Energy and Emissions Long Term Outlook
A Detailed Simulation of Energy Supply-Demand

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Mexican – US Economic and Environmental Modeling Workshop
Centro Mario Molina para Estudios Estratégicos
Hotel JW Marriott, Mexico City
July 11-12, 2005

General objective and scope of the study

To provide Mexican Institutions with modern tools for conducting comprehensive assessment of different energy options, supply options as well as total energy systems in order to identify sustainable strategies to support the expected growth in energy and electricity demand

Specific objectives of the study:

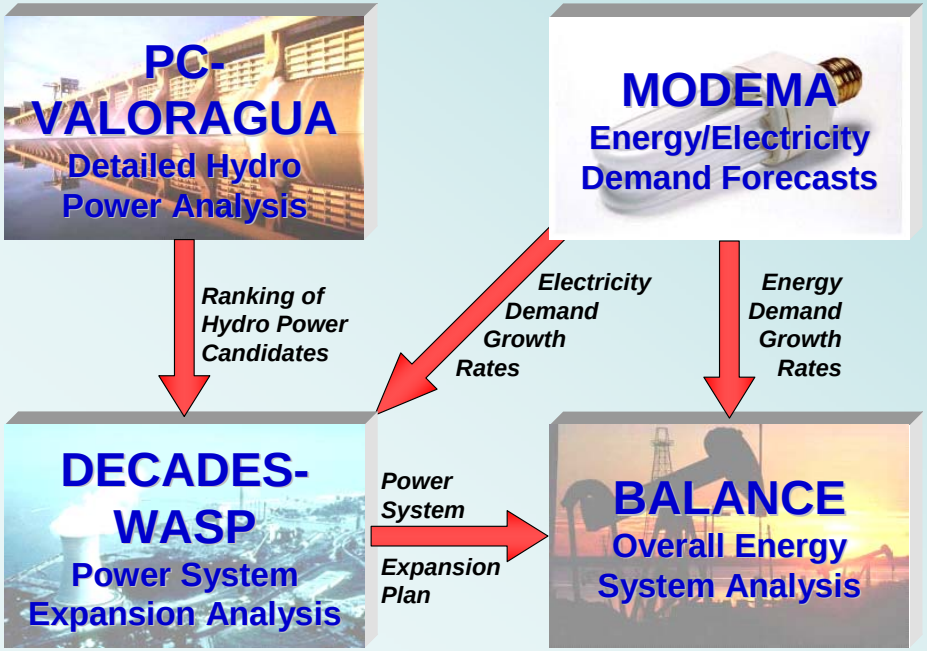
- To project the need for primary energy in Mexico for the period through 2025 that is driven by the expected demand growth for all sources;
- To identify domestic supply sufficiency for major energy resources, the long-term need for energy imports, and the potential for energy exports;
- To study energy infrastructure development to support the growing energy use in Mexico;
- To analyze, in view of the projected high reliance of the power system and other demand sectors on natural gas, the development of the gas sector in detail in order to identify possible supply constraints, price implications and relevant policy measures;
- To identify the potential role of renewable energy sources in the Mexican energy system;
- To quantify environmental emissions of the whole energy system associated with the expected growth of energy consumption and possible emission mitigation measures;
- To provide, by considering several alternative scenarios, a set of possible scenarios as input to national decision-making in the energy sector.

Modeling framework:

VALORAGUA determines the optimal generating strategy of mixed hydro-thermal electric power systems. It can simulate the operation of all forms of hydropower plants (run-of-river, weekly, monthly, seasonal, or multi-annual regulation), including pumped-storage plants and multipurpose hydro projects.

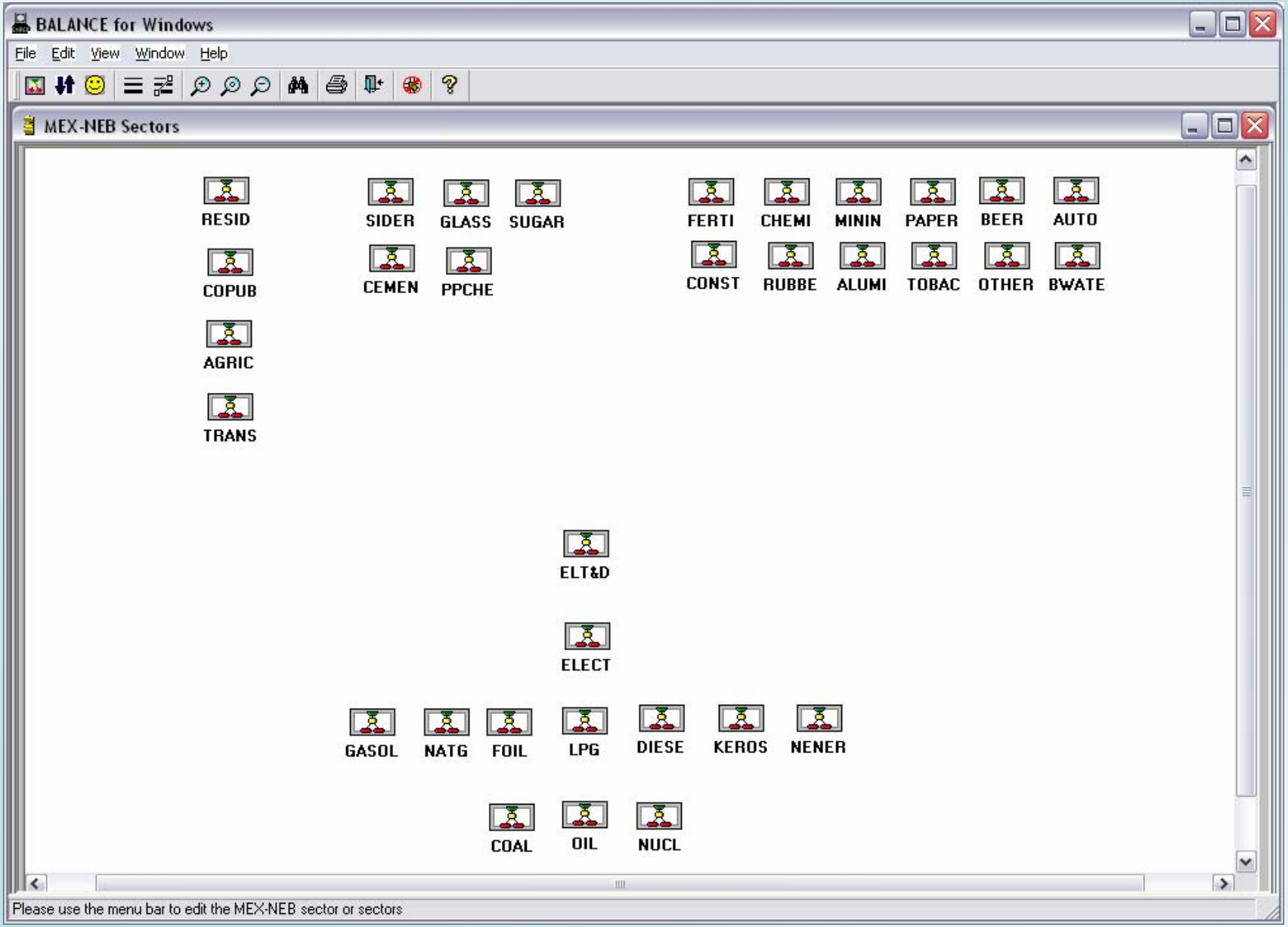
DECADES-WASP is a dynamic optimization software that determines the optimal least-cost generation system expansion path that adequately meets the growing demand for electricity while respecting user-specified constraints, such as desired system reliability, fuel limitations, or environmental constraints. WASP uses a probabilistic simulation of production costs, energy-not-served costs, and system reliability parameters to compare total costs of alternative expansion paths.

MODEMA is a simulation demand model that provides the energy demand projections based on the underlying macroeconomic and population growth assumptions. Basic input data include energy intensities, per capita consumption, GDP and GDP structure, population and population structure, etc.

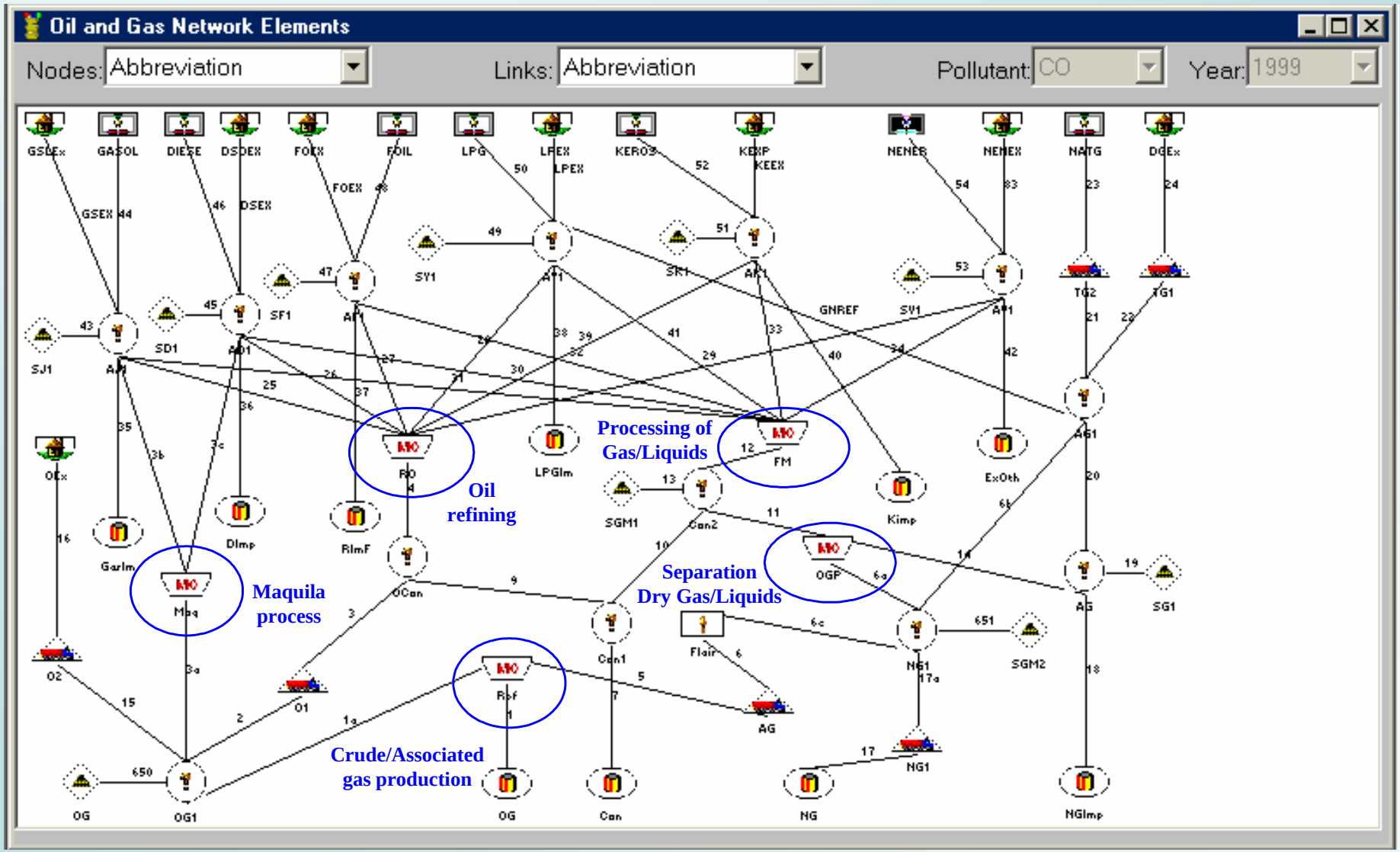


BALANCE uses a nonlinear, market-based equilibrium approach to determine the energy supply and demand balance for the entire energy system. This approach allows to determine the response of various segments of the energy system to changes in energy prices and demand levels. Basic input parameters include information on the energy system structure; base year statistics, including production and consumption levels, and prices; projected energy demand growth; and any technical and policy constraints.

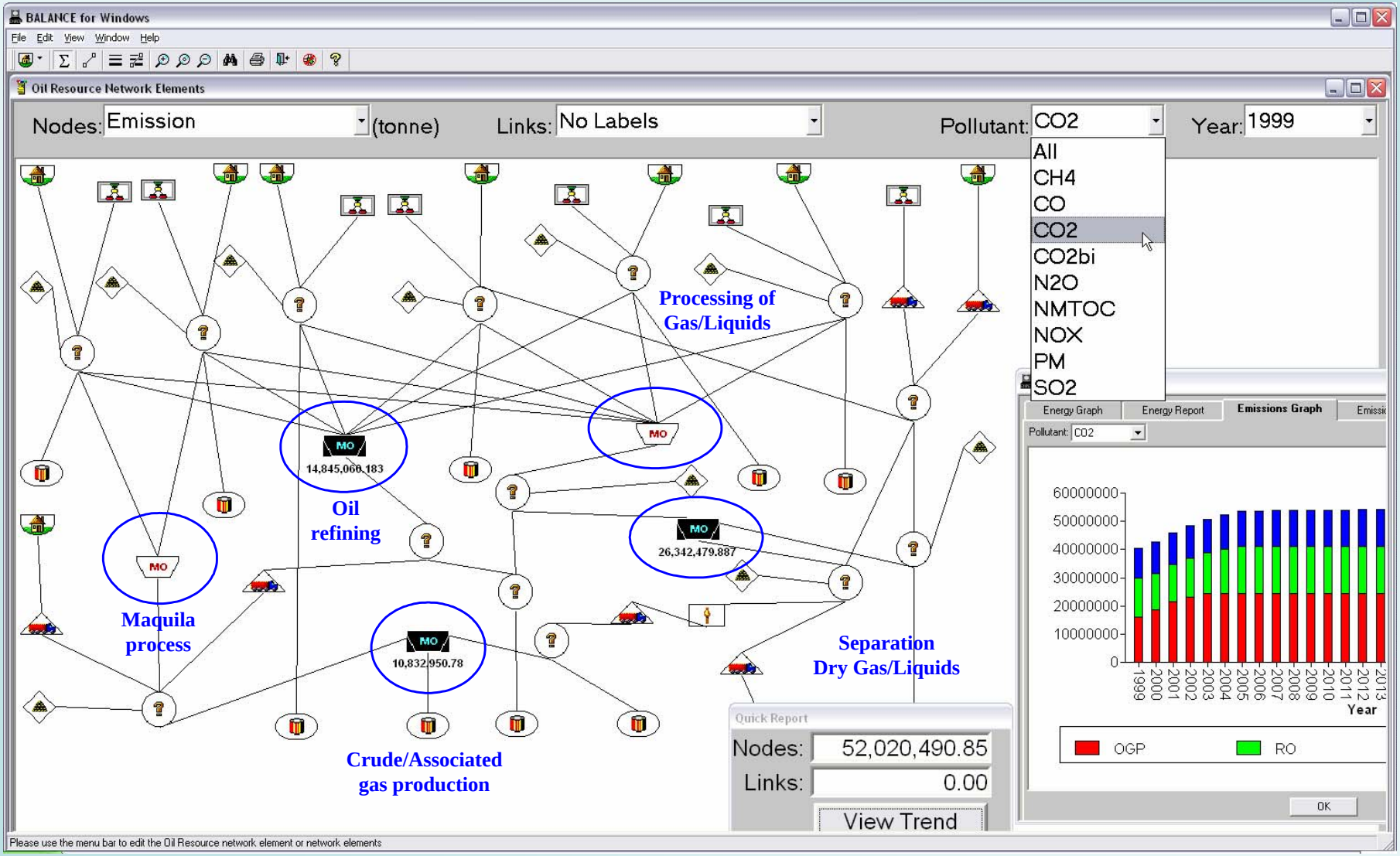
BALANCE-ENPEP Network for Mexico



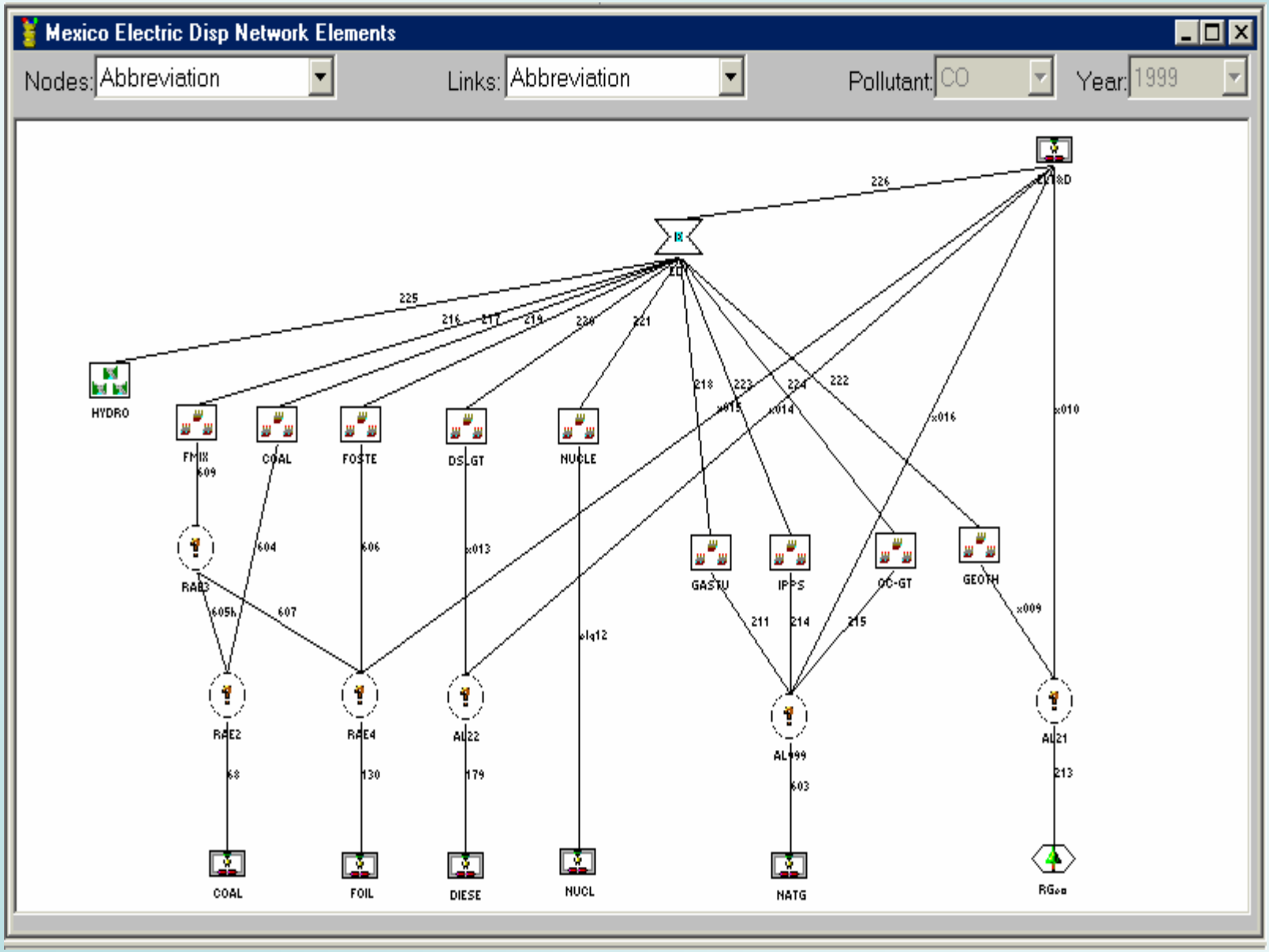
Oil and Gas Sector representation



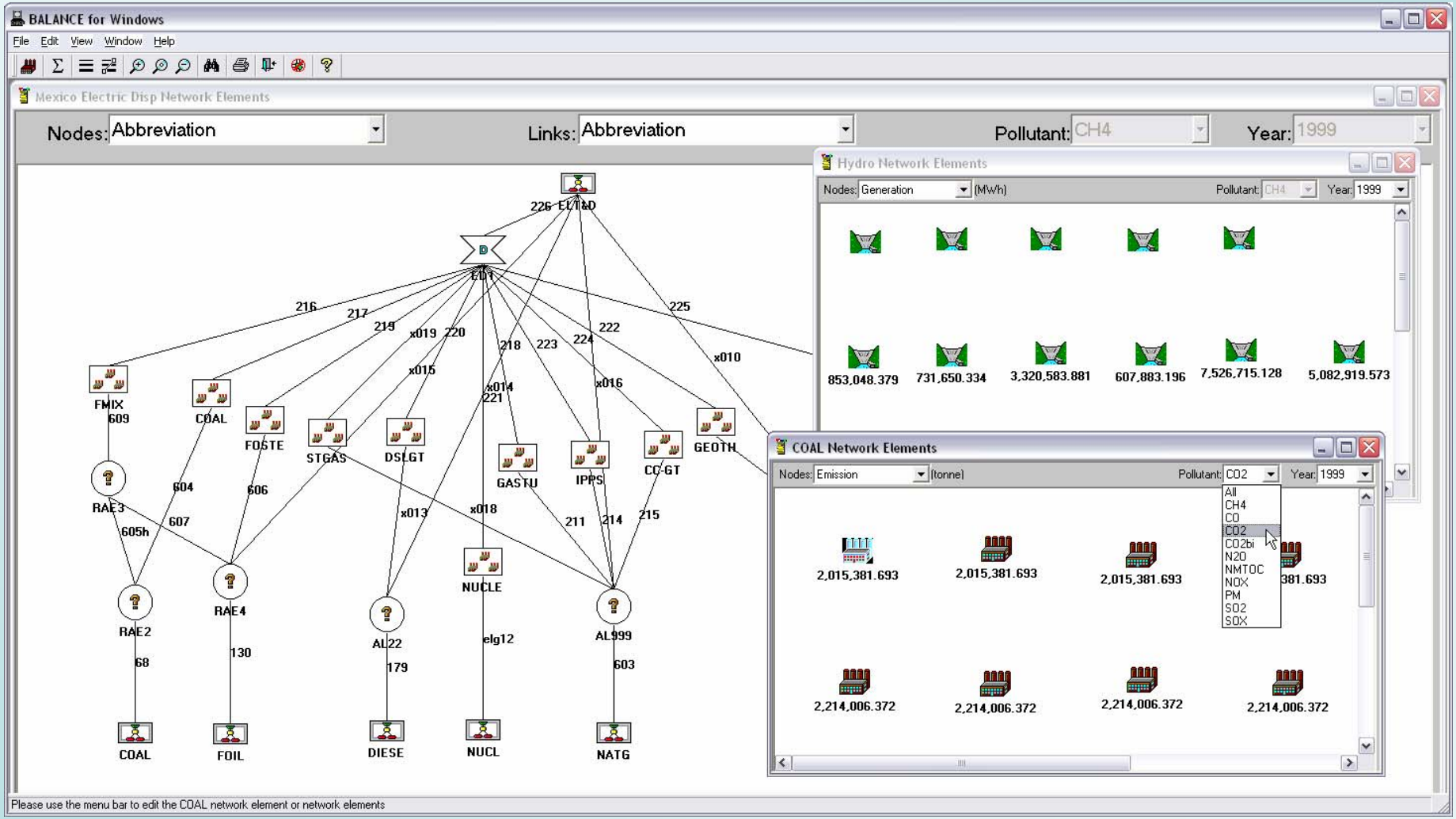
Oil and Gas Sector representation



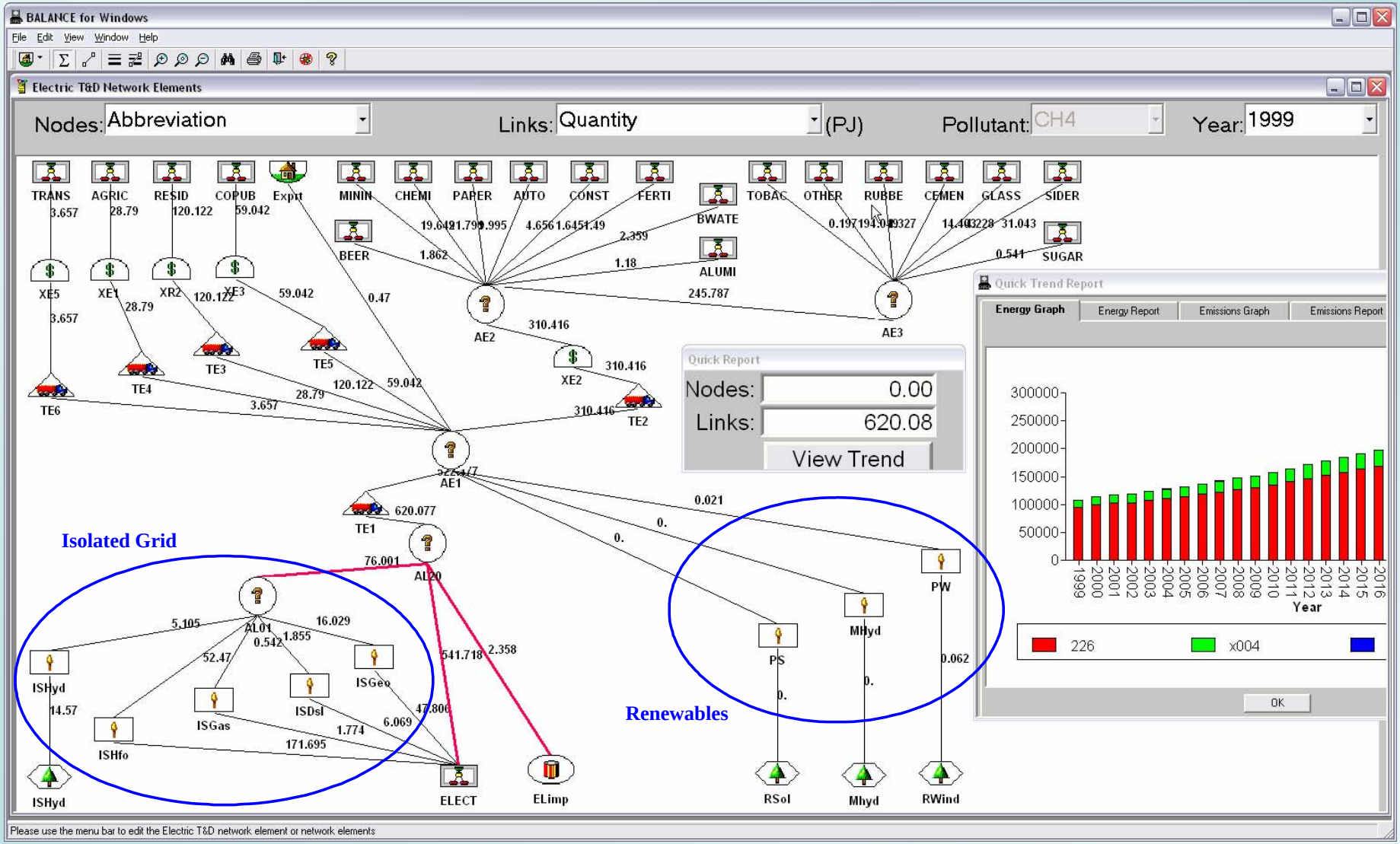
Electric Sector representation



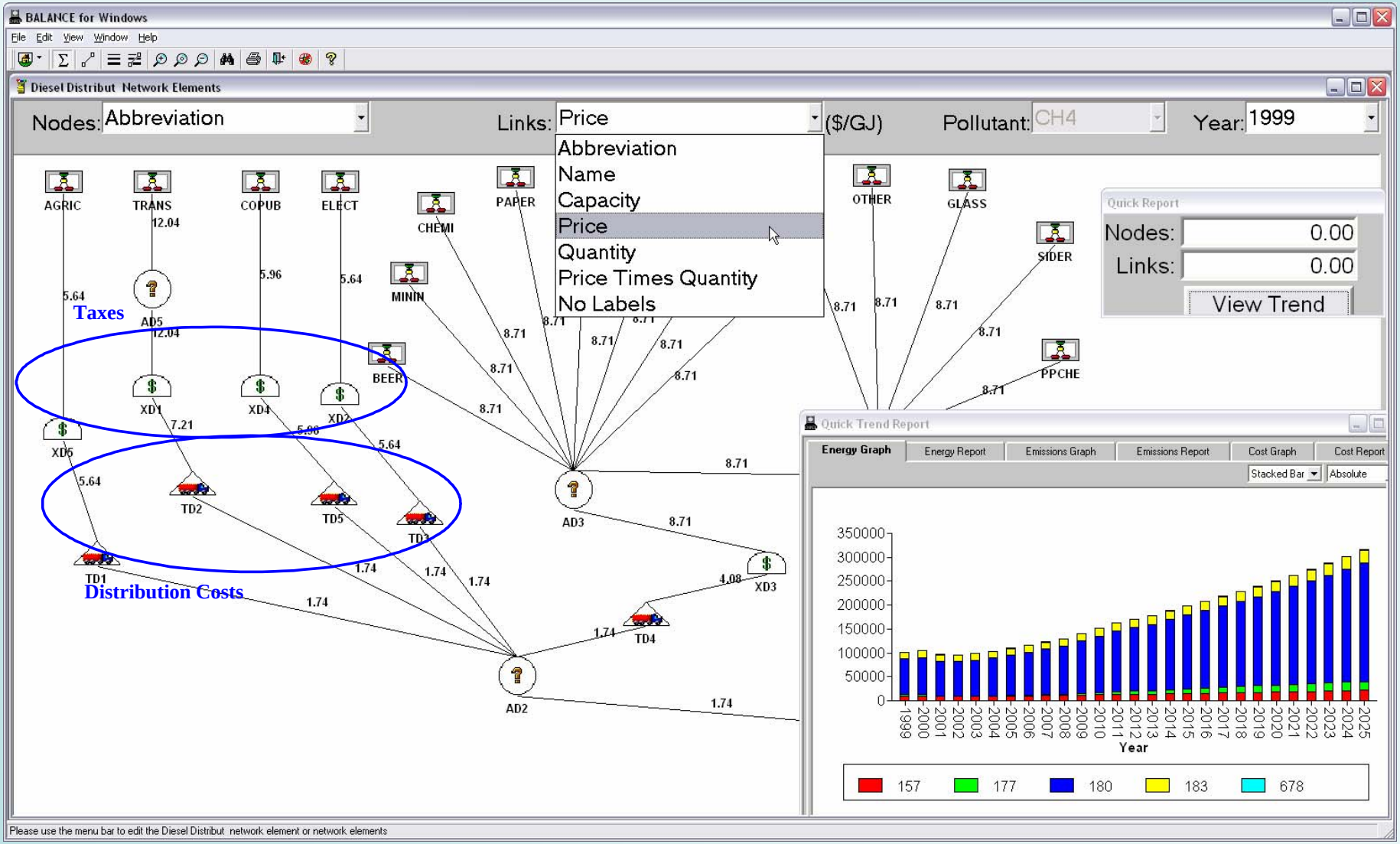
Electric Sector representation (1)



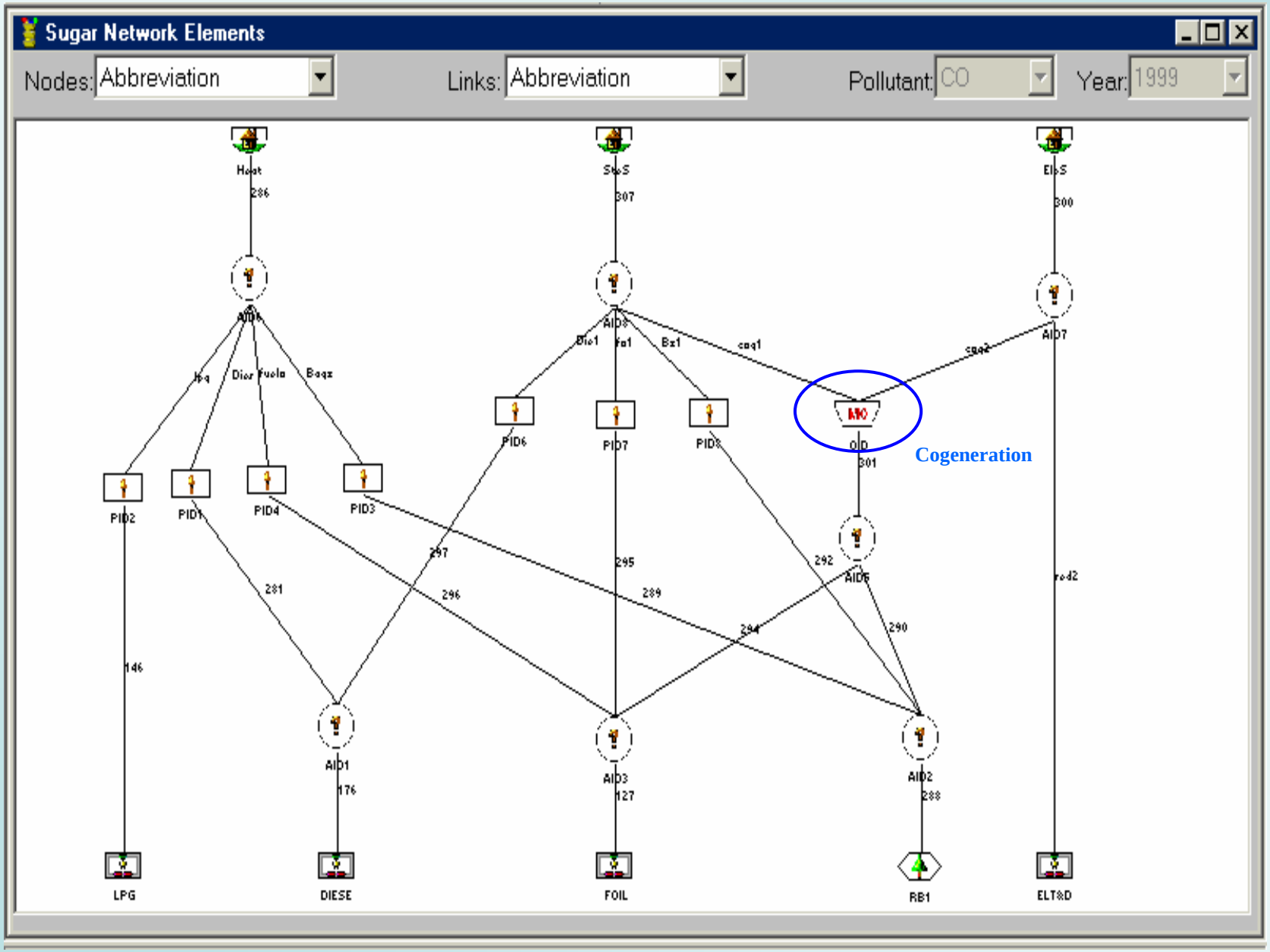
Electric Sector representation (2)



Electric Transmission and Distribution Sector



End-Use Sector representation



Macroeconomic and population assumptions:

GDP

	Average annual growth rate %
2002-2011	4.5
2012-2025	3.5

Population

Year	Total million	Urban %	Rural %
2000	100.3	65.53	34.47
2005	106.9	66.43	33.57
2010	112.8	67.40	32.60
2015	117.9	68.27	31.73
2020	122.5	68.99	31.01
2025	126.3	69.57	30.43

WASP Results

Case ID	Alternative	N1356	D350	CC546	TG179	HYD-A	HYD-B	Comments
106	Base Case	0	0	118	6	3	2	**Features:** 5% growth rate, conservative nuclear cost, moderate price escalation for fossil fuels, no supply limit for natural gas, 10% discount rate, reliability (LOLP) 3 days/year, reserve margin changing from 30% to 10%, wet FGD on new coal units
A. Impact of higher demand growth								
65	A1	0	0	157	27	3	2	**High growth demand**: A higher demand growth than in the Base Case is assumed (6.5% instead of 5%)
B. Nuclear option								
63	B1	5	0	105	9	3	2	**Low nuclear costs**: The investment cost of new nuclear power plants is assumed to be 48% lower than in the base case, allowing 5 new nuclear power plants to appear in the optimal solution
74	B2	1	0	115	9	3	2	**Forced nuclear introduction**: Includes 1 forced nuclear power plant of 1 356 MWe with the objective to see possible non-economic advantages of an additional nuclear power plant (lower emissions, a more diversified power system) and its impact on the system cost
C. Escalation of fossil fuel prices								
71	C1	0	0	119	4	3	2	**Slightly higher fossil fuel prices**: includes an alternative projection for the escalation of fossil fuel prices (natural gas and others)
78	C2	0	0	110	30	3	2	**Notably higher gas prices**: includes a recent projection for the gas prices (around 4 US$/tcf instead of 2.9 US$/tcf as in the Base Case)
82	C3	0	159	26	4	3	2	**Medium-term increase in the gas price**: assumes the peak of 12 US$/tcf in 2010 (from 2.9 in 1998) and then a decline to 4 US$/tcf in 2024
D. Limitations in the introduction of new gas fired units								
68	D1	0	57	85	4	3	2	**Limitation on the number of CC-546 units**: Annual inputs of CC units on natural gas are limited to 3 units/year (instead of 4 to 7 units as in the base case)
70	D2	0	122	45	4	3	2	**Limited gas supply**: The annual gas supply is limited starting 2010; the limit equals the gas supply in 2010
E. Variation in the discount rate								
58	E1	0	0	118	5	3	2	**Increased discount rate**: 12% discount rate instead of 10% discount rate as in the Base Case (reflecting a higher cost of capital)
31	E2	0	0	118	8	3	2	**Decreased discount rate**: 8% discount rate instead of 10% discount rate as in the Base Case (reflecting a lower cost of capital)
F. Changes in the target reliability								
73	F1	0	0	119	15	3	2	**Increased power system reliability**: The reserve margins and/or the cost of ENS are defined to obtain the LOLP of 1 day per year (instead of 3 as in the Base Case)
66	F2	0	0	116	4	3	2	**Decreased power system reliability**: The reserve margins and/or the cost of ENS are defined to obtain the LOLP of 5 days/year. The case would show the impact of a system becoming less reliable (*e.g.*, as a result of deregulation)
77	F3	0	0	113	4	3	2	**Decreased reserve margin in early years**: The case is configured to obtain a lower reserve margin in the study (by a decrease in the cost of ENS). This reflects the possible policy direction with respect to the reserve margin

Scenarios analyzed

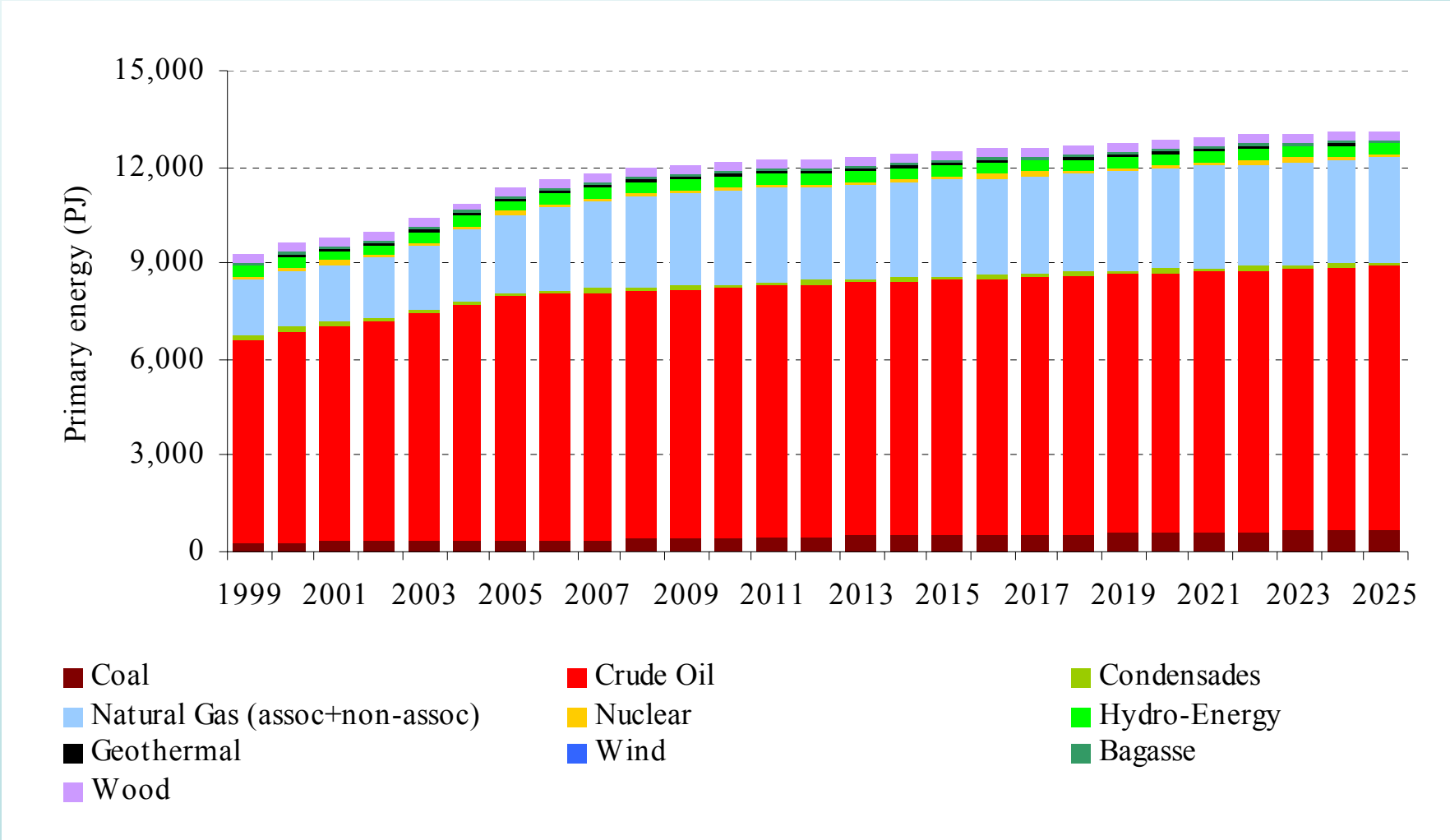
Forecasts for the entire energy system were developed for the following four scenarios:

- Reference Case (unlimited natural gas supply)
- Limited natural gas scenario (assumes limited natural gas supply for power generation starting in 2010)
- Renewables scenario (investigates impacts of additional renewables for power generation (primarily wind and some solar PV))
- Nuclear scenario (analyzes the impacts of additional nuclear power generation capacity)

Results

Reference Scenario (RS)

RS: Total Primary Energy Supply



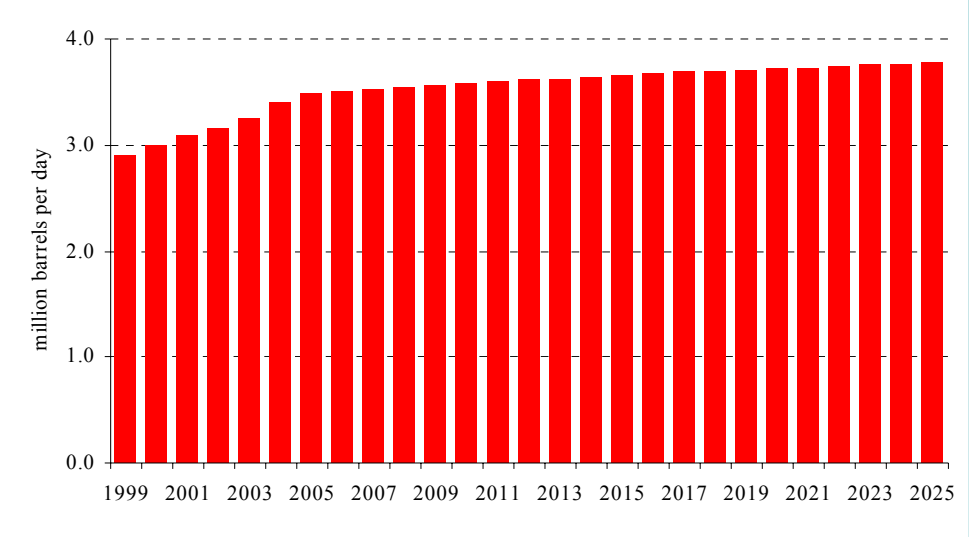
RS: Crude Oil and Natural Gas Requirements

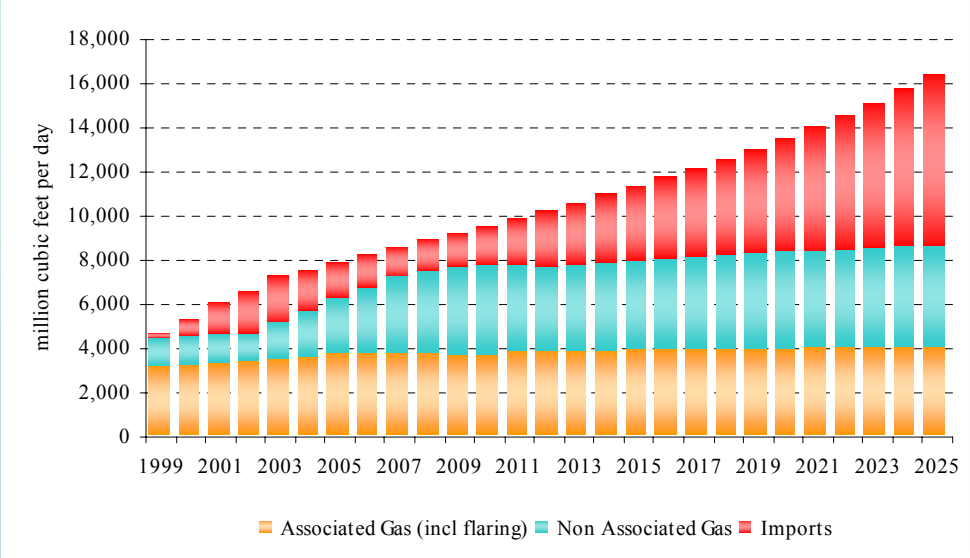
	1999	2000	2005	2010	2015	2020	2025
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Crude oil	6 351.86	6 567.30	7 609.60	7 795.85	7 958.46	8 102.63	8 231.89
Condensates	124.92	12492	124.92	124.92	124.92	124.92	124.92
Associated gas (includes flaring)	1 294.55	1 338.46	1 550.88	1 512.61	1 621.98	1 651.37	1 677.71
Non-associated gas	422.17	445.98	873.78	1 390.85	1 364.24	1 477.55	1 567.55
Natural gas imports	59.87	231.38	550.54	620.67	1 193.52	1 808.65	2 689.81
Total	8 253.37	8 708.02	10 709.73	11 444.90	12 263.12	13 165.12	14 291.87
Total natural gas	1 776.59	2 015.81	2 975.21	3 524.13	4 179.74	4 937.57	5 935.07

	1999	2000	2005	2010	2015	2020	2025
Crude oil (million barrels per day)	2.91	3.00	3.49	3.58	3.65	3.72	3.78
Condensates (thousand barrels per day)	93.48	93.48	92.87	92.87	92.87	92.87	92.87
Associated gas (includes flaring; million cf per day)	3 133.47	3 215.53	3 710.39	3 618.82	3 880.50	3 950.79	4 013.82
Non-associated gas (million cf per day)	1 264.90	1 334.83	2 580.45	4 107.45	4 028.85	4 363.49	4 629.27
Natural gas imports (million cf per day)	168.50	649.29	1 570.68	1 770.74	3 405.07	5 160.02	7 673.92

Reference Scenario: Crude Oil and Natural Gas Requirements

The assumptions under which this oil production are projected were: 1) country's total refining capacity is set to 1.565 million barrels per day and no capacity additions along the entire projection period, 2) the driving oil product is gasoline, 3) maquila's mechanism capacity is set to the maximum capacity of the current agreements, 4) excess demand of gasoline, after domestic refining and maquila's contribution, are satisfied through imports and 5) oil exports will increase at a decreasing growth rate, 6.94% from 1999 to 2000 up to 0.55% from 2024 to 2025.

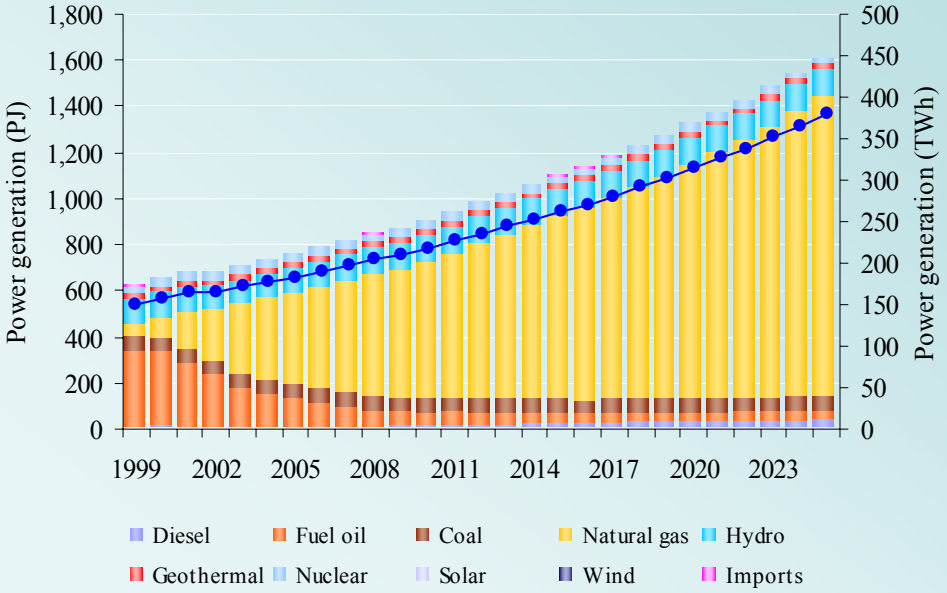


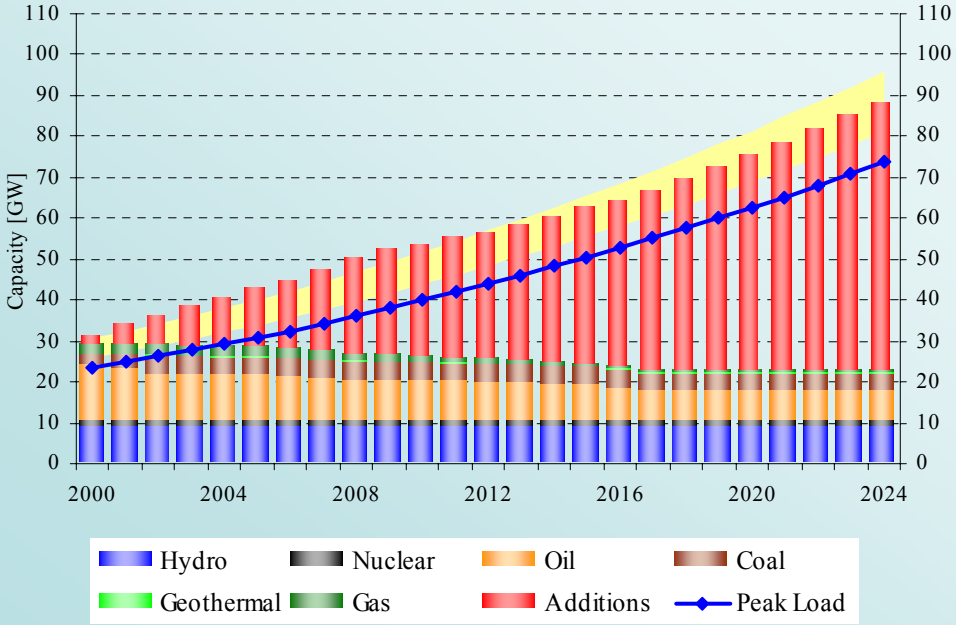


As in the case of oil production, the projections of natural gas production were developed under some assumptions, namely: 1) total capacity of gas plants is fix and equal to 5,034 million cubic feet per day, 2) total capacity of fractionating plants is also fix and equal to 554 million cubic feet per day, 3) natural gas exports are marginal with a decreasing pattern and 4) no capacity additions for gas and fractionating plants along the entire projection period. Additionally, the ratio crude oil to associated gas is kept constant and equal to the average value of the last few years

Reference Scenario: Power Generation by Fuel Type

Mexico's power sector is expected to undergo significant changes over the forecast period. Model results show a dramatically increasing reliance on natural gas for future system expansion. While Mexico's fuel oil units are either retired or converted to imported coal, natural gas-fired generation increases over 25 times by 2025. The natural gas-fired generation increases from 49.92 PJ (14 TWh) to 1,265.18 PJ (351 TWh) in 2025; natural gas generation share increases from 8.09 to 78.94 percent, meaning an average growth rate of 13.2%.

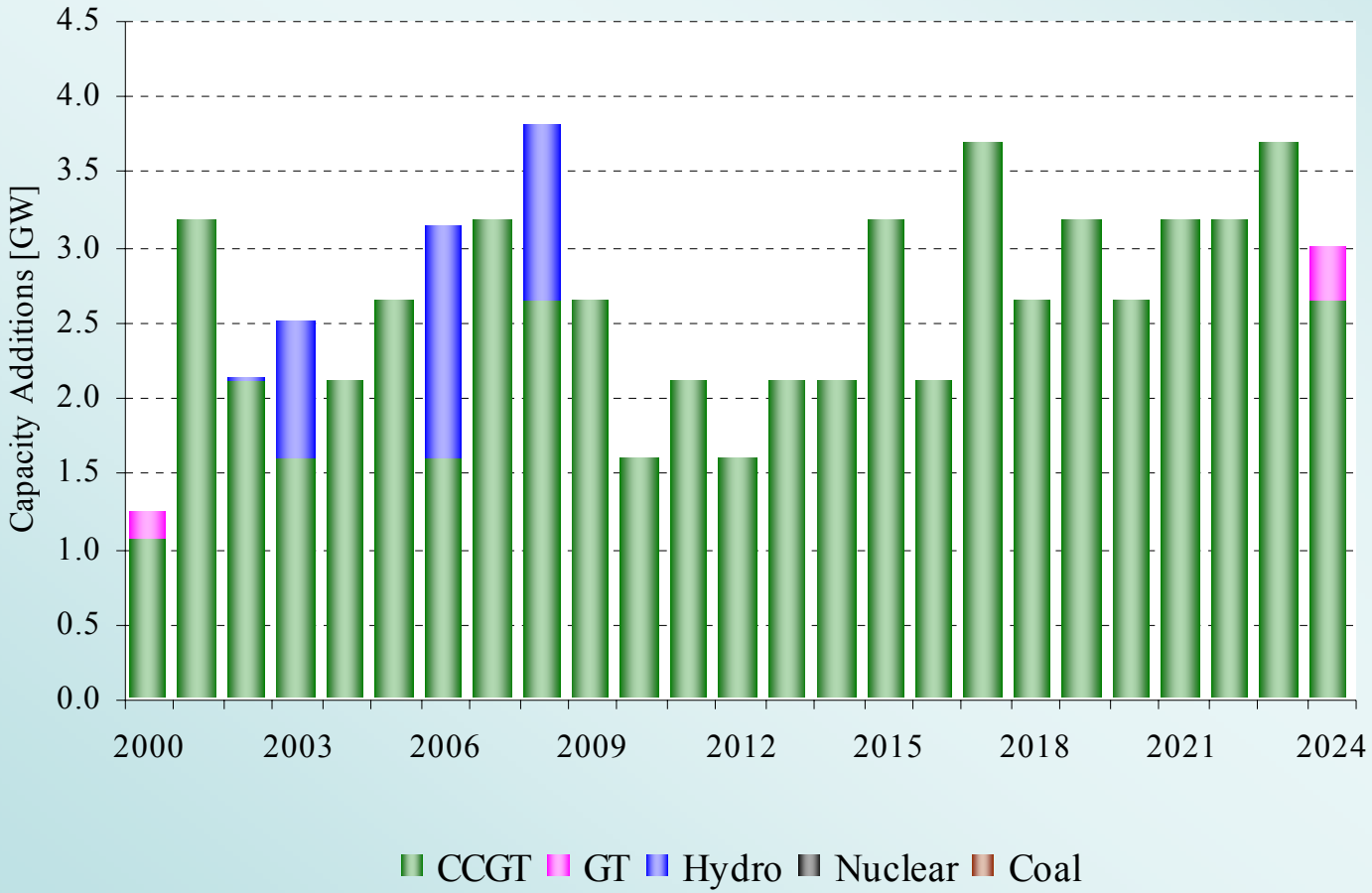




The Reference Case considers no supply limitation on fuels, no limit on annual inputs of new units, a reserve margin between 10 and 30% and the five hydroelectric projects included in the expansion plan are committed plants, among other assumptions. The results showed that the system has a reserve margin around 33% in the first 10 years (medium term) and then decreases up to 23% during the next 9 years and reaches 18% in the last years of the period.

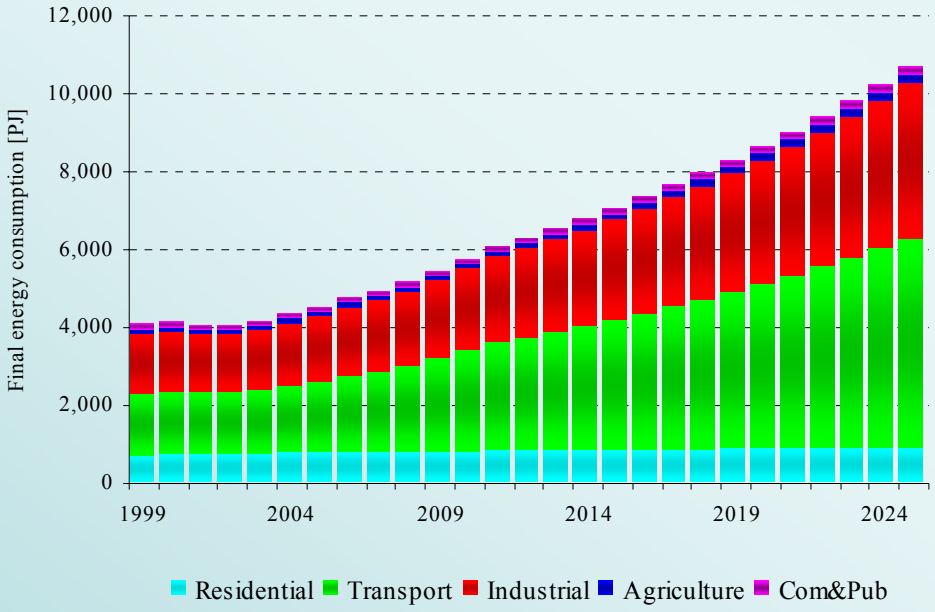
RS: Mexico projected annual capacity additions

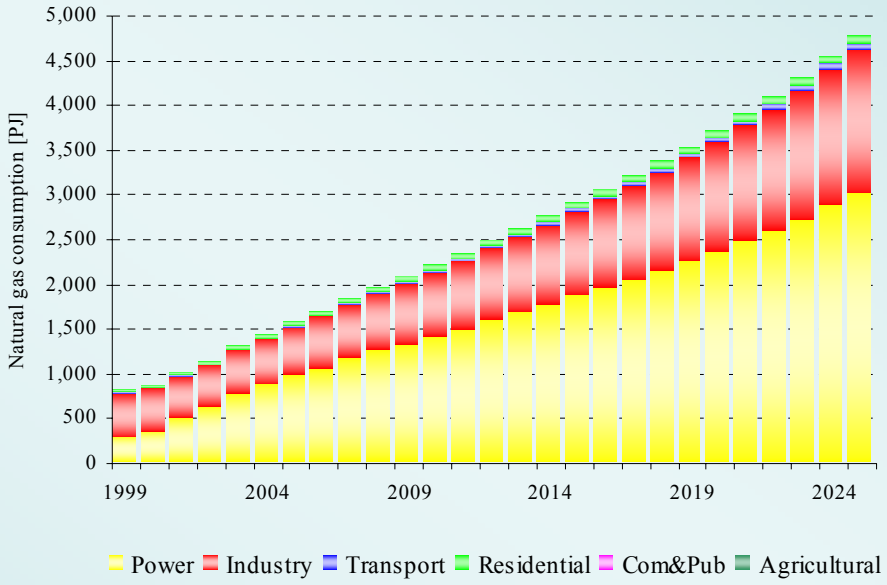
The power capacity generation expansion shows that the system develops on natural gas; a number of 4 to 7 new combined cycle units are put into operation annually. The optimal solution shows that the system will require 118 combined cycle unit of 546 MW, 6 gas turbines of 179 MW and 5 hydroelectric projects (2,539 MW). A total of capacity additions of 65.5 GW based on natural gas along the period 2000-2024 (capacity additions for the period 2000-2010 are 26.9 GW, also based on natural gas).



RS: Final Energy and Natural Gas Consumption by Sector

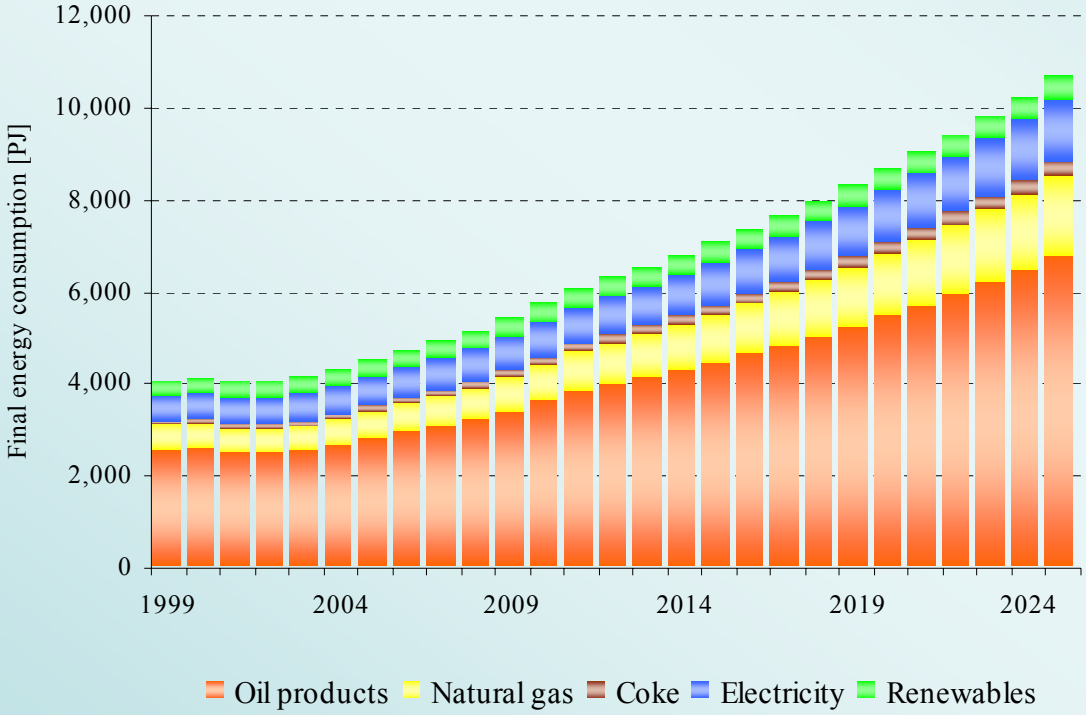
	1999 PJ	2000 PJ	2005 PJ	2010 PJ	2015 PJ	2020 PJ	2025 PJ
Residential	685.89	709.70	753.86	793.78	823.94	859.04	891.43
Transport	1 547.07	1 609.97	1 830.12	2 569.67	3 333.35	4 223.50	5 349.32
Industrial	1 560.70	1 517.63	1 674.13	2 104.10	2 589.42	3 189.85	3 991.89
Agriculture	116.90	115.32	118.70	117.70	143.22	179.19	222.08
Commercial and Public	119.40	131.75	105.47	125.90	150.25	178.71	211.50
Total	4 029.95	4 084.37	4 482.28	5 711.15	7 040.18	8 630.29	10 666.23





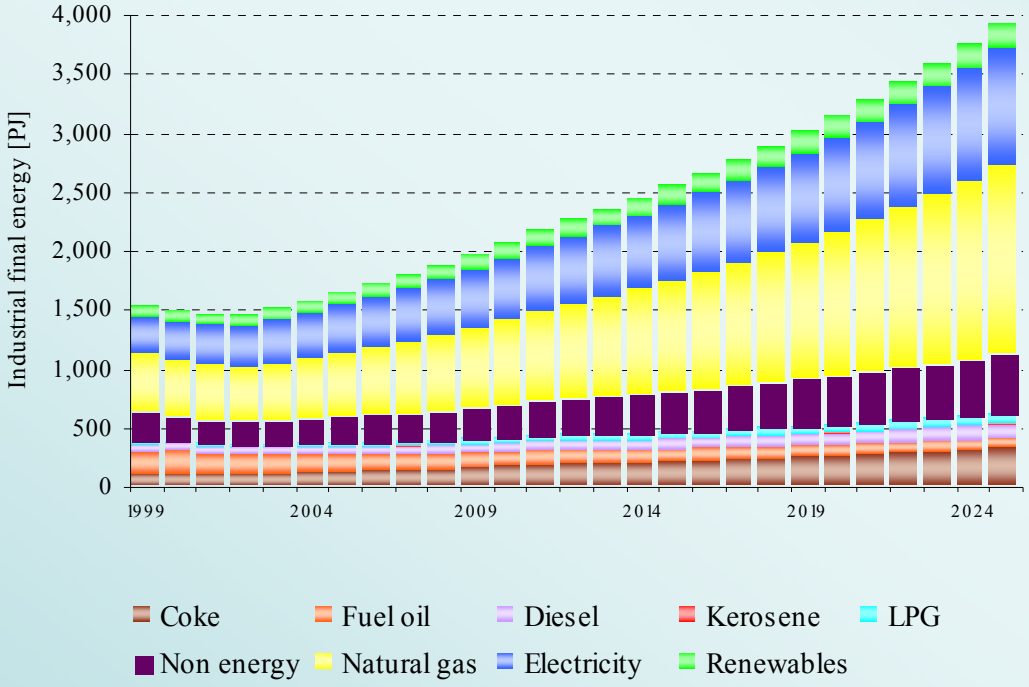
RS: Final Energy Consumption by Fuel

	1999	2000	2005	2010	2015	2020	2025
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Coke	91.55	101.69	119.49	163.72	207.27	256.77	320.14
Fuel oil	210.82	210.87	152.67	128.95	108.53	94.00	85.72
Diesel	566.29	582.38	624.22	844.29	1 077.98	1 353.91	1 703.41
Gasoline	995.47	1 030.48	1 197.19	1 673.16	2 161.53	2 731.55	3 453.73
Kerosene	116.02	116.05	133.16	182.73	231.98	287.42	356.08
LPG	425.90	437.44	437.28	478.90	515.79	561.07	615.19
Natural gas	526.64	519.27	597.03	799.67	1 038.20	1 346.81	1 764.02
Electricity	522.03	551.59	636.25	759.61	923.02	1 114.21	1 353.43
Renewables	343.88	339.05	363.54	396.07	428.69	465.08	504.03
Non-energy products	231.52	195.72	221.62	284.22	347.36	419.64	510.66
Total	4 030.11	4 084.53	4 482.45	5 711.32	7 040.35	8 630.46	10 666.40



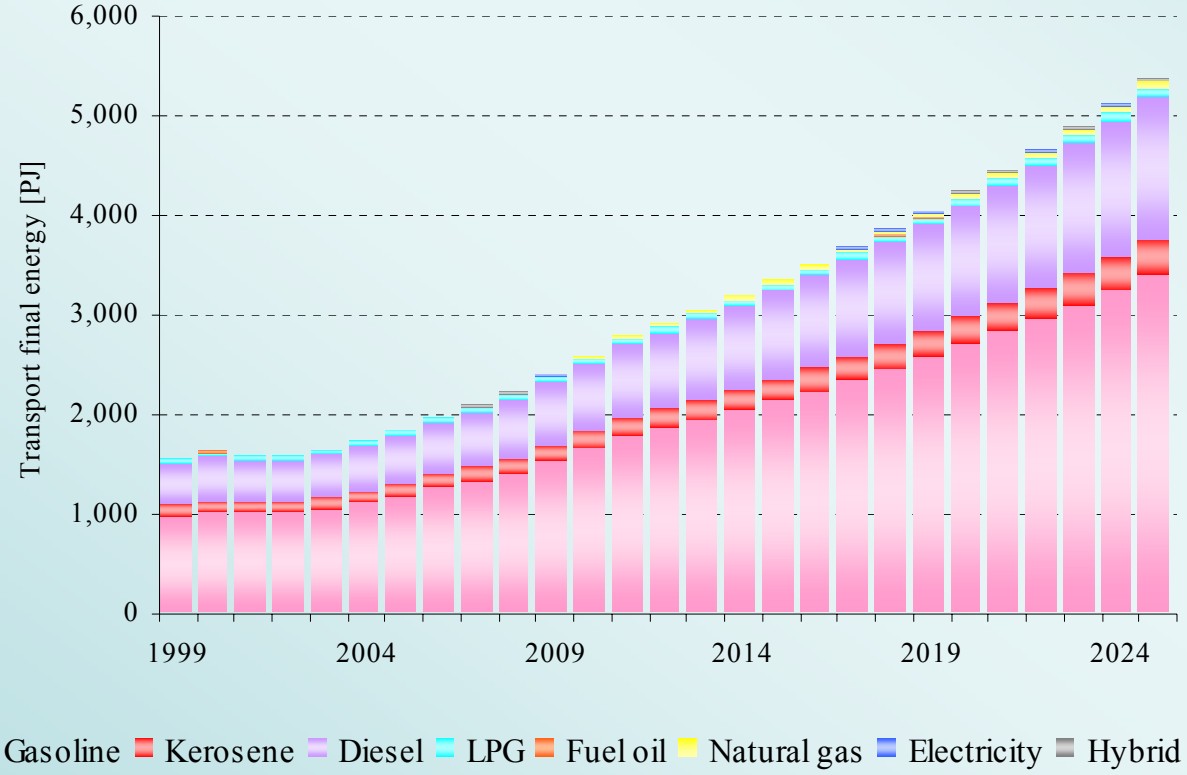
RS: Industrial Sector Final Energy Consumption by Fuel

	1999	2000	2005	2010	2015	2020	2025
	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Coke	91.55	101.69	119.49	163.72	207.27	256.77	320.14
Fuel oil	202.58	201.60	150.23	125.73	104.35	88.71	79.03
Diesel	54.41	50.56	55.28	70.10	85.28	102.80	124.28
Kerosene	0.59	0.48	0.54	0.68	0.83	1.00	1.21
LPG	38.71	33.54	36.99	47.01	56.95	68.36	82.22
Natural gas	500.41	487.71	543.55	722.27	938.24	1 223.16	1 614.69
Non energy products	231.52	195.72	221.62	284.22	347.36	419.64	510.66
Gasoline	38.52	34.67	35.30	40.51	45.34	51.06	59.38
Electricity	310.42	327.12	408.09	518.52	646.37	793.64	986.36
Renewables	91.98	84.54	103.04	131.35	157.45	184.72	213.95
Total	**1 560.70**	**1 517.63**	**1 674.13**	**2 104.10**	**2 589.43**	**3 189.87**	**3 991.91**



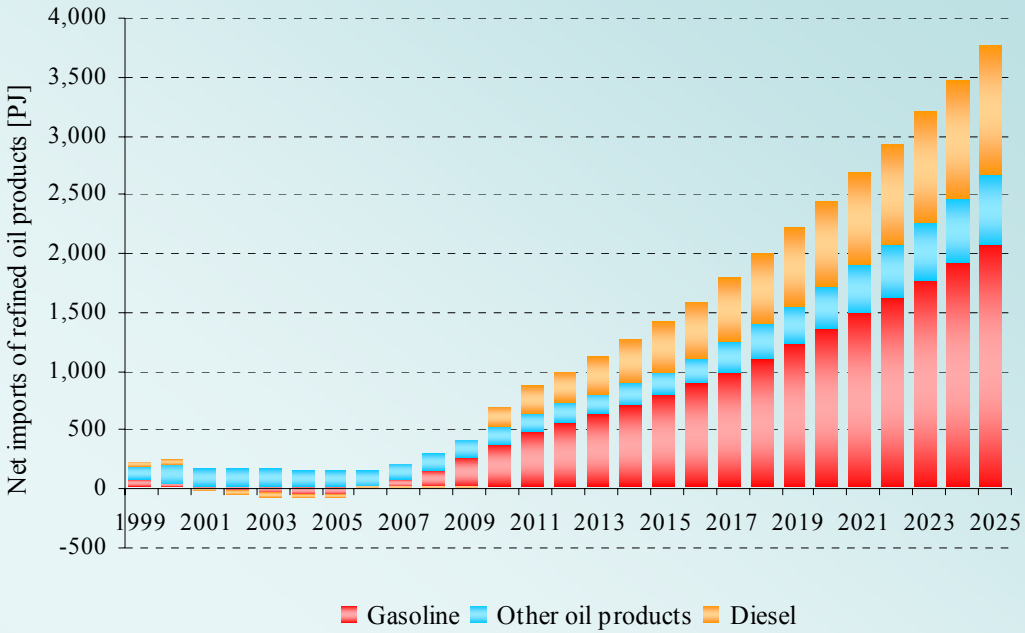
RS: Transport Sector Final Energy Consumption by Fuel

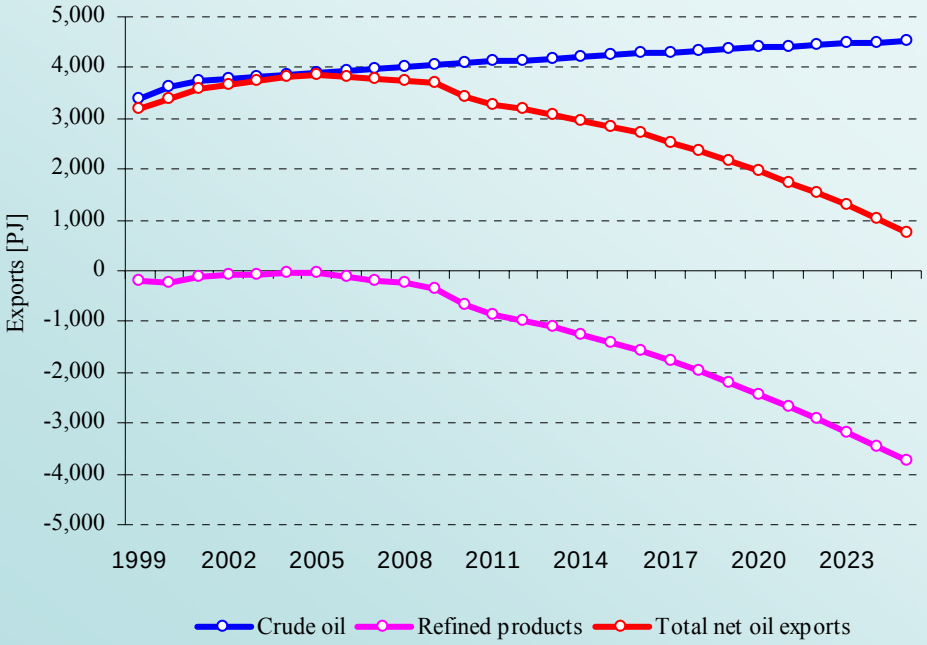
	1999 PJ	2000 PJ	2005 PJ	2010 PJ	2015 PJ	2020 PJ	2025 PJ
Gasoline	956.95	995.81	1 161.89	1 632.65	2 116.20	2 680.50	3 394.35
Diesel	428.80	449.45	483.36	676.78	881.60	1 122.24	1 426.55
Kerosene	113.83	113.82	130.37	179.42	228.25	283.28	351.55
LPG	35.35	35.79	37.58	48.19	56.99	66.71	81.27
Fuel Oil	8.24	9.26	2.44	3.22	4.18	5.29	6.69
Natural Gas	0.24	1.68	9.34	21.07	34.34	49.63	68.21
Electricity	3.66	3.86	3.46	4.78	6.11	7.82	9.85
Hybrid	0.00	0.29	1.67	3.58	5.67	8.04	10.85
Total	**1 547.07**	**1 609.97**	**1 830.12**	**2 569.67**	**3 333.35**	**4 223.50**	**5 349.32**



RS: Net imports of refined oil products

Projected net imports of refined petroleum products are shown. Net imports of refined oil products quickly increase from 215 PJ (1999) to 3,749 PJ (2025). By 2025, net gasoline imports amount to 2,063 PJ or 55% of total net oil product imports. Net diesel imports are forecast to be 1,098 PJ or 29% of total net oil product imports.



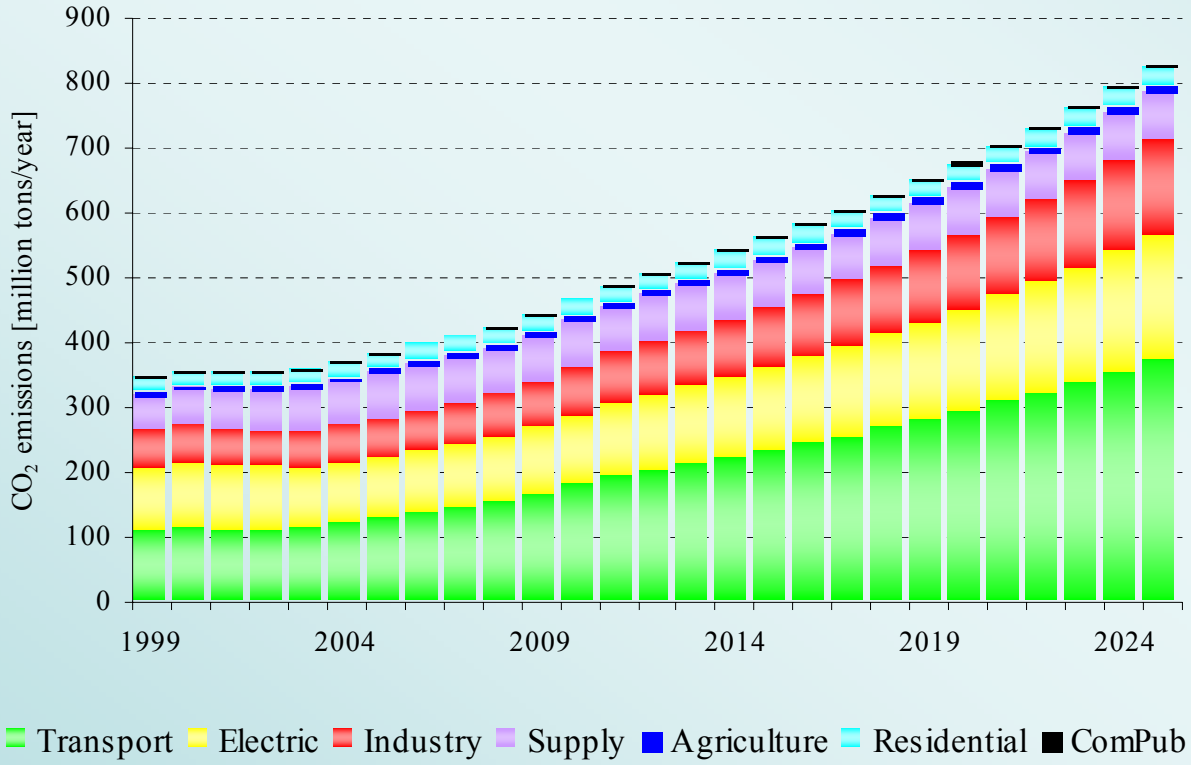


The graph clearly shows the impact of the projected growth in refined product imports. While crude oil exports are expected to continue their growth at an average rate of 0.7% per year from 3,396 PJ in 1999 to 4,520 PJ in 2025, net imports of refined products quickly increase and result in a rapid drop in net oil exports eventually declining to 771 PJ in 2025, down from a peak of 3,848 PJ in 2005.

RS: CO_2 Emissions by Sector

	1999 Mton	2000 Mton	2005 Mton	2010 Mton	2015 Mton	2020 Mton	2025 Mton
Agriculture	6.43	6.36	6.80	7.70	8.88	10.47	12.56
Residential	19.62	20.47	22.10	23.62	24.73	26.09	27.37
Transport	107.57	111.91	126.99	178.15	231.01	292.62	370.56
Commercial & Public	3.84	4.29	3.04	3.50	4.02	4.59	5.22
Industrial	58.31	58.12	60.37	75.56	93.19	116.09	147.48
Power	98.19	101.01	93.15	105.86	128.84	156.66	193.07
Supply	52.13	55.70	70.75	71.14	71.49	71.82	72.14
Total	**346.10**	**357.86**	**383.20**	**465.54**	**562.15**	**678.35**	**828.41**

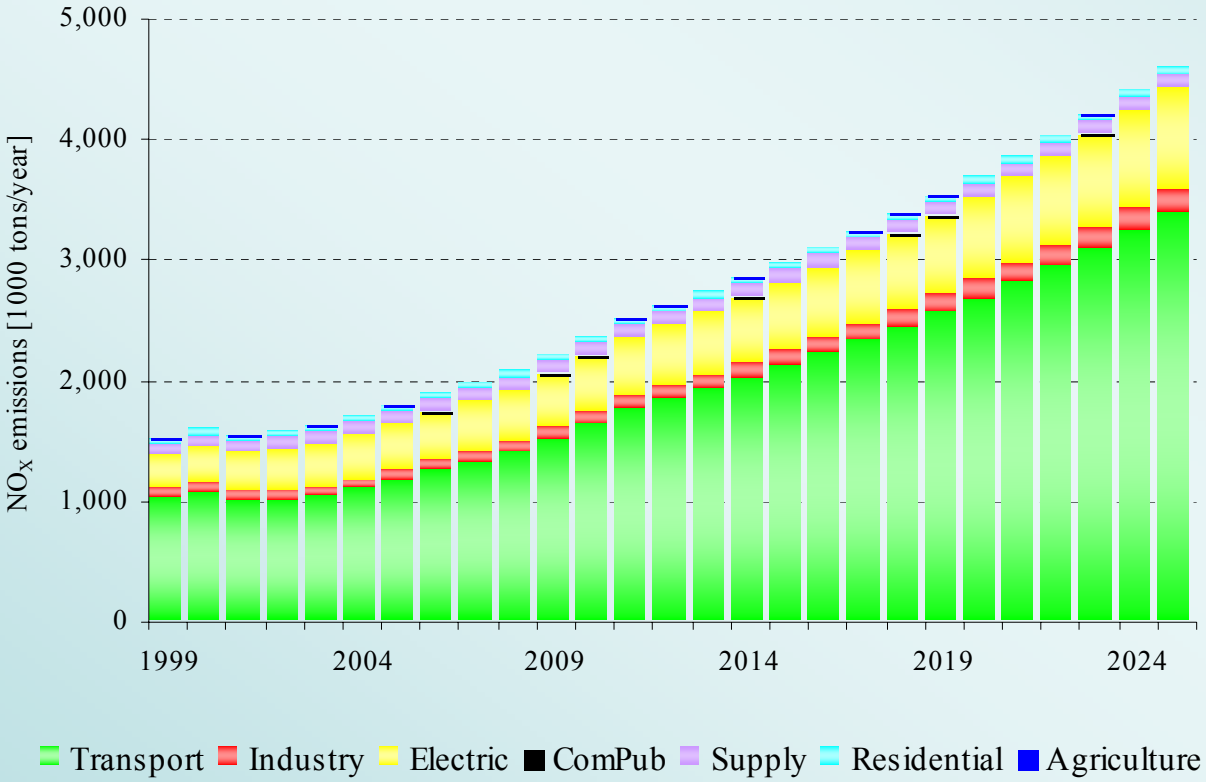
Mton = million ton



RS: NO_X Emissions by Sector

	1999 kton	2000 kton	2005 kton	2010 kton	2015 kton	2020 kton	2025 kton
Agriculture	5.99	5.92	6.33	7.17	8.27	9.74	11.69
Residential	44.99	45.84	47.41	48.89	50.01	51.41	52.71
Transport	1 013.59	1 059.52	1 161.61	1 628.92	2 113.05	2 677.72	3 392.10
Commercial & Public	4.26	4.76	3.37	3.88	4.46	5.09	5.79
Industrial	82.79	82.11	83.88	104.21	127.11	156.60	197.01
Power	281.85	301.99	380.87	457.24	561.25	681.48	837.41
Supply	82.89	85.49	109.08	109.57	110.00	110.42	110.85
Total	**1 516.36**	**1 585.64**	**1 792.55**	**2 359.88**	**2 974.14**	**3 692.46**	**4 607.56**

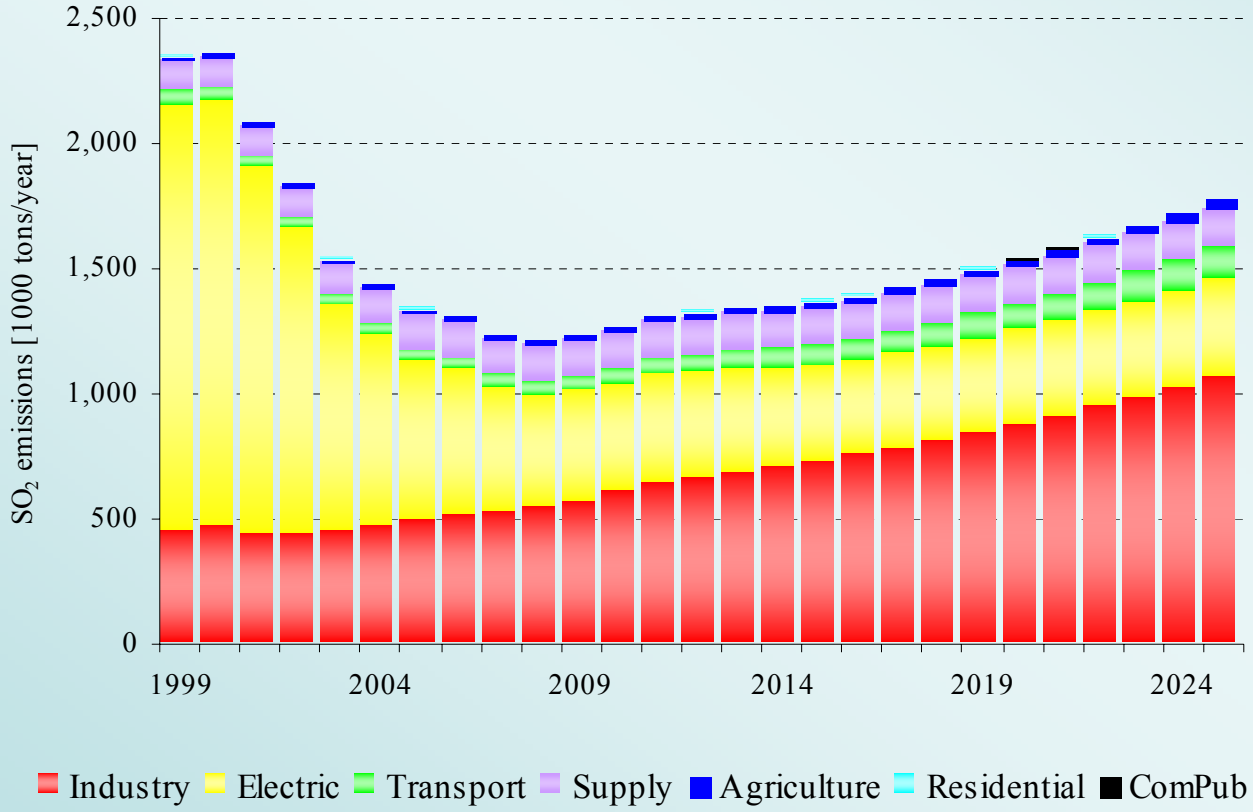
k = thousand



RS: SO_2 Emissions by Sector

	1999 kton	2000 kton	2005 kton	2010 kton	2015 kton	2020 kton	2025 kton
Agriculture	18.41	18.15	19.16	21.80	24.85	28.84	34.20
Residential	1.65	1.73	1.94	2.12	2.24	2.37	2.48
Transport	54.68	58.73	45.34	63.02	81.71	103.45	130.95
Commercial & Public	1.05	1.17	0.83	0.95	1.09	1.25	1.42
Industrial	442.44	470.93	486.05	603.79	725.80	872.45	1068.51
Power	1 711.17	1 697.01	639.99	430.69	385.20	379.41	384.69
Supply	118.03	112.15	144.47	146.37	148.25	150.37	153.10
Total	**2 347.41**	**2 359.88**	**1 337.78**	**1 268.74**	**1 369.14**	**1 538.16**	**1 775.35**

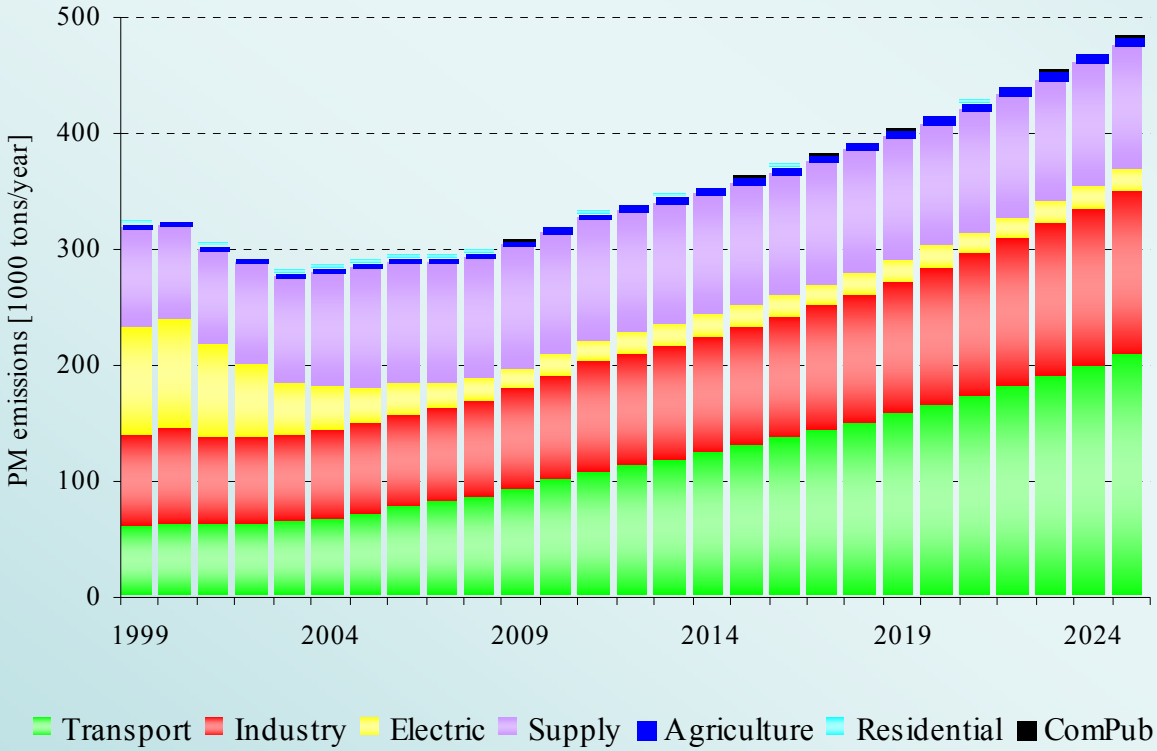
k = thousand



RS: PM Emissions by Sector

	1999	2000	2005	2010	2015	2020	2025
	kton	kton	kton	kton	kton	kton	kton
Agriculture	4.45	4.39	4.63	5.27	6.01	6.97	8.26
Residential	0.71	0.73	0.77	0.80	0.82	0.85	0.89
Transport	59.54	62.03	70.97	99.47	129.22	164.05	208.07
Commercial & Public	0.36	0.41	0.29	0.33	0.38	0.43	0.49
Industrial	79.71	82.92	78.28	89.75	102.26	118.59	141.79
Power	91.96	92.73	28.97	18.90	18.90	18.90	18.90
Supply	86.46	81.11	104.79	105.02	105.25	105.51	105.85
Total	**323.20**	**324.31**	**288.68**	**319.54**	**362.84**	**415.32**	**484.26**

k = thousand

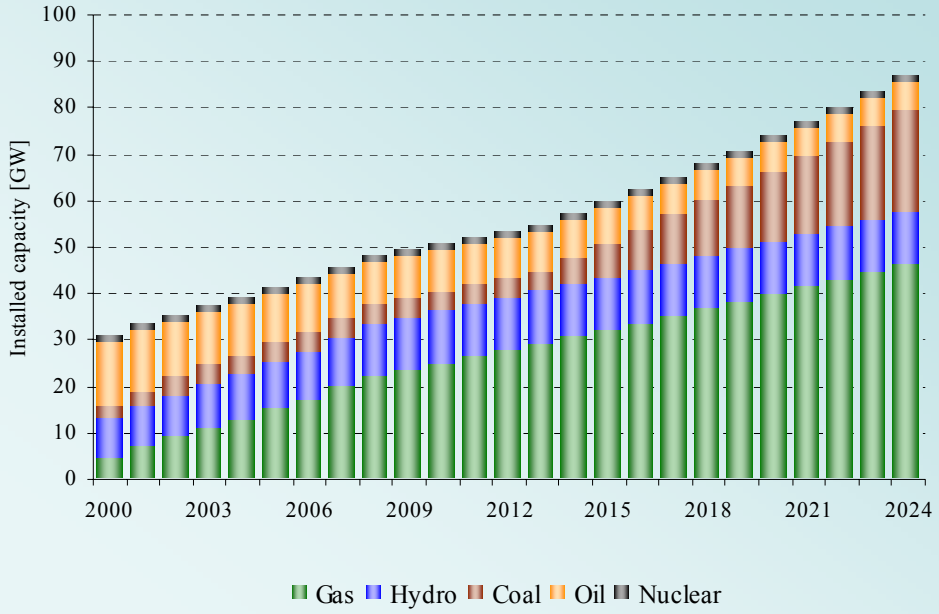


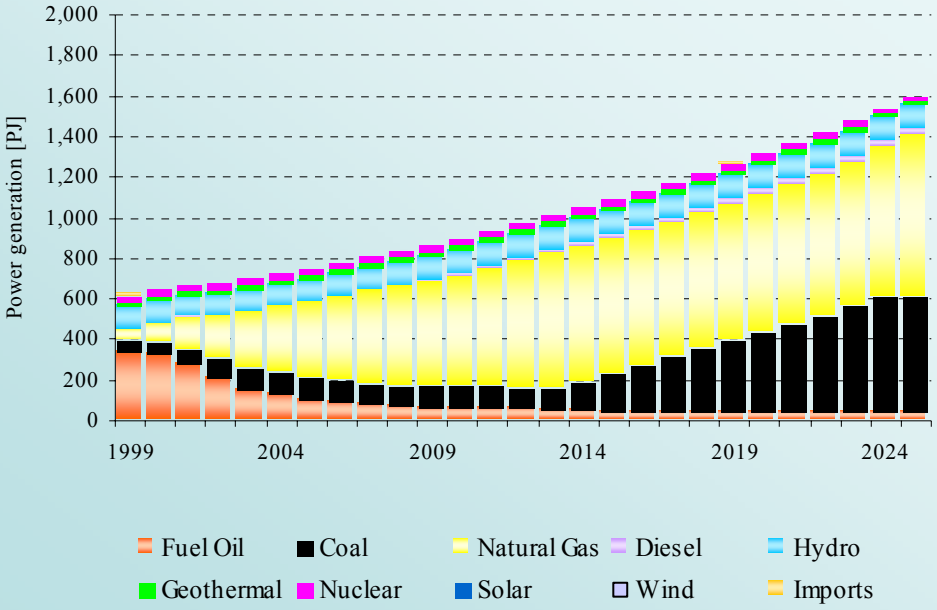
Results

Limited Gas Scenario

LNGS: Power capacity and generation

The limitation of natural gas supply for power generation changes the expected expansion of the power sector substantially. Starting in 2009, the expansion model selects the maximum of 3 combined cycle units each year instead of 3 to 7 units per year under the Reference Case. The cumulative number of combined cycle units under the Limited Natural Gas Scenario totals 85 (44.8 GW) as compared to 118 units (62.2 GW) under the Reference Case. Starting in 2014, the model projects between 4 and 6 coal-fired units to come on-line each year, with a total of 57 coal units or 17.7 GW.

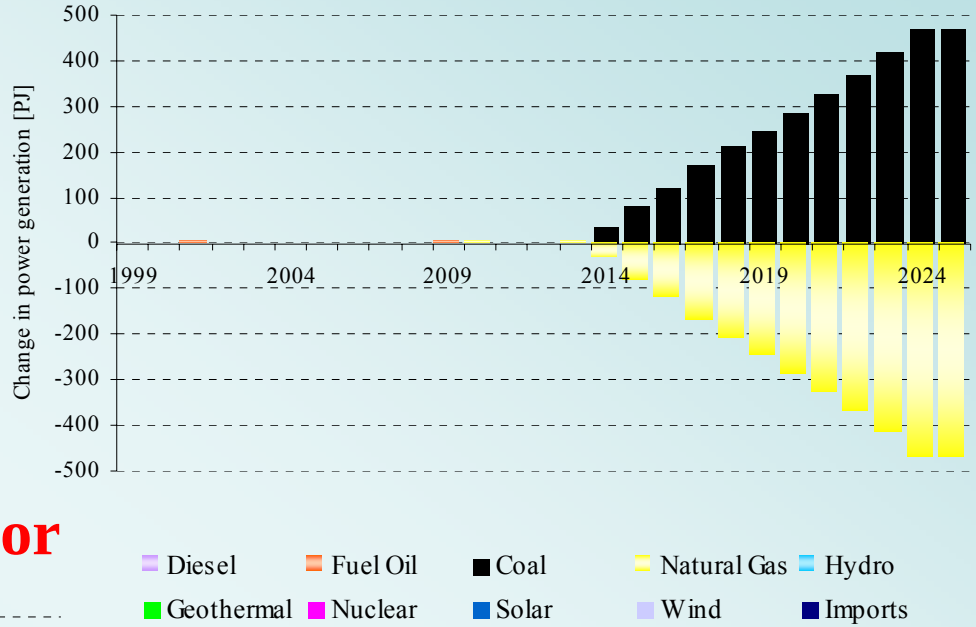




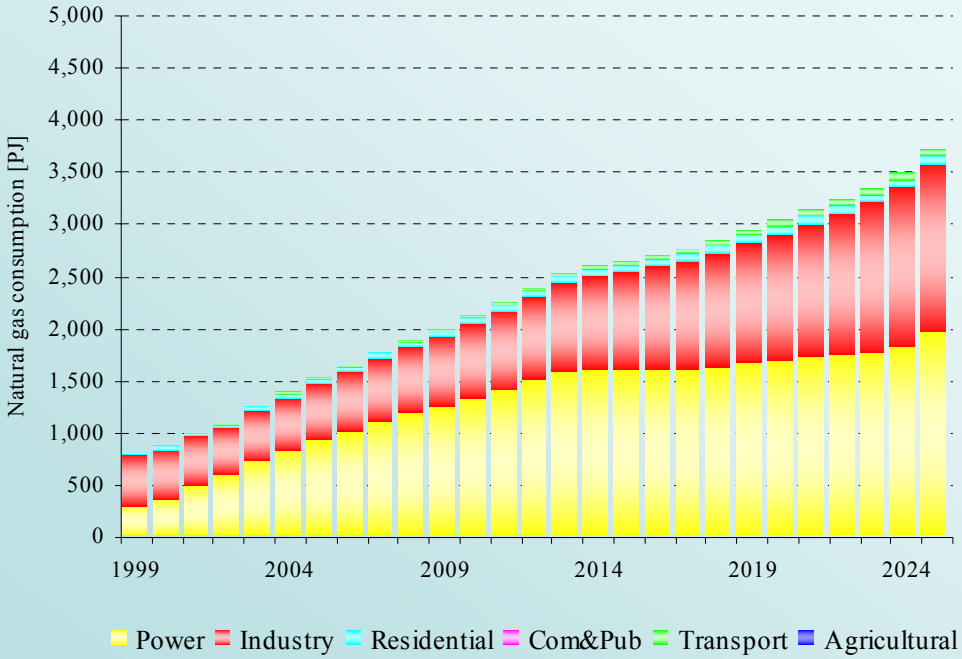
The effect on generation by fuel type can be seen in Figure. It is noteworthy that while the gas limitation becomes effective in 2009, the generation results don't show a significant difference until 2014. This is the year when WASP/DECADES projects the first coal-fired units to come on-line. During 2009 to 2013, even though there are 4 combined cycle units less than in the Reference Case, new coal units are not needed until 2014. Starting in 2014, the model projects between 4 and 6 coal-fired units to come on-line each year, with a total of 57 coal units or 17.7 GW.

LNGS: Change in generation by fuel type

Correspondingly, coal generation starts to increase quickly from 106 PJ (29 TWh) in 2013 to 572 PJ (159 TWh) by 2025 and account for 36% of total power generation. The increased coal generation essentially replaces up to 470 PJ of gas-fired generation by 2025. The share of natural gas generation, therefore, reaches only about 50% as compared to 79% under the Reference Case.



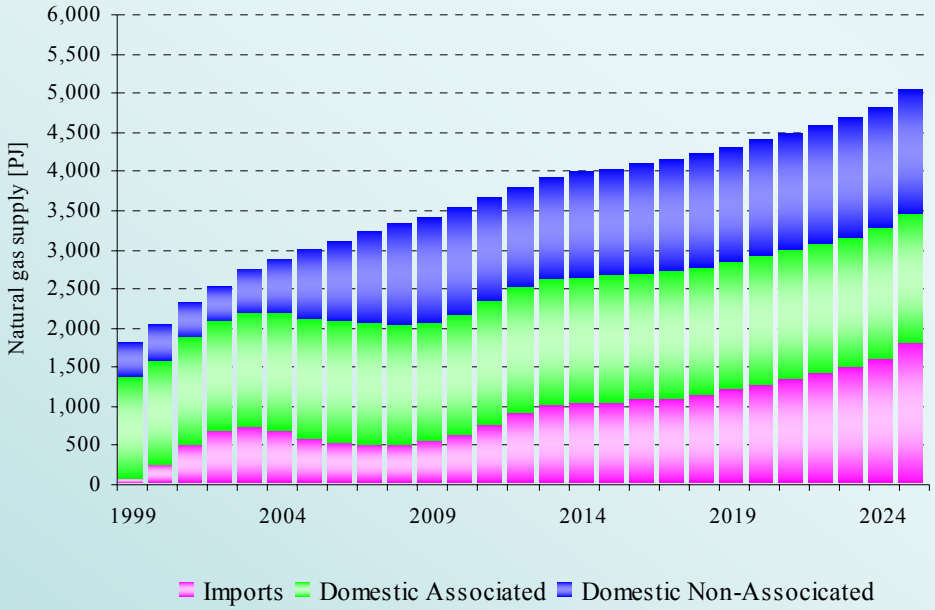
Natural gas consumption by sector

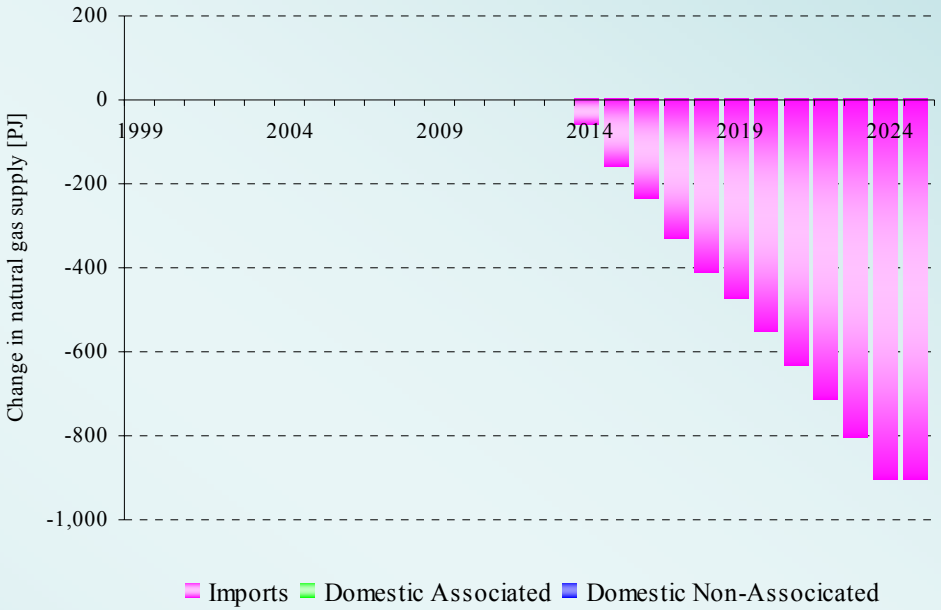


The lower gas generation noticeably slows the growth in total natural gas consumption. Gas consumption is expected to grow to 3,710 PJ, down from 4,678 PJ in the Reference Case. This reduction of 968 PJ or 21% is essentially because of reduced power sector gas demand as shown in Figure. While under the Reference Case, the power sector accounts for about 68% of total natural gas demand, under the Limited Gas Scenario, this is down to 53%.

LNGS: Supply and change in supply

In response to the reduction in gas demand for power generation, the need for new natural gas sources/imports declines. While approximately 2,690 PJ of gas has to be added/imported in the Reference Case by 2025, imports are down to 1,781 PJ under this scenario. As the Figures show, the additional coal-fired generation cannot address the near- to intermediate-term natural gas needs. Additions/imports are substantially reduced only starting in 2014. The decrease of 909 PJ by 2025 is equivalent to a 34% reduction of natural gas imports.

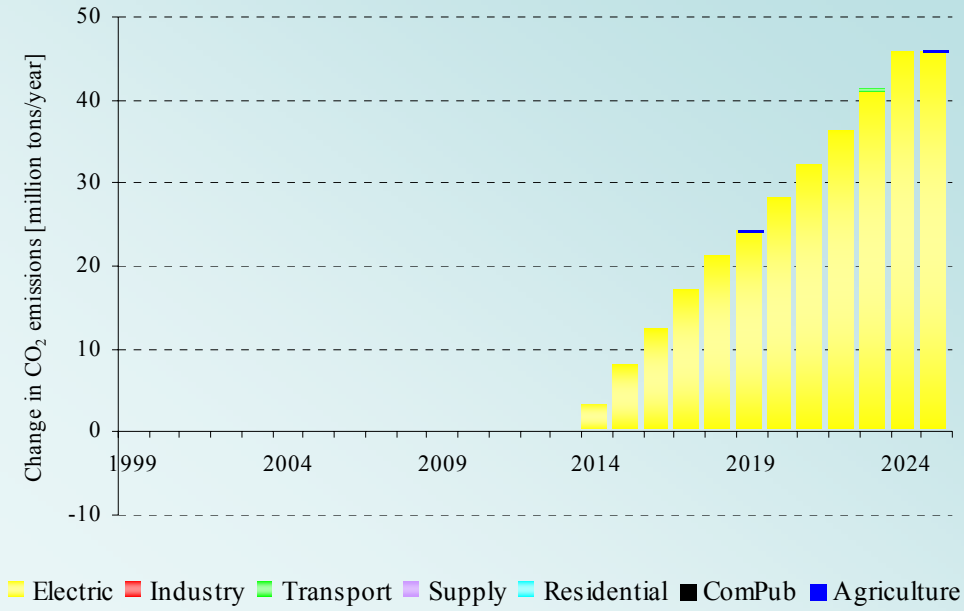


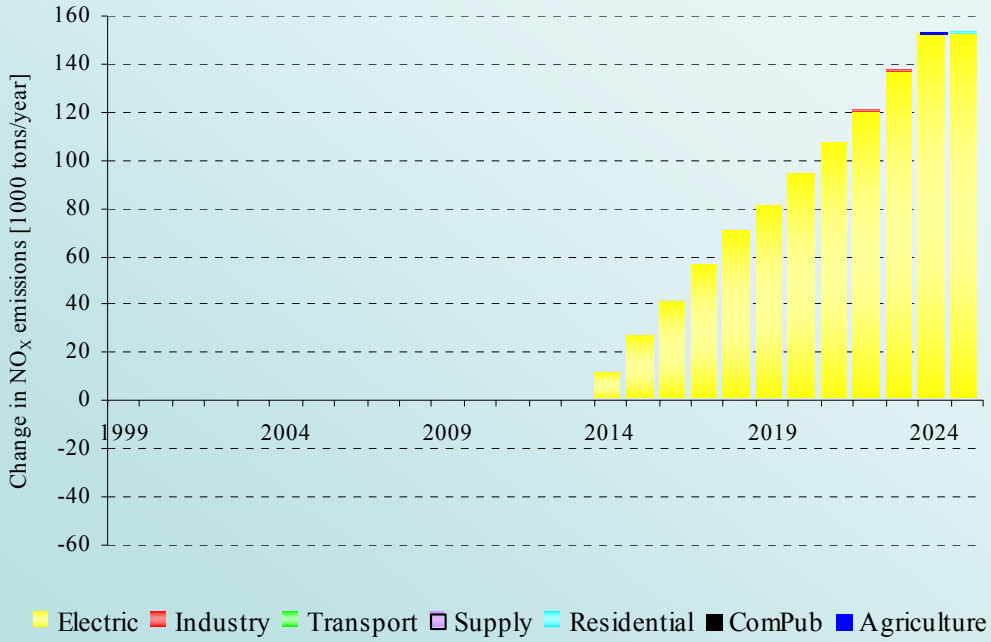


At US$709.58 billion in net present value, the total economic system cost is higher than under the Reference Scenario, that is, a limitation on natural gas supply comes at an economic cost, in this case estimated to be an incremental cost of US$2.17 billion.

LNGS: CO_2 and NO_X emissions

Not surprisingly, the shift from natural gas to coal comes at an environmental cost. Atmospheric emissions are projected to increase under the Limited Gas Scenario. For example, the Figure shows, the change in CO_2 emissions when compared to the Reference Case. Under the Limited Gas Scenario, power sector CO_2 emissions grow to 239 Mt while total national emissions reach 874 Mt. This is an increase of about 46 million tons over the Reference Case, equivalent to a 24% increase in power sector emissions or 5.5% of national CO_2 emissions.





Emissions of NO_X exhibit a similar behavior in that power sector emissions are forecast to reach about 990 kt by 2025 which is about 152 kt or 18% higher than under the Reference Case.

Results

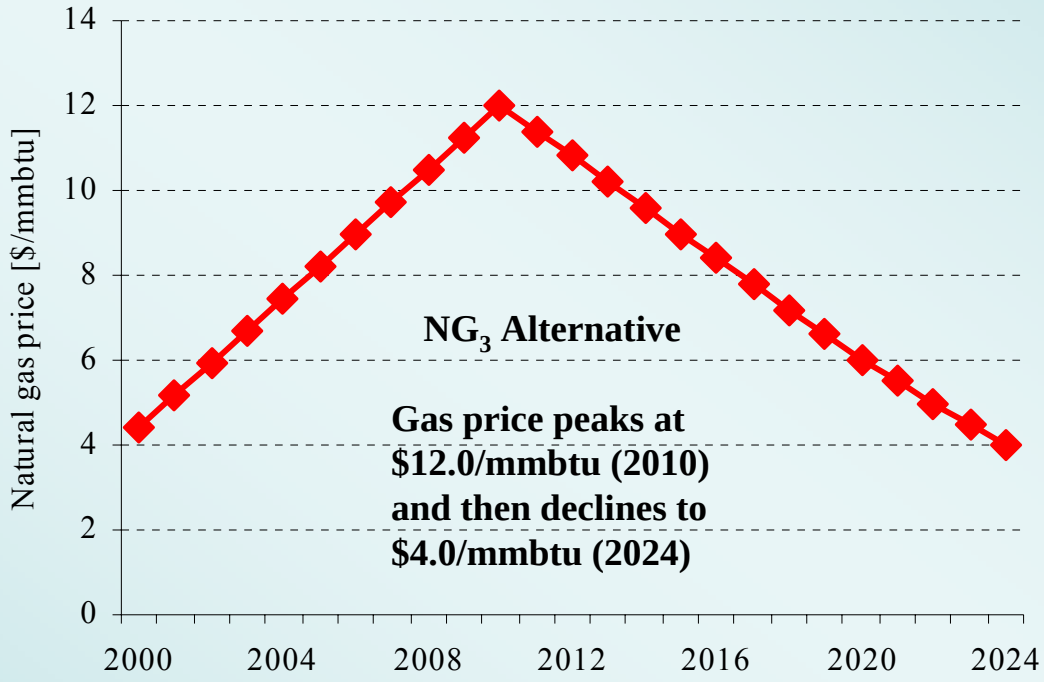
Natural gas price alternatives

NG_1 Alternative

Gas price increases from 2.88 US$/tcf to 2.96 US$/tcf

NG_2 Alternative

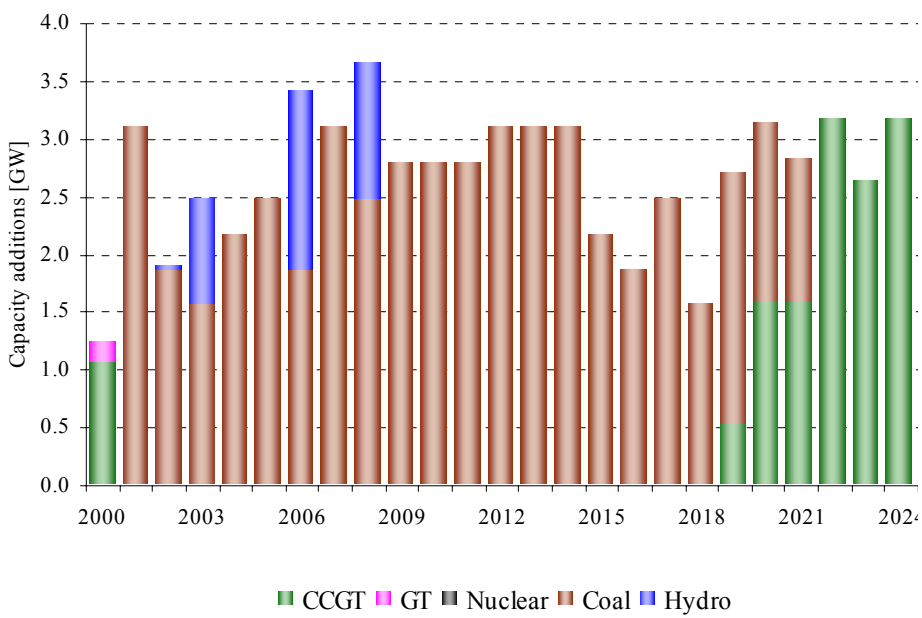
Gas price increases from 2.88 US$/tcf to 4.02 US$/tcf and remains at this last value

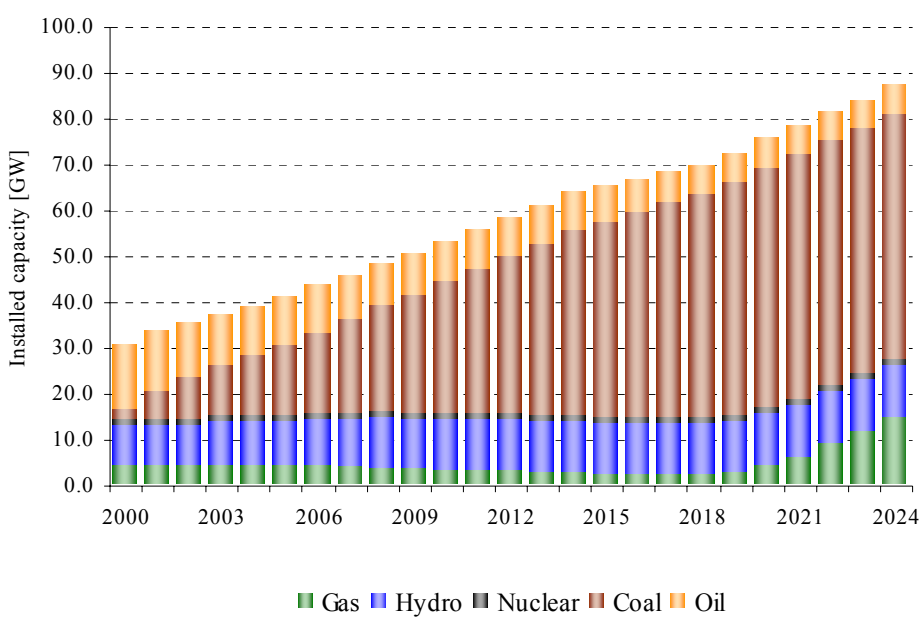


Natural gas price alternative (high-gas price):

The capacity additions and the projected installed capacity for this case are shown in Figures. The impact of the natural gas price and its future projection is high because the share of natural gas fired capacity has significantly decreased from 73% in the reference case to 17%, while the share of coal fired capacity grew from 0% in the Base Case to 61% in this alternative. Due to the efficiency of dual plants about 5 060 MW of additional capacity is required in the optimal solution compared with that in the Reference Case. At a high-gas price, a total of 159 coal units enter the market and replace mostly 92 CCGT units starting in 2001. Under high-gas price scenario, coal dominates the expansion with a total of 53 GW of coal capacity added by 2024.

Reference case	NG_1 price alternative	NG_2 price alternative	NG_3 price alternative
CO_2 (138 %)	CO_2 (138 %)	CO_2 (143 %)	CO_2 (294 %)
NO_X (53 %)	NO_X (52 %)	NO_X (68 %)	NO_X (82 %)
SO_X (-78 %)	SO_X (-78 %)	SO_X (-51 %)	SO_X (-59 %)
PM (-83 %)	PM (-84 %)	PM (-55 %)	PM (-38 %)





Results

Nuclear Scenarios

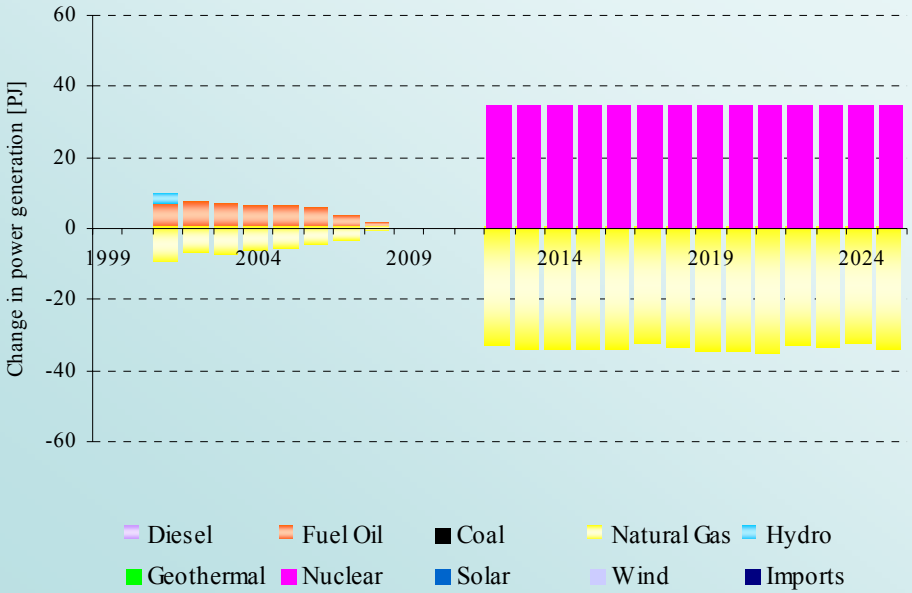
a) Forced nuclear introduction

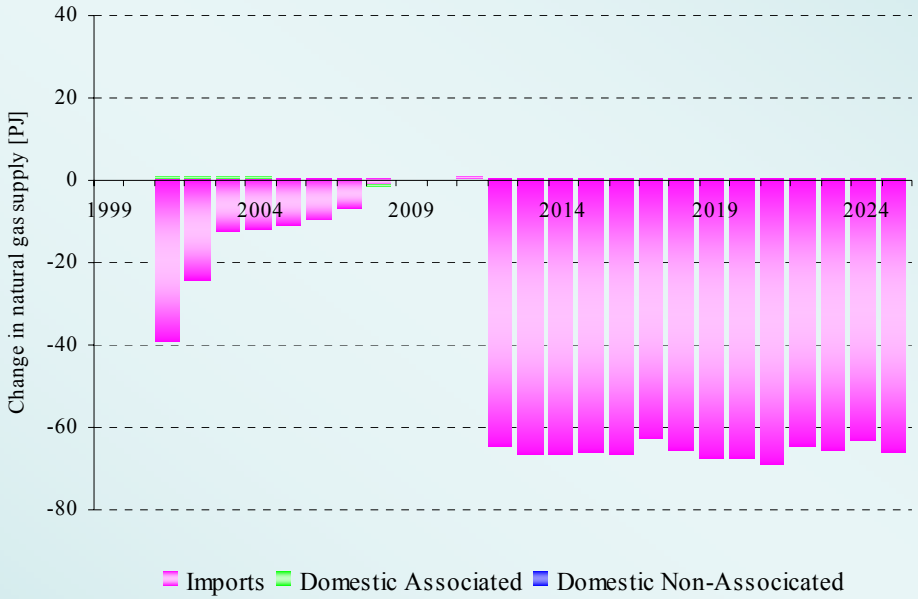
b) Low nuclear cost

Nuclear Scenario (Forced nuclear introduction):

Because of the large capacity of the nuclear unit (1,356 MW), the expansion schedule is slightly affected starting in 2001 even though the unit is not coming on-line until 2012. This leads to some minor changes in generation and fuel consumption in the power sector between 2001 and 2011. Specifically, from 2001 up to 2011 there is an additional participation of fuel oil generation, which decreases along the years and ends by 2011; hydro also participates with an additional generation, but its participation is just during the year 2001; also there is a declining reduction in the participation of natural gas in the generation along those years. During the years 2009 to 2011 the fuel type mix in the power generation keeps the reference case structure. When the nuclear unit does come on-line, it is base-loaded into the system and generates a constant level of 34 PJ of electricity per year equivalent to 1.5 percent of total generation in 2025 as compared to 1.1 percent under the reference case. The system-level analysis shows that nuclear replaces effectively base-loaded gas combined-cycle capacity and between 33-37 PJ of gas-fired generation.

The shift away from gas-fired generation leads directly to a reduction in natural gas imports. Gas imports are cut by 63-71 PJ or 2.3 percent by 2025. At US$707.69 billion in net present value, total economic system cost is higher than under the Reference Scenario, that is, an incremental cost of US$273.4 million.

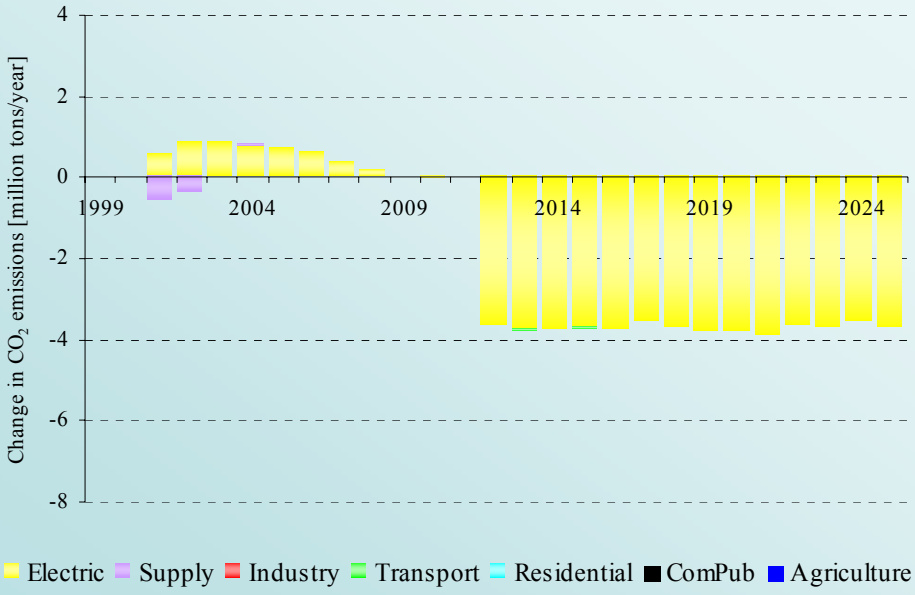


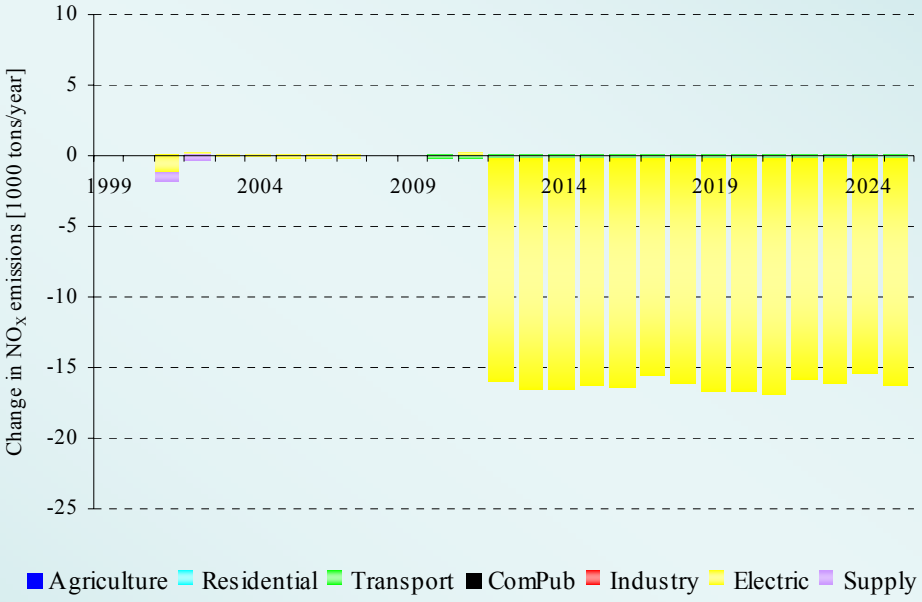


Nuclear Scenario (Forced nuclear introduction):

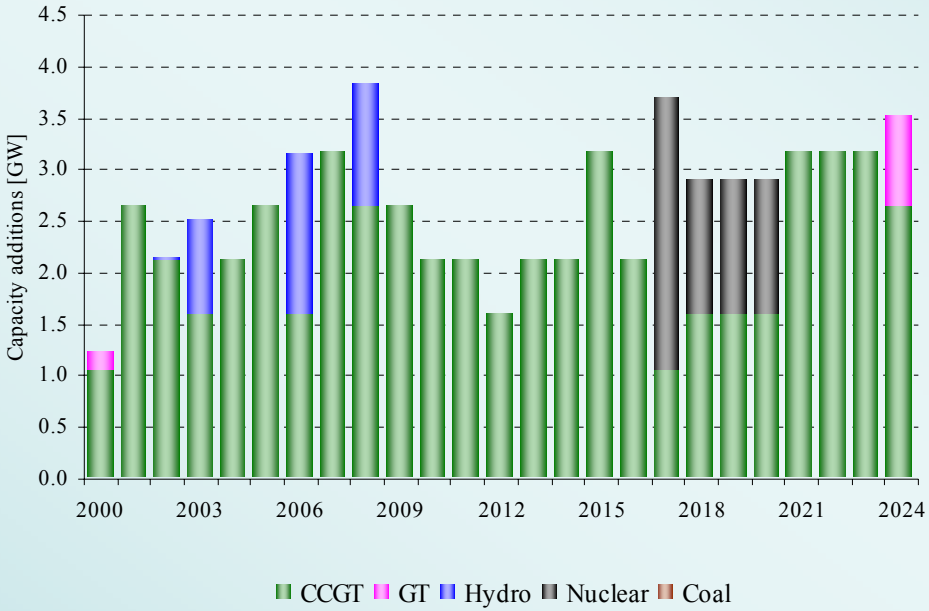
The minor changes in dispatch in the early years lead to small emissions increases of up to 1.2 million tons per year in 2003. But emissions are noticeable reduced starting in 2012 when the nuclear unit eventually comes on-line. For example, CO_2 emissions reductions vary between 3.6 and 4.0 million ton per year, equivalent to a 1.9 percent reduction in power sector emissions and a 0.4 percent reduction in national emissions. Total cumulative emissions reductions are 47.5 million ton of CO_2. The cost-effectiveness of nuclear technology as a GHG mitigation technology is therefore US$5.8/ton CO_2.

A similar behavior is exhibited by NO_X emissions. Annual reductions vary between 15,000 and 17,000 ton of NO_X. In 2025, this represents a 1.9 percent decrease in power sector NO_X emissions and a 0.3 percent decrease of total national NO_X emissions. The cumulative emissions reductions total 228,000 ton.





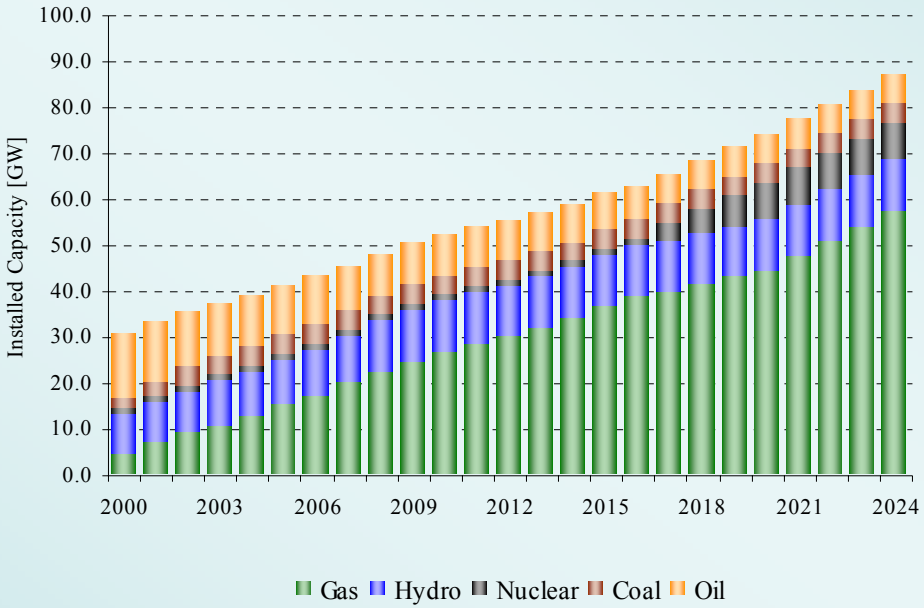
Nuclear Scenario (Low nuclear cost):



For the low nuclear costs scenario, it has been assumed that the investment cost of a new nuclear power plant is 48% lower than in the reference case. In this condition new nuclear power plants are competitive with the rest of the candidate technologies for expansion.

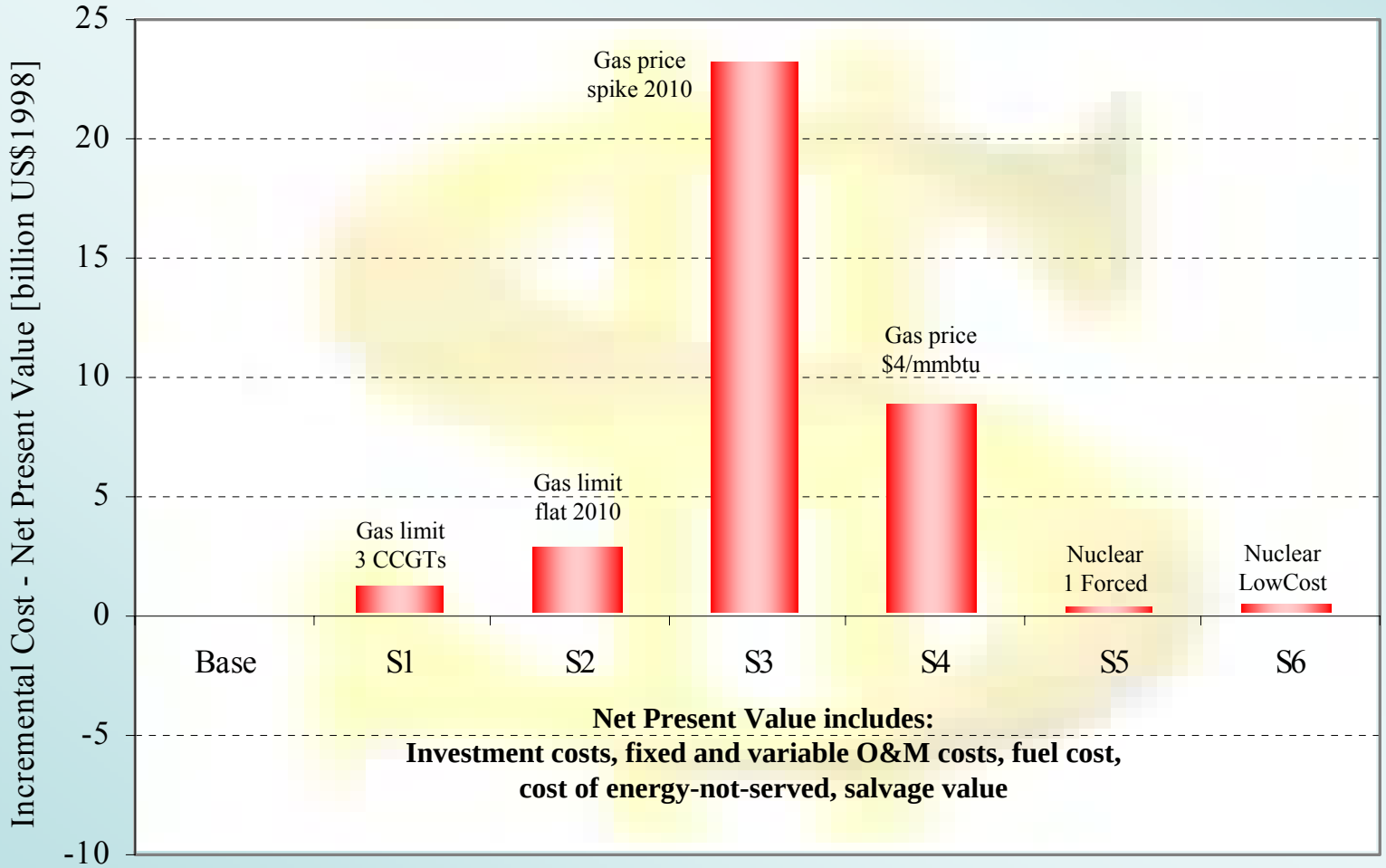
It may be noted that in this case five new nuclear power plants of 1,356 MW appeared, with 13 combined cycle plants less than in the reference case and three additional gas turbine plants than in the reference case. The coal, hydroelectric and geothermal capacities are the same as those in the reference case.

With the new nuclear capacity of 6,780 MW the share of nuclear power capacity it will be increased from 1.5% in the reference case to 9% while the share of gas based capacity will decrease from 73% in the reference case to 66% in this alternative case.



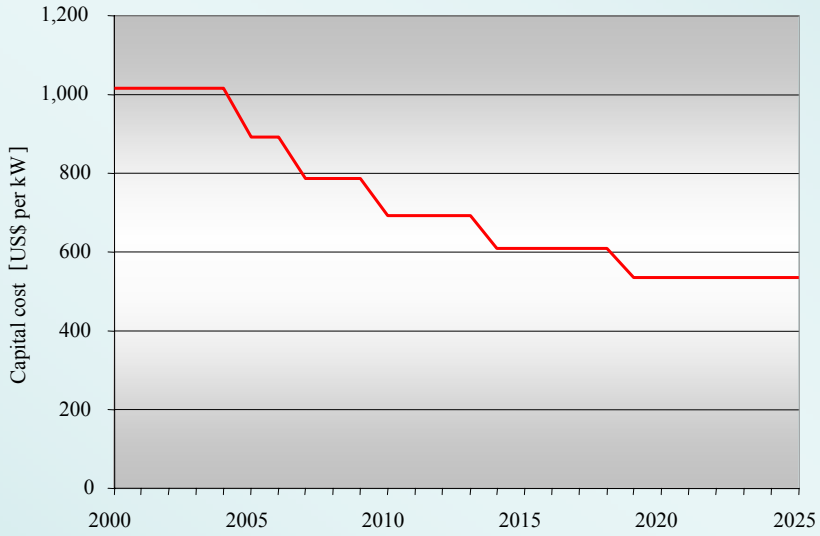
The Figure shows a summary of the economic comparison of the discussed scenarios. It becomes clear the impact of natural gas prices on the cost at Net Present Value of the alternatives for the expansion of the power sector. The power system becomes very vulnerable to natural gas prices or natural gas shocks and therefore becomes convenient to think and analyze the degree of diversity (fuels and technologies) of the power system and its expansion.

Economic comparison of the scenarios

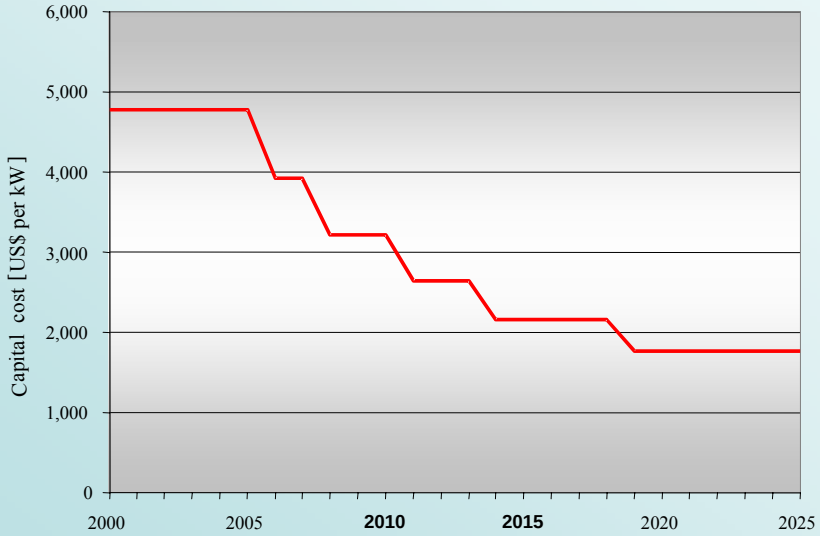


Results
Renewables Scenario
Wind and Solar PV

Renewables Scenario: Wind and Solar PV



Wind capital cost curve (experience factor = 0.88)



Solar photovoltaic capital cost curve (experience factor = 0.82)

The renewables scenario focused on the introduction of additional wind and solar PV for power generation. Other renewables, *e.g.*, mini-hydro and the application of renewables in the end-use sectors should be analyzed in future model runs. The model was configured such that solar and wind technologies compete with grid electricity on a national level, including the isolated system. Cost information was obtained from NREL and DOE-EIA. The technology assumptions are given in the following table:

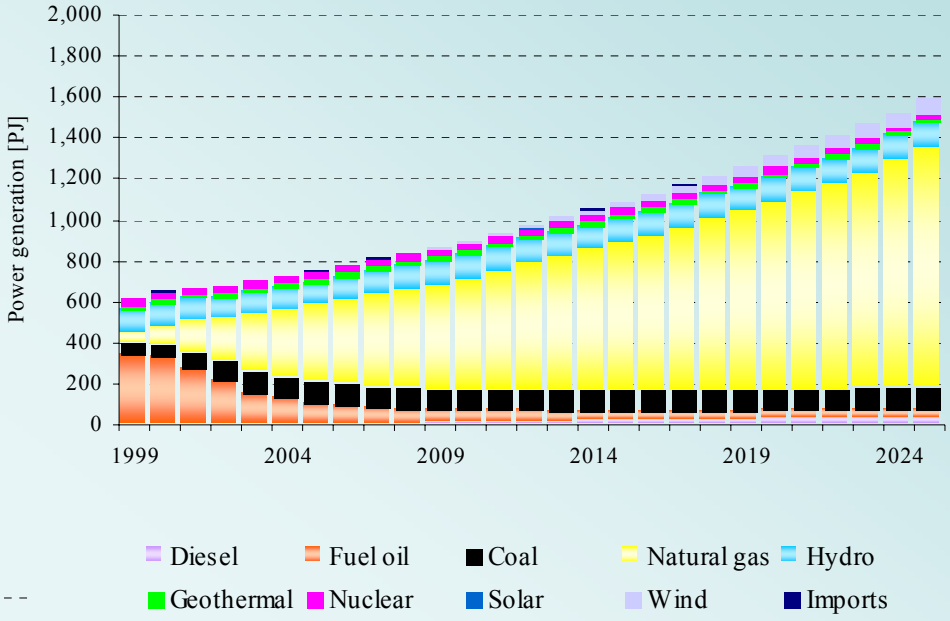
	Wind Farm	**Solar**
Capacity	50 MW	5 MW
Average capacity factor	26.2%	20%
Efficiency	65%	15%
Fixed O&M cost	26.94 $/kW-year	10.2 $/kW-year
Initial capital cost	1,154 $/kW	4,781 $/kW
Experience factor	0.88	0.82

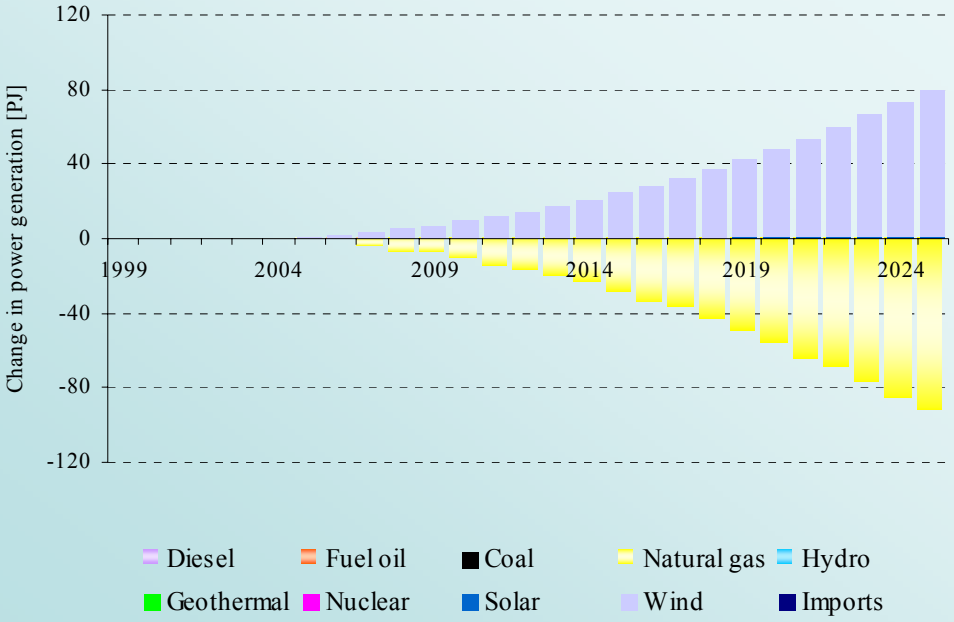
The experience factors for solar and wind essentially represents the cost reduction with each doubling of installed capacity. The resulting cost reductions for solar (from 4,781 to 1,773 $/kW) and wind (from 1,154 to 536 $/kW) over time are shown in the Figures.

Renewables Scenario: Wind and Solar PV

Because of the relative costs of wind and solar, the role of solar PV will be very limited. By 2025, solar will generate only about 1.2 PJ of electricity or 0.1 percent of total generation. This is equivalent to 195 MW of installed PV capacity.

Wind, on the other side, is forecast to penetrate the market relatively rapidly and as given in the Figure. This energy source is forecasted that will account for approximately 4.9 percent of total generation, that is, 78.3 PJ by 2025. At the assumed average capacity factor of 26.2 percent, about 9,500 MW of wind capacity will be needed to generate this power.



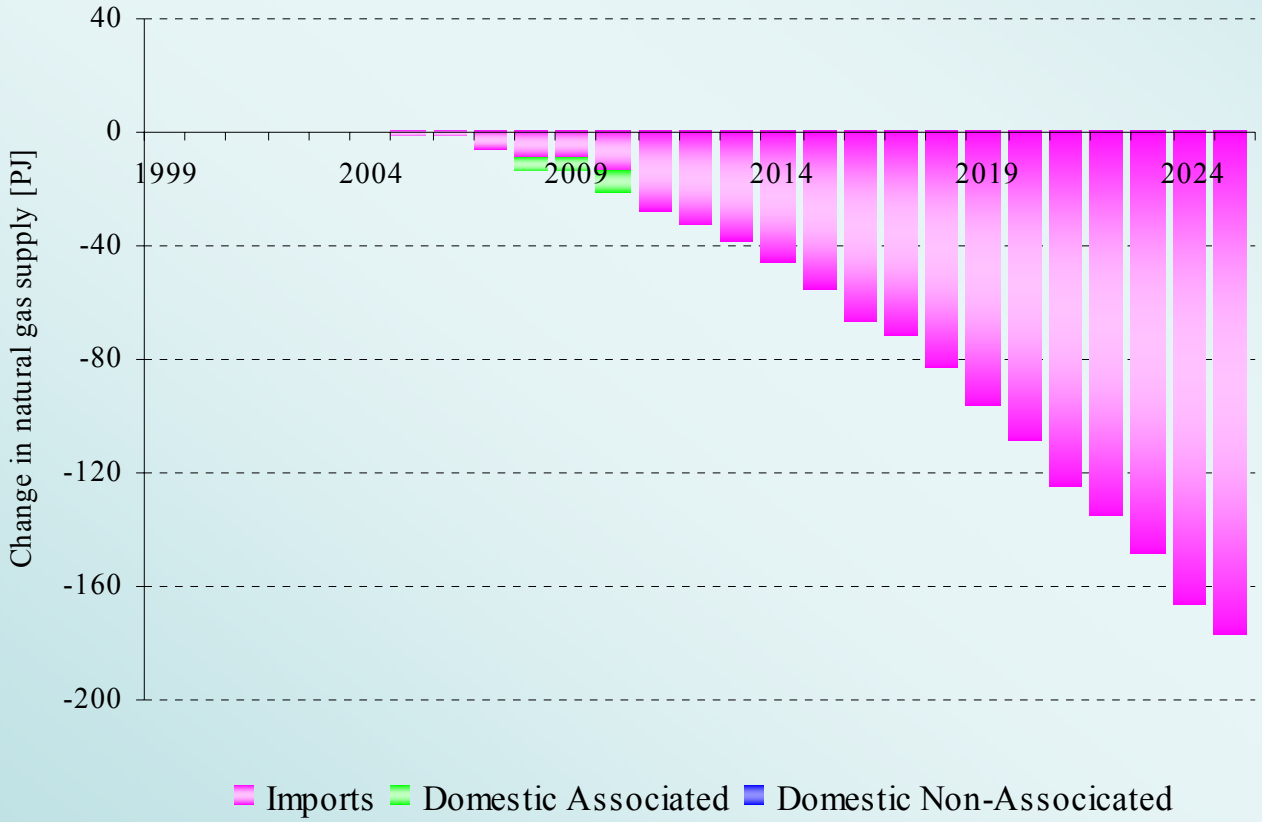


Wind will essentially replace marginal gas-fired generation by up to 93.3 PJ (2025), that is, about 19 percent more than wind electricity. The main reason for this difference is the underlying model implementation which assumes that wind generation will be more dispersed, closer to actual loads, and therefore not subject to the transmission and distribution losses in the electric grid.

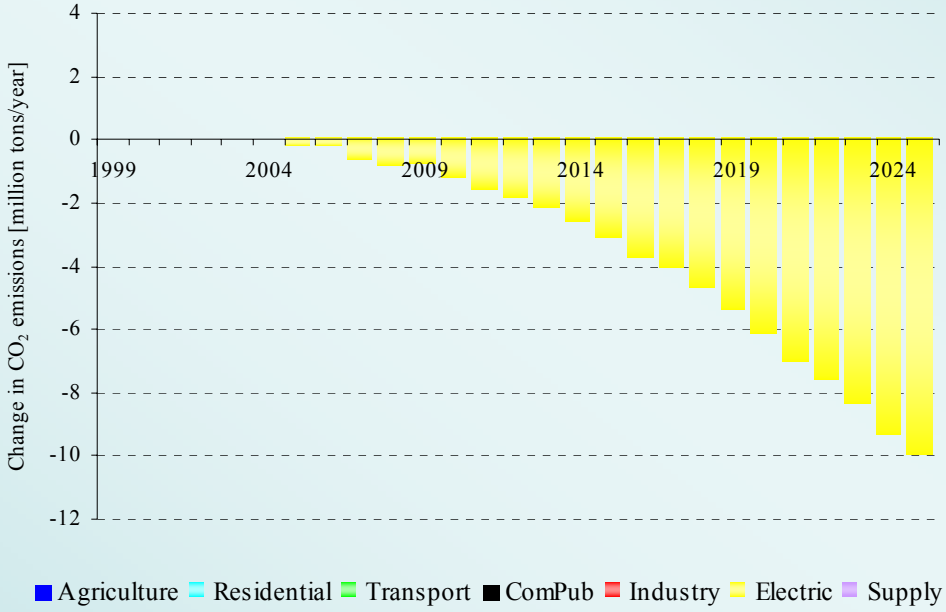
Renewables Scenario: Wind and Solar PV

Because of the change in generation mix originated by the incorporation of wind energy, the power sector will require less natural gas. This translates directly into less natural gas imports as shown in the Figure. The reduction in gas imports grows as wind generation increases and reaches approximately 180 PJ by 2025.

At US$707.87 billion in Net Present Value, total economic system cost is higher than under the reference scenario, that is, an incremental cost of US$455.64 million.

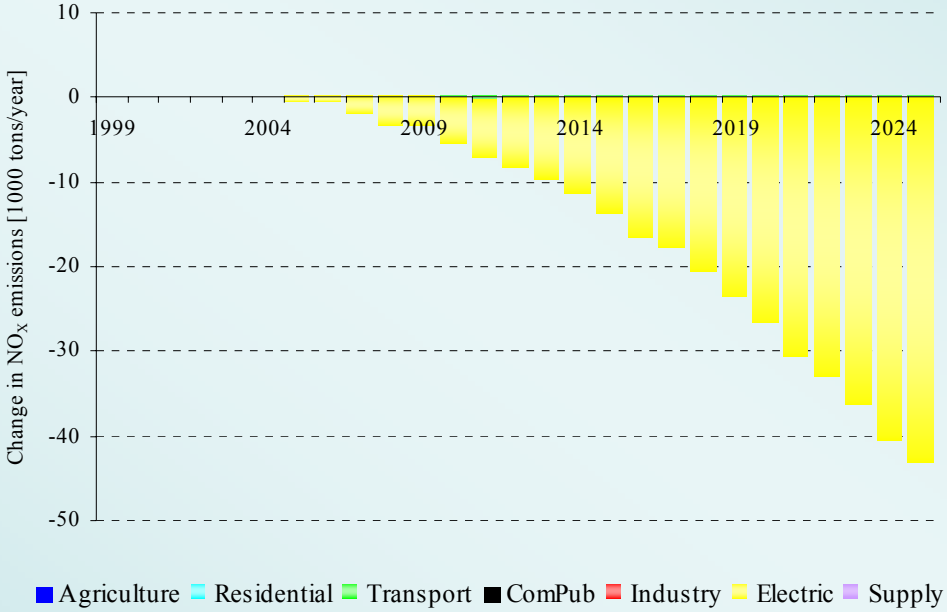


Renewables Scenario: Wind and Solar PV



The combined effect of technologies, solar PV and wind, for example, on CO_2 emissions is shown in the Figure. As can be seen, the accelerated penetration of renewable power generation results in CO_2 emissions that are up 10 million ton per year (2025) below the reference case levels. This represents a 5.4 percent decrease in power sector CO_2 emissions and a 1.2 percent decrease of total national CO_2 emissions. The total cumulative emissions reductions in the period from 2005 to 2025 are equal 81.96 million ton. The cost-effectiveness of solar and wind as a GHG mitigation technology is therefore US$5.6/ton CO_2. This value is likely to be lower if we ignore the more expensive solar technologies and include only wind in the model.

The fact that solar and wind replace electricity that is generated mostly by gas-fired combined cycle units limits the emission reduction potential of renewable technologies. NO_X emissions, for example, are 44,000 ton per year (2025) below projected reference case levels. This is equivalent to a 5.5 percent drop in power sector emissions and a 1.0 percent decrease of total national NO_X emissions. Cumulative NO_X reductions over 2005-2025 total about 351,000 ton.



General Conclusions

Reference Scenario:

- Mexico will continue to rely heavily on fossil fuels for its energy trade and final energy consumption.
- Crude oil market share decrease from 68.2 percent in 1999 to 62.7 percent in 2025, as a consequence of the non-associated gas growth share in 11.9 percent in 2025 (compared with 4.5 percent in 1999) meanwhile associated gas decrease from 13.9 percent in 1999 to 12.8 percent in 2025. Non-associated gas average annual growth rate is the highest (5.2%) followed by coal (3.7%), crude oil (1.0%), geothermal (0.8%) and sugar cane bagasse (0.2%).
- Crude oil production will have to increase, in millions of barrels per day, from 2.91 in 1999 to 3.49 in 2005, to 3.58 in 2010, to 3.65 in 2015, to 3.72 in 2020 and 3.78 in 2025. The projected production allow to satisfy the internal consumption (feedstock for the domestic refining system (1.35 million barrels per day in 1999 and 1.71 million barrels per day in 2025), including the programmed expansion of the refining capacity in the system, as well as the maquila mechanism along the entire period) plus the projected crude oil exports (1.55 million barrels per day in 1999 to 2.07 million barrels per day in 2025).

Reference Scenario *(continued)*:

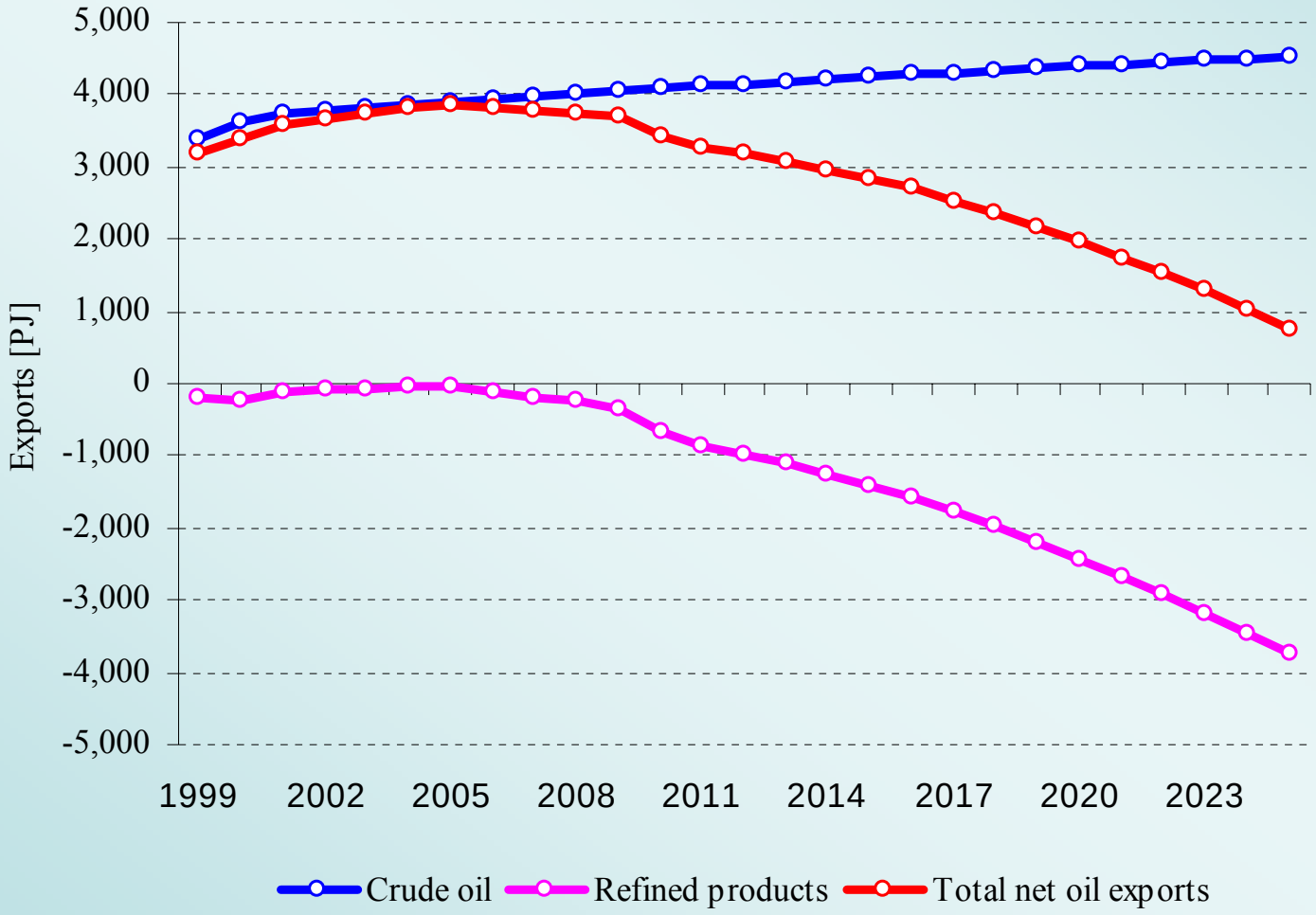
- In order to reduce the dependency on imported gasoline and increase gasoline exports refining capacity has to increase according to the following results: by 2006 domestic refining capacity increase to 1.715 million barrels per day, which will cover, in essence, the projected gasoline demand with a deficit of 27,000 barrels per day (this demand deficit could be covered through the maquila mechanism or through imports); after year 2008 and the rest of the projection period, once the completion of the reconfiguration program with a gasoline yielding of 39 percent, the total refining capacity increase, in millions of barrels per day, up to 1.94 by 2008, to 2.48 in 2015, 3.16 in 2020 and to 4.07 in 2025. Therefore, the accumulated increase capacity along the projection period is 2.36 million barrels per day. The elimination of the gasoline exports has the effect to reduce the additional capacity to 2.1 million barrels per day.
- In absolute terms coal generation grows, however its share decreases from 9.82 to 6.61 percent.
- Nuclear generation decreases in absolute and percent wise terms due to no nuclear additions and the retirement of the first unit of Laguna Verde nuclear power plant.

Reference Scenario *(continued)*:

- Natural gas production and imports increase its participation in the total primary energy supply at an average annual growth rate of 4.8 percent along the entire period. Associated and non-associated gas production grow at an average annual growth rate of 1 and 5.18 percent, respectively, while natural gas imports grow at an average annual growth rate of 15.75 percent. To keep a proper balance between supply and consumption with an important participation of domestic production, starting 2010, it will be necessary to incorporate more non-associated gas fields to production. The market share of natural gas increases to 45.3 percent by 2025.
- In order to handle the natural gas production and the imports, natural gas infrastructure (production wells, gas pipelines, processing centers and distribution) will have to grow at an accelerated level.
- Natural gas will be the primary fuel of choice for power system expansion and generation leading to a near-term and long-term need for additional gas imports (or accelerated expansion of domestic production). Natural gas-fired generation share will increases from 8.09 to 78.94 percent.

Reference Scenario *(continued)*:

Mexico's net oil export balance shows the impact of the projected growth imports of refined products. Crude oil exports are expected to continue their growth at an average rate of 0.7% per year from 3,396 PJ in 1999 to 4,520 PJ in 2025, net imports of refined products quickly increase and result in a very rapid drop in net oil exports eventually declining to 771 PJ in 2025, down from a peak of 3,848 PJ in 2005.



Limited Natural Gas Scenario:

- If natural gas supply is limited, the power sector may shift to imported coal combustion for system expansion substantially decreasing the need for gas imports. However, this shift will come at an economic and environmental expense leading to significantly higher system costs and atmospheric emissions.

- Natural gas imports will keep, essentially, the same value as in the reference case, however, starting 2014 there will be a reduction in the natural gas imports of 5.87 percent with respect to the reference case and this difference will reach a 33.78 percent by 2025, also with respect to the reference case. Clearly, this will lower the pressure for the development of the needed infrastructure for production, transportation and distribution of natural gas; however, it will transfer part of this pressure to the development of the corresponding infrastructure for the reception, transportation and distribution of imported coal. According to the available information, current coal reception, transportation and distribution infrastructure allows for the handling of 4 million ton per year. Under this scenario this infrastructure will have to grow and be able to handle 9.5 million ton in 2014. After 2014, the coal-handling infrastructure will have to grow fast reaching a total handling capacity of 84.81 million ton of coal per year by 2025.

Nuclear Scenario:

- Nuclear power also replaces base-loaded gas-fired generation and thereby can lead to lower gas imports and lower emissions.
- Because of the large capacity of the nuclear unit, the expansion schedule is slightly affected starting in 2001 even though the unit is not coming on-line until 2012. This leads to some changes in generation and fuel consumption in the power sector between 2001 and 2011. Between 2001 and 2011 there is an additional participation of fuel oil generation, which decreases along the years and ends by 2011 and a reduction in the consumption of natural gas.
- When de nuclear unit does come on-line, it is base-loaded into the system and generates a constant level of 34 PJ of electricity per year equivalent to 1.5 percent of total generation in 2025 as compared to 1.1 percent under the reference case.
- The system-level analysis shows that nuclear replaces effectively base-loaded gas combined-cycle capacity and between 33-37 PJ of gas-fired generation. This represents a reduction in the imports of natural gas of 189.6 million cubic feet per day and an additional consumption of uranium dioxide of 31.31 ton per year. The remaining sectors show minor changes.

Renewables Scenario: Wind and Solar PV

- Because of the relative costs of wind and solar, the role of solar PV will be very limited. By 2025, solar will generate only about 1.2 PJ of electricity or 0.1 percent of total generation. This is equivalent to 195 MW of installed PV capacity.
- Wind, on the other side, is forecast to penetrate the market relatively rapidly. This energy source is forecasted that will account approximately 4.9 percent of total generation that is 78.3 PJ by 2025. At the assumed capacity factor of 26.2 percent, about 9,500 MW of wind capacity will be needed to generate this power. Wind will essentially replace marginal gas-fired generation by up to 93.3 PJ in 2025, that is, about 19 percent more than wind electricity. The main reason for this difference is the underlying model implementation which assumes that wind generation will be more dispersed, closer to actual loads, and therefore not subject to the transmission and distribution losses of the electric grid.
- Due to the change in generation originated by the incorporation of wind energy, the power sector will require less natural gas and as a consequence less natural gas imports. The reduction in natural gas imports grows as wind generation increases and reaches approximately 178.31 PJ by 2025, which is equivalent to a reduction in the natural gas imports of 508.63 million cubic feet per day with respect to the reference case.

Thank you