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Technology Stories with PRIMES2 for the European Union

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Table of Contents

Technology Stories with PRIMES2 for the European Union

An analysis for demand-side, power and steam generation sector

1. Introduction

The present paper explores the implications for the European Union of accelerating the progress of key energy technologies in the demand and supply sectors over the period 2010-2030.

The paper does not consider the driving forces or policies (e.g. R&D support) that would induce the assumed technology progress. The analysis aims at deriving the benefits arising from such a progress, in terms of system costs and pollution. The use of a system model also allows estimating the likely size of the market for the technologies and the side effects on the energy system.

This paper builds on the results of PRIMES V.2 model including the interactions between demand and supply.

The baseline scenario is the one prepared recently (end September 1998) for the "Shared Analysis" project of DG XVII. The scenario is coordinated with the world energy projections made with the model POLES, in particular regarding the world energy prices evaluated by POLES as a result of demand and supply interaction in the world-wide markets.

For sensitivity analysis purposes, the approach considers two baseline scenarios, which for the EU differ, only in the dynamic evolution of world energy prices. The baseline scenario involving relatively low rates of increase of gas and oil border prices to the EU is called "low price baseline", while the one assuming high growth of gas and oil prices in the long run is called "high price baseline". Both scenarios assume stability for the price of imported coal.

For analytical purposes, the paper presents the results separately for each cluster of technologies, for which accelerated technology progress occurs. Such a set of assumption lead to a scenario quantified by using the PRIMES model and called "technology story". One such story concerns the demand-side and six concern the supply side (in fact the power and steam generation technologies). The paper also presents the combined effects in the demand and the supply side.

The following matrix summarises the definition of the model runs:

		Low Prices for oil and gas	*High Prices for oil and gas*
Demand-side	*Baseline*	Low price baseline	High Price baseline
	Demand-side story	Low price demand-side story	High price demand-side story
Supply-side (6 cases)	*Demand-side progress as in the baseline*	Low price Supply-side stories without demand effects	High price Supply-side stories without demand effects
	Demand-side progress as in the demand-side story	Low price Supply-side stories with demand effects	High price Supply-side stories with demand effects
Number of Scenarios for the EU		14	14

2. Definition of Technology Progress Stories

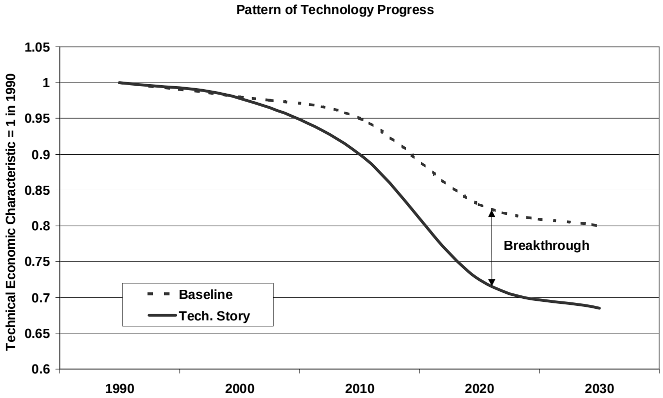
A technology story assumes a different evolution of technological progress for a group of energy technologies. The assumptions correspond to an assertion that a cluster of technologies, grouping techniques that are based on similar technological components, will improve over time at a rate higher than other technological groups.

Assumptions underlying the technology stories are described in detail in the first volume of the final report of the "Climate Technology Strategy" project, Joule-III, DG-XII. The demand-side story and a pessimistic supply-side story have been added.

In summary, the technology stories are defined as follows:

- The Nuclear story, involving considerable progress in the nuclear plant technologies (conventional and new emerging technology) regarding capital cost, flexibility of dispatching, variable and fixed operation costs.
- The Clean Coal story, involving significant reduction of investment costs of key clean coal technologies (supercritical, IGCC and PFBC plant types) and improvement of thermal efficiencies.
- The Gas story, involving continuous improvement of the technical-economic characteristics of gas turbine combined cycle plants and other small gas turbines plants, accompanied by higher resource availability of natural gas and consequently lower (than in the corresponding baseline) supply prices for natural gas.
- The Fuel Cells story, involving, in addition to the assumptions of the gas story, significant cost and performance progress in fuel cell technologies for power and steam generation, that are considered as a result of, commercialisation, hence maturity and economies of scale. This story is also accompanied by high resource availability of natural gas, as in the gas story.
- The Renewable story, involving significant improvement of the technical-economic characteristics of new renewable technologies for power generation, including technologies that involve intermittent supply of power and technologies that use biomass and wastes
- The Pessimistic (supply-side) story which assumes that the technical-economic characteristics of power and steam generation technologies do not change over time and remain frozen at their levels as in 2000.
- The Demand-side story which assumes that the capital cost of new end-use technologies (except steam generation and cogeneration) decreases gradually up to 35% compared to baseline. This concerns those technologies that are improved or advanced compared to ordinary end-use techniques.

Technology progress in cost and efficiency terms begins from 2010, accelerates between 2010-2020 and reach maturity by 2030. The generic time pattern of the assumed evolution of technology is shown in figure.



3. The Baseline scenario

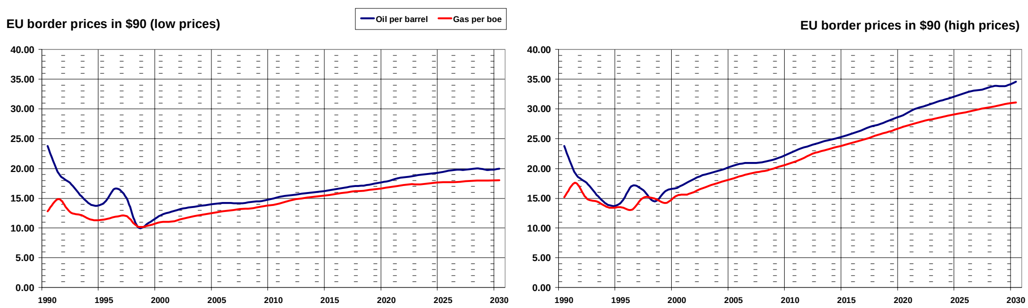
3.1. World Energy Prices

As mentioned, the border prices of energy imports to the EU change in the future as a result of interactions between demand and supply at a world level. The POLES model simulates those interactions.

In the baseline scenarios, the oil and gas prices bear relatively significant increases in the longer run, reflecting progressively binding supply and resource constraints along with high growth of world energy demand. On the contrary, the abundance of coal resources induces stability of coal prices.

The low price baseline projects an average increase of oil and gas prices, in real terms, of the order of 2.1% per year for the period 2000-2010 and 1.5% for the period 2010-2030. The corresponding assumptions of the high price baseline are 3% (2000-2010) and 2.1% (2010-2030). In the low price baseline, this leads to a price (for oil) of 19$’90/bbl in 2030, while in the high price baseline the same price becomes 33$’90/bbl in 2030. Similarly, the border price for natural gas becomes equal to 4.9$’90/Mbtu in 2030 in the low price baseline, while becoming 8.5$’90/Mbtu in 2030 in the high price baseline.

The supply-side stories that involve progress in technologies that use natural gas for power generation, also assume that world gas resources prove to be more abundant than in the baseline. In this case, the gas price decreases by 13% in 2030 compared to the low gas baseline, and by 22% in the case of high price baseline.



3.2. The Baseline Scenario

The baseline scenario for the EU assumes continuation of current trends and policies, including technology progress in both demand and supply, as well as market liberalisation in power and steam. Global environmental constraints do not influence the baseline projection.

Continuous efficiency gains prevail in the baseline trends. The overall energy intensity (primary energy requirements over GDP) improves at a rate of 1.5% per year. Final energy requirements increase with activity and income, but at rates that differ by sector. Activity in heavy industrial processes, as well as energy needs, slowdown over time. On the contrary, energy for transportation rises substantially, however at rates progressively slower than in the past. Electricity demand increases more than final energy, mainly through the accelerated adoption of electricity-based technologies and the emergence of new uses of electricity in the tertiary and domestic sectors. The end-use technological system improves, as mentioned before, but there is no profound change in the consumption patterns or the nature of technology. For example, fuel cell cars (or electric cars), renewables in final energy and new energy carriers (like hydrogen) do not emerge. The evolution pattern in the supply side is similar. There is continuous improvement in the efficiency of technologies, but there is no structural change other than that induced by electricity market liberalisation. The process of liberalisation, accompanied with a technological progress that allows small size power and steam plants to gain competitiveness relatively to the traditional large scale plants, induces a decentralisation of generation and the rapid penetration of power and steam cogeneration. The resulting change is mainly based on gas technologies (GTCC and small gas machines), that exhibit higher efficiency rates. Benefiting from low oil and gas prices, this trend continuous to develop even in the last decade (2020-2030) when massive nuclear decommissioning takes place (lifetime duration of 40 years is generally assumed for existing nuclear plants).

The penetration of natural gas in power and steam generation implies improvement of the carbon intensity, especially in the short-medium term. In the long term, the decommissioning of nuclear plants contributes to deterioration of carbon intensity. The combined effect for CO2 result in a continuous growth of CO2 emissions, at rates substantially lower than GDP growth. The rising trend slowdown towards 2020, but afterwards increases again substantially. Transportation and at a lesser degree the tertiary sector, are responsible for the increase in CO2 emissions in the medium run, while power generation is mainly responsible in the longer run.

The PRIMES model incorporates differentiation of capital cost and performance according to the size of the plant. Independent power producers, because of the size of their applications, can select from a menu of technologies that generally include lower-sized plants compared to the menu for utilities. Lower-sized plants are at present significantly more costly than larger plants. However, there is a strong trend in some technologies (like the gas turbines, for example) in favour of reducing the unit cost differences between small independent generators and utilities. Such a progress evidently enables decentralisation of generation, depending also on demand and fuel availability.

Technology progress in relation to economies of scale is introduced in the baseline scenario (and all technology stories) independently of the main technology evolution by cluster of techniques. This explains, among others, that the scenarios project relatively high penetration of cogeneration.

For example, in all scenarios CHP electrical capacity as a percentage of total thermal capacity exceeds 36% in 2030, while being about 23% in 2000. This share depends upon the nature of technology story but remains a dominant factor in the analysis. Consequently, generation decentralisation also increases. For example, while the share of utilities in power generation was more than 95 % in 1995, this share is projected to steadily grow reaching 65 % by 2030 in the baseline scenario.

The nuclear policy question practically arises beyond 2020, as decommissioning of existing capacities is considered beyond 40 years of plant lifetime. Even in the context of relatively high growth of oil and gas prices, nuclear energy is not any more competitive The baseline scenarios lead to almost full abolishment of nuclear energy by 2030.

In the baseline scenario, the gas turbine combined cycle plants and the small gas turbines and machines are very competitive in the short-medium term. Their massive deployment characterises the evolution of the power and steam generation system. In the context of the low price baseline, the domination of gas-based generation prevails in the longer run, as well. The share of electricity produced from gas rises up to 58% in 2030. According to the baseline projection, a total of about 600 GW of power and CHP generation plants will be constructed in the EU, in the period 2010-2030. The gas based small and large plants will represent 75%, while traditional technologies and clean coal will represent only 17%.

In the context of high price baseline scenario, gas based generation becomes less competitive than coal-fired plants in the period beyond 2020. This is a consequence of relative fuel prices, but also depends on the technology progress of clean coal. In this case, the share of gas-based electricity generation drops to 38% in 2030 and its market share in total investment in 2010-2030 becomes 57%. In the context of high oil and gas prices, clean coal takes a significant part of nuclear decommissioning: about 150 GW of clean coal technologies are invested in the 2010-2030 and the total share of conventional and clean coal investments is 34%.

The high price baseline scenario is more efficient than the low-price baseline in the demand side (improvement by 1% per year). However, during the last decade of the projection, coal penetrates more than gas in power and steam generation, implying a further increase of CO2 emissions and a decline of average thermal efficiency. The combined effect leads to a deterioration of CO2 emissions in the high price baseline, in 2030, compared to the low price baseline (6.5% more emissions).

Apart from coal and natural gas, there is no significant fluctuation in the use of other fuels during the projection period. The use of Lignite and peat remains high in some countries such as Greece and Germany, which have high domestic production and low prices of these fuels. The use of biomass increases after 2000, getting its biggest share by 2020. All these fuels are constrained by availability in supply.

Wind, photovoltaic and other renewable technologies lose a small part of their share at the end of the period. Concerning wind energy and photovoltaics, there is slowdown of new investment beyond the short-medium run. In case of low price baseline, renewables represent 6.5% of gross inland consumption in 2030, while that share increases in the high price baseline (7.1%).

The dynamic evolution of efficiency indicators by sector in the demand-side is continuously improving. In the industrial sectors, the efficiency indicator (energy per unit of physical production) improves at an average annual rate of about 0.45% (2000-2030). Restructuring away from traditional processes (like integrated steelworks and basic chemicals) and in favour of high value added activities (including acceleration of recycling of materials) contribute to further improvement of the overall industrial efficiency indicator. The progress in the tertiary and domestic sectors is more pronounced, being better than –1% per year (computes as a ratio of energy demand per unit of income or value added in services). The changes in the transport sector are more complex, since technology progress combines with structural shifts in the allocation of mobility by transport mean. While mobility grows at a rate similar to that of GDP, energy use becomes more efficient as activity shifts more into faster and more collective transport means. The engineering efficiency of vehicles improves at an annual rate of about 1%, while the ratio of energy for transportation over GDP improves at a rate of 1.5% per year.

The case of high prices (in the baseline scenario) has rather small effects on final energy demand. The technology improvement accelerates in most sectors. However, in some processes or sectors that decline, as a consequence of higher prices, technology progress slowdown, since capital turnover also slowdown in these sectors. The overall efficiency in the demand-side improves (energy demand decreases), accompanied with higher electricity penetration in the end-use sectors.

The following tables summarise the results for the low-price and the high-price baseline scenarios.

Baseline Scenario - Low Fuel prices			Mtoe			*annual growth rate*			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Gross Inland Consumption	*1362*	*1450*	*1576*	*1629*	*1600*	1.26%	0.84%	0.33%	-0.18%
Solid Fuels	237	220	186	167	173	-1.45%	-1.68%	-1.09%	0.37%
Liquid Fuels	574	624	673	704	700	1.71%	0.76%	0.44%	-0.05%
Natural Gas	273	313	417	472	578	2.74%	2.91%	1.24%	2.04%
Nuclear	205	212	216	191	40	0.67%	0.19%	-1.23%	-14.53%
Electricity	1	1	1	2	3	-9.98%	-2.06%	13.47%	4.72%
Renewable Energy Sources	71	79	82	94	107	2.08%	0.38%	1.33%	1.32%

Baseline Scenario - Low Fuel prices			Mtoe			*annual growth rate*			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Electricity Generation in TWh	*2306*	*2543*	*3000*	*3342*	*3652*	1.97%	1.67%	1.09%	0.89%
Nuclear	810	845	862	765	174	0.84%	0.20%	-1.19%	-13.77%
Hydro - Renewables	293	356	396	425	453	3.97%	1.06%	0.71%	0.64%
Thermal (incl. biomass)	1203	1342	1742	2152	3025	2.21%	2.64%	2.14%	3.46%
Steam Generation in TWh_{th}	*1034*	*1123*	*1288*	*1391*	*1472*	1.67%	1.38%	0.77%	0.57%
CHP plants	323	503	692	1022	1290	9.29%	3.25%	3.97%	2.36%
Boilers	711	620	596	369	181	-2.70%	-0.40%	-4.68%	-6.85%
Generation Capacity in GWe	*569*	*623*	*714*	*804*	*880*	1.83%	1.37%	1.20%	0.91%
Nuclear	132	136	134	116	23	0.68%	-0.18%	-1.46%	-14.92%
Hydro (without pumping)	106	109	110	110	106	0.58%	0.07%	0.00%	-0.33%
Thermal (incl. biomass)	328	368	448	546	711	2.29%	1.99%	2.02%	2.66%
of which CHP	64	85	141	214	255	5.79%	5.20%	4.28%	1.79%
Solar, wind, geothermal	3	10	22	32	40	25.73%	8.23%	3.66%	2.30%
Average Load Factor %	*46.2*	*46.6*	*48.0*	*47.4*	*47.4*	0.14%	0.30%	-0.11%	-0.02%
Boilers (GWth)	*239*	*209*	*157*	*114*	*85*	-2.60%	-2.85%	-3.11%	-2.95%
Fuel Inputs for Power and Steam Gen.	*364*	*386*	*443*	*499*	*608*	1.18%	1.37%	1.20%	2.00%
Solids	171	159	133	122	140	-1.49%	-1.75%	-0.87%	1.41%
Oil	88	93	99	115	106	1.03%	0.62%	1.52%	-0.85%
Gas	83	110	184	224	314	5.85%	5.25%	1.99%	3.45%
Biomass / Waste	22	24	27	38	48	2.20%	1.05%	3.54%	2.43%
Hydrogen	0	0	0	0	0	-	-	-	-
Average Thermal Efficiency %	*52.8*	*54.9*	*58.9*	*61.1*	*63.6*	0.78%	0.70%	0.37%	0.40%

Baseline Scenario - Low Fuel prices			Mtoe			*annual growth rate*			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Final Energy Demand	*883*	*946*	*1041*	*1089*	*1125*	1.39%	0.96%	0.45%	0.33%
by fuel									
Solid Fuels	43	38	33	28	21	-2.44%	-1.52%	-1.39%	-3.00%
Liquid Fuels	404	434	467	476	479	1.46%	0.75%	0.18%	0.07%
Natural Gas	177	193	216	226	233	1.73%	1.12%	0.45%	0.30%
Steam	67	73	85	93	100	1.69%	1.54%	0.90%	0.69%
Electricity	169	186	221	249	275	1.95%	1.73%	1.18%	1.00%
New fuels	0	0	0	2	5	-	4.79%	15.17%	10.10%
Renewable Energy Sources	23	21	18	15	13	-1.09%	-1.57%	-1.77%	-1.31%
by sector									
Industry	244	259	287	304	314	1.20%	1.01%	0.59%	0.33%
Residential	242	251	261	264	265	0.75%	0.42%	0.11%	0.03%
Tertiary	123	136	158	173	185	2.15%	1.48%	0.89%	0.70%
Transports	275	300	335	348	361	1.77%	1.12%	0.38%	0.37%

Baseline Scenario - Low Fuel prices			Mtoe			*annual growth rate*			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
CO2 Emissions	*3029*	*3169*	*3384*	*3505*	*3740*	0.91%	0.66%	0.35%	0.65%
industry	381	392	401	395	370	0.57%	0.21%	-0.13%	-0.65%
tertiary	200	215	232	240	243	1.48%	0.78%	0.32%	0.15%
households	430	439	447	450	446	0.42%	0.18%	0.07%	-0.10%
transports	800	871	966	988	1004	1.72%	1.04%	0.23%	0.16%
supply side	1219	1252	1338	1431	1677	0.54%	0.67%	0.67%	1.60%

Baseline Scenario - Low Fuel prices						*annual growth rate*			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Indicators									
Energy intensity (toe/1990MECU)	240	225	192	166	138	-1.33%	-1.54%	-1.47%	-1.82%
Carbon Intensity (tn of CO2/toe)	2.224	2.186	2.148	2.151	2.338	-0.35%	-0.17%	0.01%	0.84%
Import Dependency (percent)	47.6	49.3	57.5	65.1	76.6	0.72%	1.55%	1.26%	1.63%

Baseline Scenario - High Fuel prices			Mtoe			annual growth rate			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Gross Inland Consumption	*1362*	*1448*	*1577*	*1618*	*1602*	1.23%	0.85%	0.26%	-0.10%
Solid Fuels	237	228	220	231	346	-0.76%	-0.37%	0.48%	4.15%
Liquid Fuels	574	615	647	645	636	1.38%	0.52%	-0.03%	-0.15%
Natural Gas	273	311	399	443	464	2.59%	2.53%	1.04%	0.48%
Nuclear	205	213	220	195	40	0.70%	0.37%	-1.24%	-14.72%
Electricity	1	1	1	2	3	-8.25%	-1.20%	12.51%	4.85%
Renewable Energy Sources	71	81	90	103	114	2.65%	0.98%	1.43%	0.95%

Baseline Scenario - High Fuel prices			Mtoe			annual growth rate			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Electricity Generation in TWh	*2306*	*2584*	*3058*	*3404*	*3717*	2.30%	1.70%	1.08%	0.88%
Nuclear	810	845	878	778	173	0.86%	0.38%	-1.20%	-13.95%
Hydro - Renewables	293	359	400	454	513	4.11%	1.09%	1.28%	1.22%
Thermal (incl. biomass)	1203	1379	1779	2171	3031	2.77%	2.58%	2.01%	3.39%
Steam Generation in TWh $_{th}$	*1034*	*1136*	*1301*	*1400*	*1480*	1.90%	1.36%	0.74%	0.56%
CHP plants	322	510	770	1147	1415	9.61%	4.21%	4.07%	2.12%
Boilers	711	626	530	253	65	-2.54%	-1.64%	-7.15%	-12.68%
Generation Capacity in GWe	*569*	*626*	*726*	*830*	*910*	1.90%	1.50%	1.34%	0.93%
Nuclear	132	137	134	116	23	0.72%	-0.20%	-1.46%	-14.92%
Hydro (without pumping)	106	109	110	110	107	0.58%	0.07%	0.00%	-0.23%
Thermal (incl. biomass)	328	369	459	563	721	2.38%	2.20%	2.06%	2.51%
of which CHP	64	85	147	231	286	5.99%	5.60%	4.58%	2.17%
Solar, wind, geothermal	3	11	23	41	59	26.88%	8.11%	5.99%	3.55%
Average Load Factor %	*46.2*	*47.1*	*48.1*	*46.8*	*46.6*	0.38%	0.19%	-0.26%	-0.04%
Boilers (GWth)	*239*	*211*	*158*	*85*	*52*	-2.47%	-2.82%	-6.03%	-4.77%
Fuel Inputs for Power and Steam Gen.	*364*	*396*	*454*	*501*	*626*	1.69%	1.38%	0.99%	2.24%
Solids	171	166	166	184	311	-0.61%	-0.02%	1.06%	5.38%
Oil	88	88	80	67	54	0.01%	-0.98%	-1.72%	-2.20%
Gas	83	116	175	206	211	6.98%	4.22%	1.61%	0.24%
Biomass / Waste	22	26	33	44	49	3.34%	2.56%	2.92%	1.02%
Hydrogen	0	0	0	0	1	-	-	-	-
Average Thermal Efficiency %	*52.8*	*54.6*	*58.3*	*61.3*	*62.0*	0.67%	0.66%	0.50%	0.12%

Baseline Scenario - High Fuel prices			Mtoe			annual growth rate			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Final Energy Demand	*883*	*940*	*1035*	*1080*	*1116*	1.26%	0.96%	0.43%	0.33%
by fuel									
Solid Fuels	43	40	34	30	23	-1.76%	-1.40%	-1.27%	-2.73%
Liquid Fuels	404	430	463	470	473	1.29%	0.75%	0.15%	0.05%
Natural Gas	177	184	205	214	221	0.80%	1.08%	0.42%	0.33%
Steam	67	74	86	94	101	2.04%	1.54%	0.88%	0.68%
Electricity	169	189	226	253	279	2.28%	1.76%	1.17%	0.97%
New fuels	0	0	0	2	5	-	5.32%	15.74%	10.11%
Renewable Energy Sources	23	22	19	16	14	-0.48%	-1.37%	-1.64%	-1.17%
by sector									
Industry	244	256	283	300	309	0.99%	0.98%	0.58%	0.33%
Residential	242	250	262	265	267	0.73%	0.46%	0.12%	0.04%
Tertiary	123	136	157	171	183	2.08%	1.47%	0.82%	0.72%
Transports	275	297	332	345	357	1.59%	1.13%	0.36%	0.34%

Baseline Scenario - High Fuel prices			Mtoe			annual growth rate			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
CO2 Emissions	*3029*	*3170*	*3402*	*3519*	*3977*	0.91%	0.71%	0.34%	1.23%
industry	381	380	385	379	355	-0.06%	0.13%	-0.16%	-0.64%
tertiary	200	212	227	231	236	1.19%	0.70%	0.18%	0.19%
households	430	437	446	449	446	0.30%	0.21%	0.07%	-0.07%
transports	800	863	957	976	988	1.53%	1.04%	0.20%	0.12%
supply side	1219	1279	1387	1483	1952	0.97%	0.81%	0.67%	2.79%

Baseline Scenario - High Fuel prices						annual growth rate			
EUROPE 14	**1995**	**2000**	**2010**	**2020**	**2030**	***95-00***	***00-10***	***10-20***	***20-30***
Indicators									
Energy intensity (toe/1990MECU)	240	224	192	165	138	-1.36%	-1.52%	-1.54%	-1.74%
Carbon Intensity (tn of CO2/toe)	2.224	2.189	2.158	2.174	2.482	-0.32%	-0.14%	0.08%	1.33%
Import Dependency (percent)	47.6	49.1	56.3	63.3	75.0	0.64%	1.38%	1.18%	1.71%

4. *The supply-side stories*

4.1. The Nuclear story

In this scenario, we assume significant improvement in the technical-economic characteristics of the conventional nuclear technology, as well as the emergence of a new nuclear design.

In particular:

- For a standard large LWR, it is assumed that whereas in the baseline case the capital cost was slightly increasing over time, in the nuclear story the cost of capital becomes about 30 % cheaper by 2030. Furthermore fixed operation and maintenance costs were assumed to become about 35 % lower.

- A new evolutionary nuclear design with inherent safety characteristics is introduced after 2020 with capital cost about 13 % and operating costs about 25 % less than the LWR. For the nuclear scenario this type of plant was assumed to be 30 % cheaper to construct and 50 % to operate than in the baseline case.

The above changes make nuclear plants more competitive in terms of generating costs. In the baseline case they were not competitive even for the higher annual loads. In the nuclear story they become generally cost-attractive, particularly in some countries like France. In the last decade, whereas in the baseline only 23 GW of nuclear plants remain in operation in the EU, in the nuclear story the technology re-emerges leading to additional 26 GW mainly of new nuclear design type.

The additional constructions of nuclear plants are rather limited. The penetration of nuclear is effected to the detriment of mainly GTCC plants, since they both compete for the base load. Other plant types are not affected. Cogeneration and renewables remain almost unchanged from the baseline scenario.

CO2 emissions are significantly lower in the nuclear story, compared to baseline. By 2030 the emissions from power and steam generation become lower by –5.6% compared to the Baseline case. The implications on CO2 emissions appear in the last decade of the projection. For the total energy system, CO2 emission reduction is about 2.5% in 2030. The positive effect on CO2 from nuclear energy is less than expected mainly because it displaces gas-fired plants in the base load.

In the case of high price baseline, nuclear energy becomes slightly more attractive than in the case of low prices. Additional nuclear capacities amount to 42 GW. The main competitor is now clean coal, which is mainly displaced by nuclear in the base load. This results into bigger positive effects for CO2 emissions, which reduce by 4.5% in 2030 (8.8% in power and steam generation).

Finally, the nuclear story leads to a reduction of average power and steam generation costs by about 1% in 2030 compared to the Baseline scenario.

4.2. The Clean Coal story

For the purpose of this scenario three new clean coal technologies have been retained:

- Supercritical coal having a rate of 44 % efficiency by 2030, improve in terms of average specific capital cost (863 ECU/kW instead of 1114 ECU/kW in Baseline) and fixed maintenance costs (20 ECU/kW).

- IGCC plants improve in terms of thermal efficiency reaching by 2030 a rate of 50% (46 % in Baseline), and capital costs (1003 ECU/kW instead of 1333 ECU/kW in Baseline).

- PFBC plants also improve in terms of capital costs (780 ECU/kW instead of 1040 ECU/kW in Baseline) and thermal efficiency reaching a rate of 44 % by 2030.

These improvements combined with low coal prices make clean coal technologies very attractive in comparison to natural gas plants mainly for base load operation. The winner within the family of clean coal technologies seems to be PFBC. In total, the clean coal story involves the construction of about 130 GW on top of the baseline scenario. This acts to the detriment of GTCC. Small gas plants, renewables and nuclear are not affected. The clean coal story induces higher penetration of cogeneration, than in the baseline (30 GW more), implying also a slightly higher degree of production decentralisation.

The evolution within the clean coal story has substantial adverse effects on CO2 emissions, which rise by 10 % at the end of the period from baseline (24% in power and steam generation).

In the case of high prices, clean coal has already penetrated in the baseline scenario. On top of that, additional constructions of clean coal plants amount to 90 GW, again displacing GTCC plants in the base load. The adverse effects on CO2 are again significant.

Average power and steam generation costs decrease by about 4% in this story.

4.3. The Gas story

GTCC is a mature technology and investment activity is widespread around the world. In this gas story scenario we assume a significant improvement of this technology over time, both in terms of thermal efficiency (63 % compared to 59 % in Baseline) and capital cost (460 ECU/kW instead of 528 ECU/kW in Baseline. In the gas story assuming abundance of natural gas supply, reflecting lower gas prices than in the baseline, further facilitates the penetration of GTCC and smaller gas machines.

The combination of these changes provides high potential to GTCC plants for power generation and power and steam cogeneration. The considerable improvement of GTCC plants contributes to narrow the gap in generation cost terms between large utilities and small producers. Independent producers penetrate more easily in the market, further leading to higher decentralisation of generation (47% in 2030) than in the baseline scenario (41%). The increased penetration of GTCC operates to the detriment of clean coal and conventional thermal technologies. Cogeneration also penetrates more, mainly through GTCC cogeneration plants, allowing in the same time for lowering the need for peak load plants. Other power technologies, like nuclear and renewables, are slightly negatively affected.

CO2 emissions are reduced by -6 % in 2030 compared to baseline (-14% in power generation), as a consequence of the use of gas, the decline of coal use and the spectacular improvement in average thermal efficiency and cogeneration.

The gas story also involves an important decrease of average generation costs (-15%), as a consequence of lower fuel prices but also the low capital costs associated with GTCC plants.

In the case of high price baseline, the benefits for CO2 emissions are more spectacular (-12% in 2030), since in the baseline clean coal penetrates in the last decade. About 190 GW of GTCC plants are constructed on top of those in the baseline, displacing clean coal and conventional thermal technologies.

4.4. The Fuel Cells story

The fuel cells story is considered to be an extension of the Gas story, in the sense that Fuel Cells use also natural gas, since we have not included the economic development of alternative fuels for fuel cells, such as methanol and hydrogen. The fuel cells story considers that the progress is enabled through he development of SOFC (Solid Oxide Fuel Cells) which allow for high heat to power generation rates.

The main assumptions are similar to those of the Gas story, including the assumption that GTCC plants are becoming very competitive and the abundance of natural gas keeping prices low. In addition, the fuel cells story assumes an important improvement of the technical-economic characteristics of Fuel Cells. For example, regarding fuel cells we assume:

- The electrical efficiency raises up to 70 % by 2030 (65 % by 2015)
- Capital cost becomes 25 % less than in Baseline case

- O&M costs are 66.7 % lower in this story.

The evolution of technology over time is such that Fuel Cells start to be competitive after 2020 starting from a negligible initial share. By 2030 their share rises up to 4 % only. The system is again based on more conventional natural gas technologies (mainly GTCC), which represents about 64 % in terms of power generation.

The deployment of fuel cells allow for further decentralisation in generation (50%) as the cost differences due to economies of scale are the smallest among the generation technologies. In addition they allow for higher penetration of cogeneration. The use of solid fuels declines over time reaching the lowest value among the technology stories.

The fuel cells story is very efficient in terms of CO2 emissions, which are found to be reduced by -8% compared to the Baseline scenario (-21% in power and steam generation). CO2 emissions in 2030 increase only by 9% from 2000, while this rate was double in the baseline scenario.

In terms of average generation costs, the fuel cells story achieves the lowest level (-15%) among the technology stories, even lower than the gas story.

The case of high price baseline confirms these results. Clean coal is massively displaced by fuel cells, decentralisation and cogeneration augment substantially. The benefits in terms of CO2 emissions are more significant: -14% from baseline.

4.5. The Renewable story

The renewable story involves a considerable technological progress in intermittent power production technologies and a decrease of costs associated to the use of biomass. In particular:

- For wind turbines the capital cost decreases from 849 ECU/kW (in the Baseline scenario) to 355 ECU/kW in 2030.
- For photovoltaics used in buildings, the capital cost reaches 1235 ECU/kW compared to 2470 ECU/kW in the Baseline scenario.
- For small hydro plants the capital cost is reduced to 1137 ECU/kW (2104 ECU/kW in the Baseline scenario).
- For tidal-ocean techniques having capital cost that decrease from 1831 ECU/kW (in the Baseline scenario) to 990 ECU/kW.
- For geothermal plants reaching a capital cost equal to 1042 ECU/kW (1928 ECU/kW in the Baseline scenario)

The O&M costs of the above technologies are in this story also lower by 50% compared to the Baseline scenario.

Biomass gasification is assumed also to progress, in terms of capital cost (from 946 ECU/kW in the Baseline scenario to 513 ECU/kW in 2030) and O&M costs (from 29.7 ECU/kW to 19.8 ECU/kW).

The technology improvements are enough to make renewable power plant considerably more attractive. The scenario involves additional constructions of about 120 GW contributing by 35% in power and steam generation in 2030 (to be compared to 15% in 2000 and 18% in 2030 in the baseline). Renewables represent 13.5% of Gross inland consumption in 2030 (7% in the baseline).

The deployment of renewables operates mainly to the detriment of GTCC plants and has little effects on other power and steam technologies. Also, the expansion of renewables seems to develop to the detriment of decentralised gas-based generation. This explains why the system is found to be slightly more centralised than in the baseline and the penetration of cogeneration is smaller than in the baseline.

As a result of these developments CO2 emissions are significantly reduced (by –7% compared to baseline in 2030, -17% in power and steam generation) despite the adverse effects from the reduction of gas use. The average production cost reduces by 3-4%.

In the case of high price baseline, the penetration of renewables is of the same order of magnitude as in the case of low price baseline. In case of higher prices, renewables displace clean coal and conventional technologies, leading to a more spectacular decrease of CO2 emissions (-10%).

4.6. The pessimistic supply-side story

This story assumes that the technical economic characteristics of power plants remain frozen at their level of 2000. In other terms, the technology progress incorporated in the baseline scenario is cancelled.

The conventional thermal technologies keep their competitive place in the market, so over time they are displaced by new technologies, as in the baseline. Mainly cogeneration plants and GTCC are negatively affected by the frozen progress. Clean coal also suffers. Nuclear and renewables are almost not affected. Adverse affects are also observed for generation decentralisation (30% only in 2030).

The effects on CO2 emissions are significant: total CO2 emissions increase by 5% from baseline (11% in power generation). Average generation costs increase by 10% in 2030 from baseline.

Similar are the results for the case of high price baseline.

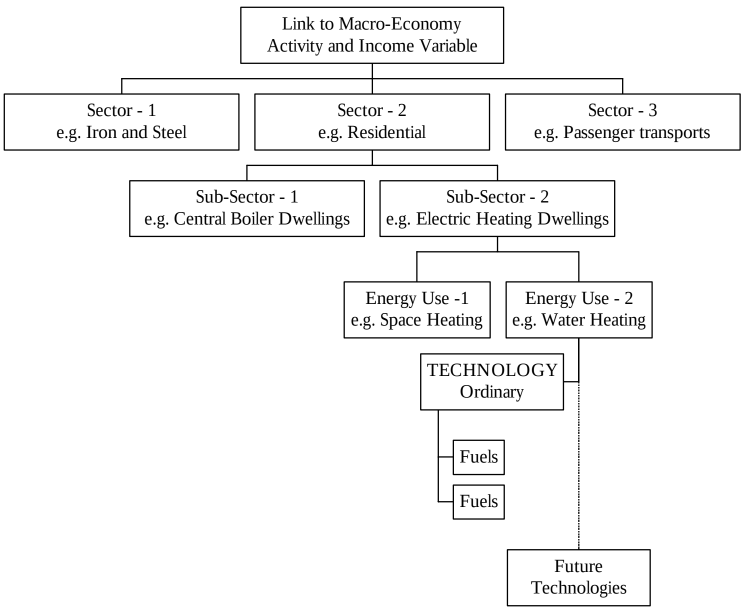
5. The demand-side story

5.1. Effects from demand-side progress

The demand-side story is defined in a rather simple way. We assume that all new technologies in end-uses become cheaper by 35% from the baseline. This occurs gradually over time, allowing for a more rapid penetration of improved and advanced technologies in all sectors. However, none of the new technologies ever becomes cheaper than the ordinary technology.

The demand-side sub-models of PRIMES V.2 have a uniform structure. Each sub-model represents a sector that is further decomposed into sub-sectors and then into energy uses. A technology operates at the level of an energy use and utilises energy forms (fuels). The following graphic illustrates the hierarchical decomposition of the demand-side models.

Decomposition Structure of the Demand-side Models



The fact that future technologies become cheaper than in the baseline induces acceleration of their penetration. This has multiple indirect effects according to the model structure. First, by means of learning by doing and market maturity mechanisms, the technology that start penetrating more is further facilitated. Then, because of differentiated structure of technology mix and cost structures by energy use and sub-sector, substitutions between uses and sub-sectors occur. Those sub-sectors that decline bear slowdown of technical progress along with slowdown of capital replacement schedule. Other sub-sectors that develop more rapidly also benefit from accelerated capital turnover and the embedded technological improvement.

The following table shows the improvement of energy efficiency indicators at the level of the model's sectors:

Energy Efficiency indicators: average rate of change per year (2000-2030)

	Baseline - Low prices	Demand Side - Low prices		Baseline - Low prices	Demand Side - Low prices
		Industry			
integrated steelworks	-0.16%	-0.34%	cement	-0.33%	-0.48%
electric prossesing	-0.32%	-0.47%	ceramics	-0.90%	-0.97%
primary aluminium	-0.26%	-0.33%	glass	-0.58%	-0.64%
secondary aluminium	-0.35%	-0.48%	glass recycled	-0.86%	-0.96%
copper	-0.48%	-0.61%	other building materials	-0.43%	-0.53%
zinc	-0.37%	-0.53%	pulp	-0.55%	-0.59%
lead	-0.11%	-0.18%	paper	-0.77%	-0.84%
other non ferrous products	-0.33%	-0.43%	food, drink, tobacco	-0.42%	-0.48%
fertilisers	-0.37%	-0.43%	engineering	-0.46%	-0.56%
petrochemical	-0.44%	-0.50%	textiles	-0.44%	-0.48%
inorganic chemicals	-0.43%	-0.55%	other industries	-0.38%	-0.47%
low energy chemicals	-0.42%	-0.51%			
tertiary	-1.06%	-1.30%	households	-1.70%	-2.15%
passenger transports (income related)	-1.12%	-1.50%	goods transports (GDP related	-1.72%	-1.78%
		Vehicle efficiency			
passenger transports (toe/Mpkm)	-1.00%	-1.38%	goods transports (toe/Mtkm)	-1.27%	-1.34%
Gross Inl Cons / GDP (toe/1990MECU)	-1.61%	-1.84%			

The effects of demand-side technology progress as defined in this scenario induces significant (but not dramatic) effects for energy efficiency improvement. The effects are more pronounced in the domestic sector and in transports. The overall effect, in terms of energy intensity, is substantial, leading to a yearly rate of improvement that is well beyond the historical average.

Final energy demand in 2030 (compared to the baseline) decreases by 8% (3% in industry, 13% in residential, 7.5% in tertiary and 8.5% in transports). Liquid fuels (-9%) and natural gas (-9.5%) are more affected than other energy forms. On the contrary, electricity and steam (-5.5%) obtain higher share, but reduce in magnitude.

Total CO2 emissions decrease in 2030 by 8% compared to the baseline. In the demand-side this reduction is 9% and in the supply side it is 7%. In 2030, the system emits 305 Mtn of CO2 less than the baseline, of which 185 come from the demand-side and 119 from the supply-side. We remind that in the supply-side there is no technological progress additional to that of the baseline.

The demand-side story also induces a decrease of total system cost: -3% in 2030 from baseline. In total, the system saves 540 billion ECU'90 in 2030, which mainly concern the purchase of energy and related equipment (85%). The savings in fuel costs represent about 10% of total savings. The transport sectors get most of the benefits (75%) followed by households (17%). Some small cost savings also occur in power and steam generation, through indirect system effects.

The indirect effects on power and steam generation mainly come from the reduction of electricity demand. The reduction affects almost at a uniform manner all technologies (compared to baseline).

The effects of the demand-side story in the case of high price baseline are similar in magnitude and nature.

The following table summarises the penetration of new technologies in the demand-side:

Technology penetration in 2030 (in cumulative investment)

	Type of Technology	Baseline - Low prices	Demand side story
Industry	improved	29.3%	30.0%
	advanced	33.4%	38.3%
Residential - Tertiary	improved	42.6%	43.7%
	advanced	40.8%	51.5%
Transports	improved	44.1%	31.7%
	advanced	49.9%	58.1%
All demand sectors	improved	39.4%	35.9%
	advanced	41.7%	49.8%

This table shows that whereas in the baseline the percent penetration of new technologies was 80% in 2030, in the demand-side story this percentage becomes 85%. In addition, the composition in terms of technology generation changes as well, allowing for higher penetration of advanced technology generations.

5.2. Effects from combining demand and supply progress

The model runs that analyse the combined effects from technology progress in the demand and the supply sectors are based on the assumptions presented above. For example, in a nuclear story with demand-side effects, progress is assumed to occur both for the nuclear power plants and the end-use technologies. The progress in the latter induces lower demand for electricity and steam (however higher market shares). The progress in the nuclear technology provides higher opportunities for penetration for this technology, but in a smaller overall market size. An interesting result is whether the size effect alters the conclusions regarding the supply-side stories, through differentiated economies of scale, since the model introduces different possibilities for economies of scale by type of supplier.

The following table summarises the CO2 emission reduction effects in 2030 on power and steam generation from the combined demand and supply progress and compares with the same effect coming from the supply-side progress.

CO2 emission change from baseline in power and steam generation	Nuclear Story	Clean Coal Story	Gas Story	Fuel Cells	Renewables	Pessimistic
Combined demand and supply progress	-86	+355	-215	-272	-273	+171
Supply side progress only	-94	+388	-229	-352	-272	+184

The table shows that the economies of scale mechanism play an important role mainly in those scenarios that involve decentralisation of generation, like for example the fuel cells. The additionality of the effects can be generally assumed, except the fuel cell story.

The combined effects from progress in the demand and the supply sides are spectacular in terms of reducing CO2 emissions and cost savings.

The fuel cell story combined with progress in the demand side leads to stabilisation of CO2 emissions in total (at the level of 2000) and in power and steam generation. The decrease of emissions from the baseline is 15% in 2030. The total system cost saving amount to more than 600 billion ECU per year (in 2030) of which 85% come from the demand-side and 15% from the supply side. This represents in total –3.5% in 2030.

The gas story (with demand-side progress) also provides significant benefits. CO2 emissions in 2030 decrease by 14% from baseline.

The renewables story combined with demand-side progress also leads to stabilisation of CO2 emissions at the level of emissions in 2000. The cost savings are of the order of 550 billion ECU in 2030.

The nuclear story (with demand side progress) leads to a drop of CO2 emissions in 2030 (-10%), but this scenario does not involve stabilisation of emissions.

The combination of the clean coal story with the demand side progress leads to a small increase of CO2 emissions (1.5% more in 2030 compared to the baseline). The effects from the demand-side almost cancel the adverse effects on CO2 emissions from the supply-side. Similar is the result for the pessimistic supply-side story, leading however to a decrease of emissions by 4% in 2030.

6. Concluding remarks

The analysis through the idea of technology stories proved analytically successful. Conclusions are drawn regarding the analysis of differential effects on energy and emissions from the development of technology progress in power and steam generation techniques and in the end-use sectors.

The case of the European Union energy system seems to be very sensible in the long run, as after 2020 the massive decommissioning of old plants opens up a large decision area regarding technology choice in power and steam generation. The differential technology progress may directly influence the strategic choice for the EU leading to highly varying profiles of the future power and steam system.

The stories revealed the strategic importance of natural gas and the related technologies in compliance with the emissions, cogeneration development and generation decentralisation objectives. The clean coal technological development, event though attractive for exports of power equipment, may have adverse effects for the emissions within the EU. The development of nuclear energy seem to be limited in scope and gains, as restricted from load constraints and the interaction with decentralised steam generation. The incremental improvement of renewable technologies may be significant in size to change the profile of the system in terms of emissions and costs.

The importance of technology progress in the end-use sectors is without any doubt. It leads to significant CO2 emissions both directly in the demand sectors and indirectly in energy conversion sectors. It also induces considerable system cost savings and has interesting distributional effects as resulting from high savings for the households and transports.

Three of the stories that combine supply-side and demand-side technology progress lead to stabilisation of CO2 emissions in the EU, namely the gas, the fuel cell and the renewables stories.

The following table summarises the results of the combined demand-side and supply-side stories:

	Baseline - Low prices	Demand side story	Nuclear story	Clean Coal story	Gas story	Fuel cells story	Renewables story	Pessimistic story
Import dependency	100.0	97.7	94.7	97.9	98.6	98.8	89.0	98.9
Energy intensity	100.0	93.0	93.4	94.9	89.1	88.6	93.8	97.6
Carbon intensity	100.0	91.9	89.6	101.3	86.1	84.6	84.6	96.4
System cost	100.0	97.0	96.9	96.9	96.8	96.8	96.9	97.1
Avoided CO2 emissions in 2030 (Mtn)		-304	-390	50	-519	-577	-577	-133
Avoided cumulative CO2 emissions 2010-2030 (Mtn)		-3149	-3551	-660	-6057	-6335	-5946	-937

Further analysis is needed to further check the above results and confirm their accuracy. It would also be important to combine the analysis with a macro-economic equilibrium model to analyse the significance of the results for the economy and the welfare.