values calculated by PRIMES for the Post-Kyoto targets in EU-25.

Table 5: Calculation of Carbon Values [$€_{2005}/tCO_2$] as provided by PRIMES

	2005	2010	2015	2020	2025	2030
Carbon Value	0.00	25.00	31.00	37.00	42.00	51.50

Regarding electricity generation by nuclear, the same assumptions as for Baseline scenario (BL) has been used. The same policy assumptions as in the Baseline scenario has been kept for electricity generation by renewable energy sources.

2.4 Post-Kyoto, All Technologies (PKAT)

„Calculation of an economically optimal solution for the assumed Post-Kyoto target of -16 % CO_2-emissions until 2030, allowing for free technological choice“

Within the Post Kyoto – All Technologies scenario (PKAT) the same climate policy assumptions as in the Post Kyoto scenario (PK) have been made, i.e. to reduce emissions from energy in the EU-25 by 8% in 2020 and by 16% in 2030, from the level of emissions in 1990.

The restrictions on nuclear generation capacities, e.g. the premature phase-out in Germany, Belgium and Sweden are relaxed for this scenario. Therefore new investments in nuclear power plants are possible throughout EU-25, except for the countries listed in Table 6. However, the option to extend the lifetime for the already existing nuclear power plants in EU-25 is not allowed.

Table 6: Countries without an investment option in nuclear generation capacities

No investment in nuclear power plants in:			
Austria	Latvia	Luxembourg	Estonia
Denmark	Greece	Portugal	Ireland

As in the Post Kyoto scenario, Carbon Values are calculated by PRIMES, so as to meet the emission reduction target and they are used as an exogenous input to TIMES-EG. Due to the possibility of investment in nuclear generation plants in many of the EU-25 countries, the calculated Carbon Values are lower than for the Post Kyoto scenario (PK). Table 7 presents the Carbon Values that have been calculated with the PRIMES energy system model.

Table 7: Calculation of Carbon Values [$€_{2000}/tCO_2$] as provided by PRIMES

	2005	2010	2015	2020	2025	2030
Carbon Value	0.00	25.00	26.50	28.00	29.20	31.50

Regarding electricity generation by renewable energy sources, the same policy measures in the EU-25 to support RES supply as in the Baseline scenario (BL) have been assumed for the Post Kyoto scenario.

2.5 Limited Import Dependency (LID)

„Improving security of supply by forcing the energy system to be more energy efficient and less import dependent“

For the Limited Import Dependency scenario (LID), it is assumed that EU25 is restricted not to import in 2030 fossil fuels more than -10% from the level of imports calculated with PRIMES for 2030 in the context of the PK scenario. This constraint is met through an energy tax on fossil fuels (coal, gas, oil but not on lignite). The level of the tax is calculated by the PRIMES model and used as an exogenous input to TIMES-EG.

Regarding climate policy, it is assumed that for LID the same Carbon Values apply as calculated for the Post Kyoto scenario (PK). Regarding electricity generation by RES as well as for electricity generation by nuclear the assumptions made for Baseline (BL) projections are maintained. Table 8 presents the calculation of energy taxes that apply in EU-25 on oil, coal and gas until 2030.

Table 8: Calculation of energy taxes [$€_{2000}$/toe] as provided by PRIMES

Energy carrier	2005	2010	2015	2020	2025	2030
Coal	0.00	0.00	15.4	30.4	37.8	43.1
Oil	0.00	0.00	51.8	103.9	141.3	166.1
Gas	0.00	0.00	39.5	80.0	111.3	129.0

3 Results of the energy system model PRIMES

3.1 The PRIMES energy system model

The PRIMES model 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 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 (sectors and sub-sectors) that decide individually about their supply, demand, combined supply and demand, and prices. The market integrating part of PRIMES simulates market clearing.

The model is organised by energy production sub-systems (oil products, natural gas, coal, electricity and heat production, others) for supply and by end-use sectors for demand (residential, commercial, transport, nine industrial sectors). Some demanders may be also suppliers, as for example industrial co-generators of electricity and steam.

Several end-uses and processes are distinguished: a) 12 industrial sectors, subdivided into 26 sub-sectors using energy in 12 generic processes (e.g. air compression, furnaces); b) 5 tertiary sectors, using energy in 6 processes (air conditioning, office equipment); c) 4 dwelling types using energy in 5 processes and 12 types of electrical durable goods (e.g. refrigerator, washing machine, television); d) 4 transport modes, 10 transport means and 10 vehicle technologies, 14 fossil fuel types, 4 new fuel carriers (e.g. hydrogen, methanol, biofuels) 10 renewable energy types, e) several supply sub-systems: power and steam generation, refineries, gas supply, biomass supply, hydrogen supply (not used in this project), primary energy production. The power generation sub-model represents 150 power and steam technologies, the electricity grid with import and export links in the EU internal energy market and details of load curves (typical days and hours) for electricity and steam; f) 7 types of pollutants emitted from energy processes and a series of associated policy instruments, including emission trading schemes.

The PRIMES model fully covers 34 actual, associated or potential EU member-states. The simulations for the EUSUSTEL project concerned 30 countries (25 EU members plus Bulgaria, Romania, Turkey, Norway and Switzerland). In this report only aggregated results for EU-25 are presented. Results by country and for all 30 countries are available upon request.

The model's database includes historical data, on which the model is calibrated. This concerns electricity demand data, electricity price data and detailed data on existing power plants and their use. The present database covers 1990-2000 and 2000 to 2005. The model produces results for 2000 and 2005 as calibrated years. Results for year 2010 and beyond (up to 2030, 2050) are considered as projections (scenario years).

Exogenous to PRIMES are: GDP growth, industrial activity per sector, world fossil fuel prices, energy and environment taxes and other parameters of policies, power plants and infrastructures that are known to be under construction in base year, baseline energy technology progress. Results from PRIMES are time series on: energy demand, supply and balances, energy prices, energy investment and emissions for 34 European countries.

3.2 Baseline Scenario

The baseline scenario reflects business as usual trends. Dynamic trends and changes are reflected in this scenario, however the evolution is considered to result only from past policies and trends, as well as market forces, without consideration of new policy instruments or policy targets. The baseline scenario is not a forecast, but just a simulation of what would be the limitations of the system if evolution just continued from past without consideration of market failures or adverse effects. The baseline scenario is essentially a least cost projection of future energy system without consideration of external costs and impacts, such as the effects on environment or the geopolitical risks affecting security of energy supply. In particular, the baseline scenario does not include policies to reduce greenhouse gases in view of the Kyoto commitments. No attempt has been made, in this scenario, to forecast how Europe might endeavour to fulfil the Kyoto or post-Kyoto commitments.

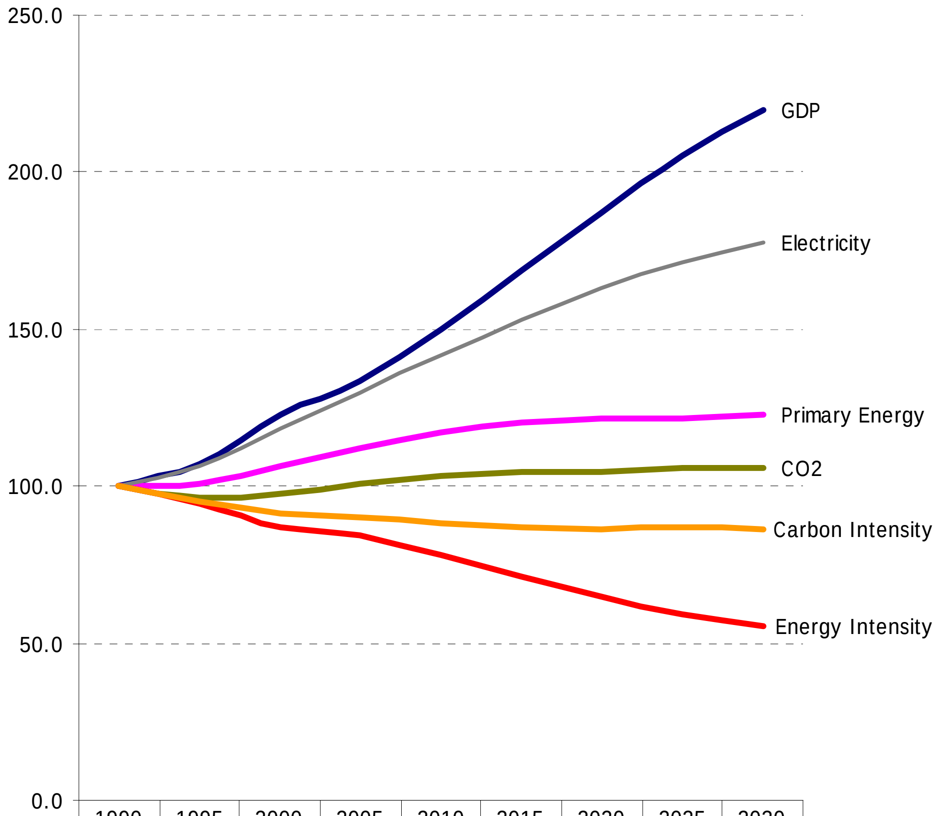
The baseline scenario does not involve freezing energy efficiency progress or penetration of new technologies or renewables. On the contrary, energy efficiency policies, but also market trends that lead to energy productivity improvement, do continue in the future under the conditions envisaged for baseline scenario. However, contrary to alternative scenarios that will be presented below, the baseline scenario policies, standards and measures are only those that have been put in place in the past (particularly before 2004). Energy efficiency and productivity gains are driven by the aim of minimizing costs and maximizing economic growth without any consideration of externalities such as the impacts on climate change and without consideration of possible risks and threats related to security of long term energy supply. Similarly, renewables, given the supportive policies which continue under baseline but do not magnify, are increased and develop further as a result of market forces and least cost supply.

The results of the Baseline scenario of 2003 show that, despite the evidence of relative saturation for certain energy uses in the EU-25, energy demand is expected to continue to grow, albeit at rates significantly lower than those experienced in the recent past. Primary energy demand in the EU-25 is projected to increase at an annual rate of 0.35% from 2005 to 2030 compared to an annual growth rate of 2 % for GDP, implying that the energy intensity of the EU-25 energy system (expressed as primary energy demand per unit of GDP) is projected to improve at a rate of 1.7% pa in 2000-2030.

The evolution of the EU-25 energy system to 2030 driven by Baseline assumptions reflects a continuation of the decoupling between energy demand and economic growth. In 2030, one unit of GDP in EU-25 is expected to be produced with only approximately half the energy input that was needed in 1990. The main reasons that justify this significant gain in energy intensity under the Baseline scenario include improvements in energy efficiency (both on the demand and the supply sides), changes in the structure of EU industry, saturation in demand for some intensive energy uses, and the policies already in place in the past. The energy intensity improvement trend is in line with observed statistics over the long period post oil crisis of 1973. The projection to 2030 for the baseline scenario shows a slight acceleration of the decoupling of energy consumption from GDP growth, as compared to past trends, a trend which is associated to the assumption about high oil and gas prices throughout the projection horizon.

Renewable energy forms and natural gas and are projected to remain the fastest growing energy forms in the EU-25 energy system (as was the case during the last decade). Gas needs grow at rates two and a half times faster than overall energy needs over the projection period (+0.81% pa in 2005-2030). Renewable energy forms are projected to grow at a remarkable rate: +2.91% per annum (pa) in 2005-2030. Primary energy demand for petroleum exhibits alomost stabilisation over the projection period. Although oil products tend to be used almost exclusively in specific energy uses (transport and petrochemical), their share remain considerable at 34.4% in 2030 compared to 38.5% in 2000.

Figure 1: Baseline Scenario Indicators (PRIMES model)



	1990	1995	2000	2005	2010	2015	2020	2025	2030
GDP	100.0	106.8	122.7	133.2	150.1	168.7	187.2	205.1	220.0
Primary Energy	100.0	101.0	106.3	112.3	117.1	120.0	121.8	121.7	122.5
CO2	100.0	96.3	97.3	101.0	103.6	104.5	104.8	105.6	105.7
Electricity	100.0	106.2	118.3	129.7	142.0	153.3	163.1	171.5	177.8
Energy Intensity	100.0	94.5	86.6	84.3	78.0	71.2	65.1	59.3	55.7
Carbon Intensity	100.0	95.4	91.6	90.0	88.4	87.0	86.0	86.7	86.2

Solid fuels, after experiencing a strong decline in their share up to 2010, are projected to re-establish their market share in the EU-25 energy system beyond 2015 as a result of: increasing competitiveness of imported coal; decommissioning of nuclear plants and phase-out in some countries; uncertainties associated with incremental supply of gas for further expanding its use in power generation. By 2030, primary energy demand for solid fuels is projected to come close to that observed in 2000.

Figure 2: Baseline Scenario, EU-25 - Primary Energy Requirements (Mtoe)

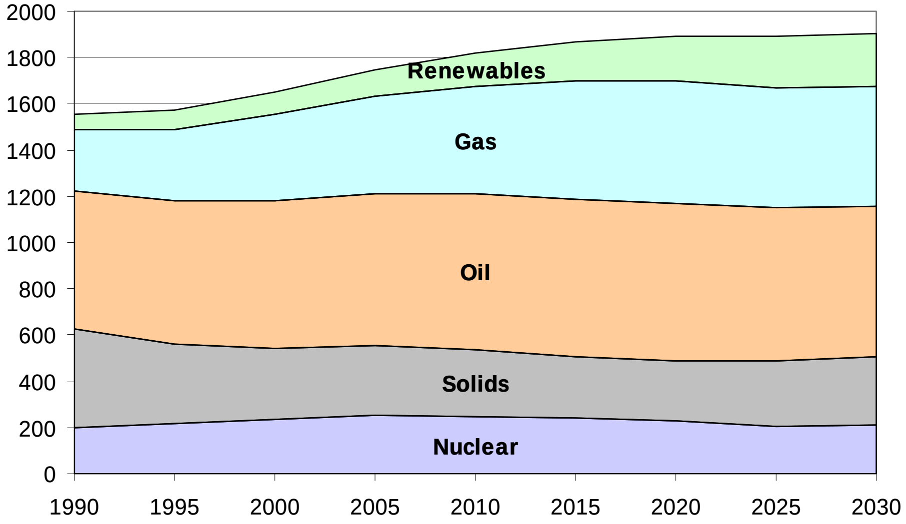
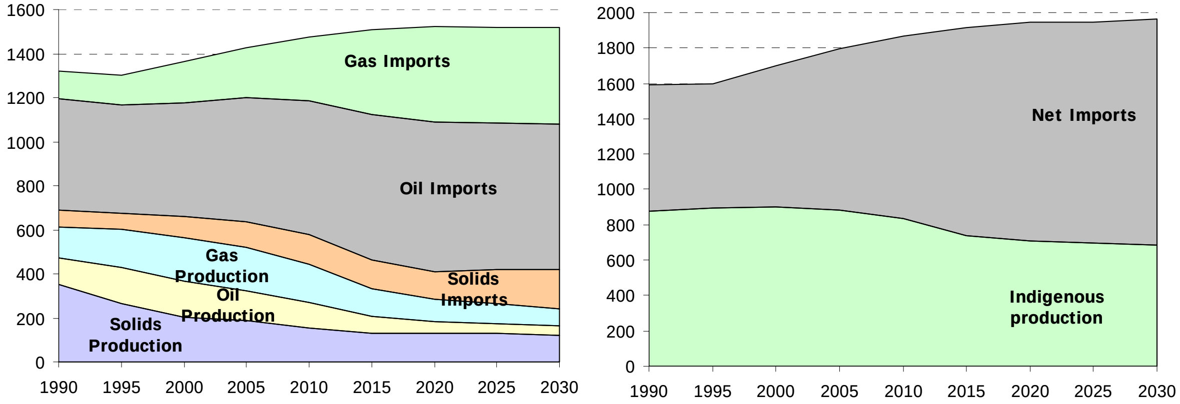


Table 1: Baseline Scenario for EU-25: Energy Balances (PRIMES model)

										Growth rate (% pa)	
Mtoe	*1990*	*1995*	*2000*	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*	up to 2010	2010-2030
Primary Energy Needs											
Gross Inland Cons.	1556	1572	1654	1748	1822	1868	1896	1895	1907	0.79	0.23
Solids	432	345	307	305	287	264	259	281	294	-2.02	0.12
Oil	596	621	635	653	677	682	680	661	651	0.64	-0.20
Gas	261	308	376	423	463	512	530	521	518	2.92	0.55
Nuclear	197	215	238	251	249	241	229	207	210	1.17	-0.83
Renewables	69	81	96	113	144	167	196	223	231	3.74	2.41
Primary Energy Supply											
Indigenous production	878	897	899	885	836	740	707	694	685	-0.24	-1.00
Solids	352	264	204	190	155	132	131	128	120	-4.02	-1.27
Oil	120	162	164	134	117	75	53	47	43	-0.13	-4.85
Gas	140	174	197	197	172	125	98	89	80	1.05	-3.77
Net Imports	711	701	801	908	1034	1178	1242	1254	1278	1.89	1.06
Solids	75	74	94	115	132	132	128	152	174	2.84	1.39
Oil	510	491	518	564	608	658	680	667	663	0.88	0.44
Gas	124	135	186	225	291	387	432	432	438	4.38	2.06
Energy Consumption by sector											
Industry	341	317	330	339	356	372	383	389	392	0.22	0.47
- energy intensive	217	203	212	215	221	226	228	227	225	0.09	0.09
- other industry	124	114	118	125	136	146	154	161	167	0.44	1.04
Residential	261	275	273	295	312	328	339	346	351	0.90	0.60
Tertiary	147	149	159	174	188	201	212	219	225	1.26	0.90
Transport	273	295	333	365	390	401	415	418	413	1.79	0.29
Energy Consumption by fuel											
Solids	124	80	57	51	45	42	39	37	34	-4.92	-1.41
Oil	428	446	468	501	526	534	539	533	522	1.03	-0.03
Gas	200	227	252	269	279	296	310	316	322	1.67	0.71
Electricity	176	188	211	234	259	282	303	321	334	1.94	1.28
Distr. Heat	63	60	69	74	80	84	88	92	95	1.22	0.86
Other	30	35	38	44	57	64	69	72	74	3.25	1.30

Figure 3: Baseline EU-25 - Primary Energy Supply (Mtoe)



Increasing primary energy demand for fossil fuels and declining primary production in the EU lead together to a considerable increase of dependence of the EU-25 energy system on imports of fossil fuels. The import dependence indicator, from 50% in 2005, rises to 65% in 2030. This is particularly pronounced for imports of natural gas, for which import dependence from 53 % in 2005 goes up to 85% in 2030, as a result of high incremental demand for gas in power generation combined with the decline of indigenous gas production in the EU (without considering Norway). The incremental needs for gas imports are considerable: the analysis has shown that the incremental gas quantities need mainly to be imported from Russian, Caspian and Middle East areas. Since geopolitical risk is associated with the projected incremental gas needs, consideration of scenarios that put emphasis on security of supply is justified.

Final demand for polluting fuels, such as solids and residual fuel oil, is declining. However, the demand for lighter oil products, mainly diesel oil and gasoline, is maintained as a result of their massive use primarily for transport and secondarily for chemicals. Final demand for natural gas increases at rather moderate rates. Therefore, the need for high gas imports is mainly associated with development of power generation, particularly in the medium term. In the longer term, further expansion of gas in power generation is found to slowdown. Energy demand in industry is projected to grow at moderate rates due to considerable energy intensity gains related to the structural changes towards less energy intensive manufacturing processes. Energy demand by the tertiary sector increasing at rather high rates is partly the sequel of gradual shifting of European economy towards services. The increase of final energy demand by households is projected to slow down as a result of saturation effects, except for electricity demand which is expected to grow driven by new specific uses of electricity. The predominant role of transport sector in final energy demand growth is remarkable. Transport remains the fastest growing energy demand sector. However in the long term, growth is slowing down as a result of saturation effects, high oil prices and technology progress. The continued growth of transport sector explains the persistence of high demand for petroleum products throughout the projection period.

Figure 4: Baseline Scenario EU-25 - Final Energy by Sector and Fuel (Mtoe)

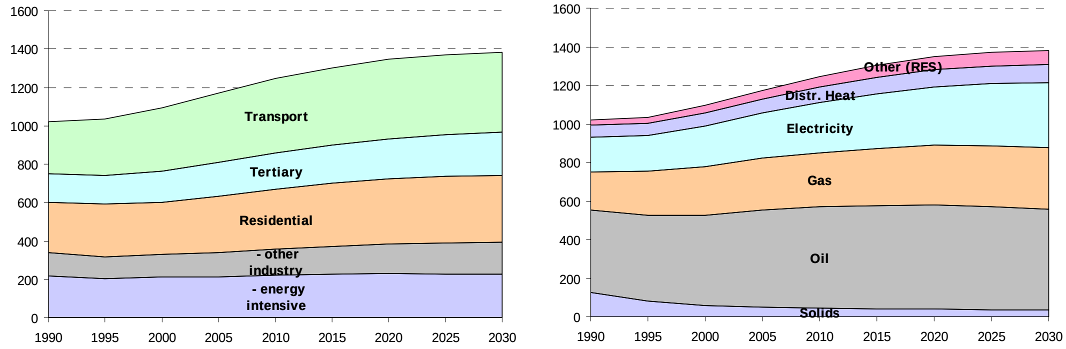


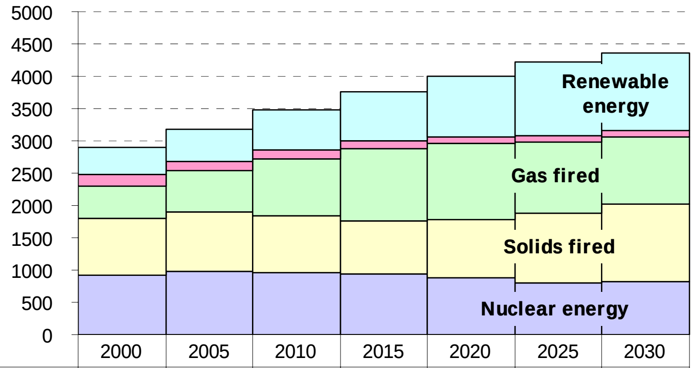
Table 2: Baseline Scenario EU-25 - Electricity Demand and Supply Balance (TWh)

EU25: Baseline scenario (TWh)										***Annual % Change***			
	1990	1995	2000	2005	2010	2015	2020	2025	2030	'90-'00	'00-'10	'10-'20	'20-'30
FINAL ELECTRICITY CONSUMPTION	2052	2184	2458	2718	3015	3283	3523	3734	3886	*1.8*	*2.1*	*1.6*	*1.0*
INDUSTRY	922	921	1042	1111	1201	1270	1321	1371	1399	*1.2*	*1.4*	*1.0*	*0.6*
RESIDENTIAL	569	637	695	784	881	987	1097	1197	1273	*2.0*	*2.4*	*2.2*	*1.5*
SERVICES AND AGRICULTURE	503	561	652	748	855	948	1031	1093	1143	*2.6*	*2.7*	*1.9*	*1.0*
TRANSPORT SECTOR	59	64	69	75	79	78	74	73	71	*1.5*	*1.4*	*-0.6*	*-0.4*
Transmission and Distribution Losses	160	182	200	198	195	201	196	189	191	*2.2*	*-0.3*	*0.0*	*-0.3*
Electricity consumed in ENERGY BRANCH	260	259	268	291	300	307	313	316	319	*0.3*	*1.1*	*0.4*	*0.2*
of which self consumption of power plants and of pumping	167	170	185	194	195	199	203	208	211	*1.0*	*0.6*	*0.4*	*0.4*
of which electricity consumption in REFINERIES	27	30	29	37	41	43	45	45	44	*0.7*	*3.6*	*0.8*	*-0.1*
of which electricity consumption in Other Energy Industries	66	59	54	60	64	64	65	64	63	*-1.9*	*1.6*	*0.2*	*-0.3*
TOTAL GROSS DEMAND OF ELECTRICITY	2472	2625	2926	3207	3510	3791	4033	4240	4395	*1.7*	*1.8*	*1.4*	*0.9*
TOTAL DOMESTIC GENERATION	2456	2609	2901	3176	3483	3766	4008	4215	4370	*1.7*	*1.8*	*1.4*	*0.9*
of which from thermal power stations (incl. biomass)	1403	1435	1620	1790	1995	2230	2434	2617	2708	*1.5*	*2.1*	*2.0*	*1.1*
of which from nuclear power stations	780	864	921	974	963	934	888	803	816	*1.7*	*0.4*	*-0.8*	*-0.8*
of which from renewables (excl. biomass)	273	310	359	412	525	602	686	795	846	*2.8*	*3.9*	*2.7*	*2.1*
TOTAL NET IMPORTS (+ Imports, - Exports)	25	16	25	31	27	25	25	25	26	*-0.2*	*0.8*	*-0.9*	*0.4*

Electrification manifested by an expanding use of electricity in all sectors is projected to continue in the baseline scenario, as also exhibited in past trends. In baseline scenario, electricity demand grows by 1.3% per year and gets a market share of 24% in 2030 steadily growing from a share of 17% in 1990. Electrification reflects the fact that electricity drives technological progress, comfort and competitiveness of the new economic growth of Europe. It is therefore justified to consider sustainability and economic efficiency in the power sector as playing a key role in the European energy strategy. The numerous processes, appliances and applications that can use energy only in the form of electricity, but also the special features of electricity, such as easy controllability, cleanliness at the point of use, etc., explain the increasing use of electricity in the EU-25 energy system.

Even though demand for electricity grows faster than total energy, the rate of growth slows down in the long term, mainly as a result of saturation effects. At the last decade of projection horizon, electricity demand grows by a mere 1% per year. For the baseline scenario, as a consequence of the underlying assumptions about technology development, electricity is not projected to penetrate in the transport sector, except for specific uses such as train transport.

Figure 5: Baseline Scenario EU-25 – Power generation by Source (TWh)



	2000	2005	2010	2015	2020	2025	2030
🟦 Renewable energy	428	490	625	762	942	1135	1208
🟥 Oil fired	177	145	133	121	105	99	97
🟩 Gas fired	504	645	892	1127	1182	1093	1039
🟨 Solids fired	875	923	870	822	892	1084	1210
🟪 Nuclear energy	921	974	963	934	888	803	816
Total Power Generation	2906	3176	3483	3766	4008	4215	4370

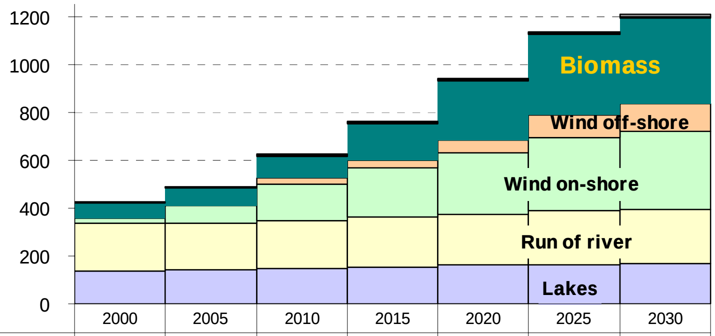
In baseline scenario the structure of power generation by source exhibit the following trends:

- Renewables in power generation show a remarkable progress as a result of supportive policies which, for baseline scenario, are assumed to continue in the future. Renewables' technology benefits from learning by doing and economies of scale; hence over time renewable energy penetrates in power generation. Technology improvement counterbalances the gradually decreasing subsidies to renewables, as assumed for baseline scenario. Wind power, in particular, displays economic competitiveness over time. As a consequence, on shore wind develops rapidly in the short and medium term. However, in the long term, further development of on shore wind slows down as a result of saturation effects. Off shore wind starts from lower levels and develops slowly in the medium term in line with slowness of progress related with scale and connectivity. Off shore wind is projected to develop much faster in the longer term and gain relative economic competitiveness in power generation. Biomass based power generation also develops in baseline scenario. Waste energy is used in niche market applications. Co-firing with biomass, as well as CHP with biomass, is among the main new developments. It is remarkable that under baseline scenario, renewable electricity becomes in 2030 as large as total coal generation and even exceeds nuclear electricity by 50%. Renewable electricity represented only half of nuclear energy in 2005. Renewables attain a share of 27% in total power generation by 2030 from a share of 15% in 2005.

- The baseline scenario shows that gas-based power generation is likely to grow fast in the short and medium term, despite high gas prices, since over the recent past massive decision investment to build GTCC plants have been taken. An additional driving factor is economic and efficiency advantage of combined cycle plants particularly in medium load operation, which grows in importance as the electricity load curve gradually transforms as a result of changes in end use of electricity. Also, CHP applications, which display high growth in baseline scenario, drive higher use of gas-based electricity. The share of gas-based power peaks in 2015 reaching 30% in total power generation.
- In the longer term, however, the continued deterioration of gas competitiveness in power generation vis-à-vis coal results in a reversal of this trend. Gas power investment considerably slows down and investment in coal plant re-emerges. Coal-based power is also favoured by the diminishing contribution of nuclear in base load since nuclear energy gradually decreases as a result of nuclear policy assumed for baseline scenario. The use of coal in power generation considerably increases after 2015 and particularly more after 2020. As a consequence, despite new investment in supercritical coal and other technologies with high thermal efficiency, carbon dioxide emissions from power generation significantly rise after 2020. Coal-based power, which represented 30% of total power generation in 2000, decline reaching a share of 22% in 2015, but afterwards it gains in share attaining 30% in 2030. Since total power generation also increases, the volume of coal based generation is n 2030 becomes 30% larger than in 2005.
- The nuclear electricity sector, under the conditions assumed for the baseline scenario, faces four main issues: EU-requirements to close a number of plants in new member states; end of conventional life time of many plants after 2020; nuclear phase out in three EU countries; likely decisions in large nuclear countries not to replace the entire nuclear park after decommissioning. This explains the decline of nuclear capacity which reduces in 2030 at a level lower by 30% from its level in 2005. New nuclear investment of 70.5 GW as projected in baseline scenario is not enough to counterbalance decommissioning and phasing-out. In baseline scenario, nuclear energy in 2030 gets a mere 10% as share in total power generation (30.8% in 2005).

- Petroleum products have a very small share in power generation and their role is limited in certain specific applications (like in isolated islands or areas).

Figure 6: Baseline Scenario EU-25 - Renewables in Power Generation (TWh)



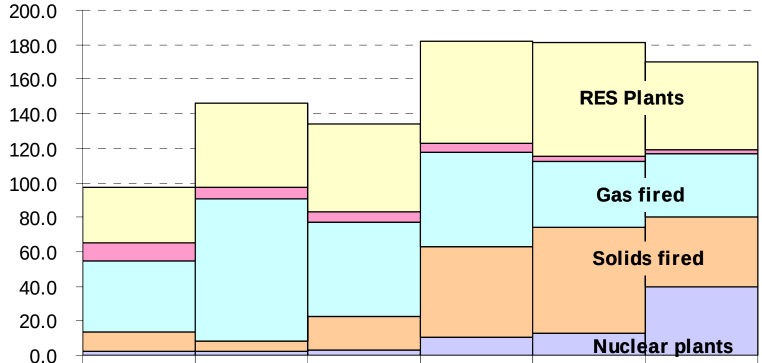
	2000	2005	2010	2015	2020	2025	2030
■ Geothermal and Tidal	5	6	6	7	8	8	9
■ Solar	0	1	1	2	4	5	8
■ Biomass	63	72	94	153	249	333	355
□ Wind off-shore	0	3	23	33	50	96	119
□ Wind on-shore	22	73	153	204	257	306	325
□ Run of river	201	196	201	209	214	222	226
□ Lakes	136	140	146	155	160	165	168
RES Power	428	490	625	762	942	1135	1208

In the whole time period, from 2000 to 2030, the power generation sector is projected to undertake investment of 1 trillion Euros of 2005 to build 910 GW of new power plants. This means that on average 30 GW of new plants per year have to be commissioned. New investment is needed to replace old plants and expand the system in order to meet the growing demand for electricity. In baseline scenario, it is found that 8% of total power investment will be in nuclear power, 60% in thermal power with fossil fuels and the rest 32% in renewables (of which 22% in wind power).

In baseline scenario, nuclear investment takes place towards the end of the projection period and in countries such as France and the UK that need to replace old nuclear plants as well as in few old and new EU member states that expand nuclear capacity (e.g. Spain, Finland, Eastern Europe) or build nuclear for the first time (e.g. Poland). We remind that for the baseline scenario it is assumed that the three countries (Germany, Belgium and Sweden) that have announced phase-out of nuclear maintain this decision.

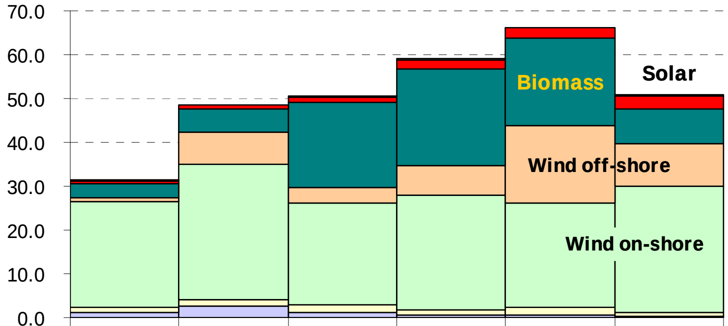
The market for new (clean) coal plants is considerable under the conditions of the baseline scenario: 155 GW of new coal plants after 2015 have to be built. This volume is comparable with existing capacity, which in 2006 consisted of 188 GW of coal plants. The market for new gas plants (mainly combined cycle gas turbine) is also large: on average around 30 plants of 400 MW are built per year until 2020. However, this market becomes smaller in the long term and so after 2020 only 18 new plants of 400 MW are built per year.

Figure 7: Baseline Scenario EU-25 - Power Generation Investment (GW per 5-years period)



	2000-2005	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
□ RES Plants	31.6	48.6	50.5	59.1	66.2	50.8
□ Oil fired	10.9	6.4	6.3	4.8	2.7	2.2
□ Gas fired	41.4	82.7	54.8	55.1	37.9	37.1
□ Solids fired	10.5	5.8	19.7	52.6	61.5	40.2
□ Nuclear plants	2.6	2.5	2.6	10.3	13.0	39.9
Total Expansion	97.0	146.0	133.9	181.8	181.3	170.3

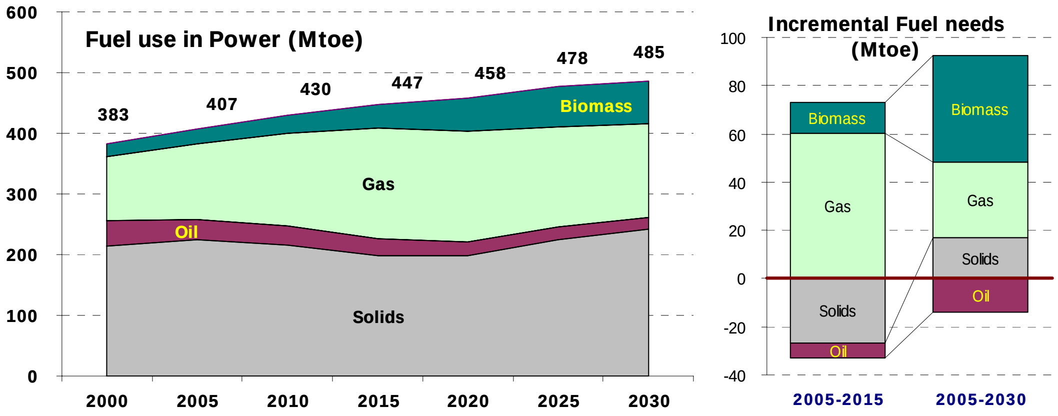
Figure 8: Baseline Scenario EU-25 - Investment in RES (GW per 5-years period)



	2000-2005	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
■ Geothermal and Tidal	0.6	0.0	0.0	0.3	0.1	0.2
■ Solar	0.6	0.9	1.3	1.9	2.4	3.1
■ Biomass	3.0	5.4	19.5	22.1	19.8	8.0
□ Wind off-shore	1.0	7.3	3.5	6.9	17.8	9.6
□ Wind on-shore	23.9	30.8	23.4	26.1	23.8	28.7
□ Run of river	1.2	1.7	1.7	1.2	1.8	1.1
□ Lakes	1.2	2.6	1.2	0.7	0.5	0.2
RES Power	31.6	48.6	50.5	59.1	66.2	50.8

Thermal efficiency of fossil fuel power plants considerably progresses under the conditions of the baseline scenario. From an average thermal efficiency of 37.5% in 2005, it improves up to an average level of 47.5% in 2030. The share of electricity from cogeneration plants also rises: from 16.4% in 2005 it goes up to 24.3% in 2030. This means that CHP electricity doubles in volume from 2005 to 2030.

Figure 9: Baseline Scenario - EU25 - Use of fuels in Thermal Power Generation

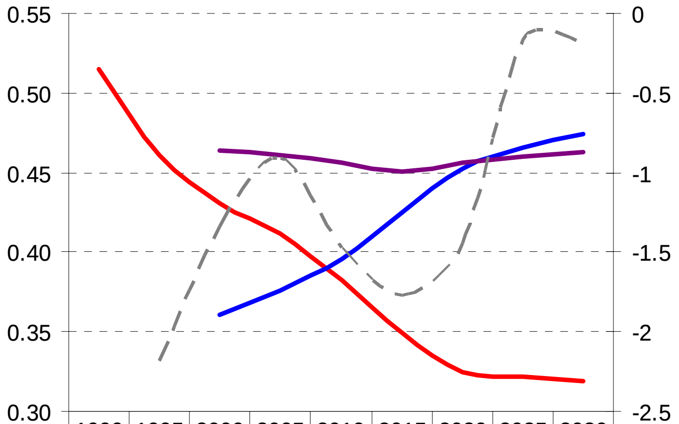


Gas requirements of power generation peak in the period from 2015 to 2020. If year 2005 is taken as basis, incremental gas imports in the period from 2015 to 2020 is around 70 bcm per year, which represents a 50% increase from the level of total gas imports in 2005, which was 140 bcm. Security of supply concern is therefore raised. Beyond 2015, the total volume of gas used in power generation shows a declining trend and its level in 2030 is close to its level in 2010. In the long term, the incremental gas imports, as compared with 2005, are lower (half) than in the medium term, but still significant. The difference between the medium term and the long term volumes of gas imports raises an issue regarding the possibility to conclude affordable long term gas procurement contracts. If oligopoly conditions in upstream gas supply persist, long term contracts to ensure high gas needs in the medium term would probably be expensive, given that total gas demand beyond medium term is expected to decline. This justifies the assumption of relatively high gas prices for power generation for the baseline scenario.

The use of solid fuels in power generation declines in the medium term (by 12% from 2005) but increases substantially in the long term (8% higher in 2030 than in 2005). The incremental needs are mostly covered with imported coal which implies that net imports of solid fuels increase in 2030 (by 50% from 2005).

The changing structure of power generation in the medium term explains the considerable decline of its carbon intensity. In the long term, however, this improvement slows down and almost stops in 2030. Nevertheless, carbon intensity is found in 2030 in baseline to be lower than it was in 1990 by 38% (in 2005 it was already lower than in 1990 by 20%).

Figure 10: Baseline Scenario - EU25 - Carbon Indicators for Power Generation



	1990	1995	2000	2005	2010	2015	2020	2025	2030
▬ Carbon Intensity	0.51	0.46	0.43	0.41	0.38	0.35	0.32	0.32	0.32
▬ Thermal efficiency			0.361	0.375	0.395	0.425	0.453	0.466	0.475
▬ Share of carbon free			0.464	0.461	0.456	0.450	0.457	0.460	0.463
– – carbon intensity % change pa (second axe)		-2.2	-1.3	-0.9	-1.5	-1.8	-1.5	-0.2	-0.2

The progress of carbon intensity of power generation is mainly due to the improvement of thermal efficiency and secondarily to the growth of renewables which produce carbon free power. Regarding carbon-free generation, the remarkable growth of renewable energy in power generation does not counterbalance the decline of nuclear energy: carbon-free power, albeit the increase in volume (by 38% in 2030 from 2005), it keeps a constant share in total power generation not exceeding 45% by the end of the projection period.

The baseline scenario projects increasing cost of energy as a result of increasing oil and gas prices. However, mainly because of substantial energy efficiency gains and structural shifts in favour of less energy intensity materials and processes, the total cost of energy taken as percentage of GDP decreases over time: the ratio reaches a level of 9.5% in 2030, down from 10.6% in 2005. Industry is less affected by increasing energy prices, mainly because this sector undergoes restructuring shifting away from energy intensiveness. The domestic sector (households and tertiary) are likely to face considerable increases of their energy bill, which is related to increasing prices, but also to higher use of energy, electricity in particular. The tertiary sector partly compensates increasing energy costs by energy productivity gains. The increasing spending for energy used by households is also attributed to the increasing purchase of appliances and other entertainment devices which use more electricity. The cost of transportation also increases over time. In this sector capital expenditures grow faster than fuel expenditures, a trend that is related to growing efficiency of engines and transport means.

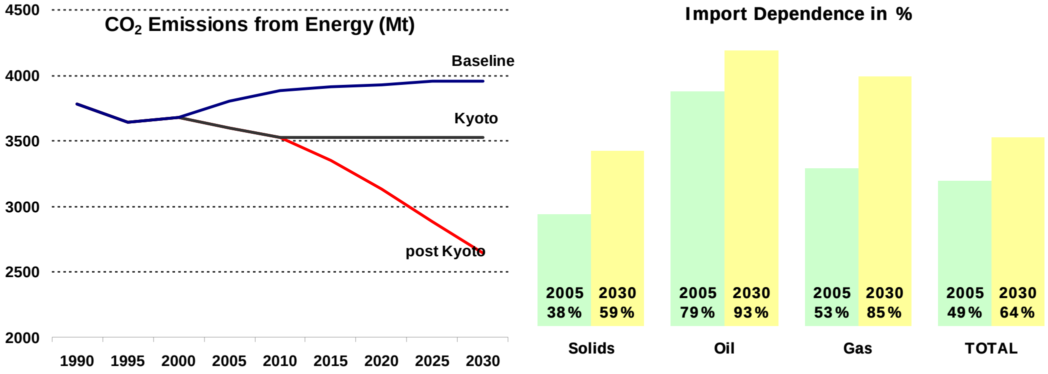
Table 3: Baseline - EU25 - Energy Cost Information

								Annual % change		
System Cost Information	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**'00-'10**	**'10-'20**	**'20-'30**
Industry										
total unit cost of production (index 2000=100)	100.0	101.8	101.3	100.8	100.4	100.0	99.8			
energy related costs as part of production cost (%)	3.2	3.3	3.1	3.0	2.9	2.9	2.8			
energy related costs per toe consumed (in Euro'00 per toe)	506	546	545	554	578	618	639	0.7	0.6	1.0
of which related to energy equipment (capital and O&M)	141	142	145	152	163	175	186	0.3	1.2	1.3
of which related to fuel purchases	365	404	400	402	415	442	453	0.9	0.4	0.9
Households										
energy related expenditure per household	1464	1597	1769	1967	2157	2326	2424	1.9	2.0	1.2
energy equipment expenditure	507	569	700	853	984	1073	1131	3.3	3.5	1.4
fuel expenditure	958	1028	1069	1113	1174	1254	1292	1.1	0.9	1.0
energy related cost as % of income (excl. transport costs)	5.23	5.53	5.74	5.94	6.09	6.18	6.16	0.9	0.6	0.1
energy related costs per toe consumed (in Euro'00 per toe)	994	1061	1164	1282	1407	1526	1606	1.6	1.9	1.3
of which related to energy equipment (capital and O&M)	344	378	460	556	641	704	750	3.0	3.4	1.6
of which related to fuel purchases	650	683	703	726	765	822	856	0.8	0.8	1.1
Tertiary										
energy related unit cost of production (index 2000=100)	100.0	104.2	104.9	104.7	105.9	107.3	107.6	0.5	0.1	0.2
of which related to energy equipment (capital and O&M)	100.0	112.8	118.3	124.1	128.7	130.2	131.8	1.7	0.8	0.2
of which related to fuel purchases	100.0	101.6	100.8	98.8	98.9	100.4	100.3	0.1	-0.2	0.1
energy related costs per toe consumed (in Euro'00 per toe)	891	938	991	1050	1122	1209	1268	1.1	1.2	1.2
of which related to energy equipment (capital and O&M)	207	236	260	290	318	341	361	2.3	2.0	1.3
of which related to fuel purchases	683	702	731	760	804	867	906	0.7	1.0	1.2
Total cost per pkm/tkm travelled ((in Euro'00 per pkm/tkm)										
Passenger transport	0.258	0.260	0.257	0.259	0.266	0.278	0.290	0.0	0.3	0.9
Freight transport	0.339	0.349	0.355	0.362	0.371	0.380	0.391	0.5	0.4	0.5
Fuel cost per pkm/tkm travelled ((in Euro'00 per pkm/tkm)										
Passenger transport	0.041	0.043	0.038	0.035	0.034	0.034	0.032	-0.8	-1.0	-0.8
Freight transport	0.046	0.050	0.049	0.049	0.049	0.049	0.048	0.6	0.0	-0.1
Power and Steam Supply Sector										
Average production costs (Euro'00 per MWhe+MWhth)	36.51	39.23	39.98	40.85	42.49	44.95	46.49	0.9	0.6	0.9
Fixed costs (Capital & fixed operating costs)	15.34	16.17	16.54	16.91	18.11	19.63	20.99	0.8	0.9	1.5
Variable costs (Variable operating & fuel costs)	16.79	17.71	17.48	17.75	17.81	18.36	18.10	0.4	0.2	0.2
Investment expenditure (in bill. Euro'00-for 5 years period)	0	89	112	119	186	200	191	0.0	5.2	0.2
Unit investment expenditure (4) (Euro'00 per KW)	0	482	516	525	569	629	715	0.0	1.0	2.3
Total system costs										
Total Cost of Energy in bill Euro	904	1029	1116	1218	1338	1454	1523	2.1	1.8	1.3
Total Cost per unit of Final Energy in Euro/MWh	71.0	75.5	77.0	80.4	85.3	91.2	94.8	0.8	1.0	1.1
Total Cost of Energy as % of GDP in % of GDP	10.1	10.6	10.2	9.9	9.8	9.7	9.5	0.1	-0.4	-0.3
Average prices of electricity (pretax in Euro'2005/MWh)										
All consumers	84.9	82.3	84.5	86.3	89.3	94.0	96.8	0.0	0.6	0.8
Industry	55.7	56.1	55.6	55.1	55.0	56.0	55.6	0.0	-0.1	0.1
Households	103.4	98.6	101.0	102.7	105.8	111.2	114.5	-0.2	0.5	0.8

The average cost of power generation increases on average by 0.9% per year. Capital and fixed costs increase faster than average cost, because the sector undergoes gradual shifting of investment from low capital cost power plants (such as gas plants) to high capital cost plants (like coal and nuclear). Average electricity prices increase over time mainly as a result of increasing fuel prices. The baseline scenario shows that the increase of electricity prices is likely to affect more the tariffs of households and tertiary and less the industrial tariffs. This is related to the change of load patterns and the increasing marginal cost of supply at peak and mid-load hours.

In summary, the Baseline scenario represents an energy future for Europe which is efficient with respect to cost of energy but is unsustainable with respect to carbon emissions and security of supply. According to baseline, carbon emissions deviate form targets, both with respect to the Kyoto protocol commitments and to the post-Kyoto objectives as recently proposed by the EC. The recent EC policy package envisages a target of -30% CO_2 emissions in 2030 from 1990. According to baseline, energy import dependence of Europe is likely to dramatically increase. Concerns particularly refer to exposure to risk regarding gas procurement conditions and the adverse effects on Europe's power generation sector.

Figure 11: Baseline Scenario - EU25 - Summary graphs



3.3 Alternative Scenarios with PRIMES

3.3.1 Methodology regarding emission reduction

As mentioned above, the alternative scenarios are essentially constrained to reduce carbon dioxide emissions. They determine an economically optimal allocation of carbon abatement effort among sectors and countries under technical and resource constraints. Hence the scenarios determine the recommended changes in energy demand and supply patterns. To meet the overall emissions constraint, all demanders and suppliers consider the marginal abatement cost associated with the emissions constraint as a cost factor which renders carbon intensive energy forms more expensive than others. The PRIMES model simulates how demanders for energy and suppliers modify their demand and supply behaviour in order to shift away from carbon intensive energy forms.

Energy demanders solve a problem of utility maximization under income constraint (residential and transport consumers) or a problem of production cost minimization under output production constraint (industrial and tertiary consumers). In both problems, the aim is to determine the optimal purchase of commodities or production factors. The model considers that this choice is made in a dynamic way over time, involving not only the choice of commodities that are consumed but also the choice of technology and investment in end user devices, processes and appliances, including energy efficiency and energy saving. As a result of these decisions taken separately by sector, demand for energy changes.

The producers of energy as for example power generators adapt their supply behaviour to meet the modified level of demand and to optimise their cost influenced by the modified relative costs of energy forms that are used as inputs to their energy conversion processes. The optimisation is considered to be dynamic over time and involves choice of technologies and investment in new energy production processes. Carbon intensive inputs to energy production are more expensive as being affected by carbon values reflecting the overall marginal abatement cost associated to the overall emissions constraint. Once energy producers adapt their choice of investment and energy inputs, they determine energy prices so as to recover the eventual high costs of adaptation. It is assumed that energy producers apply a Ramsey-Boiteux pricing policy: they determine a level of prices that on average allow for full recovering of total cost, including fixed and stranded costs; they also specify sectoral prices that differ by sector so as to reflect the different price elasticities of demand.

Consequently energy commodities’ prices change and demanders respond by adapting their demand behaviour. An iterative cycle is thus taking place until market equilibrium is reached. A similar process takes place when imposing an energy tax. The only difference is that the energy tax affects income of consumers because it implies transfer of money from consumers to the State. Therefore, by reducing available income, the energy tax directly affects energy demand.

In the presence of an overall constraint on carbon emissions, demanders and suppliers of energy have a series of means to reduce carbon emissions. These means can be classified in the following categories:

1. Energy Efficiency: Reduction of overall energy consumption as a result of energy saving investment and behaviour aiming at a rational use of energy; also choice of end use process technologies and appliances which display higher energy efficiency, i.e. energy consumption per unit of useful energy; cogeneration of heat and power and also advanced heat pump applications involving recovery of waste heat.
2. Change of fossil fuel mix: Shift in favour of natural gas and away from carbon intensive fossil fuels, notably coal and lignite.
3. Renewables: Higher investment and use of renewables both in demand and supply sectors, since renewables are carbon free resources.
4. Nuclear energy: Higher investment in nuclear power, since nuclear is a carbon free source for power generation; the treatment of nuclear fuel is energy intensive but the net effect on carbon emissions is clearly negative.
5. Carbon capture and storage (CCS): Applicable on power generation plants burning fossil fuels. Carbon capture reduces the thermal efficiency of the plant. The captured CO_2 is transported to specific sites where it can be stored underground for an undetermined period of time. Since CO_2 is not emitted to the atmosphere, CCS is considered as a carbon free technology (for the part corresponding to net contribution to CO_2 emission reduction).

For different technical and economic reasons, all means of CO2 emission reduction have a limited potential. If deployed beyond a certain scale, all means exhibit diminishing returns to scale. Beyond a certain scale, additional implementation and deployment costs incur which counter-balance negative costs associated with learning by doing. Therefore, for scales beyond learning by doing, a long-term cost supply curve with increasing slope is associated with the deployment of carbon reducing means.

Since the energy system has to deliver lower emissions and since all emission reduction means have an increasing marginal cost curve, the optimal mix of means to meet the emission constraint has to follow the rule of equality of marginal abatement costs across all means. In other words, every mean must be used up to the volume to which marginal abatement cost is the same for all means.

If any of the above emission reduction means is not allowed to be used because of some policy or technical reasons, then total cost of emission reduction increases as compared with a case in which this reduction means is available. The absence of some of the carbon reduction means implies that other means have to be used at higher scale in order to meet the same emission reduction. Since all means exhibit increasing marginal costs, in other terms diminishing returns, total cost also increases.

It is also possible that for different policy or institutional reasons the baseline scenario may not represent a fully optimised energy system. This may be due to distortions which may be assumed to persist in the baseline scenario. In this case, there exist opportunity to improve the cost of energy if the distortions that lead to non optimality were removed. For the current baseline scenario for EU25 at least three categories of distortion are identified.

The first category includes the distortions that prevent full exploitation of energy efficiency potential. This is often termed the “efficiency gap”. There exist certain possibilities to improve energy efficiency which are economically beneficial, but which are not fully exploited in the baseline scenario. An example is energy efficient lighting for which economic calculations suggest that the pay back period can be below one or two years. However, the baseline trends do not show full exploitation of efficiency in lighting. There are two contrasted interpretations concerning the efficiency gap: one interpretation considers that this efficiency gap is not a distortion but is rather due to a subjective discount rate, as effectively considered by decision makers, which happens to be very high for certain consumers and for households in particular. This point of view implies that there is always a positive non-zero cost associated with efficiency gains. The second interpretation considers that institutional and information distortions exist: they are qualified as non-market “barriers”. These barriers could be removed as a result of adequate policy, so as to enable negative (profit) costs for the consumer. The PRIMES model retains a mixed approach regarding the efficiency gap issue.

The model recognises that the process of efficiency improvement is slow and may not lead to complete exploitation of potential. The slowness is attributed to several reasons: inertia due to persisting consumers’ habits; existing stock of relatively inefficient end-use equipment with slow replacement rate; high subjective discount rates (PRIMES uses discount rates up to 25% for certain consumers, which however are considerably smaller than subjective discount rates that have been proposed in the literature and suggested by econometric studies); barriers related to lack of information and experience with new and advanced end-user technologies (learning by doing is one of the mechanisms represented in the model).

The PRIMES model includes mechanisms which involve exogenous parameters to influence the degree of inertia of consumers in adopting advanced technologies and in pursuing energy efficiency behaviour. The model represents the degree of market acceptance and confidence attributed to new technologies, as well as the degree of awareness and sensitivity of consumers regarding energy efficiency and rational use of energy. These parameters are linked with scenario assumptions and may change in proportion to the degree of stringency of environmental constraints assumed for a scenario.

For the scenarios quantified for EUSUSTEL project, the mechanism of acceleration of energy efficiency is not used. In other words, concerning the efficiency gap, the inertia and behaviour that refer to barriers and acceptance of advanced end-use technologies remain in the alternative scenarios the same as in the baseline. Of course, in the alternative scenarios efficiency improvement is higher than in baseline as a result of imposing the environmental constraints. The improvement is not accelerated as it could be if partial removal of barriers was assumed.

The second category concerns the distortions that may prevent high exploitation of the potential of renewables. The deployment of power or heat production from renewable sources is by nature very dispersed and decentralised. This deployment is therefore confronted with several obstacles and barriers which are related to non-energy policies and various institutional regimes, such as land use, basic infrastructure in remote areas, architectural and urban constraints, agricultural policy, etc. For example, it has been observed that lack of information and other barriers induce low acceptance of renewable plants at a small community level. The PRIMES model includes exogenous parameters that enable partial removal of these barriers to development of renewables. In modelling terms, the removal of barriers allow for shifting the cost-supply curve of renewables to the right allowing for higher potential for the same unit cost. Acceleration of deployment of renewables can be obtained by changing these parameters in proportion to the degree of stringency of environmental constraints. However, for the scenarios quantified for EUSUSTEL project, this mechanism is not used. Renewables penetrate in alternative scenarios more than in baseline but not as high as they would develop if this accelerating mechanism was used.

The third category of distortions concerns nuclear energy. In the baseline scenario it is assumed that, because of general policy reasons, the following restrictions apply on nuclear energy: nuclear phase out is followed in three member-states and premature decommissioning of nuclear capacity takes place according to an announced time schedule; extension of life time of old nuclear plants, where this is possible, does not take place in baseline; nuclear energy does not develop in ten member-states where nuclear has not been used in the past. In economic terms, these restrictions are partly non optimal. For example, according to engineering studies, the life time of some of the old nuclear plants can be extended at low investment cost and without safety risks. If this option was taken, then electricity generation costs could be lower than in baseline. However, this option of extending the life time of old nuclear plants is not taken in any of the scenarios of EUSUSTEL. The abolishment of nuclear phase out in three member states is assumed for scenario PKAT. This implies that, at least as a result of the absence of premature decommissioning of nuclear plant, the cost of electricity supply will be lower in PKAT than in baseline. This effect obviously moderates the additional energy system cost which are due to restructuring in compliance with the cap on carbon dioxide emissions.

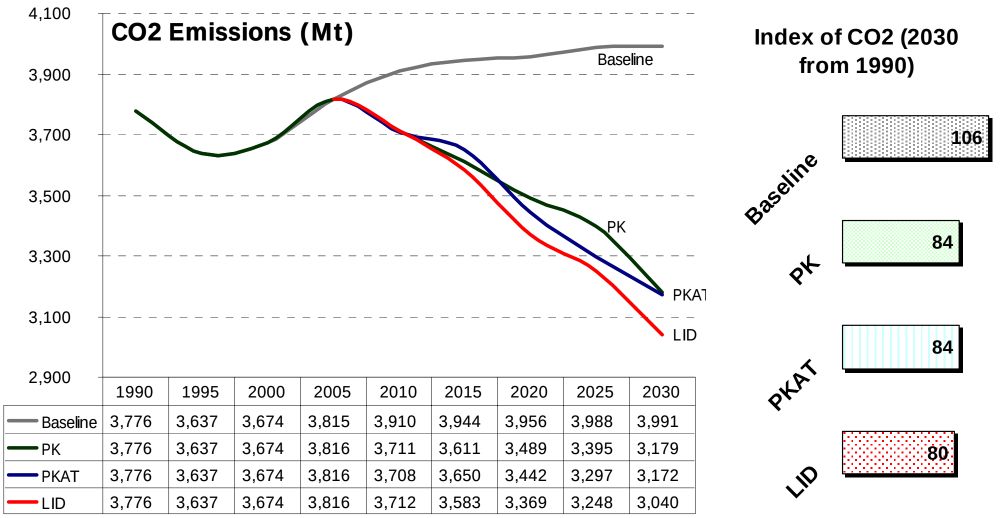
3.3.2 Carbon values and energy import tax as determined by PRIMES

All alternative scenarios assume the imposition of an overall cap on emissions of carbon dioxide from energy demand and supply. For scenarios PK and PKAT the cap has been set at -16% by 2030 with reference to base year (1990) and applies on EU-25 taken as a whole. The PRIMES model determined endogenously the carbon value needed to meet this constraint. For the LID scenario, the carbon value as determined for scenario PK is fixed, but in addition an energy tax on fossil fuels is determined in order to reduce imports of fossil fuels by 10% from PK scenario in 2030. It is expected that in the LID scenario the emissions of CO_2 may reduce even more than in PK, since the carbon value is combined with an energy tax.

By construction, the PK and PKAT scenarios meet the objective, which is set at -16% lower emissions in 2030 from 1990. As expected, the LID scenario was found to overshoot this objective and reduce emissions by 20% in 2030 from 1990. The energy tax, since it induces lower energy demand because of higher cost of energy for consumers, contributes to emission reduction acting in addition to the carbon value.

The level of carbon value associated with the overall emission constraint increases over time, as the constraint becomes more stringent. As expected, the scenario PK involves the highest carbon value, because it assumes that the development of some of the carbon abatement technologies is excluded, notably the development of nuclear in certain member-states. The PKAT scenario, taking benefit from the additional nuclear possibilities, involves lower carbon values, which are found to be for 2030 lower by 40% than in the PK scenario.

Figure 12: Alternative Scenarios EU-25: CO_2 Emissions



	1990	1995	2000	2005	2010	2015	2020	2025	2030
Baseline	3,776	3,637	3,674	3,815	3,910	3,944	3,956	3,988	3,991
PK	3,776	3,637	3,674	3,816	3,711	3,611	3,489	3,395	3,179
PKAT	3,776	3,637	3,674	3,816	3,708	3,650	3,442	3,297	3,172
LID	3,776	3,637	3,674	3,816	3,712	3,583	3,369	3,248	3,040

The LID scenario takes as given the carbon value of scenario PK and in addition applies the energy tax in order to reduce net imports of fossil fuels. The energy tax is determined by the PRIMES model after an iterative process. It is assumed that the tax rate is uniformly applied on all European Union member states and has the form of an excise tax. The rate of taxation is first determined on an average level and then it is further determined by type of fossil fuel so as to be proportional to their market prices.

Table 4: Alternative Scenarios - EU25 - Carbon Values

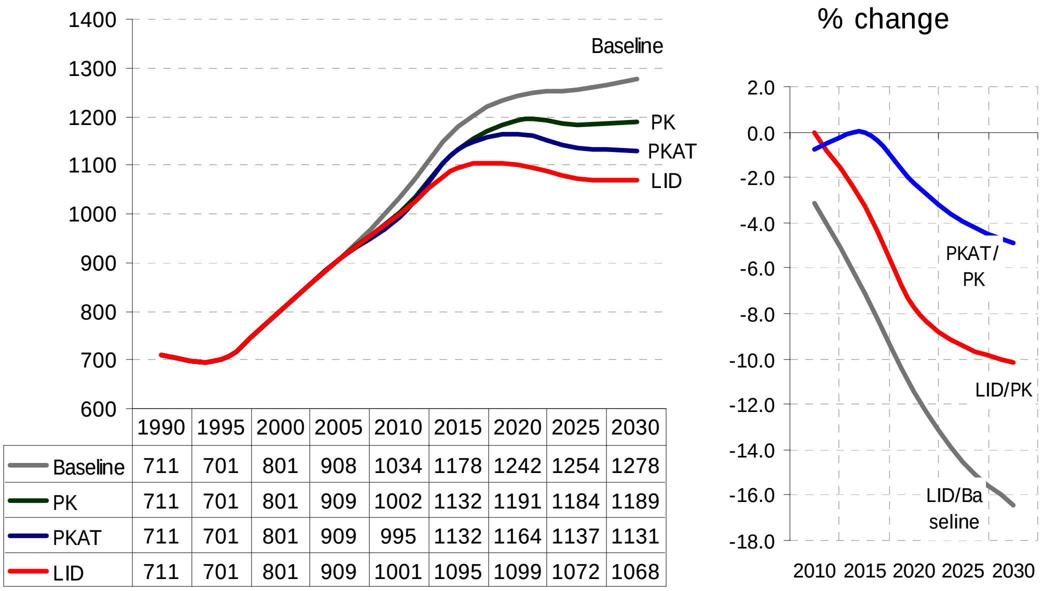
€'05/t CO2	2010	2015	2020	2025	2030
PK	*27.4*	*34.0*	*40.6*	*46.1*	*56.5*
PKAT	*27.4*	*29.1*	*30.7*	*32.0*	*34.6*
LID	*27.4*	*34.0*	*40.6*	*46.1*	*56.5*

Table 5: LID Scenario - EU25 - Energy Tax in €’2005/toe

€'05/toe	2010	2015	2020	2025	2030
Coal	*0.0*	*16.9*	*33.3*	*41.5*	*47.3*
Oil	*0.0*	*56.8*	*114.0*	*155.0*	*182.2*
Gas	*0.0*	*43.3*	*87.8*	*122.1*	*141.5*

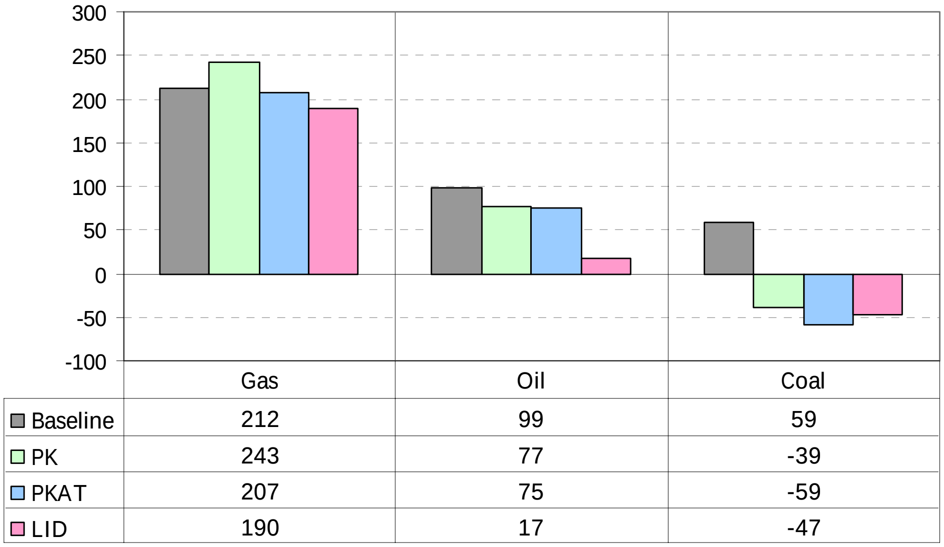
We remind that the carbon value is not implying a direct cost to energy consumers and producers and is not a tax, since it does not entail direct transfers of money from the energy sector to the State. The carbon value alters the relative competitiveness of the different energy forms and induces restructuring of energy demand and supply. The restructuring involves indirect costs on consumers and producers. Conversely, the energy tax implies direct transfers of money from the energy sector to the State; hence it involves direct costs on consumers and producers. As the carbon value, the energy tax changes the relative competitiveness of the energy forms and drives restructuring of demand and supply involving indirect costs.

Figure 13: Alternative Scenarios EU-25 - Total Net Imports in Mtoe



	1990	1995	2000	2005	2010	2015	2020	2025	2030
— Baseline	711	701	801	908	1034	1178	1242	1254	1278
— PK	711	701	801	909	1002	1132	1191	1184	1189
— PKAT	711	701	801	909	995	1132	1164	1137	1131
— LID	711	701	801	909	1001	1095	1099	1072	1068

Figure 14: Alternative Scenarios EU-25 - Incremental Energy Imports in 2030 from 2005 (Mtoe)



	Gas	Oil	Coal
■ Baseline	212	99	59
■ PK	243	77	-39
■ PKAT	207	75	-59
■ LID	190	17	-47

By construction, the LID scenario obtains a reduction of energy imports in 2030 by 10% as compared with results of scenario PK for the same year. In comparison to the baseline, the LID scenario leads to lower energy imports by 17% in 2030; hence import dependence of Europe, from 65% in 2030 in baseline, drops to 57.7% in LID (it was equal to 50% in 2005). Import dependence in PKAT scenario is equal to 56.9% in 2030, but total net imports in volume in 2030 are higher than in LID. The PKAT scenario, as a result of the availability of the nuclear, leads to lower energy imports than PK (by -5% in 2030).

The alternative scenarios do not substantially reduce incremental imports of gas in comparison to baseline. Given that these scenarios are constrained to reduce carbon emissions, gas remains one of the cheapest ways for curbing emissions. The carbon value favours gas vis-à-vis coal. The PK scenario, in particular, leads to higher incremental needs for gas imports than the baseline, because PK is not allowed to fully develop certain carbon free options, such as nuclear. The LID scenario reduces incremental gas needs by 10% from baseline because in addition to the carbon value an energy import tax is imposed. Otherwise, all scenarios reducing carbon emissions exhibit a remarkable inelasticity of gas demand. This finding, which has been confirmed by numerous studies and models, implies that at least in the medium term the emission mitigation pathway of Europe is vulnerable with respect to security of supply.

Total net imports of fossil fuels are found lower in all alternative scenarios than in baseline. This improvement mainly involves substantially lower imports of coal, which is the outcome of the carbon emission constraint. Only when the energy tax is imposed, in the LID scenario, oil and gas imports are found to decrease at a significant degree. Therefore, to address security of supply and the related geopolitical risks, imposition of an energy import tax seems imperative. Such taxation induces lower energy demand and larger substitution of oil and gas, and so it complements the carbon value reflecting the emissions cap. The carbon value alone is effective regarding carbon mitigation but may lead to higher exposure with respect to security of supply, at least in the medium term.

The availability of additional carbon free options such as nuclear, which is fully exploited in the PKAT scenario, improves the situation as regards exposure to high imports of gas. This is of course is related with the indigenous character of most carbon free options. However, the improvement induced by the availability of nuclear is small. The energy tax as studied in the LID scenario leads to superior improvement in terms of security of supply.

Figure 15: LID Scenario EU25 - Impact of energy tax on end user prices of fossil fuels (%)

% change from baseline	2010	2015	2020	2025	2030
Coal	0.0	20.6	38.5	45.5	49.9
Gasoline	0.0	4.1	8.1	10.6	12.2
Diesel Oil	0.0	5.0	9.7	12.7	14.7
Fuel Oil	0.0	23.7	43.5	49.2	52.9
Gas Final Demand	0.0	9.5	18.4	23.5	26.1
Gas Power Gen.	0.0	19.8	36.9	44.3	48.9

3.3.3 The PK scenario

For the PK scenario it is assumed that the EU-25 energy system has to meet a cap on CO_2 emissions: emissions are not allowed to exceed in 2030 a level defined to be 16% lower than their level in 1990. It is assumes that all policy restrictions on nuclear energy remain the same as for baseline scenario. In addition, it is assumed that no barrier-removing or technology-acceleration policies and measures other than in baseline are adopted. This assumption means that no mechanism, on top of baseline scenario, is put in place to accelerate energy efficiency and renewables.

Evidently, to comply with the cap on emissions, the energy system has to use more renewables, adopt more advanced technologies, improve efficiency and change the fuel mix.

The results show that the PK scenario leads to 4% lower overall energy intensity of GDP than baseline, throughout the period 2015 to 2030. Energy efficiency in industry improves in PK in a range between 2.1% in 2015 and 3.4% in 2030, as compared with baseline. Similar improvements are found for the other final energy demand sectors: between 2.4% and 3.2% for residential, 3.1% to 4.2% for tertiary and 1.7% to 2.4% for transport sector. Thermal efficiency of power generation which is projected in baseline to go from 37.5% in 2005 up to 47.5% in 2030 is in found in PK scenario further improved by 3.3 percent points in 2020 and 2.3 percent points in 2030. Cogeneration of heat and power develops slightly more in PK gaining additional share of one percent from baseline.

The changes effectuated in the PK scenario lead to a substantial drop of carbon intensity (CO_2 emissions per unit of total primary energy requirements) as compared with baseline. This reduction is small in the short and medium term and magnifies in the long term. Compared with baseline, carbon intensity of primary energy requirements decreases by 5% in 2015, 10% between 2020 and 2025 and by 17% in 2030.

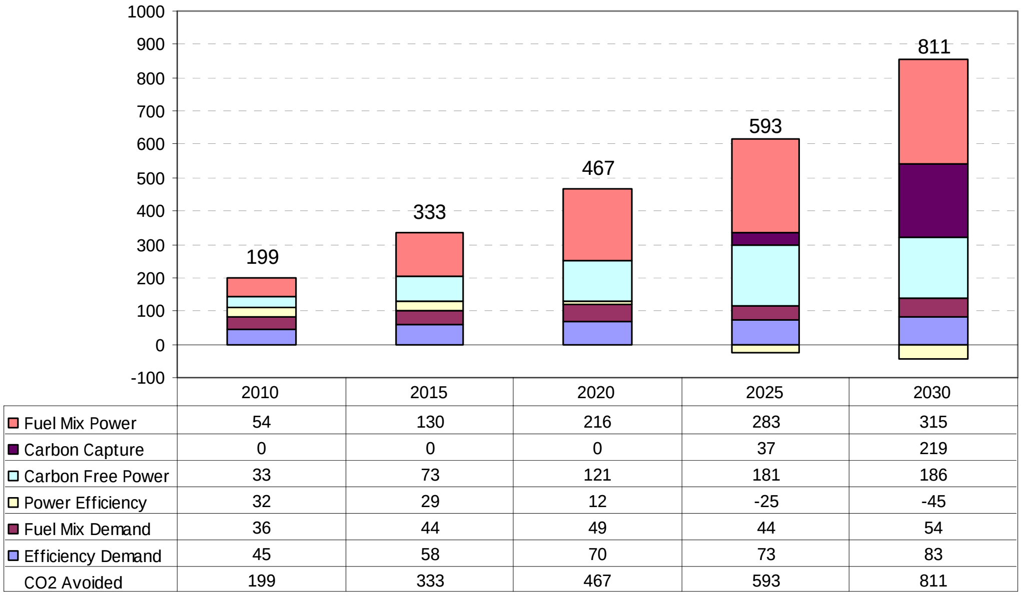
The dynamic pace of carbon intensity improvement reflects the slowness of equipment replacement in energy use and conversion. On the contrary, the energy intensity improvement develops earlier in time but remain constant in the long term, particularly beyond 2015. This reveals that price elasticity of demand induces improvement in the short and medium term.

The decomposition of CO_2 emission reduction by sector shows that the final energy demand sectors carry out 17% of total reduction. The rest (83%) is carried out by power generation (including cogeneration) and district heating sectors. Energy efficiency improvement in demand sectors accounts for 10% of total emission reduction and change of fuel mix in final demand sectors account for 7%. The power generation sector develops carbon free resources, such as nuclear and renewables, by which it carries out 23% of total reduction of emissions. Carbon capture and storage avoids emissions which account for 23% of total reduction but involves lower thermal efficiency of CCS power plants. Hence, the net abatement by CCS represents 17% of total reduction of emissions. Change of fuel mix within the bulk of fossil fuels used in power generation leads to emission reduction which represents 39% of total reduction. These results refer to EU-25 and to the year 2030 representing changes in PK scenario as compared with baseline results for the same year.

The PK scenario has limited possibilities, relatively to PKAT scenario, of recourse to nuclear energy, so renewables is the main additional carbon free power developed. The CCS technology is not mature before 2020 and yet remains rather expensive until 2030. The role CCS would then increase beyond the horizon of 2030. Given that in PK scenario high dependence on gas imports is not a matter of concern, contrary to the LID scenario, changing the fuel mix, in favour of gas and to the detriment of coal, is a non expensive way to reduce carbon emissions. Energy efficiency and carbon intensity improvement in final energy demand sectors play an important role in emission reduction only in short-medium term, representing 30% of total reduction in 2015.

Energy efficiency progress in demand sectors leads to final energy demand lower by 3.2% in 2030 from baseline. Industry is more responsive than other sectors, particularly the energy intensive industry where final energy demand decreases by 4.9% in 2030 from baseline. The transport sector is the most inelastic sector where energy demand becomes in 2030 lower than baseline by a mere 2.4%. The use of fossil fuels in final energy consumption decreases by 18% for solids, 3% for oil and 5.8% for gas (in 2030 from baseline). Electricity demand drop is far less pronounced (decreases by less than 1%), whereas final demand for renewables show a positive change (+5.9%). The share of electricity in final energy demand increases by half a percentage point. This means that the optimal allocation of emission abatement to sectors involves displacement of emission abatement from final energy sectors to power generation sector, because marginal abatement costs are found lower in the latter than in the former sector.

Figure 16: PK Scenario - EU25 - Decomposition of CO_2 Emission Reduction (Mt from baseline)



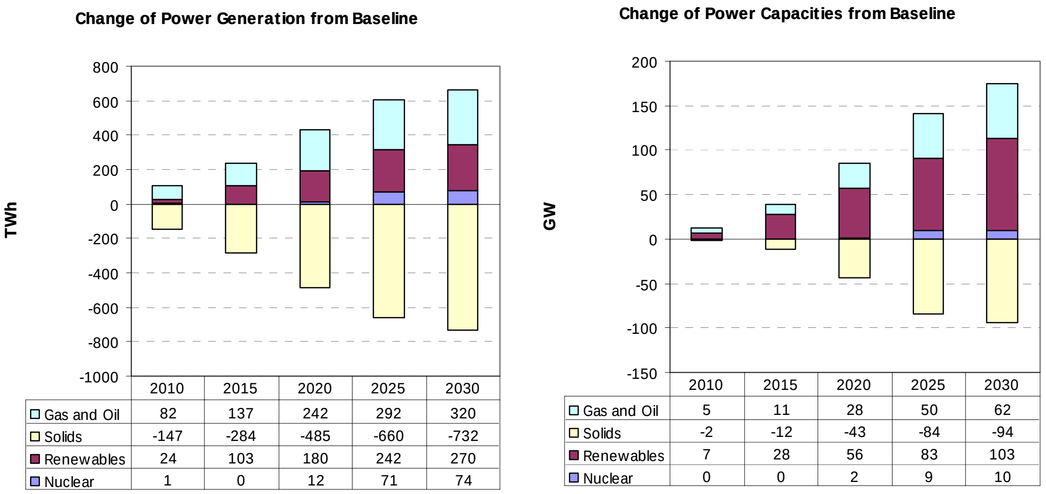
	2010	2015	2020	2025	2030
🟥 Fuel Mix Power	54	130	216	283	315
🟪 Carbon Capture	0	0	0	37	219
🟦 Carbon Free Power	33	73	121	181	186
🟨 Power Efficiency	32	29	12	-25	-45
🟫 Fuel Mix Demand	36	44	49	44	54
🟦 Efficiency Demand	45	58	70	73	83
CO2 Avoided	199	333	467	593	811

The power generation sector undergoes considerable change in PK scenario. Renewables develop considerably and reach in 2030 a share of 23% in total power generation (19% in baseline). Installed capacity of renewables increases by 25% from baseline in 2030. Wind power and biomass plants are among the most developing renewable power sources. Solar photovoltaic also show a tremendous progress: its capacity in 2030 triples from baseline.

Nuclear energy increases in scenario PK by 9.5 % from baseline in 2030. Despite this, nuclear capacity in PK scenario is in 2030 still lower, by 10%, than in 2005. The use of solid fuels in power generation considerably declines in the PK scenario, despite the development of CCS technology by the end of the projection horizon. Power generation from solids in 2030 is found lower by 60% from baseline. Instead of 190 GW of new solid fuel plants that would have been built in baseline, only 100 GW are built in PK scenario, of which 40 GW are equipped with CCS technology. The fuel mix in thermal power generation substantially changes in favour of gas: 70 GW additional gas plants (of which 17 GW are equipped with

CCS technology) are built in PK scenario, as compared with baseline. The share of gas in total power generation rises to 37% in 2030 in PK scenario (21% in 2005 and 24% in 2030 in baseline).

Figure 17: PK Scenario – EU25 – Changes in Power Supply sector



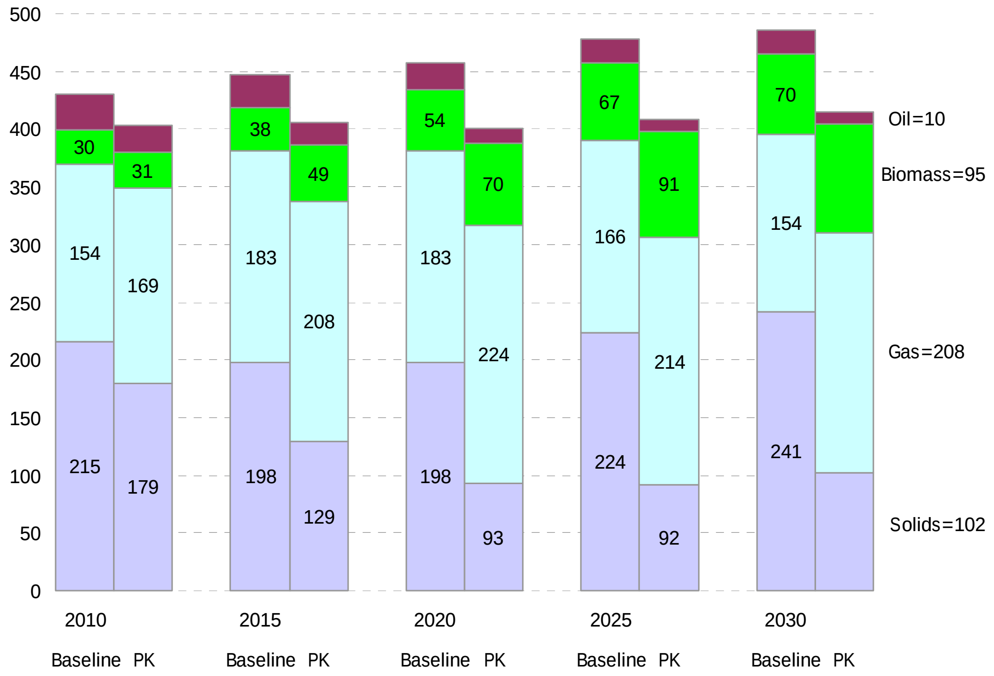
Change of Power Generation from Baseline

	2010	2015	2020	2025	2030
☐ Gas and Oil	82	137	242	292	320
☐ Solids	-147	-284	-485	-660	-732
■ Renewables	24	103	180	242	270
■ Nuclear	1	0	12	71	74

Change of Power Capacities from Baseline

	2010	2015	2020	2025	2030
☐ Gas and Oil	5	11	28	50	62
☐ Solids	-2	-12	-43	-84	-94
■ Renewables	7	28	56	83	103
■ Nuclear	0	0	2	9	10

Figure 18: PK Scenario - EU25 - Changes in Fuel Use in Power Sector (Mtoe)



As a result of this restructuring carbon intensity of power generation reduces by 48% from baseline in 2030. The CCS equipments capture 20% of CO_2 emissions in 2030. Despite the loss of thermal efficiency induced by CCS, the overall thermal efficiency of power generation in the PK scenario improves by 5% from baseline in 2030. As a result of changes in fuel mix, the PK scenario needs considerable more volumes of gas as compared with baseline. In PK, incremental gas needs in 2030 with respect to 2005 are equal to 125 Mtoe, instead of 95 Mtoe in baseline: 30% higher gas needs in PK.

Due to higher investment and higher operation costs, total cost of power generation increases in the PK scenario, relatively to baseline (10% more in 2030 for total generation cost and 15% more for capital costs). Consequently electricity prices increase: they are in 2030 on average higher by 8.5% from baseline. Total energy cost (for the entire system) also increases: in PK energy per unit of service becomes higher in 2030 by 11.8% from baseline. Energy cost as a percentage of GDP increases by 0.8 percent points from baseline.

Despite the higher use of gas, the overall import dependence of EU-25, calculated in percentage terms, becomes in 2030 lower by 3 percentage points from baseline. However, imports of gas increase in 2030 by 7% from baseline, imports of coal drops by 56% and imports of oil drops by only 3%. These results raise concerns about vulnerability of security of supply with respect to gas imports in the context of the PK scenario.

3.3.4 The PKAT scenario

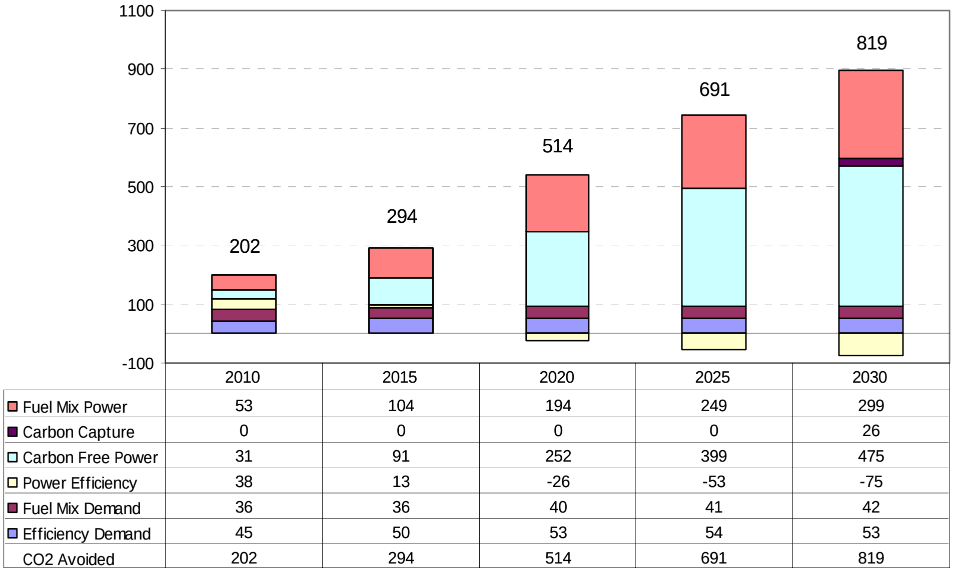
The PKAT scenario is equally constrained as the PK scenario to reduce carbon dioxide emissions so as the overall emissions from energy at EU-25 do not exceed in 2030 a level lower by 16% from emissions in 1990. The PKAT scenario differs from PK only regarding nuclear energy. Nuclear is assumed to be allowed to develop in three member-states which have announced nuclear phase-out and also in Italy. All other assumptions concerning technological possibilities, as well as policies and measures remain in PKAT as assumed for the PK scenario.

The PKAT scenario, as also the PK, having to deliver significant reduction of CO_2 emissions in comparison with baseline, has additional possibilities to invest in nuclear power. Therefore, the overall marginal abatement cost is in PKAT lower than in PK. Table 4 shows that the carbon value in PKAT is likely to be in 2030 lower than in PK by 38%. The additional nuclear possibilities allow PKAT to follow a more balanced approach than PK in reducing emissions. So, the allocation of abatement effort among the different carbon reduction means becomes more cost-effective.

Table 6: PKAT Scenario - EU25 - Nuclear Capacity

		2005	2010	2015	2020	2025	2030	Index (100=2005)
Nuclear Capacity (GW)	Baseline	137	136	125	117	98	101	73.5
	PK	137	136	125	119	107	111	80.6
	PKAT	137	138	133	155	178	207	150.4
Nuclear Generation (TWh)	Baseline	974	963	934	888	803	816	83.8
	PK	974	965	934	900	874	890	91.4
	PKAT	974	965	991	1229	1459	1646	169.0
		2000-2010	2010-2020	2020-2030		2000-2030		Diff. from baseline
Nuclear Investment (GW)	Baseline	5.1	12.9	52.9		70.9		
	PK	5.1	14.4	61.1		80.6		9.8
	PKAT	5.1	41.0	128.9		175.0		104.1

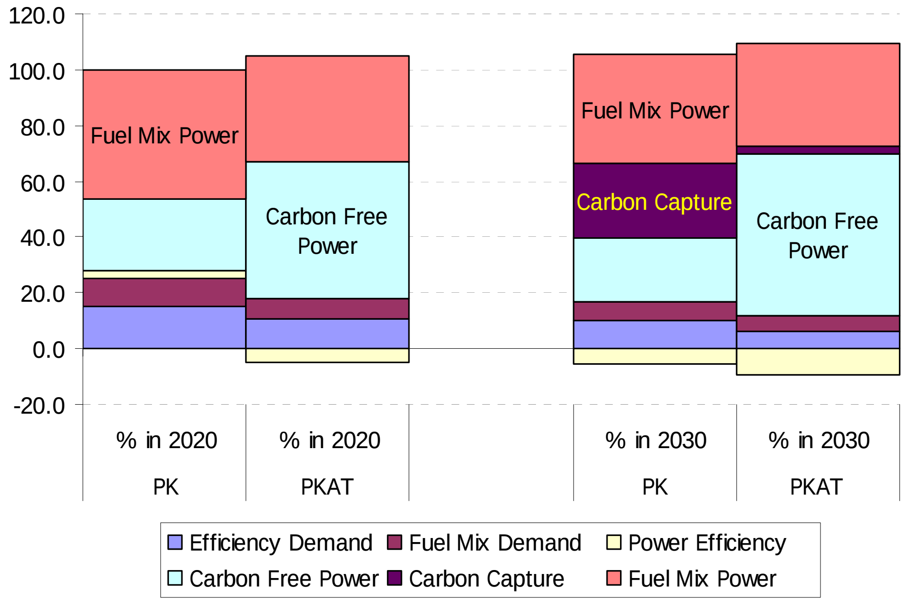
Figure 19: PKAT Scenario - EU25 - Decomposition of CO2 Emission Reduction (Mt)



	2010	2015	2020	2025	2030
🟥 Fuel Mix Power	53	104	194	249	299
🟪 Carbon Capture	0	0	0	0	26
🟦 Carbon Free Power	31	91	252	399	475
🟨 Power Efficiency	38	13	-26	-53	-75
🟫 Fuel Mix Demand	36	36	40	41	42
🟪 Efficiency Demand	45	50	53	54	53
CO2 Avoided	202	294	514	691	819

The results show that in PKAT scenario the decomposition of emission reduction substantially differs from the PK scenario. The PKAT mostly relies on carbon free power generation, notably nuclear energy and renewables, and much less on CCS technology. Emission reduction from efficiency and fuel mix changes in final energy demand remain about the same. Fuel mix within the bulk of fossil fuels used for power generation in PKAT differ from PK: recourse to gas-fired power contributes to emission reduction in PKAT less than in PK.

Figure 20: EU25 Comparison of PK and PKAT in terms of emission reduction (%)



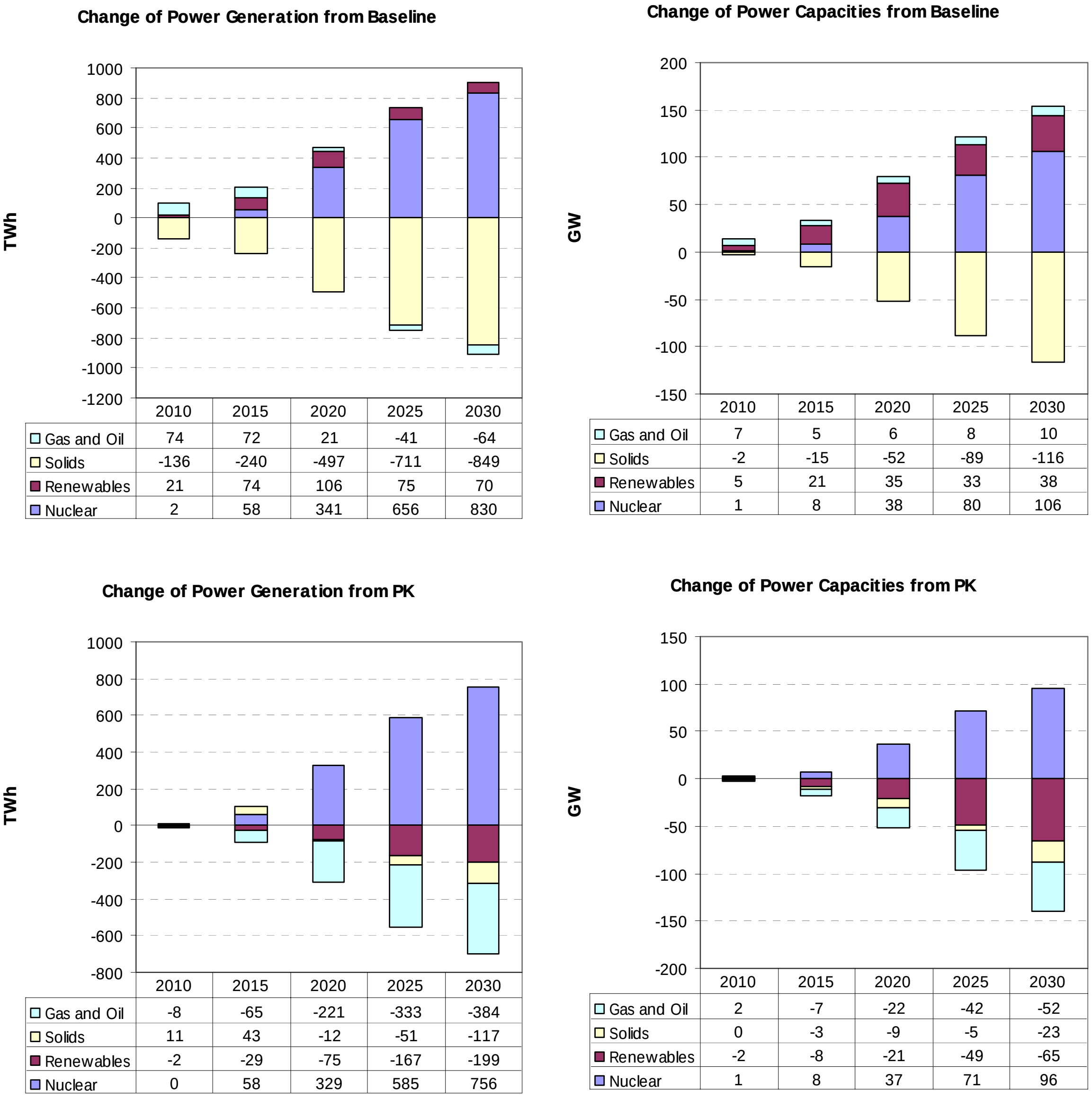
The results show that the additional nuclear development mainly substitutes coal plants with CCS equipment. Nuclear and coal compete to each other for base load generation. CCS-based carbon reduction is by 2030 marginally more expensive than nuclear. Nuclear energy also displaces other energy forms within power generation: renewables are found in PKAT lower by 12% from PK in 2030 and gas is found lower by -25% from PK in 2030.

The partial substitution of gas in power generation re-establishes in 2030 gas imports at their level projected for baseline, despite carbon emissions constraints. Still however the needs for gas imports are high and so security of supply concerns may be raised. The recourse to additional nuclear energy is not enough to curb gas imports.

Similar conclusions are drawn by comparing capacity expansion of power generation in PKAT scenario with expansion in PK scenario. In the medium term, the additional capacity expansion of nuclear in PK takes place to the detriment of renewables and gas power plants. In the long term, the additional nuclear expansion takes place mainly to the detriment of coal plants: the development of coal plants with CCS equipment found in PK scenario is almost completely cancelled in the PKAT scenario.

Total power generation investment in PKAT is found higher from baseline but lower from PK scenario. However, total investment expenditure in PKAT is found higher from PK. High capital cost in PKAT is compensated by lower variable costs; hence total generation cost in PKAT is lower than in PK.

Figure 21: PKAT Scenario - EU25: Changes in Power Generation



Change of Power Generation from Baseline (TWh)

	2010	2015	2020	2025	2030
☐ Gas and Oil	74	72	21	-41	-64
☐ Solids	-136	-240	-497	-711	-849
■ Renewables	21	74	106	75	70
☐ Nuclear	2	58	341	656	830

Change of Power Capacities from Baseline (GW)

	2010	2015	2020	2025	2030
☐ Gas and Oil	7	5	6	8	10
☐ Solids	-2	-15	-52	-89	-116
■ Renewables	5	21	35	33	38
☐ Nuclear	1	8	38	80	106

Change of Power Generation from PK (TWh)

	2010	2015	2020	2025	2030
☐ Gas and Oil	-8	-65	-221	-333	-384
☐ Solids	11	43	-12	-51	-117
■ Renewables	-2	-29	-75	-167	-199
☐ Nuclear	0	58	329	585	756

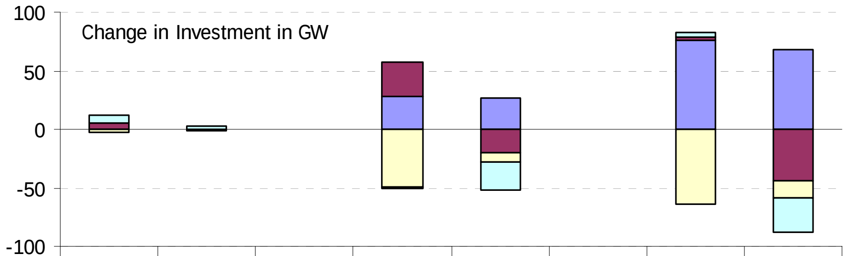
Change of Power Capacities from PK (GW)

	2010	2015	2020	2025	2030
☐ Gas and Oil	2	-7	-22	-42	-52
☐ Solids	0	-3	-9	-5	-23
■ Renewables	-2	-8	-21	-49	-65
☐ Nuclear	1	8	37	71	96

Figure 23 shows that in PK scenario, the additional possibilities for nuclear power development allows for substantial reduction of the use of fossil fuels in power generation. The reduction in the use of gas is larger than for solid fuels.

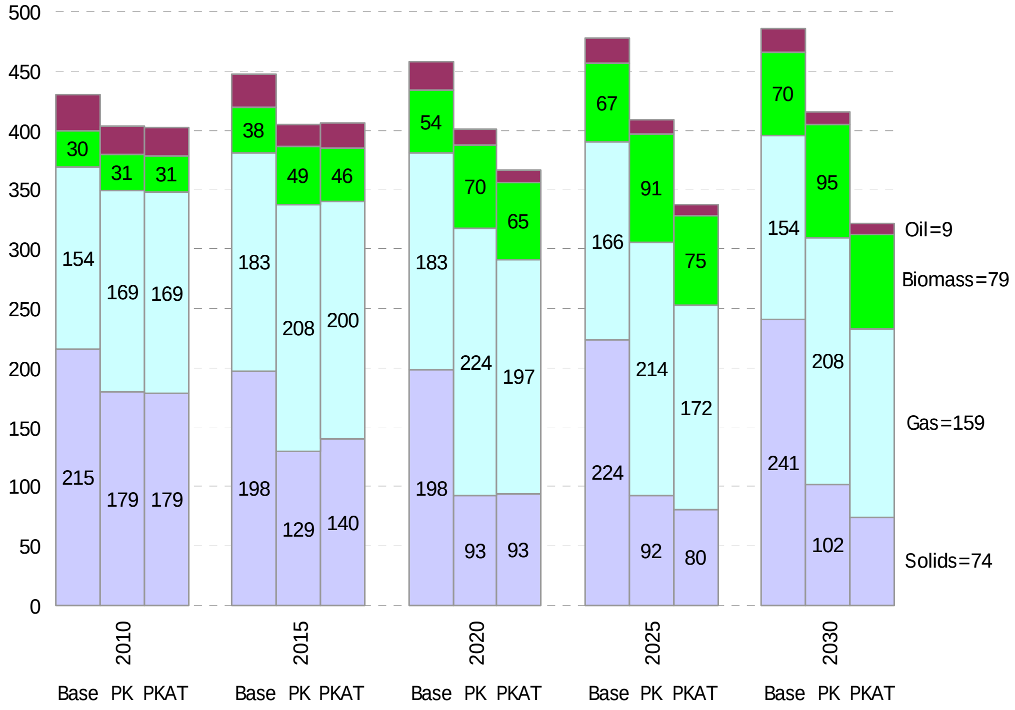
The additional nuclear power reduces total cost of power generation and allows for lower electricity prices. This result is obtained also when allowing development of additional nuclear power within the context of the baseline scenario. This result is due to the assumption of high fossil fuel prices for the baseline scenario.

Figure 22: PKAT Scenario EU25 - Changes in Power Capacity Expansion



	from base 2000-2010	from PK 2000-2010		from base 2010-2020	from PK 2010-2020		from base 2020-2030	from PK 2020-2030
■ Gas and Oil	7	2		-1	-24		3	-30
■ Solids	-2	0		-50	-8		-64	-14
■ Renewables	5	-2		30	-20		3	-44
■ Nuclear	0	0		28	27		76	68

Figure 23: Fuel use in Thermal Power Generation (Mtoe) - EU25



Despite the cost gains due to nuclear development, in total the constraint on emissions induces higher costs as a result of the restructuring of the energy system. The net effect on costs and prices is uncertain: electricity prices are found lower than in baseline in certain tariff categories but total energy costs, as well as the end-user energy prices, are found higher from baseline.

Induced by additional nuclear development, despite restructuring of power generation to reduce emissions, the net effect on electricity prices is negative in PKAT, as compared with baseline. Electricity prices in 2030 drop in PKAT on average by 1.6% from baseline. However, total system cost of energy increases in 2030 from baseline by 3.7%, total energy investment increases by more than 10% and total energy cost as percentage of GDP rises in 2030 by 0.4 percent points above baseline.

The PKAT scenario delivers emission reduction at substantially lower cost for the economy than the PK scenario. However, despite a small but noticeable progress, the PKAT scenario does not alleviate security of supply vulnerability of the European Union in the long term, because dependence on gas imports is not significantly altered from baseline. Economic optimality suggests that despite additional nuclear, gas has still a role to play in cutting emissions of carbon dioxide.

3.3.5 The LID Scenario

In order to address import dependence of the EU on imported hydrocarbons, for the LID scenario it is assumed that taxes on fossil fuels are raised. The LID scenario also addresses reduction of CO_2 emissions by applying the same level of Carbon Value as found for the PK scenario. The rate of taxation on fossil fuels is determined so as to reduce net imports of fossil fuel in 2030 by 10% from their level in the PK scenario. The LID scenario, as the PK scenario, assumes that current nuclear restrictions persist; hence nuclear phase out is maintained in three member-states.

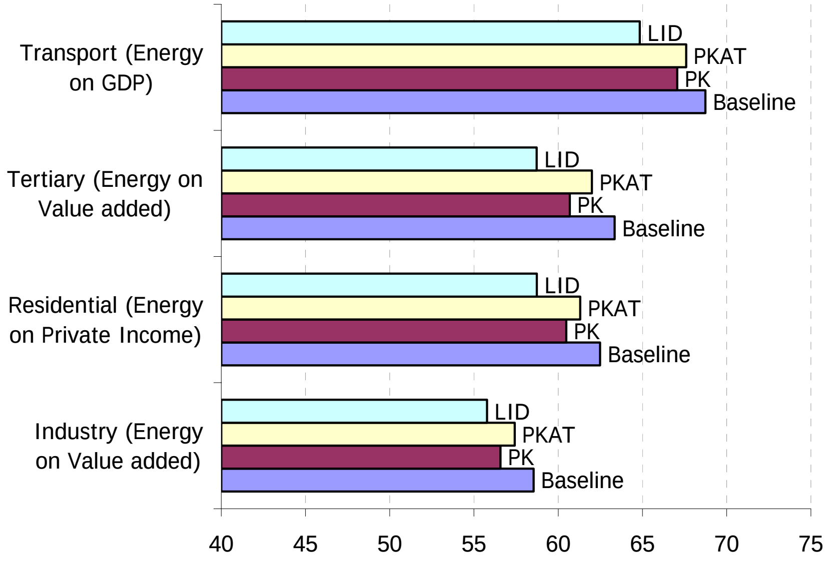
The energy taxes raised on fossil fuels exert direct price effect on consumers, who constrained by their total budget are incited to reduce spending on energy. So they reduce their demand for energy. As a matter of fact, the LID scenario shows significantly higher energy efficiency gains than other scenarios for a similar scale of emission reduction.

Energy taxes on fossil fuels also act by favouring substitution of fossil fuels for indigenous and renewable sources. In LID scenario, imported fossil fuels become more expensive than other energy forms. In addition, fossil fuels are perceived as more expensive than other energy forms because of the carbon value. Therefore fossil fuel taxation complements carbon values and lead to higher emission abatement than in other scenarios. In LID scenario, total CO_2 emissions decrease in 2030 by 20% from their level in 1990, instead of 16% in PK and in PKAT scenarios.

The direct benefit of the change in relative prices is the decrease of net imports of fossil fuels. In the LID scenario, net imports of fossil fuels decrease in total by 10% from the PK scenario. Net imports of oil are more inelastic than other fuels and they drop by a mere 6% from their level in PK (in 2030); this result is related to the high inertia of adjustments in the transport sector.

Table 7: LID Scenario EU25 - Effects on Energy Efficiency

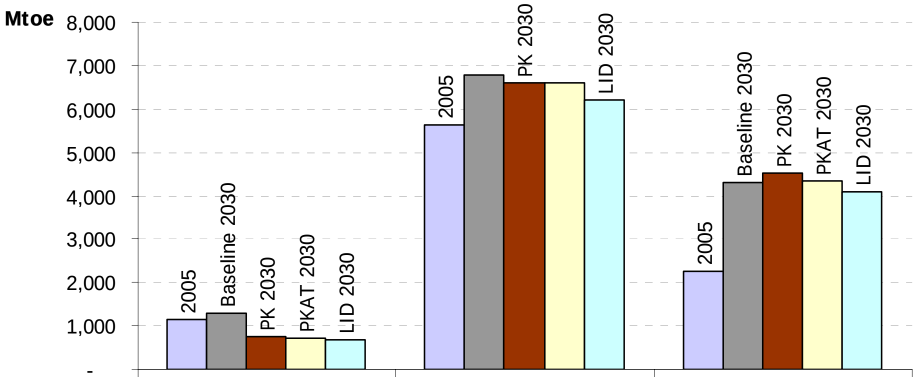
Indicators in 2030 (1990 = 100)	*Baseline*	*PK*	*PKAT*	*LID*	*% LID/PK*
Industry (Energy on Value added)	58.54	56.57	57.42	55.77	-1.4%
Residential (Energy on Private Income)	62.49	60.48	61.31	58.74	-2.9%
Tertiary (Energy on Value added)	63.35	60.70	62.01	58.73	-3.2%
Transport (Energy on GDP)	68.74	67.07	67.60	64.85	-3.3%
Gross Inl. Cons./GDP (toe/MEUR'00)	118.80	113.93	120.37	112.04	-1.7%



The price effects on demand explain why the decomposition of carbon emission reduction in LID differs from PK. The contribution of energy efficiency gains in demand sectors to carbon emission reduction is substantial and remarkably higher than in other scenarios. This is a direct outcome of higher cost of energy resulting from taxation. In addition, the emission cuts due to changes in fuel mix in demand sectors are considerably larger from other scenarios.

This is an implication from changed relative fuel prices induced by taxation. In total, carbon reduction in the demand sector accounts for 37-40% of total reduction, whereas they accounted for only 12-17% in other scenarios. Consequently, emission cuts in supply sectors are lower than in other scenarios. This implies that the lack of additional nuclear power plays a smaller role in LID than in PK scenario, as compared with the PKAT scenario.

Figure 24: Net Imports of Fossil Fuels - EU25

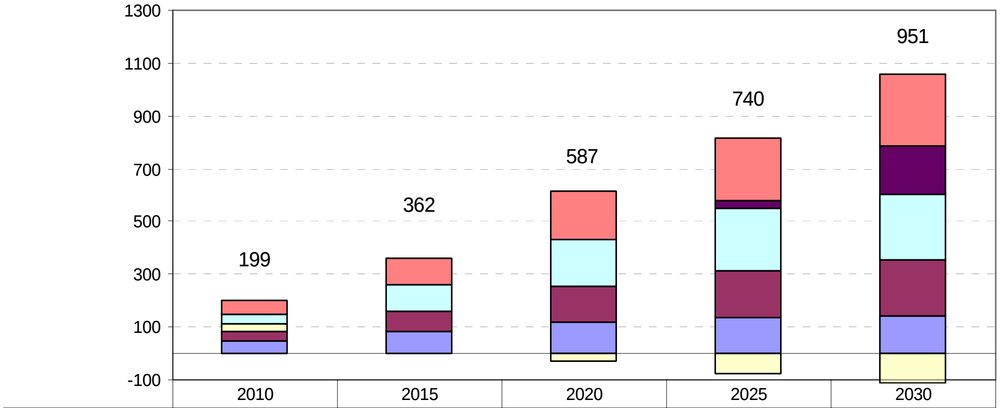


	Solids	Oil	Gas
□ 2005	1,155	5,643	2,254
■ Baseline 2030	1,278	6,796	4,321
■ PK 2030	768	6,600	4,523
□ PKAT 2030	707	6,591	4,324
□ LID 2030	684	6,194	4,095

The LID scenario increases the use of nuclear, CCS and renewables to curb emissions. However their relative contribution is smaller than in PK scenario. Also, the contribution of changes in the fuel mix of fossil fuels in power generation is in LID smaller than in PK. In other words, to curb emissions LID relies less on gas, than PK; hence LID is less depending on gas imports than PK.

Concerning the structure of power generation, the results show that in LID scenario power generation shifts in favour of renewables and coal equipped with CCS, and away from gas. The structure pf power generation differs from PK. However, nuclear energy remains at similar levels in both scenarios. Among the renewables, biomass resources are more used in LID, than in PK. Since in LID scenario total demand for electricity is slightly lower than in PK scenario, the restructuring of power generation requires lower total investment. It must be noted that despite relatively demand for electricity in LID, the share of electricity in final energy demand is higher than in PK. This reflects a displacement of emission abatement from demand to supply, as suggested by economic optimality.

Figure 25: LID Scenario - EU25 - Decomposition of CO_2 Emission Reduction



	2010	2015	2020	2025	2030
🟥 Fuel Mix Power	53	104	187	238	274
■ Carbon Capture	0	0	0	28	181
☐ Carbon Free Power	34	100	178	240	250
☐ Power Efficiency	30	-1	-30	-77	-109
■ Fuel Mix Demand	37	76	133	177	210
■ Efficiency Demand	45	83	120	135	145
CO2 Avoided	199	362	587	740	951

Figure 26: LID Scenario - EU25 - Comparison of scenarios in terms of carbon reduction

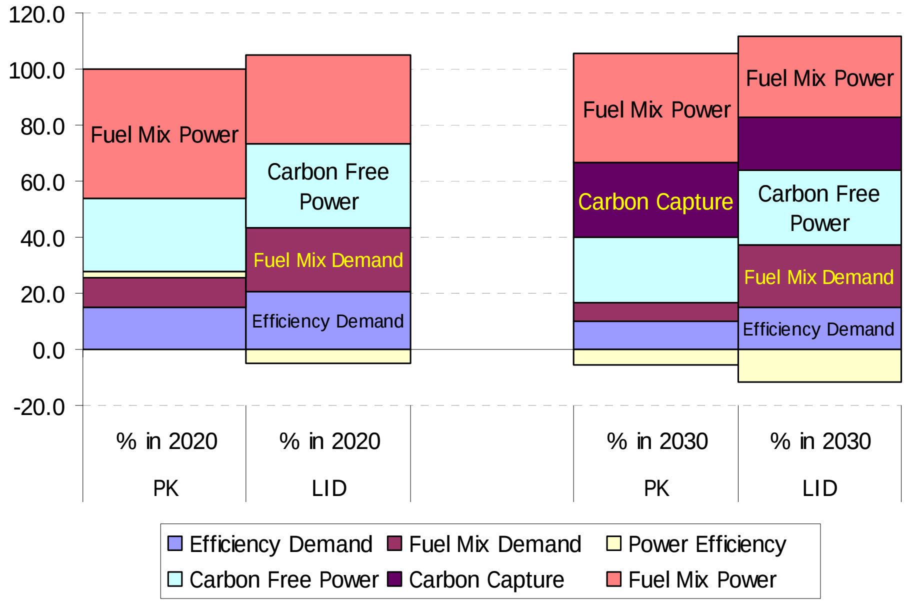
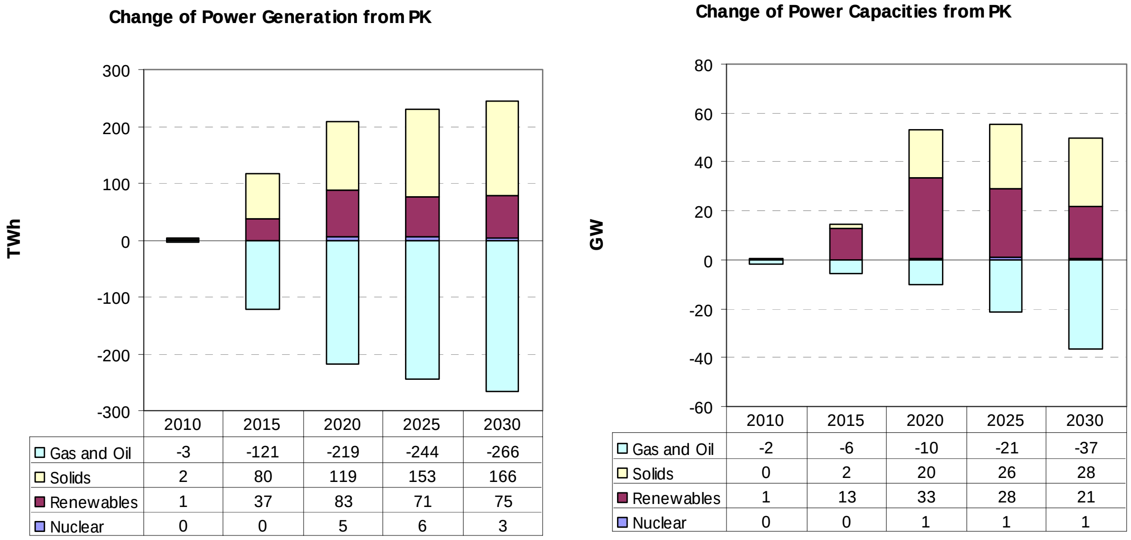


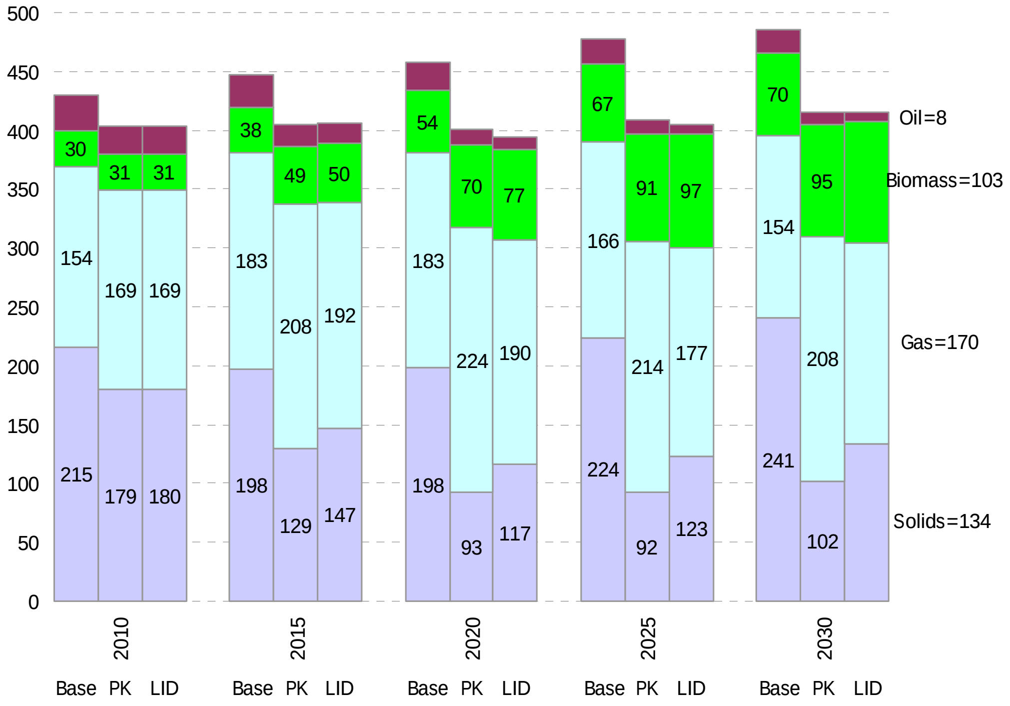
Figure 27: LID Scenario EU25 - Changes in Power Generation



	2010	2015	2020	2025	2030
☐ Gas and Oil	-3	-121	-219	-244	-266
☐ Solids	2	80	119	153	166
■ Renewables	1	37	83	71	75
■ Nuclear	0	0	5	6	3

	2010	2015	2020	2025	2030
☐ Gas and Oil	-2	-6	-10	-21	-37
☐ Solids	0	2	20	26	28
■ Renewables	1	13	33	28	21
■ Nuclear	0	0	1	1	1

Figure 28: LID Scenario EU25- Fuels used in Power Generation (Mtoe)



The cost of power generation in LID is significantly higher from baseline. This is not only attributed to indirect costs involved in the restructuring reducing carbon dioxide emissions, but also to direct costs from energy taxation of fossil fuels. Hence demand sectors face in LID scenario high energy costs. Energy taxation has adverse effects on energy prices. End user electricity prices in LID increase in 2030 by 19% from baseline. The rate of increase is double from the PK scenario. All categories of tariffs are equally affected. Total cost of energy at the level of the whole energy system increases in 2030 by 25% from baseline (11.5% in PK). Energy cost as percentage of GDP in 2030 increases in LID by 1.6 percentage points, instead of 0.8 points in PK. The results show clearly a trade-off between policy aiming at alleviating vulnerability with respect to security of supply and the economic costs borne by consumers of energy.

3.4 Comparison of Scenarios – PRIMES results for EU25

The following table summarises the model results in terms of the performance of the scenarios with respect to strategic policy objectives of the EU.

Table 8: Performance of Scenarios

	Baseline	PK	PKAT	LID
Avg Electricity Prices in 2030				
€'05/MWh	94.0	97.1	92.7	107.7
Avg Cost of Energy Services in 2030				
€'05/MWh	91.2	99.5	96.2	110.3
CO2 Emissions in 2030				
Mt of CO2	3,991	3,179	3,172	3,040
% change from 1990	5.7	-15.8	-16.0	-19.5
Import Dependence in 2030				
%	65.1	63.1	56.9	57.7
% diff. from 2005	14.5	12.4	6.2	7.1
Add. Gas Imports in 2030 from 2005				
Bcm per year	241	276	235	216
Energy Taxes as % of import price	0	0	0	50%
Carbon Value in €'00/MtCO2 in 2030	-	51.5	31.5	51.5

Table 9: Summary of changes in Power Sector and on Efficiency

2030	Baseline	PK	PKAT	LID
Nuclear Investment up to 2030 (GW)	70.9	80.6	175.0	81.3
Nuclear Plants with Extension of life time (GW)	-	-	-	-
New Plants with CCS Capacity (GW)	-	56.8	7.3	40.6
Load factor of gross electric capacities (%)	45.4	41.6	43.8	40.9
Share of Electricity (%)	24.2	24.8	24.8	25.3
Gross Inl. Cons./GDP (2005=100)	66.0	63.3	66.9	62.2
Efficiency of thermal electricity production (%)	47.5	49.8	48.2	48.9
CHP indicator (% of electricity from CHP)	24.4	24.7	24.5	24.8
Non fossil fuels in electricity generation (%)	46.3	55.0	67.1	57.2
CO2 Emissions per MWh	0.32	0.17	0.15	0.18

The results illustrate that the baseline scenario represents an unsustainable evolution of the EU energy system. Non sustainability is evident with respect to carbon dioxide emissions and import dependence.

All alternative scenarios deliver substantially lower carbon dioxide emissions but differ in their assumptions about means and policies.

The PK scenario, based on policies that are already in place within the baseline scenario, reduce emissions mainly by means of switching fuel mix in favour of gas, by developing renewables and by applying CCS technology on new thermal power plants. This menu of actions is characterized by relatively low cost-effectiveness, does not mobilise the efficiency potential in demand sectors and does not address the security of supply issue.

The PKAT scenario assumes removal of restrictions on nuclear energy and considerably employs nuclear energy as a means for lower carbon emissions. This relaxes constraints and lowers abatement costs from their high levels found for the PK scenario; hence overall cost-effectiveness is improved. The nuclear option induces lower generation costs and reduces the overall cost of curbing emissions. However, in the PKAT scenario, energy efficiency in demand sectors does not progress as it could if additional policies were in place. The PKAT scenario allows for a small but noticeable improvement in terms of import dependence. The new structure of energy in PKAT scenario favours nuclear to the detriment of coal-based CCS technology and renewables. However, it still relies on gas. Therefore in PKAT dependence on gas imports remains a matter of concern.

The LID scenario illustrates the implications from applying energy taxation on fossil fuels. Energy taxation induces lower energy demand, higher efficiency and larger switching in fuel mix in final energy sectors. Hence, the contribution of demand sectors to carbon emission reduction is considerable. In addition, the energy taxation considerably improves the situation with respect to imports of hydrocarbons; however the transport sector, hence the imports of oil display inertia of adjustment. The improvement with respect to security of supply takes place at the expense of energy costs: consumers and the economy bear high costs in all domains of energy use and conversion.

4 Results of the electricity and gas market model TIMES-EG

4.1 Introduction

For analyzing different policy options and strategies, the four contrary scenarios described in chapter 2 have been analyzed using the electricity and gas market model TIMES-EG. Beside these four main scenarios, TIMES-EG has been used to analyze efficient CO_2 mitigation strategies for the electricity sector in Europe within three additional scenario variants. Considering the assumptions made within the project regarding fuel prices, technological development for the various power plant types and policy measures, TIMES-EG calculates an intertemporal optimal development of the electricity generation structure for the EU-25 (EU-30). Based on this modelling framework, different policy measures regarding energy, environment and technology can be simulated to support optimal electricity and gas market policy in the European Union.

4.2 Model overview – TIMES-EG

TIMES (The Integrated MARKAL-EFOM System) is a model generator that has been developed over the last 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 continuously undergo development and refinement.

The European Electricity and Gas Model TIMES-EG is a technically oriented model which illustrates in detail the electricity supply industry of the member states of the EU-25 for the period from 2000 to 2030. Furthermore, CHP plants are also considered within the model. The different basic conditions of the different regions are seized through regionally differentiated parameters such as fuel prices, data for the potentials of renewable energy sources and region characteristic load curves for the different customer groups (residential, commercial, energy-intensive and energy-extensive industry, traffic). Not only the energy flows but also the energy-related greenhouse gas emissions are modelled. Thus, it is possible to analyse the possibilities of an emission trade scheme.

Figure 1: Regional structure of electricity and gas model TIMES-EG

The structure of the TIMES-EG model considers processes especially of the supply side. The supply side data comprises over 200 conversion technologies for central electricity and district heat. These conversion technologies are fossil based (coal, oil, gas), nuclear based, and renewable (hydro, wind, solar, biomass, geothermal). The supply side technologies are divided into different groups of technology generations, depending on the plant size and on operation time. The technical-economical data for supply side technologies are described by the attributes as e.g. availability factor, capacity factor, electrical efficiency, gross capacity, self consumption rate, specific fixed O&M costs, specific variable O&M costs, external costs and further more. The data contained in the technology data base consider both the technological progress and anticipated price developments in the power station market. With the temporal differentiation of the technology data also the dynamic viewpoint of the model is supported. Additionally also the possibility exists of changing existing power stations by efficiency-increasing measures or life time-extending measures in its economic classification in the model.

It is assumed that in the sense of a complete competition within the European electricity market the total costs for the entire regarded region are to be minimized. Restricted by the technical parameters of the plants, the enterprises' decision is made based on economic values. By coupling different regions an interregional competition structure arises. This leads to an electricity exchange within the system whenever the difference of the marginal costs of the load covering of a certain load segment at a certain time is larger than the total costs for transmission and transmission losses. For the electricity market copied in the model from this intra and inters regional competition relations results.

4.3 Scenario analysis

4.3.1 Electricity generation

Assuming a business as usual (Baseline, BL) development in the European Union, coal remains the most important energy carrier for electricity generation within the production portfolio. Coal based generation has a share of approximately 36.5 % in the year 2030.

Due to an only limited effort for CO_2 mitigation in the EU-25, implementing a Carbon Value of 5 €/t CO_2, climate policy does not induce a fuel shift in electricity generation from CO_2 intensive energy carriers like hard coal and lignite to gas. However, CO_2 free electricity generation based on renewable energy sources shows a total amount of 1250 TWh in the EU-25 and a share of 29.1 %, respectively, given an ongoing support for RES technologies up to the year 2030. Nuclear electricity generation is limited to 880 TWh (20.6 %) induced by phase-out policy in some European countries like Germany, Sweden and the Netherlands as well as the assumptions made for investment restrictions for nuclear power plants in the European Union. The projected structure of the electricity generation in the EU-25 is presented in Figure 1.

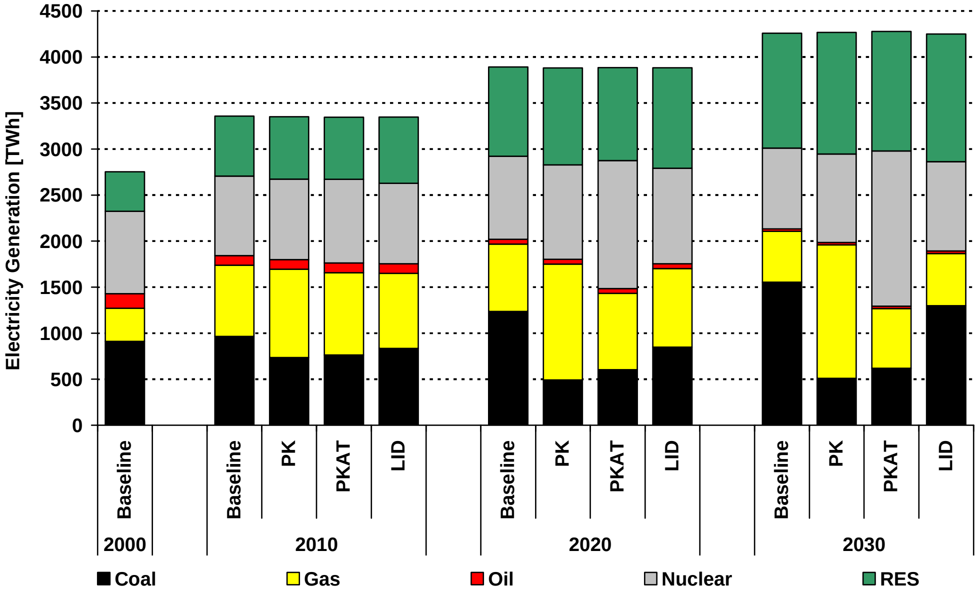


Figure 1: Structure of electricity generation in the EU-25

Strengthening the climate policy instruments to increase CO_2 mitigation in Europe within a Post-Kyoto regime (PK) by increasing the Carbon Value from 5 €/t CO_2 to 51.5 €/t CO_2 in the year 2030, has a strong effect on the electricity generation structure. Due to the cost increase for CO_2 emissions, coal based production is projected to decrease from 1554 TWh in the Baseline (BL) to 510 TWh in the PK scenario in 2030. The share of coal based electricity generation is reduced to 12 %. Coal is mainly substituted by gas fired technologies which show a total production of 1450 TWh and an overall share of 34 %. RES based generation remains nearly the same as in the baseline. Due to the assumption that the support policies for RES electricity generation are ongoing within the PK scenario, renewables hold comparably high market shares.

Considering the same CO_2 emission target like in the PK scenario but allowing for a more cost oriented development of the generation portfolio within the PKAT scenario where some of the limiting technology restrictions especially regarding nuclear generation are removed, leads to changes in the fuel shift for substituting coal fired technologies. Contrary to the PK scenario, where gas was projected to be the major competitive technology to substitute for coal based electricity production, nuclear electricity production is increasing to reach the Post-Kyoto target. As nuclear generation was projected to have a share of approximately 22.5 % in the PK scenario its share increases to 39.4 % in the PKAT scenario. Nuclear electricity generation thus reaches an amount of 1685 TWh in the year 2030. For RES based generation, the same holds like in the PK scenario.

For the Limited Import Dependence (LID) scenario electricity generation by coal is reduced by approximately 16.5 % compared to the Baseline scenario due to the tax increase on fossil fuel consumption for electricity generation. For gas based generation, the opposite effect holds. Even with a tax increase for gas consumption, electricity production in gas power plants increase by 2.7 %. Thus, fuel substitution for coal compensates the cost induced decrease of gas power plants.

Regarding the electricity generation capacity development within the various scenarios (cf. Figure 2) similar structural changes can be observed. Given the lower utilisation rates for renewables and oil fired power plants, RES is projected to have a higher overall share in generation capacity in the year 2030. As RES based production was projected to reach an overall share of approximately 29.3 % in 2030, the capacity share becomes 39.7 % (Baseline). Due to the high availability and utilisation rates of baseload technologies like lignite and nuclear power plants, their share results in lower values compared to the shares in overall generation. Nuclear is projected to show a share between 12.2 % in the Baseline scenario and 21.3 % in the PKAT scenario, whereas capacity share of coal power plants becomes 9.8 % in the PK scenario and 23.3 % in the Baseline scenario.

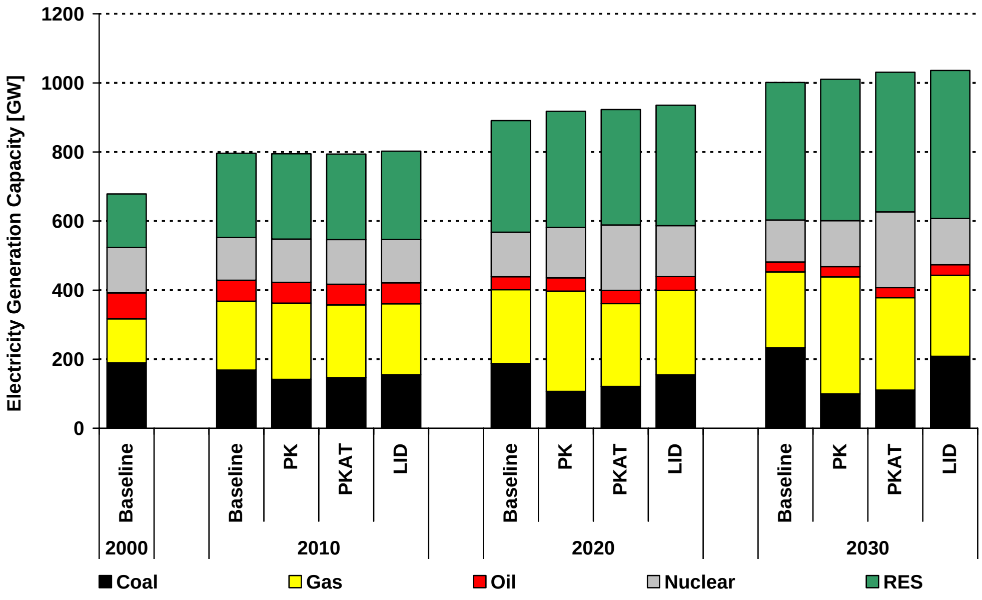


Figure 2: Structure of electricity generation capacity in the EU-25

As can be seen in Figure 2, the generation capacities in the PKAT scenario is projected to be slightly higher than in the PK scenario. This result can be explained by a construction time of

5 years for new nuclear power plants and that therefore additional natural gas CCGT are needed to face demand, resulting in some overcapacity at time of operation of the new nuclear capacities.

An additional effect that can be observed due to the different policy scenarios is the impact in interregional electricity trade within Europe. As assumptions on technology specific restrictions differ among the European member states, changes in interregional trade are induced by cost differences. Given the Post Kyoto targets, the traded volume increases compared to the baseline by approximately 160 TWh in 2030. Allowing for new nuclear power plants within the PKAT scenario leads to a decrease in overall trade of 240 TWh compared to the baseline. This result can be explained by a more homogenous electricity generation structure in Europe, reducing relative cost advantages for these countries that are not supposed to restrict their generation portfolio regarding specific options.

4.3.2 Electricity related CO_2 emissions

In the business as usual scenario (Baseline), electricity related CO_2 emissions in the EU-25 increases from approximately 1300 Mt in 2000 to approximately 1500 Mt in the year 2030. Reducing CO_2 emissions by a Carbon Value (PK), TIMES-EG calculates electricity related CO_2 emissions of 950 Mt in 2030. Allowing for unrestricted technological development in the PKAT scenario, CO_2 emissions are further reduced by 16 % reaching 800 Mt in the year 2030 (cf. Figure 7).

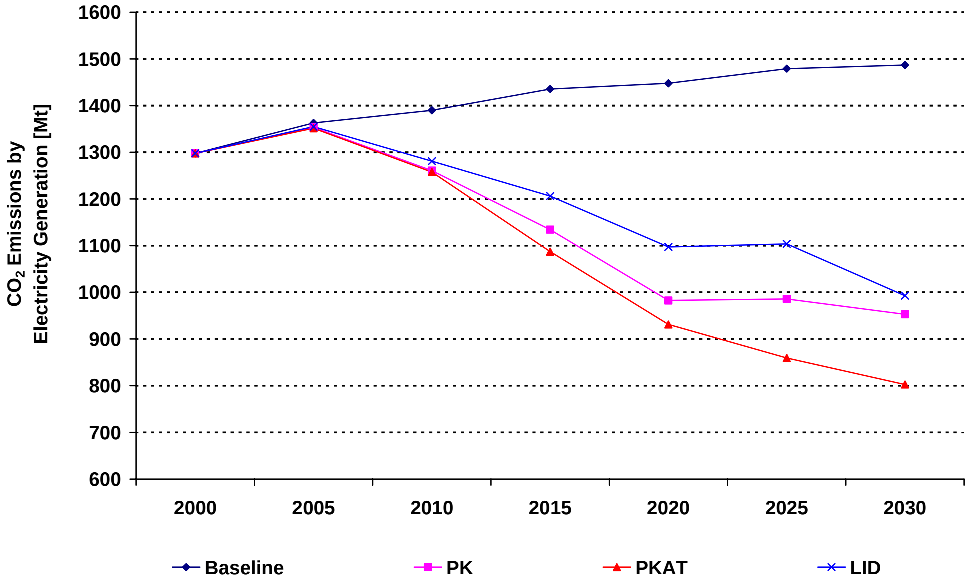


Figure 3: Electricity related CO_2 emissions in the EU-25

Regarding electricity generation technologies using Carbon Capture and Storage (CCS), the TIMES-EG shows approximately 17 Mio t CO_2 captured within the PK scenario, whereas only 4 Mio. t CO_2 are projected to be captured within the PKAT scenario in 2030. CCS technologies are going to be utilized within the electricity system from the year 2020 on.

4.3.3 Fossil Fuel input in electricity generation

The fossil fuel input in electricity generations mirrors the structural development within the various scenarios (cf. Figure 4). Focusing again on the year 2030 the fossil fuel use for electricity generation in the Baseline is dominated by coal, followed by gas. Intensifying the climate policy goal, i.e. increasing the Carbon Value to reduce the CO_2 emissions to 16 % compared to the 1990 emissions, leads to a shift in fossil fuel consumption for generation from coal to gas.

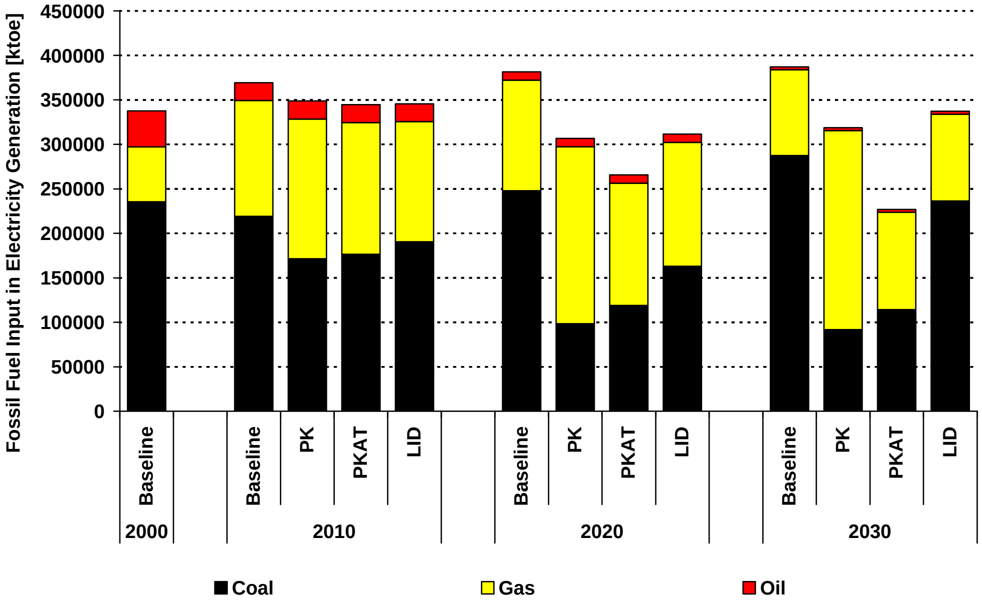


Figure 4: Fossil fuel input for electricity generation in the EU-25

Regarding the changes in overall fossil fuel demand for electricity generation, it can be concluded that the climate protection strategy (PK) leads to a reduction in overall fuel use and therefore a decrease in energy imports into the EU-25. This effect will be enforced allowing for more technological options, e.g. nuclear generation. The CO_2 mitigation policy, especially combined with an option for new nuclear generation capacities contributes to a better situation regarding security of supply. Moreover, TIMES-EG project this policy measures to be more efficient than the assumed increase in fossil fuel taxes within the LID scenario.

4.3.4 Cost of electricity generation

Regarding the economic consequences of the various policy frameworks, differences in the costs for electricity generation can be observed. Comparing the four main scenarios, electricity generation in the LID scenario is projected to be most costly, due to the energy carrier taxation to reduce the consumption of imported fuels in Europe. Compared to the Baseline the production costs are approximately 26 % higher in 2030. Given average generation costs of 45 €/MWh in the Baseline, the strategy for limiting the imports leads to 56 €/MWh.

Restricting the CO_2 emissions within the Post-Kyoto scenarios (PK and PKAT) to reach a reduction of 16 % compared to the 1990 emissions, changes in generation costs to 49 €/MWh (PK) and 39 €/MWh (PKAT) are calculated. Due to the increased flexibility for optimization in the electricity and gas market, the CO_2 emission reductions in the year 2030 can be reached with approximately 20 % less average costs in the PKAT scenario compared to the PK scenario (cf. Table 9).

Table 9: Cost of electricity generation in the EU-25 in 2020-2030

[EURO$_{2000}$/MWh]	2020	2025	2030
Baseline	40.7	43.0	44.6
PK	45.4	49.7	48.6
PKAT	41.3	42.9	38.7
LID	50.4	58.7	56.4

4.4 Efficient CO_2-mitigation in the electricity sector

Beside the four main scenarios, three additional scenarios have been simulated to analyze the economic implication of various energy policies under a joint CO_2 control target. The additional scenarios have been characterized as follows:

1. PK800 – Post-Kyoto with a CO_2 emission target of 800 Mt CO_2 in the year 2030. The same assumptions have been made as in the PK scenario.

2. PKAT800 – Post-Kyoto with a CO_2 emission target of 800 Mt CO_2 in the year 2030 allowing for free technological optimization. The same assumptions have been made as in the PKAT scenario.

3. LC800 – Least Cost electricity and gas market development in the EU-25, considering a CO_2 emission target of 800 Mt CO_2 in the year 2030. Within the LC800 scenario, the restrictions on nuclear generation technologies regarding new investments and life time extension as well as the support measures for electricity generation using renewable energy sources have been removed.

4.4.1 Electricity generation

Allowing for portfolio optimization regarding the electricity generation structure within a CO_2 mitigation regime that defines an upper bound for CO_2 emissions rather than a carbon value, TIMES-EG shows some changes compared to the main scenario results described above. Considering the more stringent CO_2 targets for the electricity sector in EU-25 within the PK800, PKAT800, and LC800 scenarios, it is projected that this policy will bring more coal based generation with Carbon Capture and Storage (CCS) as well as nuclear generation capacity into the market.

Regarding coal based generation, it can be observed that the contribution in the year 2030 increases in the PK800 (576 TWh) as well as the PK scenario (510 TWh). This effect can be explained with a higher deployment of CCS production. However, gas based technologies are projected to show the highest increase compared to the Baseline. Allowing for a more cost oriented development of the generation portfolio without restricting nuclear generation as assumed in the Baseline scenario, the PK800 show a much higher contribution of nuclear power plants to the overall electricity generation in the EU-25. Contrary to the PK800 scenario, coal based generation is reduced to 601 TWh in the PK800 scenario compared to the PKAT scenario with 620 TWh. Parts of the coal based production is substituted by gas power plants, which increase from 648 TWh in the PKAT to 659 TWh in the PKAT800 scenario.

In scenario LC800 where most of the technology oriented restrictions are removed, nuclear generation becomes an even more important generation option. Given the option to increase the technical lifetime of nuclear power plants and allowing for new investments, nuclear generation increase from 878 TWh in the Baseline scenario to 1967 TWh in the LC800 scenario. As the support schemes for renewable electricity generation are not implemented in the Least Cost scenario, RES share is projected to decrease by 31 % compared to the Baseline. Most of the RES based generation is substituted by nuclear generation as well as gas fired power plants, which increase their share from 12.9 % in the Baseline to 22.0 % in the LC800 scenario.

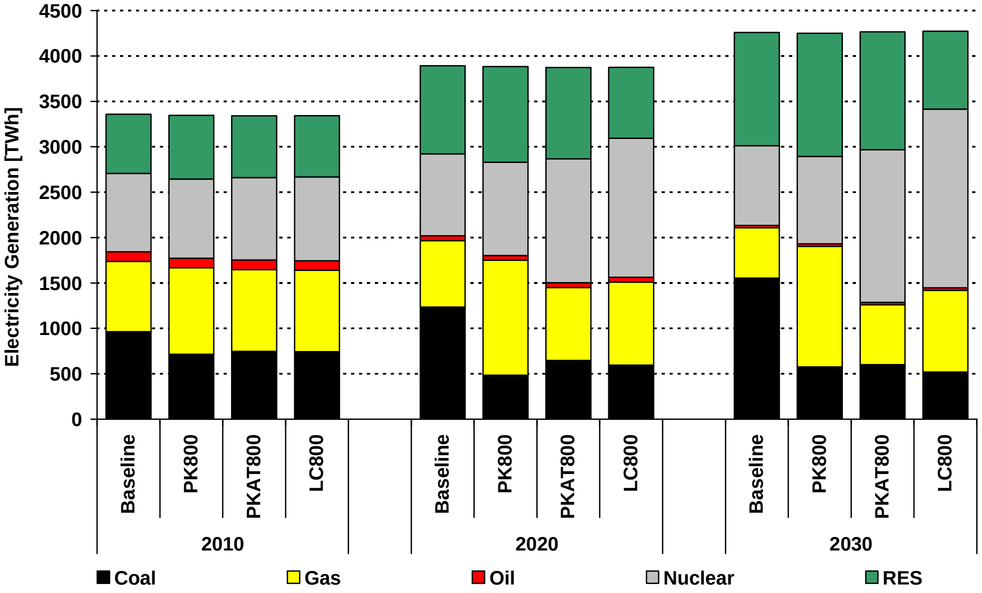


Figure 5: Structure of electricity generation in the EU-25, scenario variants

Regarding the capacity development within the scenario variants, the same observations hold as for the impact on electricity generation, taking into account the utilisation induced differences in capacity shares (cf. Figure 6).

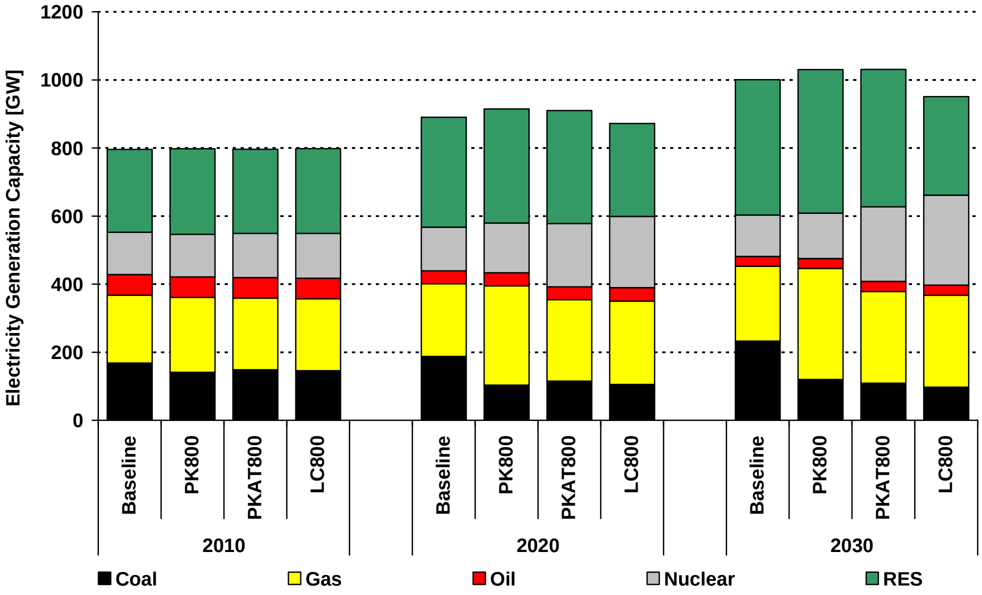


Figure 6: Structure of electricity generation capacity in the EU-25, scenario variants

4.4.2 Fossil fuel input in electricity generation

Regarding the scenario variants analyzed with TIMES-EG, it can be observed that coal based electricity generation in the PK800 is increased slightly compared to the PK scenario. Due to the Post-Kyoto emission targets, gas based electricity generation has the biggest share within the portfolio. This development is mainly driven by the restrictions on nuclear power plants. Removing these restrictions within the PKAT800 and LC800 scenarios lead to a strong decrease in gas use for electricity production. The use of gas is mainly substituted by nuclear. However, gas remains a more important energy carrier for electricity generation within the LC800 scenario compared to the PKAT and PKAT800 scenarios, if the support schemes for renewables are omitted.

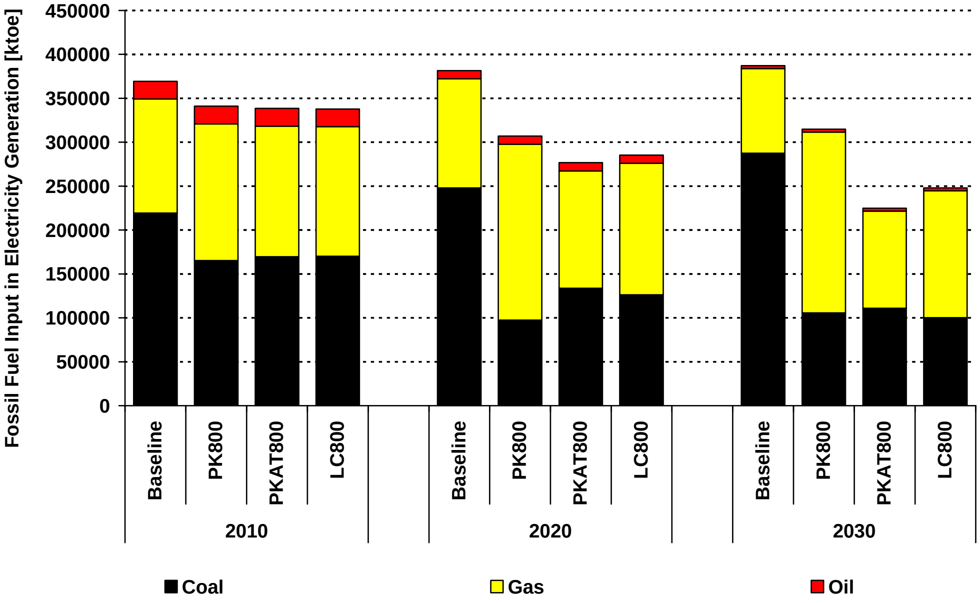


Figure 7: Fossil fuel input for electricity generation in the EU-25, scenario variants

4.4.3 Cost of electricity generation and CO_2 reduction costs

The changes in electricity generation structure and fossil fuel input due to an efficient CO_2 mitigation strategy, leads to lower cost of electricity production. As is presented in Table 10, the LC800 scenario results in average generation costs of 38.2 €/MWh, whereas baseline costs are 44.6 €/MWh, i.e. a decrease by approximately 14 % in 2030.

Table 10: Cost of electricity generation in the EU-25 in 2020-2030

[EURO$_{2000}$/MWh]	2020	2025	2030
Baseline	40.7	43.0	44.6
PK800	45.8	51.4	53.4
PKAT800	41.4	42.9	38.6
LC800	38.9	41.4	38.2

The differences in average electricity generation costs can be mirrored by comparing the changes in overall system costs within the various scenarios. As can be seen in Table 11, the LC800 scenario results in 232 bn. € lower accumulated system cost until 2030 compared to the baseline. It can therefore be concluded that additional costs for climate protection can be more than compensated, if all options for a cost optimal production structure will be considered.

Table 11: Cumulated total cost differences until 2030 and CO_2 reduction costs in the EU-25

	Compared with baseline (BL)	
Scenarios	**Total Cost Difference [bn $Euro_{00}$]**	**Average CO_2 reduction costs in 2030 [Euro/t CO_2]**
PK 800	351.0	20.9
PKAT 800	-86.5	-3.4
LC 800	-232.4	-9.7

4.5 Conclusions and recommendations

The scenario analysis shows that different policy measures for CO_2 mitigation and security of supply strategies lead to significant differences in costs and performance of the electricity market in the European Union.

It can be concluded, that a policy which combines emission control strategies with the present technology policy measures is not projected to be the least cost strategy for the European electricity market. Support schemes for RES and the phase-out policy for nuclear generation in some of the European countries induce higher costs without reducing the import dependence of fossil fuel significantly.

Assuming for a least cost approach to reach essential CO_2 mitigation targets, nuclear generation and efficient natural gas power plants as well as modern coal based power plants with Carbon Capture and Storage technologies are projected to be the most favourable options.

4.6 Appendix I – Comparison of model results

4.6.1 Electricity generation

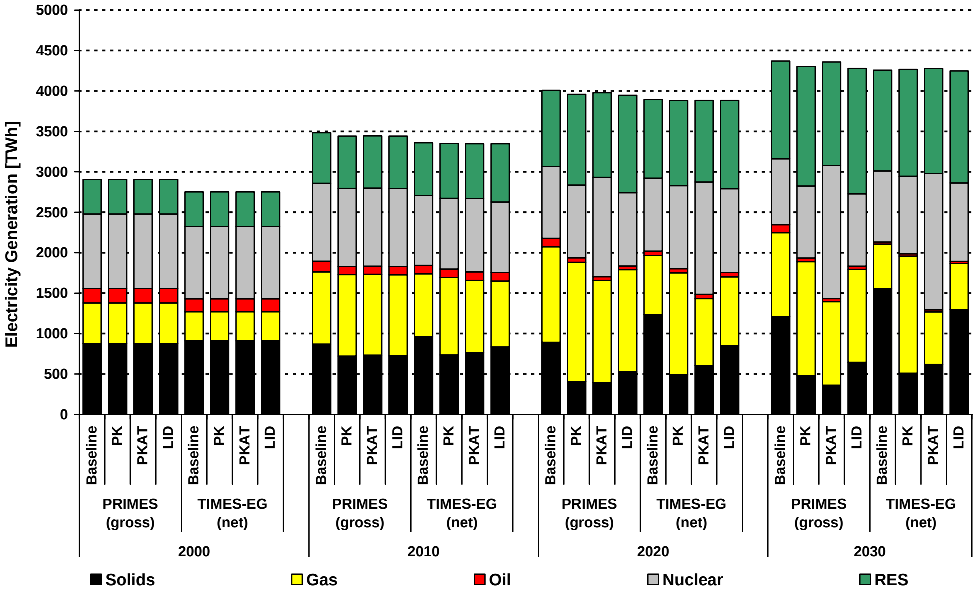


Figure A1: Electricity generation in the EU-25 – results of PRIMES and TIMES-EG

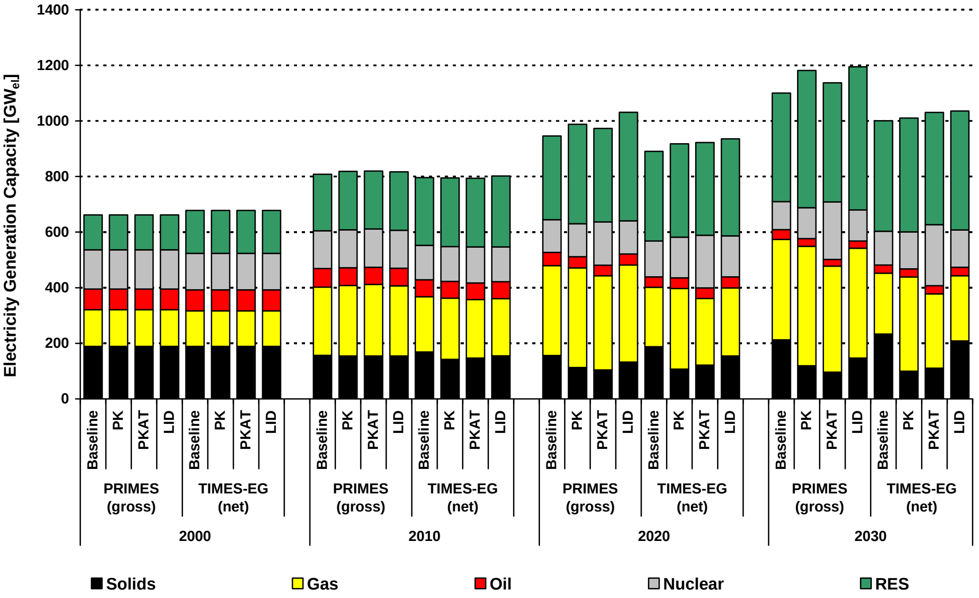


Figure A2: Electricity generation capacity in the EU-25 – results of PRIMES and TIMES-EG

4.6.2 Fossil Fuel input in electricity generation

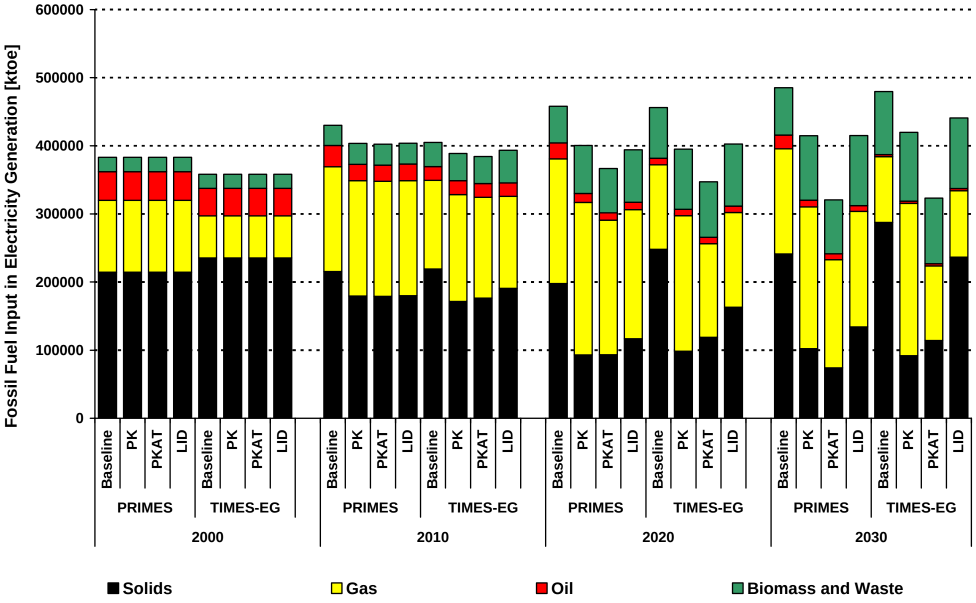
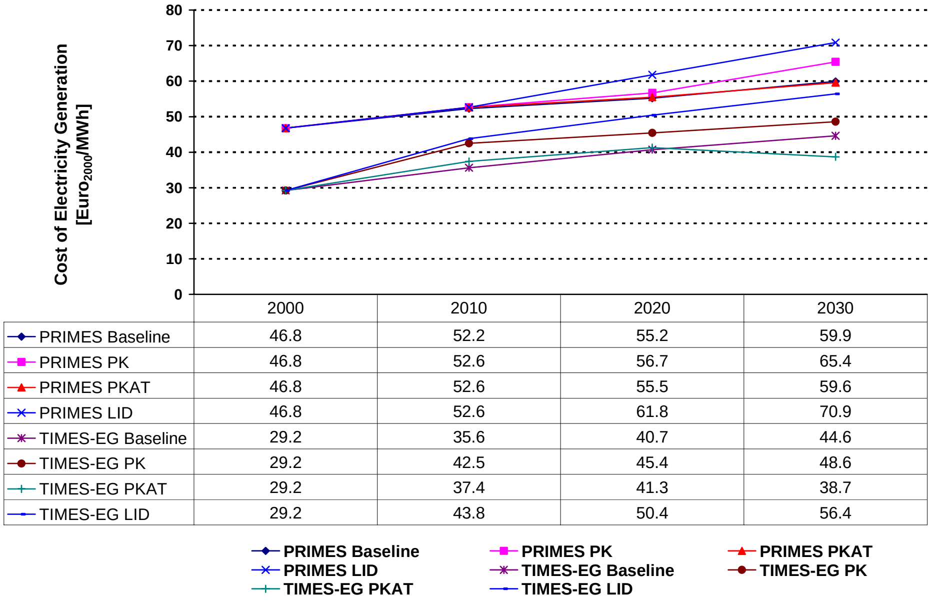


Figure A3: Fuel input in electricity generation in the EU-25 – results of PRIMES and TIMES-EG

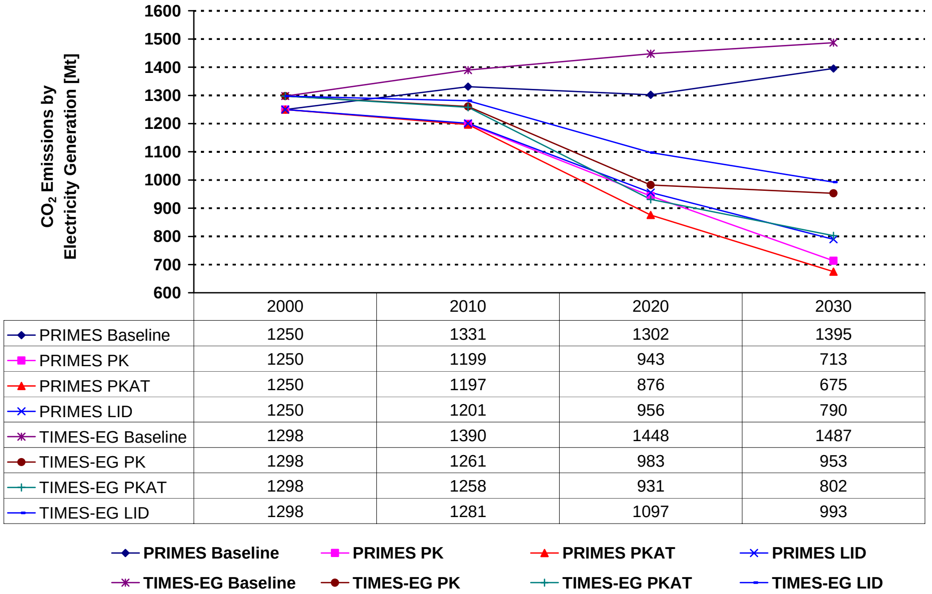
4.6.3 Cost of electricity generation



	2000	2010	2020	2030
PRIMES Baseline	46.8	52.2	55.2	59.9
PRIMES PK	46.8	52.6	56.7	65.4
PRIMES PKAT	46.8	52.6	55.5	59.6
PRIMES LID	46.8	52.6	61.8	70.9
TIMES-EG Baseline	29.2	35.6	40.7	44.6
TIMES-EG PK	29.2	42.5	45.4	48.6
TIMES-EG PKAT	29.2	37.4	41.3	38.7
TIMES-EG LID	29.2	43.8	50.4	56.4

Figure A4: Cost of electricity generation in the EU-25 – results of PRIMES and TIMES-EG

4.6.4 Electricity related CO_2 emissions



	2000	2010	2020	2030
PRIMES Baseline	1250	1331	1302	1395
PRIMES PK	1250	1199	943	713
PRIMES PKAT	1250	1197	876	675
PRIMES LID	1250	1201	956	790
TIMES-EG Baseline	1298	1390	1448	1487
TIMES-EG PK	1298	1261	983	953
TIMES-EG PKAT	1298	1258	931	802
TIMES-EG LID	1298	1281	1097	993

Figure A5: Electricity related CO_2 emissions in the EU-25 – results of PRIMES and TIMES-EG

Table A1a: PRIMES model results of the Baseline scenario (BL)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [$Euro_{2000}$/MWh]			46.8	50.9	52.2	53.2	55.2	58.1	59.9
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	ktoe	**Solids**	214488.3	224417.2	215291.1	197564.5	197890.6	223806.3	241341.4
		Gas	105479.5	122942.4	153832.6	183066.2	182811.9	165795.4	154140.9
		Oil	41869.7	34252.5	31389.5	28216.5	23493.7	21242.8	20202.3
		Biomass and Waste	21211.0	25206.2	29708.6	38314.4	53793.3	67119.8	69673.0
		Sum	**383048.5**	**406818.2**	**430221.8**	**447161.6**	**457989.5**	**477964.4**	**485357.7**
	GW_e	**Solids**	188.9	186.5	156.4	143.7	156.1	188.1	212.6
		Gas	131.9	171.2	245.6	287.9	322.8	344.6	360.8
		Oil	74.3	74.9	66.5	59.9	47.9	41.3	35.1
		Nuclear	141.1	137.5	136.4	125.3	117.2	97.9	101.1
		RES	125.6	156.1	203.2	248.7	301.4	361.4	390.4
		Sum	**661.7**	**726.1**	**808.2**	**865.4**	**945.5**	**1033.3**	**1100.0**
	TWh	**Solids**	875.4	922.6	869.8	822.2	891.6	1084.3	1209.7
		Gas	504.3	644.9	892.5	1126.9	1182.1	1093.4	1038.6
		Oil	177.1	144.7	132.9	121.1	104.6	99.3	97.0
		Nuclear	921.2	974.1	963.4	933.5	888.2	802.7	815.9
		RES	427.7	490.0	624.6	762.0	941.6	1135.3	1208.4
		Sum	**2905.6**	**3176.3**	**3483.2**	**3765.8**	**4008.0**	**4215.0**	**4369.6**
CO_2 Emissions by Electricity Generation [Mt]			1250.0	1307.6	1331.0	1316.1	1302.1	1357.8	1395.2
Share of Domestic Primary Energy Supply [%]			47.2	50.6	55.3	61.4	63.7	64.4	65.1

Table A1b: TIMES-EG model results of the Baseline scenario (BL)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			29.24	33.15	35.62	37.19	40.72	43.03	44.63
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Coal**	235415.8	232596.2	219261.4	238457.2	247899.3	263973.5	287576.7
		Gas	61818.5	99852.4	130037.8	130795.2	124268.0	110591.6	96336.3
		Oil	40368.2	28293.5	20043.4	11181.2	9462.9	7949.8	3262.2
		Biomass and Waste	20675.8	15209.7	35638.5	57172.5	74641.3	82714.0	92352.1
		Sum	**358278.4**	**375951.8**	**404981.2**	**437606.1**	**456271.5**	**465228.8**	**479527.3**
	GW$_e$	**Coal**	189.0	186.9	168.4	177.6	187.7	204.1	232.9
		Gas	127.7	164.7	199.2	211.6	213.3	233.4	219.5
		Oil	75.2	67.4	60.9	46.3	37.8	32.8	29.0
		Nuclear	131.5	131.1	123.7	125.0	128.8	122.5	121.7
		RES	154.7	186.2	243.7	271.5	322.8	376.4	397.7
		Sum	**678.1**	**736.3**	**796.0**	**832.0**	**890.4**	**969.3**	**1000.7**
	TWh	**Coal**	910.7	958.0	963.8	1120.1	1235.9	1372.6	1553.8
		Gas	359.6	594.4	774.6	782.1	731.2	650.0	552.3
		Oil	159.0	134.3	104.7	64.2	52.4	45.4	26.5
		Nuclear	894.3	900.1	862.8	872.4	901.6	868.1	878.1
		RES	428.6	462.6	652.7	790.2	970.9	1170.2	1247.7
		Sum	**2752.2**	**3049.4**	**3358.6**	**3629.1**	**3892.0**	**4106.3**	**4258.4**
CO$_2$ Emissions by Electricity Generation [Mt]			1297.6	1362.9	1389.9	1435.5	1447.7	1479.2	1487.0
Share of Domestic Primary Energy Supply [%]									

Table A2a: PRIMES model results of Post Kyoto scenario (PK)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			46.8	50.9	52.6	54.2	56.7	60.5	65.4
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Solids**	214488.3	223272.0	179486.0	129357.3	93149.1	92178.7	102106.1
		Gas	105479.5	125440.7	169247.8	207856.9	223680.3	213821.9	208075.6
		Oil	41869.7	33397.1	24091.4	19039.3	13292.2	11062.5	9938.7
		Biomass and Waste	21211.0	24860.6	30732.5	48916.6	70434.0	91336.8	94736.2
		Sum	**383048.5**	**406970.5**	**403557.6**	**405170.1**	**400555.6**	**408399.9**	**414856.7**
	GW$_e$	**Solids**	188.9	184.5	154.5	131.9	112.7	103.8	119.0
		Gas	131.9	172.0	253.2	304.5	358.4	402.5	429.9
		Oil	74.3	73.6	64.0	54.4	40.5	33.9	27.8
		Nuclear	141.1	137.5	136.4	125.3	118.7	106.8	110.8
		RES	125.6	156.3	210.0	277.1	357.6	443.9	493.8
		Sum	**661.7**	**723.9**	**818.1**	**893.2**	**987.9**	**1090.9**	**1181.3**
	TWh	**Solids**	875.4	915.6	722.6	538.7	407.0	424.1	477.8
		Gas	504.3	653.4	1006.6	1303.6	1473.2	1437.5	1410.3
		Oil	177.1	141.8	101.1	81.0	55.9	47.5	45.9
		Nuclear	921.2	973.6	964.8	933.5	900.3	873.8	890.0
		RES	427.7	491.8	648.2	864.8	1121.8	1376.9	1477.9
		Sum	**2905.6**	**3176.1**	**3443.1**	**3721.7**	**3958.1**	**4159.8**	**4301.9**
CO$_2$ Emissions by Electricity Generation [Mt]			1250.0	1306.1	1199.0	1071.4	943.3	873.4	713.5
Share of Domestic Primary Energy Supply [%]			47.2	50.7	54.9	61.1	63.7	63.2	63.1

Table A2b: TIMES-EG model results of Post Kyoto scenario (PK)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			29.24	33.15	42.51	45.94	45.43	49.72	48.60
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Coal**	235415.8	227651.3	171474.9	132768.9	98429.5	94790.0	91828.7
		Gas	61818.5	103279.8	157021.0	186210.5	198913.1	209790.0	223640.8
		Oil	40368.2	28336.4	20256.9	11251.6	9308.6	7885.0	3256.6
		Biomass and Waste	20675.8	15695.8	39867.2	61852.0	88287.1	92912.1	101129.6
		Sum	358278.4	**374963.2**	**388620.0**	**392083.0**	**394938.3**	**405377.0**	**419855.6**
	GW$_e$	**Coal**	189.0	183.1	141.8	121.4	107.0	100.6	99.4
		Gas	127.7	165.0	220.5	258.2	289.9	322.3	338.9
		Oil	75.2	67.4	60.2	45.9	38.6	33.3	29.5
		Nuclear	131.5	131.1	125.2	137.5	145.9	137.8	133.0
		RES	154.7	187.8	247.1	276.3	336.3	391.3	409.4
		Sum	678.1	**734.3**	**794.9**	**839.2**	**917.7**	**985.3**	**1010.3**
	TWh	**Coal**	910.7	934.6	735.6	605.3	492.9	506.4	509.5
		Gas	359.6	607.8	958.0	1163.4	1257.9	1336.2	1449.8
		Oil	159.0	134.3	105.4	64.7	52.1	45.2	26.5
		Nuclear	894.3	900.1	874.1	961.8	1025.8	978.7	960.3
		RES	428.6	467.9	677.3	819.7	1053.0	1238.8	1320.2
		Sum	2752.2	**3044.8**	**3350.3**	**3614.9**	**3881.6**	**4105.4**	**4266.3**
CO$_2$ Emissions by Electricity Generation [Mt]			1297.6	1353.3	1260.6	1134.2	982.5	985.8	953.0
Share of Domestic Primary Energy Supply [%]									

Table A3a: PRIMES model results of the Post Kyoto – All Technologies scenario (PKAT)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			46.8	50.9	52.6	53.7	55.5	57.8	59.6
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Solids**	214488.3	223470.6	178952.4	139822.2	93322.9	80465.5	74044.0
		Gas	105479.5	125233.9	168910.1	199622.3	197406.8	172285.8	158754.5
		Oil	41869.7	33288.1	23809.8	20397.1	10819.3	9401.9	8655.4
		Biomass and Waste	21211.0	24868.7	30711.3	45767.8	65202.6	75392.9	79330.5
		Sum	**383048.5**	**406861.3**	**402383.6**	**405609.4**	**366751.6**	**337546.1**	**320784.4**
	GW$_e$	**Solids**	188.9	184.9	154.1	128.8	104.1	99.2	96.2
		Gas	131.9	172.1	257.5	299.9	338.6	363.6	381.2
		Oil	74.3	73.7	62.0	52.6	38.5	30.7	24.4
		Nuclear	141.1	137.5	137.7	133.1	155.3	178.2	206.7
		RES	125.6	156.3	208.4	269.3	336.3	394.8	428.6
		Sum	**661.7**	**724.4**	**819.6**	**883.6**	**972.8**	**1066.5**	**1137.0**
	TWh	**Solids**	875.4	916.5	733.7	582.1	394.9	373.5	361.1
		Gas	504.3	652.9	999.7	1231.4	1263.1	1112.4	1034.2
		Oil	177.1	141.1	100.0	88.3	44.7	39.3	37.8
		Nuclear	921.2	973.9	965.0	991.2	1228.8	1459.1	1646.1
		RES	427.7	491.7	645.8	835.8	1047.1	1210.2	1278.6
		Sum	**2905.6**	**3176.1**	**3444.3**	**3728.8**	**3978.6**	**4194.5**	**4357.8**
CO_2 Emissions by Electricity Generation [Mt]			1250.0	1306.0	1196.5	1099.0	876.0	761.9	674.9
Share of Domestic Primary Energy Supply [%]			47.2	50.7	54.5	60.5	60.5	58.2	56.9

Table A3b: TIMES-EG model results of the Post Kyoto – All Technologies scenario (PKAT)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			29.24	33.15	37.40	42.13	41.30	42.92	38.69
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Coal**	235415.8	229002.0	176563.3	143858.5	118936.4	115179.4	114225.0
		Gas	61818.5	100273.7	147860.8	144563.0	137451.9	114685.0	109384.4
		Oil	40368.2	28337.2	20184.5	11249.2	9314.5	7880.7	3247.9
		Biomass and Waste	20675.8	15737.4	39539.5	62783.9	81441.3	88612.8	96405.2
		Sum	358278.4	**373350.4**	**384148.1**	**362454.5**	**347144.0**	**326357.9**	**323262.6**
	GW$_e$	**Coal**	189.0	184.2	146.7	129.9	121.0	114.1	110.3
		Gas	127.7	164.9	210.2	232.0	239.9	265.4	267.7
		Oil	75.2	67.4	60.0	45.7	38.4	33.1	29.2
		Nuclear	131.5	131.4	129.4	165.2	189.5	206.6	219.5
		RES	154.7	188.2	247.6	275.5	333.7	385.1	403.6
		Sum	678.1	**736.2**	**794.0**	**848.3**	**922.5**	**1004.2**	**1030.4**
	TWh	**Coal**	910.7	941.9	763.8	666.5	603.6	614.2	619.5
		Gas	359.6	595.7	893.7	879.4	829.1	681.4	647.8
		Oil	159.0	134.3	105.1	64.7	52.1	45.2	26.5
		Nuclear	894.3	902.9	908.3	1188.9	1389.5	1555.1	1685.0
		RES	428.6	468.8	675.7	815.7	1010.0	1214.2	1298.8
		Sum	2752.2	**3043.6**	**3346.7**	**3615.2**	**3884.3**	**4110.3**	**4277.7**
CO_2 Emissions by Electricity Generation [Mt]			1297.6	1351.5	1257.6	1087.2	931.2	859.3	802.4
Share of Domestic Primary Energy Supply [%]									

Table A4a: PRIMES model results of the Limited Import Dependency scenario (LID)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			46.8	50.8	52.6	56.8	61.8	66.1	70.9
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Solids**	214488.3	223155.5	179891.5	147129.9	116765.7	123206.2	134178.8
		Gas	105479.5	125298.5	168910.7	191630.8	189661.6	176602.3	169575.3
		Oil	41869.7	33694.5	24417.4	16765.5	10629.9	8725.6	8376.0
		Biomass and Waste	21211.0	24893.2	30639.5	50262.0	77067.0	96651.3	103034.2
		Sum	**383048.5**	**407041.6**	**403859.0**	**405788.2**	**394124.2**	**405185.4**	**415164.3**
	GW$_e$	**Solids**	188.9	184.5	154.3	133.4	132.4	130.3	146.9
		Gas	131.9	172.0	252.4	299.7	349.0	382.8	395.3
		Oil	74.3	73.7	63.3	53.7	39.5	32.2	25.8
		Nuclear	141.1	137.5	136.4	125.3	119.3	107.8	111.5
		RES	125.6	156.3	210.5	290.2	390.7	472.0	514.9
		Sum	**661.7**	**724.0**	**816.9**	**902.3**	**1031.0**	**1125.2**	**1194.5**
	TWh	**Solids**	875.4	915.2	724.3	618.2	526.4	576.7	643.8
		Gas	504.3	652.7	1001.4	1192.8	1263.9	1200.4	1150.8
		Oil	177.1	142.5	103.1	70.5	45.9	40.5	39.3
		Nuclear	921.2	973.8	964.8	933.5	905.4	880.0	893.4
		RES	427.7	491.8	649.2	901.4	1205.2	1447.4	1552.7
		Sum	**2905.6**	**3176.0**	**3442.7**	**3716.5**	**3946.8**	**4145.0**	**4280.0**
CO_2 Emissions by Electricity Generation [Mt]			1250.0	1306.3	1201.0	1099.7	955.5	918.0	789.8
Share of Domestic Primary Energy Supply [%]			47.2	50.7	54.8	59.4	59.8	58.3	57.7

Table A4b: TIMES-EG model results of the Limited Import Dependency scenario (LID)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			29.24	33.15	43.80	48.66	50.42	58.70	56.38
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Coal**	235415.8	229899.4	190652.0	173884.4	163076.1	196701.8	236499.1
		Gas	61818.5	100018.9	135025.7	146633.5	139140.2	119089.0	97436.1
		Oil	40368.2	28456.0	19835.6	10751.9	9282.8	7867.6	3259.2
		Biomass and Waste	20675.8	15739.9	48076.1	67241.9	91050.3	95910.5	103679.8
		Sum	358278.4	**374114.2**	**393589.5**	**398511.7**	**402549.4**	**419569.0**	**440874.1**
	GW$_e$	**Coal**	189.0	184.9	154.8	149.6	154.5	176.2	208.3
		Gas	127.7	164.8	205.6	227.7	244.9	250.2	234.7
		Oil	75.2	67.4	61.0	47.7	39.7	34.2	30.4
		Nuclear	131.5	131.1	125.2	138.7	147.5	138.3	134.1
		RES	154.7	188.2	255.4	285.8	348.8	405.3	428.3
		Sum	678.1	**736.4**	**802.1**	**849.5**	**935.3**	**1004.3**	**1035.8**
	TWh	**Coal**	910.7	946.2	834.7	825.5	848.4	1062.6	1298.0
		Gas	359.6	594.7	814.9	898.2	852.7	714.9	567.6
		Oil	159.0	134.8	104.0	63.8	52.6	46.0	27.4
		Nuclear	894.3	900.1	874.1	970.6	1037.6	983.1	969.2
		RES	428.6	469.1	720.3	865.5	1092.0	1295.9	1386.1
		Sum	2752.2	**3044.9**	**3347.9**	**3623.5**	**3883.3**	**4102.5**	**4248.4**
CO_2 Emissions by Electricity Generation [Mt]			1297.6	1354.8	1281.1	1206.2	1097.3	1103.8	992.8
Share of Domestic Primary Energy Supply [%]									

4.7 Appendix II – Data for TIMES-EG results for the EU-30

Table 9: TIMES-EG model results of the Baseline scenario for the EU-30 (BL)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			26.2	30.2	35.6	37.2	40.7	43.0	44.6
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	**ktoe**	**Coal**	248848.8	254976.8	245723.3	275122.6	295747.1	322196.2	362388.4
		Gas	74528.5	112162.2	150493.1	149942.2	144593.3	132597.7	117226.1
		Oil	46140.0	33586.5	24073.7	13525.7	10708.3	8789.3	3754.5
		Biomass and Waste	21464.0	16132.4	36755.6	58717.6	76723.7	86174.2	96729.2
		Sum	**390981.3**	**416857.9**	**457045.6**	**497308.1**	**527772.4**	**549757.5**	**580098.2**
	GW$_e$	**Coal**	205.8	207.8	189.8	204.8	221.6	247.5	289.1
		Gas	143.1	180.3	220.3	232.9	234.8	256.7	244.2
		Oil	83.2	75.3	66.4	51.2	42.1	36.8	31.7
		Nuclear	138.9	137.6	129.7	135.2	139.7	133.4	133.2
		RES	214.5	249.2	309.6	338.8	391.7	448.7	472.8
		Sum	**785.4**	**850.2**	**915.9**	**962.9**	**1029.9**	**1123.2**	**1171.1**
	TWh	**Coal**	960.4	1044.4	1067.0	1279.6	1459.3	1666.6	1949.0
		Gas	436.8	669.9	893.1	894.9	849.8	779.3	673.0
		Oil	182.9	156.1	121.4	74.0	57.6	48.9	28.6
		Nuclear	944.3	948.5	907.5	947.3	981.6	948.1	962.7
		RES	640.2	656.5	855.8	998.4	1183.9	1396.6	1484.0
		Sum	**3164.6**	**3475.4**	**3844.8**	**4194.2**	**4532.2**	**4839.4**	**5097.4**
CO_2 Emissions by Electricity Generation [Mt]			1406.3	1507.1	1575.2	1652.3	1707.3	1781.9	1846.4
Share of Domestic Primary Energy Supply [%]									

Table 10: TIMES-EG model results of Post Kyoto scenario for the EU-30 (PK)

Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			26.2	30.2	42.8	44.7	45.2	49.0	48.1
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	ktoe	Coal	248848.8	248901.2	239827.0	227480.4	227522.4	229868.4	229714.1
		Gas	74528.5	115699.7	179697.3	218204.2	238678.3	257273.9	274363.3
		Oil	46140.0	33629.3	24223.0	13592.2	10517.3	8705.3	3714.0
		Biomass and Waste	21464.0	16609.5	41090.5	63737.8	92012.4	97713.1	107196.0
		Sum	**390981.3**	**414839.7**	**484837.7**	**523014.6**	**568730.5**	**593560.7**	**614987.4**
	GW$_e$	Coal	205.8	203.9	162.6	139.6	123.7	118.6	125.6
		Gas	143.1	180.6	244.7	291.4	329.4	369.6	392.3
		Oil	83.2	75.2	65.7	50.7	42.9	37.4	32.3
		Nuclear	138.9	137.6	131.2	152.1	160.7	152.2	147.0
		RES	214.5	250.8	313.1	343.8	406.9	465.1	486.8
		Sum	**785.4**	**848.1**	**917.3**	**977.5**	**1063.7**	**1142.9**	**1184.0**
	TWh	Coal	960.4	1020.6	822.9	659.6	555.6	600.8	680.6
		Gas	436.8	683.8	1093.9	1362.5	1509.6	1642.2	1780.6
		Oil	182.9	156.2	121.8	74.4	57.2	48.7	28.6
		Nuclear	944.3	948.5	918.8	1068.7	1134.3	1083.5	1062.4
		RES	640.2	661.7	879.8	1028.7	1275.6	1474.3	1569.0
		Sum	**3164.6**	**3470.8**	**3837.2**	**4194.0**	**4532.2**	**4849.5**	**5121.1**
CO_2 Emissions by Electricity Generation [Mt]			1406.3	1497.4	1432.8	1281.0	1148.4	1190.4	1169.4
Share of Domestic Primary Energy Supply [%]									

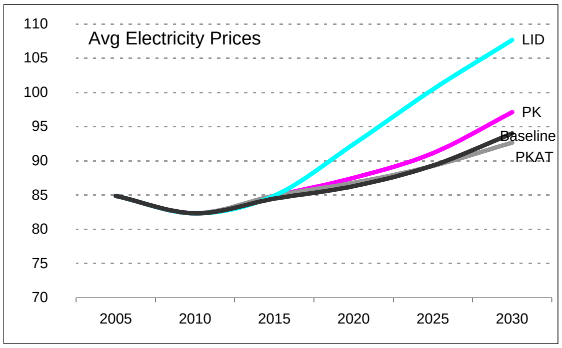
Table 11: As TIMES-EG model results of the Post Kyoto – All Technologies scenario for the EU-30 (PKAT)

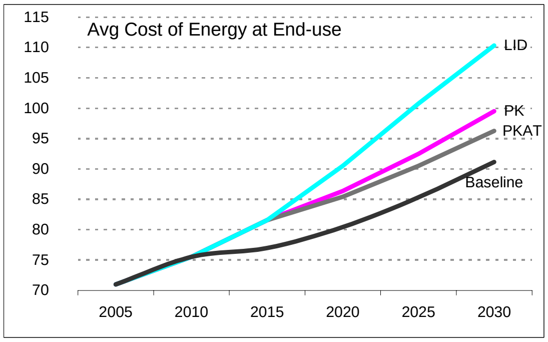
Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			26.2	30.2	37.2	41.6	41.2	42.6	39.2
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	ktoe	Coal	248848.8	254976.8	245723.3	275122.6	295747.1	322196.2	362388.4
		Gas	74528.5	112162.2	150493.1	149942.2	144593.3	132597.7	117226.1
		Oil	46140.0	33586.5	24073.7	13525.7	10708.3	8789.3	3754.5
		Biomass and Waste	21464.0	16132.4	36755.6	58717.6	76723.7	86174.2	96729.2
		Sum	**390981.3**	**416857.9**	**457045.6**	**497308.1**	**527772.4**	**549757.5**	**580098.2**
	GW$_e$	Coal	205.8	207.8	189.8	204.8	221.6	247.5	289.1
		Gas	143.1	180.3	220.3	232.9	234.8	256.7	244.2
		Oil	83.2	75.3	66.4	51.2	42.1	36.8	31.7
		Nuclear	138.9	137.6	129.7	135.2	139.7	133.4	133.2
		RES	214.5	249.2	309.6	338.8	391.7	448.7	472.8
		Sum	**785.4**	**850.2**	**915.9**	**962.9**	**1029.9**	**1123.2**	**1171.1**
	TWh	Coal	960.4	1044.4	1067.0	1279.6	1459.3	1666.6	1949.0
		Gas	436.8	669.9	893.1	894.9	849.8	779.3	673.0
		Oil	182.9	156.1	121.4	74.0	57.6	48.9	28.6
		Nuclear	944.3	948.5	907.5	947.3	981.6	948.1	962.7
		RES	640.2	656.5	855.8	998.4	1183.9	1396.6	1484.0
		Sum	**3164.6**	**3475.4**	**3844.8**	**4194.2**	**4532.2**	**4839.4**	**5097.4**
CO_2 Emissions by Electricity Generation [Mt]			1406.3	1507.1	1575.2	1652.3	1707.3	1781.9	1846.4
Share of Domestic Primary Energy Supply [%]									

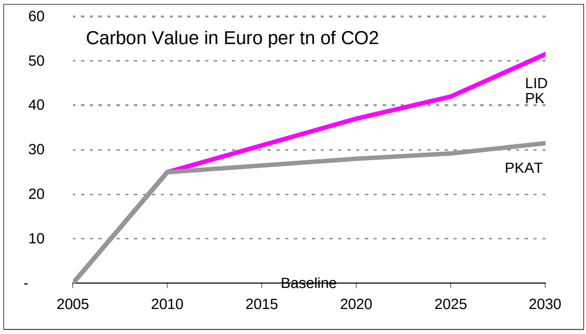
Table 12: TIMES-EG model results of the Limited Import Dependency scenario for the EU-30 (LID)

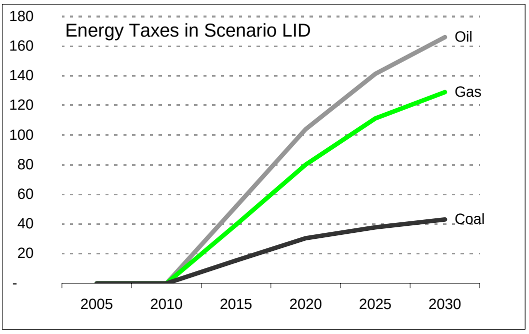
Indicator		Fuel	2000	2005	2010	2015	2020	2025	2030
Cost of Electricity Generation [Euro$_{2000}$/MWh]			26.2	30.2	43.8	47.2	49.7	57.2	55.2
Fuel Input, Installed Electricity Generation Capacity and Production in Europe by Fuel	ktoe	Coal	248848.8	252178.0	216078.2	192235.8	193184.0	242037.0	307468.1
		Gas	74528.5	112394.7	156371.9	172976.6	166136.8	146687.5	120089.3
		Oil	46140.0	33748.9	23801.7	13093.3	10498.7	8688.0	3716.7
		Biomass and Waste	21464.0	16692.1	49297.7	69530.0	94855.7	100707.0	109647.6
		Sum	**390981.3**	**415013.7**	**445549.6**	**447835.7**	**464675.0**	**498119.4**	**540921.6**
	GW$_e$	Coal	205.8	205.7	175.8	171.6	182.4	212.8	261.7
		Gas	143.1	180.5	228.8	255.9	273.6	279.8	266.4
		Oil	83.2	75.2	66.5	52.5	43.9	38.2	33.2
		Nuclear	138.9	137.6	131.2	153.1	161.8	152.7	148.2
		RES	214.5	251.2	321.4	353.7	419.8	479.4	505.7
		Sum	**785.4**	**850.3**	**923.7**	**986.8**	**1081.5**	**1162.9**	**1215.2**
	TWh	Coal	960.4	1032.1	934.1	909.6	997.5	1294.4	1668.8
		Gas	436.8	670.7	942.5	1059.6	1017.8	884.1	702.3
		Oil	182.9	156.6	120.4	73.5	57.7	49.4	29.5
		Nuclear	944.3	948.5	918.8	1075.5	1142.4	1088.0	1072.0
		RES	640.2	662.2	922.8	1076.9	1316.0	1531.4	1633.2
		Sum	**3164.6**	**3470.1**	**3838.5**	**4195.0**	**4531.4**	**4847.3**	**5105.8**
CO_2 Emissions by Electricity Generation [Mt]			1406.3	1498.8	1464.3	1367.8	1298.9	1317.5	1200.2
Share of Domestic Primary Energy Supply [%]									

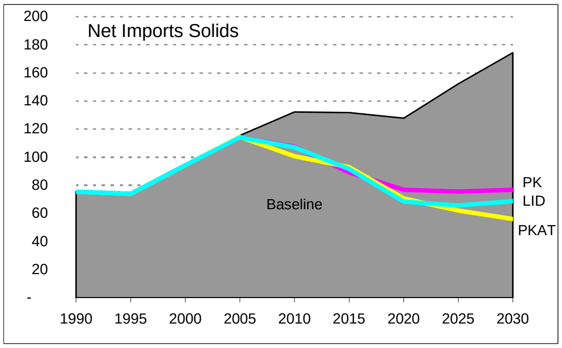
4.8 Appendix III – Graphics for PRIMES results for the EU-25

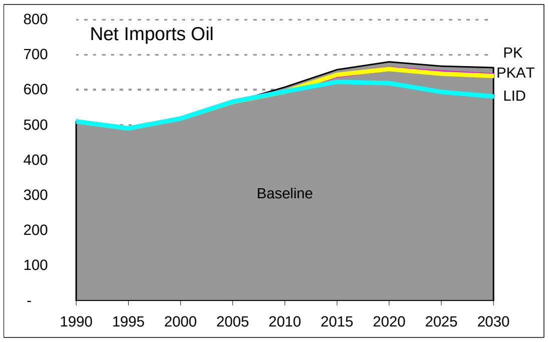


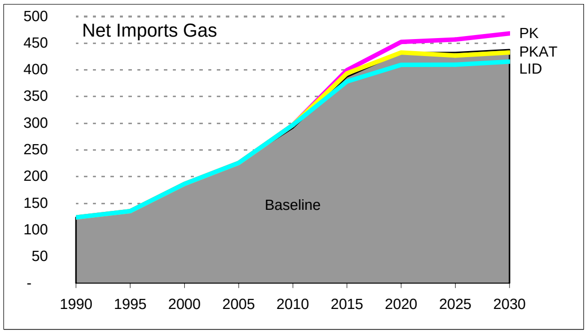


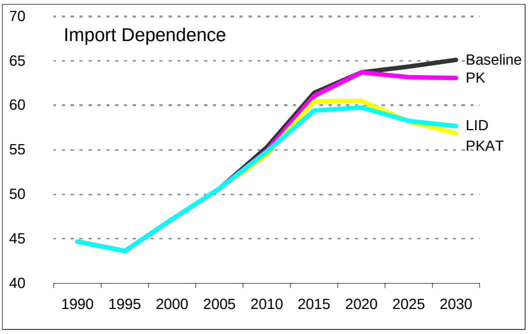




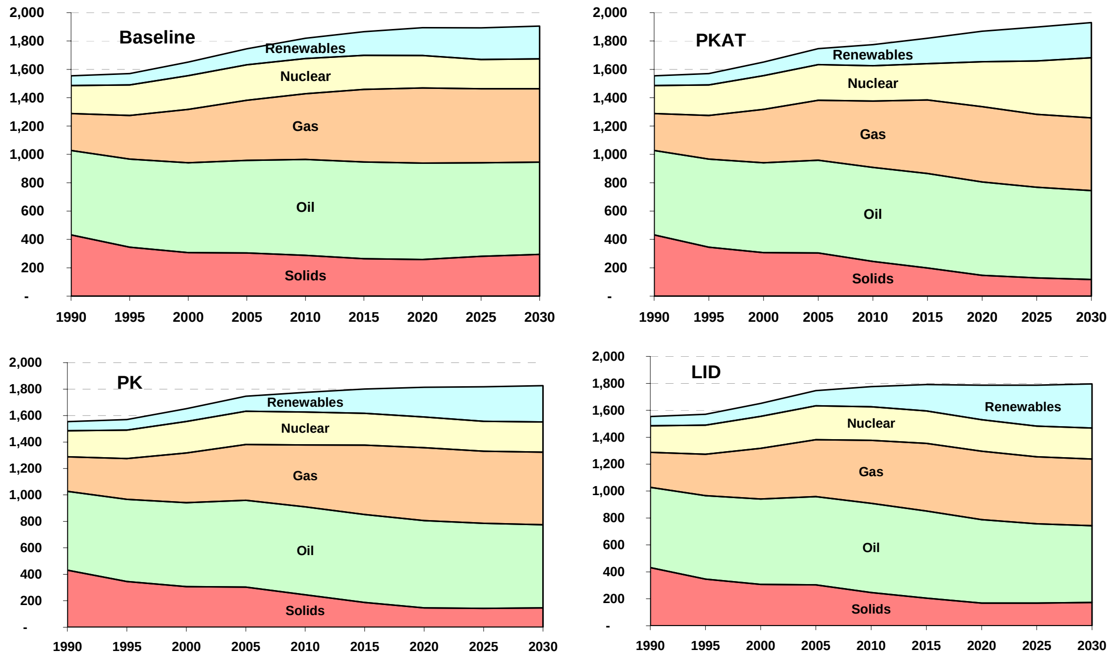




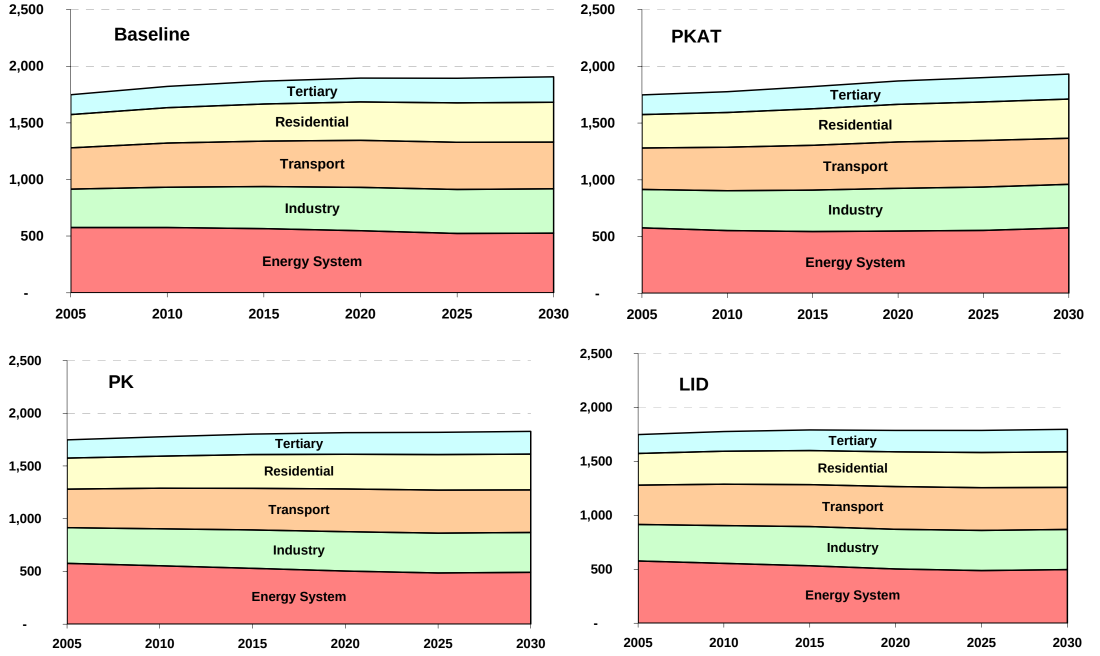




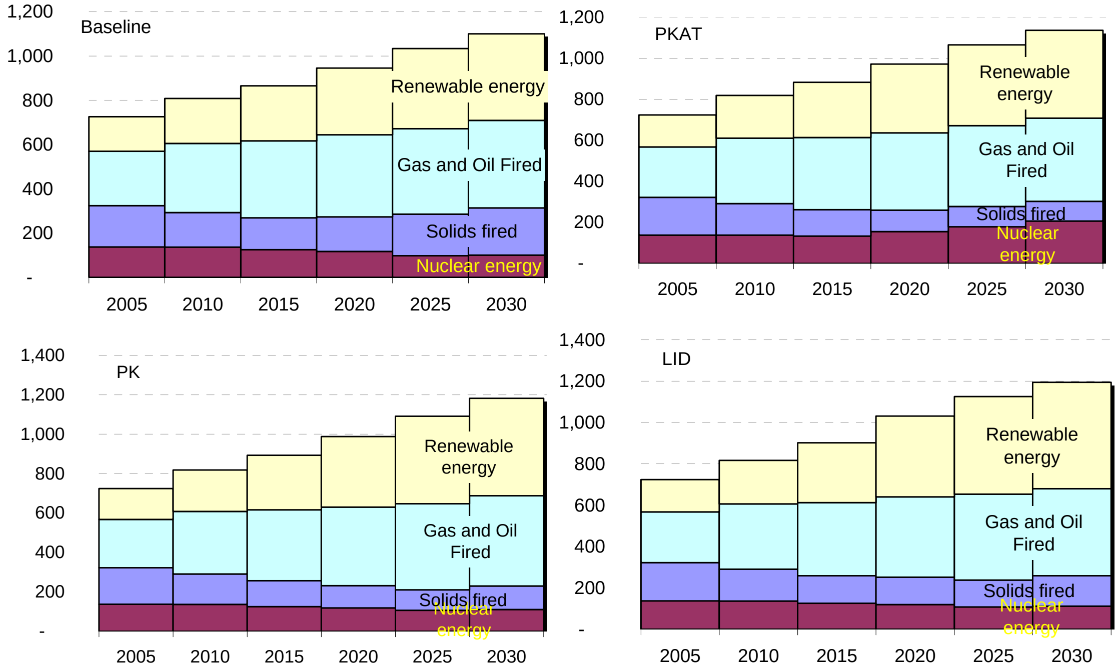
Primary Energy Demand (Mtoe)



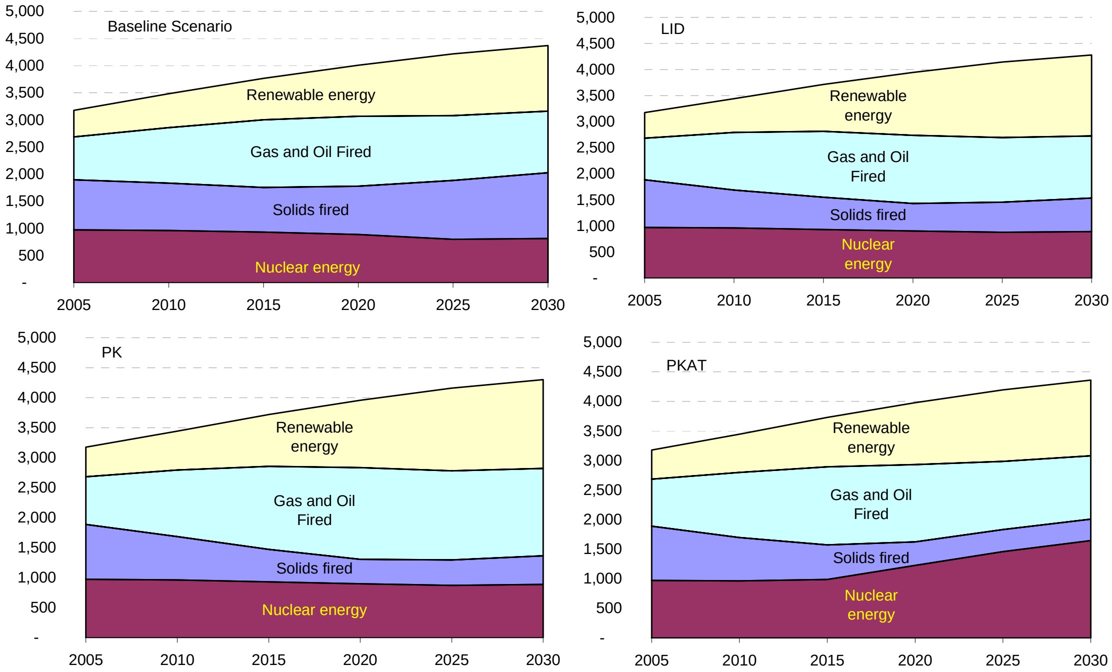
Final Energy Demand (Mtoe)

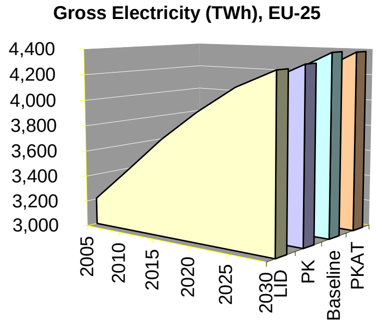


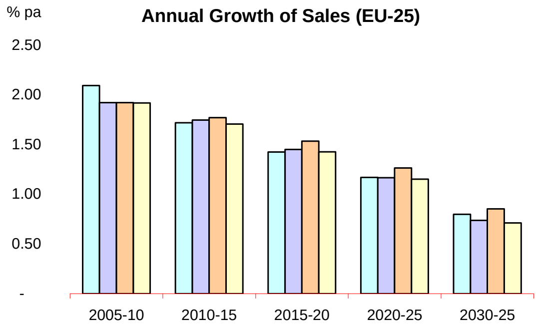
Power Generation Capacity (GW)

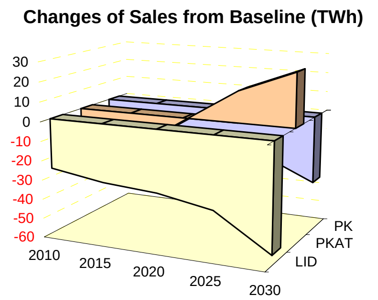


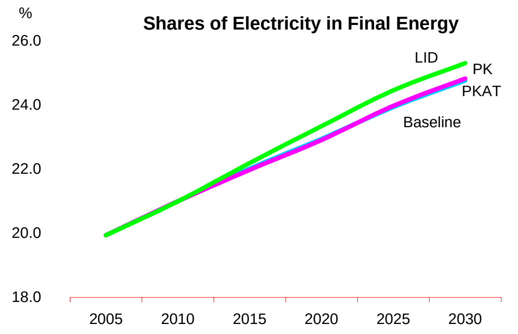
Power Generation (GWh)

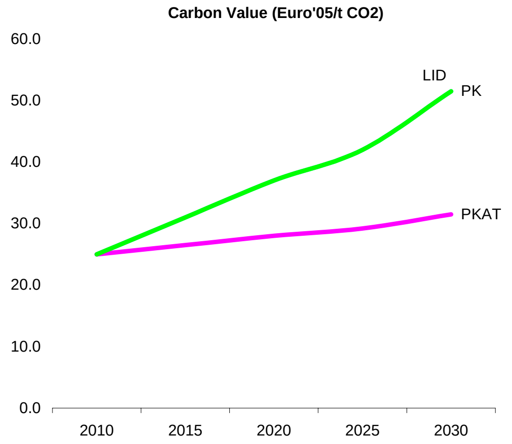


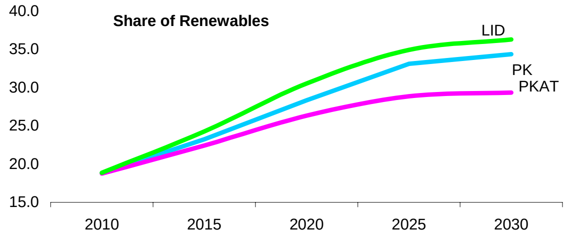

Gross Electricity (TWh), EU-25
4,400
4,200
4,000
3,800
3,600
3,400
3,200
3,000
2005
2010
2015
2020
2025
2030
LID
PK
Baseline
PKAT

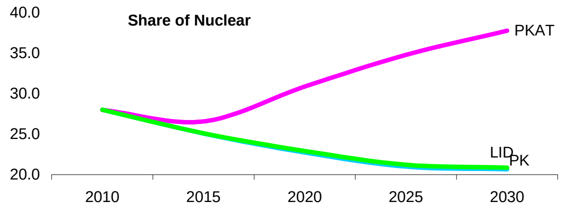

% pa
Annual Growth of Sales (EU-25)
2.50
2.00
1.50
1.00
0.50
-
2005-10
2010-15
2015-20
2020-25
2030-25

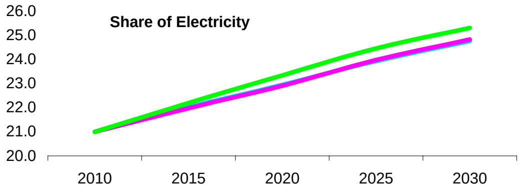

Changes of Sales from Baseline (TWh)
30
20
10
0
-10
-20
-30
-40
-50
-60
2010
2015
2020
2025
2030
PK
PKAT
LID

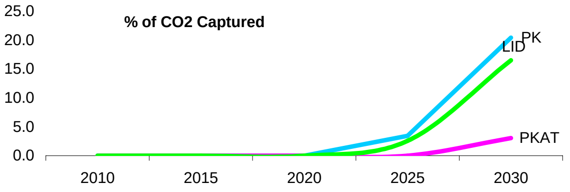

%
Shares of Electricity in Final Energy
26.0
24.0
22.0
20.0
18.0
LID
PK
PKAT
Baseline
2005
2010
2015
2020
2025
2030

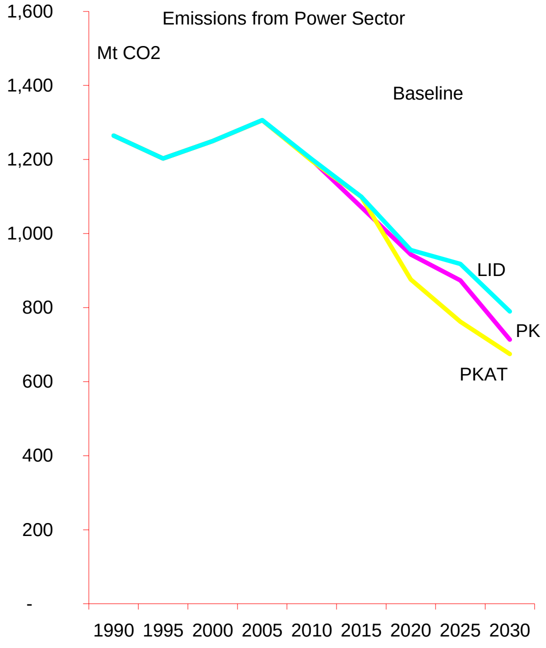

Carbon Value (Euro'05/t CO2)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
LID
PK
PKAT
2010
2015
2020
2025
2030

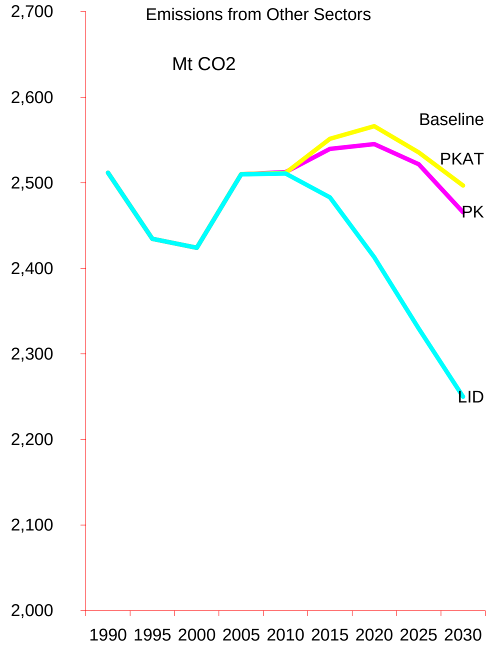

40.0
Share of Renewables
35.0
30.0
25.0
20.0
15.0
LID
PK
PKAT
2010
2015
2020
2025
2030

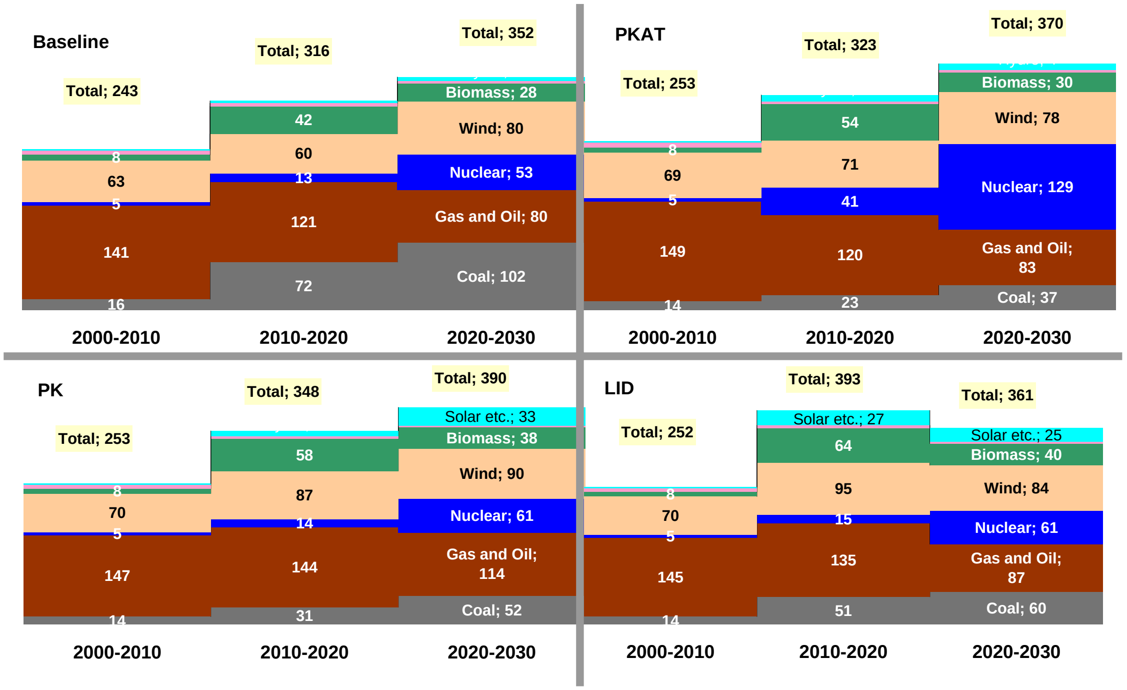

40.0
Share of Nuclear
35.0
30.0
25.0
20.0
PKAT
LID
PK
2010
2015
2020
2025
2030


26.0
Share of Electricity
25.0
24.0
23.0
22.0
21.0
20.0
2010
2015
2020
2025
2030


25.0
% of CO2 Captured
20.0
15.0
10.0
5.0
0.0
PK
LID
PKAT
2010
2015
2020
2025
2030

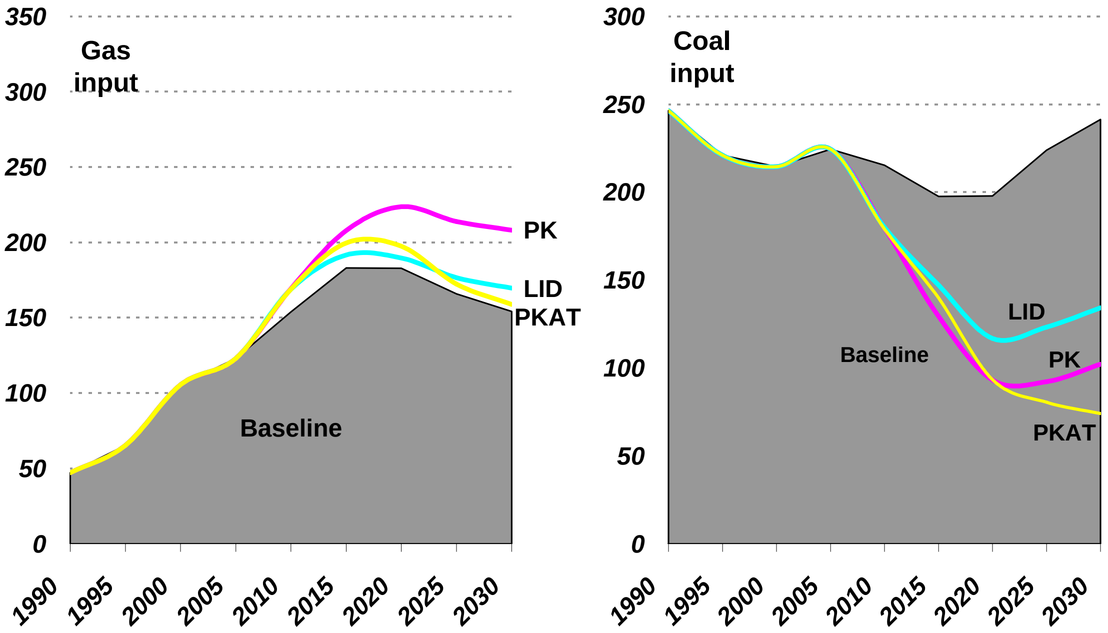

Emissions from Power Sector
Mt CO2
1,600
1,400
1,200
1,000
800
600
400
200
-
1990 1995 2000 2005 2010 2015 2020 2025 2030
Baseline
LID
PK
PKAT


Emissions from Other Sectors
Mt CO2
2,700
2,600
2,500
2,400
2,300
2,200
2,100
2,000
1990 1995 2000 2005 2010 2015 2020 2025 2030
Baseline
PKAT
PK
LID


Baseline
Total; 243
8
63
5
141
16
Total; 316
42
60
13
121
72
Total; 352
Biomass; 28
Wind; 80
Nuclear; 53
Gas and Oil; 80
Coal; 102
2000-2010
2010-2020
2020-2030
PKAT
Total; 253
8
69
5
149
14
Total; 323
54
71
41
120
23
Total; 370
Biomass; 30
Wind; 78
Nuclear; 129
Gas and Oil; 83
Coal; 37
2000-2010
2010-2020
2020-2030
PK
Total; 253
8
70
5
147
14
Total; 348
58
87
14
144
31
Total; 390
Solar etc.; 33
Biomass; 38
Wind; 90
Nuclear; 61
Gas and Oil; 114
Coal; 52
2000-2010
2010-2020
2020-2030
LID
Total; 252
8
70
5
145
14
Total; 393
Solar etc.; 27
64
95
15
135
51
Total; 361
Solar etc.; 25
Biomass; 40
Wind; 84
Nuclear; 61
Gas and Oil; 87
Coal; 60
2000-2010
2010-2020
2020-2030

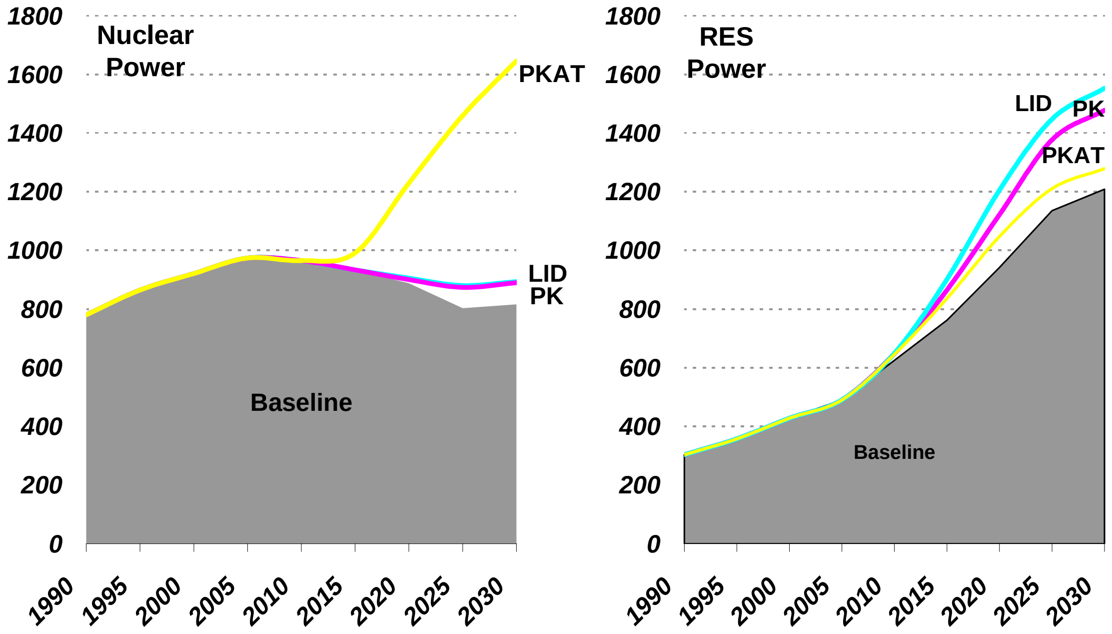
Use of Gas and Coal in Power Generation

(Mtoe) PRIMES - EU25



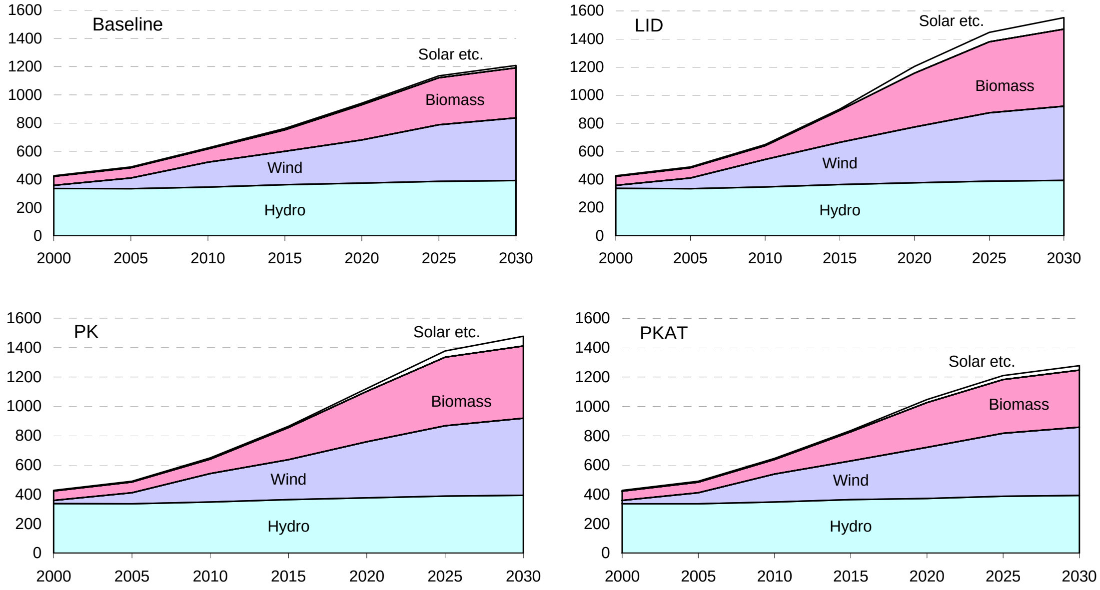
Power from Nuclear and Renewables

(TWh) PRIMES - EU25



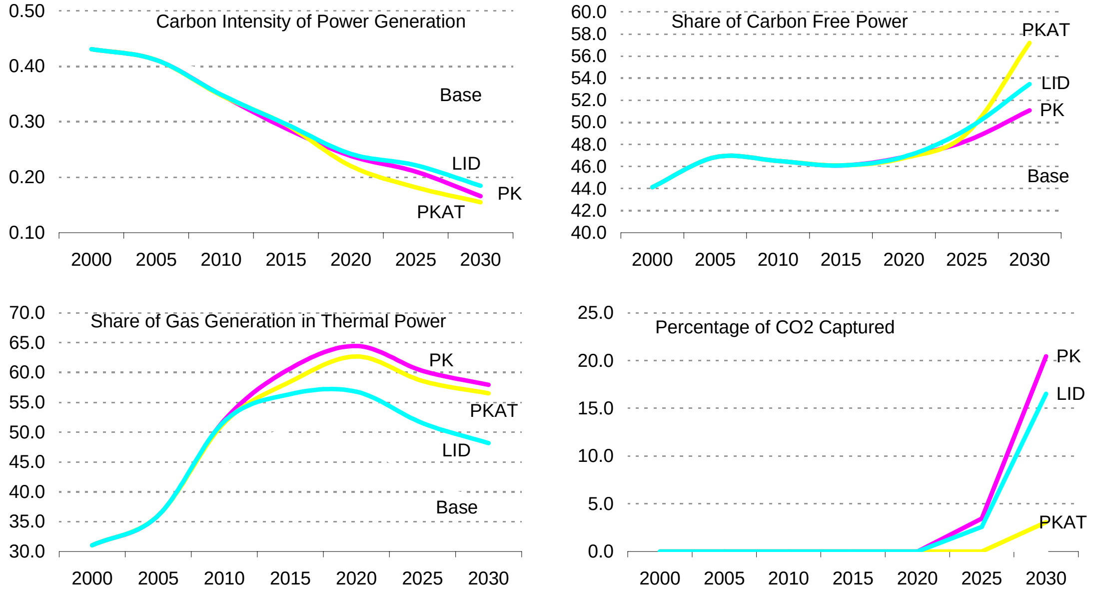
Power from Renewables

(TWh) PRIMES - EU25



Carbon Indicators for Power Generation

PRIMES - EU25



4.9 Appendix IV – Data for PRIMES results for the EU-25

Baseline

Electricity Consumption (GWh)	2005	2010	2015	2020	2025	2030
Industry	1,111	1,201	1,270	1,321	1,371	1,399
Residential	784	881	987	1,097	1,197	1,273
Tertiary	748	855	948	1,031	1,093	1,143
Transport	75	79	78	74	73	71
Energy System	489	495	508	509	506	509
Total Gross Demand	**3,207**	**3,510**	**3,791**	**4,033**	**4,240**	**4,395**

PK

Electricity Consumption	2005	2010	2015	2020	2025	2030
Industry	1,111	1,198	1,273	1,326	1,377	1,408
Residential	784	874	983	1,096	1,195	1,266
Tertiary	748	840	927	1,009	1,069	1,108
Transport	75	78	77	73	72	70
Energy System	489	481	486	479	472	476
Total Gross Demand	**3,207**	**3,470**	**3,746**	**3,983**	**4,185**	**4,327**

PKAT

Electricity Consumption	2005	2010	2015	2020	2025	2030
Industry	1,111	1,198	1,272	1,332	1,392	1,427
Residential	784	874	984	1,098	1,201	1,279
Tertiary	748	839	931	1,018	1,085	1,136
Transport	75	78	77	73	72	70
Energy System	489	482	490	481	469	470
Total Gross Demand	**3,207**	**3,471**	**3,753**	**4,003**	**4,219**	**4,383**

LID

Electricity Consumption	2005	2010	2015	2020	2025	2030
Industry	1,111	1,197	1,276	1,333	1,385	1,416
Residential	784	874	981	1,092	1,189	1,255
Tertiary	748	839	919	994	1,052	1,090
Transport	75	78	76	73	71	70
Energy System	488	481	488	480	472	475
Total Gross Demand	**3,207**	**3,470**	**3,741**	**3,971**	**4,170**	**4,305**

Baseline

Energy (Mtoe)	2005	2010	2015	2020	2025	2030
Industry	339	356	372	383	389	392
Residential	295	312	328	339	346	351
Tertiary	174	188	201	212	219	225
Transport	365	390	401	415	418	413
Energy System	575	576	566	547	523	525
Total Gross Primary	**1,748**	**1,822**	**1,868**	**1,896**	**1,895**	**1,907**

PK

Energy (Mtoe)	2005	2010	2015	2020	2025	2030
Industry	339	351	364	373	378	379
Residential	295	305	320	329	336	340
Tertiary	174	184	195	205	211	216
Transport	365	384	394	406	409	403
Energy System	576	554	530	504	485	491
Total Gross Primary	**1,749**	**1,778**	**1,803**	**1,817**	**1,819**	**1,829**

PKAT

Energy (Mtoe)	2005	2010	2015	2020	2025	2030
Industry	339	351	365	376	381	384
Residential	295	305	321	331	339	345
Tertiary	174	184	195	207	214	220
Transport	365	384	395	409	411	406
Energy System	576	552	544	549	555	577
Total Gross Primary	**1,748**	**1,777**	**1,821**	**1,871**	**1,900**	**1,932**

LID

Energy (Mtoe)	2005	2010	2015	2020	2025	2030
Industry	339	351	363	369	372	373
Residential	295	305	317	322	327	330
Tertiary	174	184	192	199	205	209
Transport	365	384	389	396	396	390
Energy System	576	554	532	502	488	496
Total Gross Primary	**1,749**	**1,778**	**1,793**	**1,789**	**1,788**	**1,798**

Baseline, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Fuel Inputs Power Generation	410	434	451	463	483	491
Solids	224	215	198	198	224	241
Oil (including refinery gas)	34	31	28	23	21	20
Gas	123	154	183	183	166	154
Biomass & Waste	25	30	38	54	67	70
Final Energy Demand by Fuel	1172	1246	1302	1348	1372	1381
Solids	51	45	42	39	37	34
Oil	501	526	534	539	533	522
Gas	269	279	296	310	316	322
Electricity	234	259	282	303	321	334
Heat (from CHP and District Heating)	74	80	84	88	92	95
Other	44	57	64	69	72	74

PK, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Fuel Inputs Power Generation	410	407	409	405	414	420
Solids	223	179	129	93	92	102
Oil (including refinery gas)	33	24	19	13	11	10
Gas	125	169	208	224	214	208
Biomass & Waste	25	31	49	70	91	95
Final Energy Demand by Fuel	1172	1224	1273	1313	1334	1338
Solids	50	39	35	33	32	28
Oil	502	516	523	525	519	506
Gas	268	274	287	296	299	303
Electricity	234	257	280	301	319	331
Heat (from CHP and District Heating)	74	79	82	85	88	91
Other	44	59	66	73	76	78

PKAT, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Fuel Inputs Power Generation	410	406	410	371	343	326
Solids	223	179	140	93	80	74
Oil (including refinery gas)	33	24	20	11	9	9
Gas	125	169	200	197	172	159
Biomass & Waste	25	31	46	65	75	79
Final Energy Demand by Fuel	1172	1224	1277	1322	1345	1356
Solids	51	39	36	33	30	27
Oil	502	516	524	529	522	511
Gas	268	274	289	300	305	312
Electricity	234	257	281	303	323	337
Heat (from CHP and District Heating)	74	79	82	86	90	93
Other	44	60	66	72	75	76

LID, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Fuel Inputs Power Generation	410	408	410	399	410	421
Solids	223	180	147	117	123	134
Oil (including refinery gas)	34	24	17	11	9	8
Gas	125	169	192	190	177	170
Biomass & Waste	25	31	50	77	97	103
Final Energy Demand by Fuel	1172	1224	1261	1287	1300	1302
Solids	51	39	35	31	28	23
Oil	502	516	509	494	476	456
Gas	268	274	283	286	287	289
Electricity	234	257	280	300	318	329
Heat (from CHP and District Heating)	74	79	81	84	88	91
Other	44	60	73	90	104	113

Baseline Scenario

Power Generation (TWh)	2005	2010	2015	2020	2025	2030
Nuclear energy	974	963	934	888	803	816
Renewable energy	490	625	762	942	1,135	1,208
Solids fired	923	870	822	892	1,084	1,210
Gas and Oil Fired	790	1,025	1,248	1,287	1,193	1,136

PK

Power Generation	2005	2010	2015	2020	2025	2030
Nuclear energy	974	965	934	900	874	890
Renewable energy	492	648	865	1,122	1,377	1,478
Solids fired	916	723	539	407	424	478
Gas and Oil Fired	795	1,108	1,385	1,529	1,485	1,456

PKAT

Power Generation	2005	2010	2015	2020	2025	2030
Nuclear energy	974	965	991	1,229	1,459	1,646
Renewable energy	492	646	836	1,047	1,210	1,279
Solids fired	916	734	582	395	374	361
Gas and Oil Fired	794	1,100	1,320	1,308	1,152	1,072

LID

Power Generation	2005	2010	2015	2020	2025	2030
Nuclear energy	974	965	934	905	880	893
Renewable energy	492	649	901	1,205	1,447	1,553
Solids fired	915	724	618	526	577	644
Gas and Oil Fired	795	1,104	1,263	1,310	1,241	1,190

Baseline

Power Capacity (GW)	2005	2010	2015	2020	2025	2030
Nuclear energy	137	136	125	117	98	101
Renewable energy	156	203	249	301	361	390
Solids fired	186	156	144	156	188	213
Gas and Oil Fired	246	312	348	371	386	396

PK

Power Capacity	2005	2010	2015	2020	2025	2030
Nuclear energy	137	136	125	119	107	111
Renewable energy	156	210	277	358	444	494
Solids fired	185	154	132	113	104	119
Gas and Oil Fired	246	317	359	399	436	458

PKAT

Power Capacity	2005	2010	2015	2020	2025	2030
Nuclear energy	137	138	133	155	178	207
Renewable energy	156	208	269	336	395	429
Solids fired	185	154	129	104	99	96
Gas and Oil Fired	246	319	352	377	394	406

LID

Power Capacity	2005	2010	2015	2020	2025	2030
Nuclear energy	137	136	125	119	108	112
Renewable energy	156	211	290	391	472	515
Solids fired	185	154	133	132	130	147
Gas and Oil Fired	246	316	353	389	415	421

Baseline, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Primary Production	885	836	740	707	694	685
Solids	190	155	132	131	128	120
Oil	134	117	75	53	47	43
Natural gas	197	172	125	98	89	80
Nuclear	251	249	241	229	207	210
Renewable energy sources	113	144	167	196	223	231
Net Imports	908	1034	1178	1242	1254	1278
Solids	115	132	132	128	152	174
Oil	564	608	658	680	667	663
Natural gas	225	291	387	432	432	438
Gross Inland Consumption	1748	1822	1868	1896	1895	1907
Solids	305	287	264	259	281	294
Oil	653	677	682	680	661	651
Natural gas	423	463	512	530	521	518
Nuclear	251	249	241	229	207	210
Renewable energy forms	113	144	167	196	223	231
as % in Gross Inland Consumption						
Solids	17.5	15.8	14.1	13.6	14.8	15.4
Oil	37.4	37.2	36.5	35.9	34.9	34.1
Natural gas	24.2	25.4	27.4	28.0	27.5	27.1
Nuclear	14.4	13.6	12.9	12.1	10.9	11.0
Renewable energy forms	6.4	7.9	8.9	10.3	11.7	12.1

PKAT, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Primary Production	885	830	740	760	817	857
Solids	190	144	106	76	67	62
Oil	134	116	75	53	47	43
Natural gas	197	172	125	98	88	80
Nuclear	251	249	256	317	376	425
Renewable energy sources	113	149	179	216	239	248
Net Imports	909	995	1132	1164	1137	1131
Solids	114	101	93	71	62	56
Oil	566	595	643	659	646	640
Natural gas	226	297	394	432	427	433
Gross Inland Consumption	1748	1777	1821	1871	1900	1932
Solids	304	245	199	147	129	118
Oil	655	663	667	659	639	627
Natural gas	423	468	518	531	515	512
Nuclear	251	249	256	317	376	425
Renewable energy forms	113	149	179	216	239	248
as % in Gross Inland Consumption						
Solids	17.4	13.8	10.9	7.8	6.8	6.1
Oil	37.5	37.3	36.6	35.2	33.6	32.5
Natural gas	24.2	26.4	28.5	28.4	27.1	26.5
Nuclear	14.4	14.0	14.0	16.9	19.8	22.0
Renewable energy forms	6.5	8.4	9.8	11.5	12.6	12.8

PK, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Primary Production	885	824	722	679	690	696
Solids	190	138	98	69	67	69
Oil	134	116	74	53	47	43
Natural gas	197	172	125	98	89	80
Nuclear	251	249	241	232	225	230
Renewable energy sources	113	149	183	226	261	274
Net Imports	909	1002	1132	1191	1184	1189
Solids	114	108	89	77	76	77
Oil	566	596	641	660	649	641
Natural gas	226	297	400	452	457	468
Gross Inland Consumption	1749	1778	1803	1817	1819	1829
Solids	304	246	188	146	143	146
Oil	655	664	665	660	642	629
Natural gas	423	468	524	551	546	548
Nuclear	251	249	241	232	225	230
Renewable energy forms	113	149	183	226	261	274
as % in Gross Inland Consumption						
Solids	17.4	13.8	10.4	8.0	7.8	8.0
Oil	37.5	37.3	36.9	36.3	35.3	34.4
Natural gas	24.2	26.3	29.1	30.3	30.0	30.0
Nuclear	14.4	14.0	13.4	12.8	12.4	12.6
Renewable energy forms	6.5	8.4	10.2	12.4	14.4	15.0

LID, Mtoe	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
Primary Production	885	825	748	740	768	783
Solids	190	139	113	99	102	104
Oil	134	116	74	52	46	42
Natural gas	197	172	125	98	89	80
Nuclear	251	249	241	234	227	231
Renewable energy sources	113	150	195	257	304	328
Net Imports	909	1001	1095	1099	1072	1068
Solids	114	107	92	68	66	69
Oil	566	595	623	619	594	581
Natural gas	226	297	378	410	410	415
Gross Inland Consumption	1749	1778	1793	1789	1788	1798
Solids	304	246	205	168	168	172
Oil	655	663	647	621	589	571
Natural gas	423	469	503	508	498	495
Nuclear	251	249	241	234	227	231
Renewable energy forms	113	150	195	257	304	328
as % in Gross Inland Consumption						
Solids	17.4	13.8	11.4	9.4	9.4	9.6
Oil	37.5	37.3	36.1	34.7	32.9	31.7
Natural gas	24.2	26.3	28.1	28.4	27.9	27.5
Nuclear	14.4	14.0	13.4	13.1	12.7	12.8
Renewable energy forms	6.5	8.4	10.9	14.4	17.0	18.2

Baseline, Mt	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
CO2 Emissions (Mt of CO2)	3815	3910	3944	3956	3988	3991
Power generation/District heating	1343	1365	1349	1331	1387	1427
Energy Branch	127	125	122	115	106	101
Industry	575	576	591	594	583	569
Residential	468	483	494	495	490	487
Tertiary	252	262	270	276	279	282
Transport	1051	1100	1118	1145	1144	1125
CO2 Emissions Index (1990=100)	101	104	104	105	106	106

PK, Mt	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
CO2 Emissions (Mt of CO2)	3816	3711	3611	3489	3395	3179
Power generation/District heating	1341	1230	1102	968	896	735
Energy Branch	129	127	122	115	107	101
Industry	576	553	559	557	548	524
Residential	468	463	471	467	462	456
Tertiary	252	253	258	263	265	266
Transport	1051	1085	1099	1118	1117	1097
CO2 Emissions Index (1990=100)	101	98	96	92	90	84

PKAT, Mt	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
CO2 Emissions (Mt of CO2)	3816	3708	3650	3442	3297	3172
Power generation/District heating	1341	1228	1129	902	786	700
Energy Branch	129	127	123	114	104	98
Industry	576	553	564	562	548	532
Residential	468	463	473	473	468	465
Tertiary	252	253	260	266	268	271
Transport	1051	1085	1103	1125	1123	1106
CO2 Emissions Index (1990=100)	101	98	97	91	87	84

LID, Mt	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
CO2 Emissions (Mt of CO2)	3816	3712	3583	3369	3248	3040
Power generation/District heating	1341	1232	1128	979	938	808
Energy Branch	129	126	118	107	97	91
Industry	576	553	552	538	517	495
Residential	468	463	460	447	435	427
Tertiary	252	253	253	252	250	248
Transport	1051	1085	1071	1046	1012	970
CO2 Emissions Index (1990=100)	101	98	95	89	86	80

Total Cost of Energy in billion Euro

	2005	*2010*	*2015*	*2020*	*2025*	*2030*
baseline	1029	1116	1218	1338	1454	1523
PK	1030	1162	1279	1412	1544	1649
PKAT	1030	1162	1269	1392	1506	1580
LID	1030	1162	1327	1508	1668	1787

Total Cost per unit of Final Energy in Euro per MWh

	2005	*2010*	*2015*	*2020*	*2025*	*2030*
baseline	75.5	77.0	80.4	85.3	91.2	94.8
PK	75.5	81.6	86.4	92.5	99.5	106.0
PKAT	75.5	81.6	85.4	90.5	96.2	100.2
LID	75.5	81.6	90.5	100.8	110.3	118.1

Total Cost of Energy as % of GDP

	2005	*2010*	*2015*	*2020*	*2025*	*2030*
baseline	10.6	10.2	9.9	9.8	9.7	9.5
PK	10.6	10.6	10.4	10.3	10.3	10.3
PKAT	10.6	10.6	10.3	10.2	10.1	9.8
LID	10.6	10.6	10.8	11.0	11.1	11.1

Average Electricity Prices in Euro of 2005 per MWh

	2005	*2010*	*2015*	*2020*	*2025*	*2030*
baseline	82.3	84.6	86.4	89.4	94.1	96.9
PK	82.5	85.0	87.7	91.3	97.3	104.9
PKAT	82.4	85.0	86.9	89.4	92.8	95.4
LID	82.5	85.1	92.7	100.7	108.0	115.4