Turkey's Options to Control Energy Sector Air Pollution

Emissions Outlook until 2025 for Greenhouse Gases and Other Pollutants

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Background and Study Objective

- **Analysis performed as part of a comprehensive World Bank Energy and Environment Review (EER)**
  - Energy Management Assistance Program (ESMAP)
  - Japan Staff and Consultant Trust Fund
  - Included total of 8 individual studies or tasks

- **Work presented here was part of Task 7 – Energy Sector Modeling**
  - Combine information obtained in other EER tasks and provide an integrated systems analysis of the various options for addressing climate change and local pollution concerns

- **Objective was to simulate Turkey's energy markets and develop long-term emissions forecasts for a variety of pollutants and scenarios**
  - Reference Case or Baseline Scenario
  - GHG mitigation scenarios
  - Local pollution scenarios (primarily focused on PM, SO_2, NO_X)

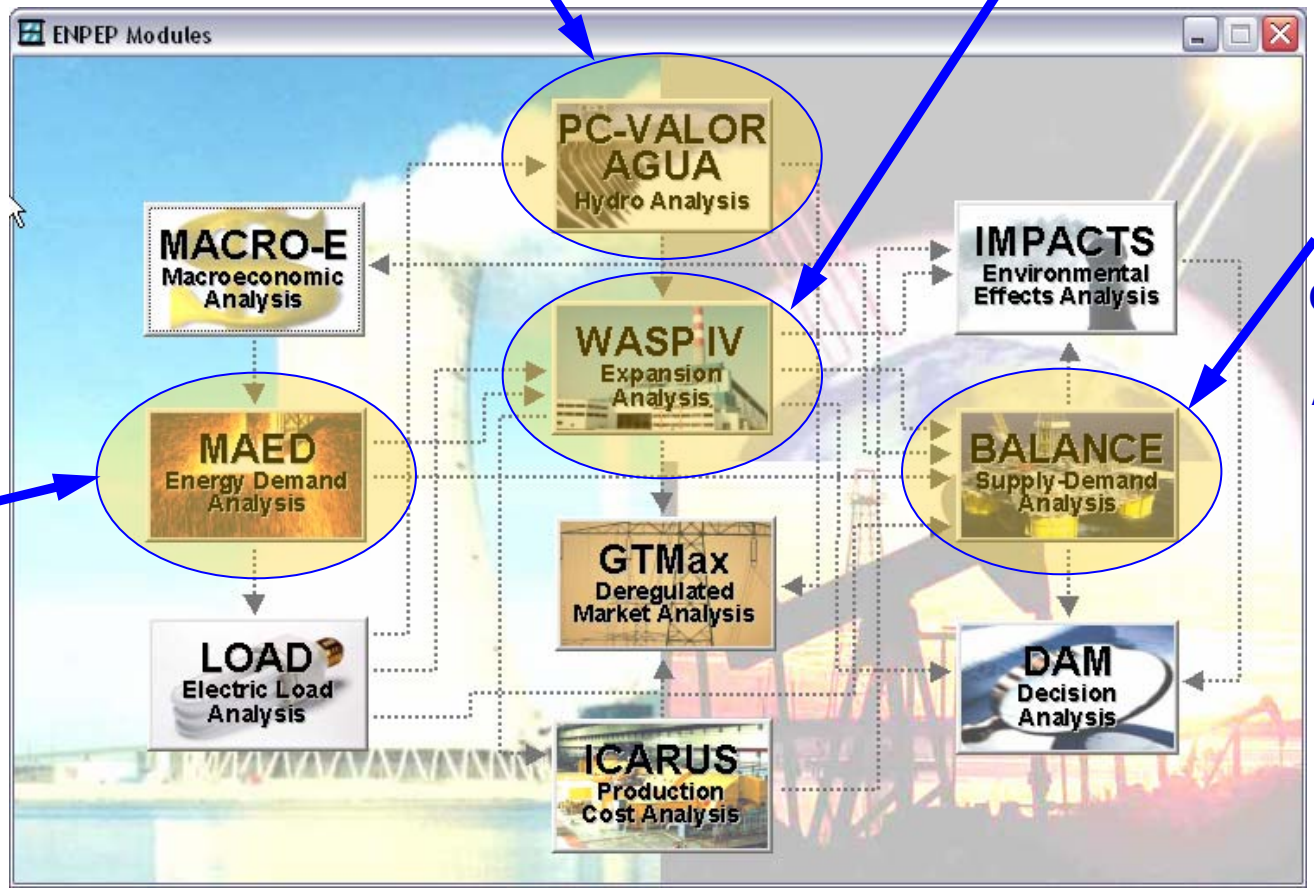
Analysis was Conducted with the Energy and Power Evaluation Program (ENPEP)

VALORAGUA for detailed Hydro Power System Analysis

WASP for Power System Expansion Analysis

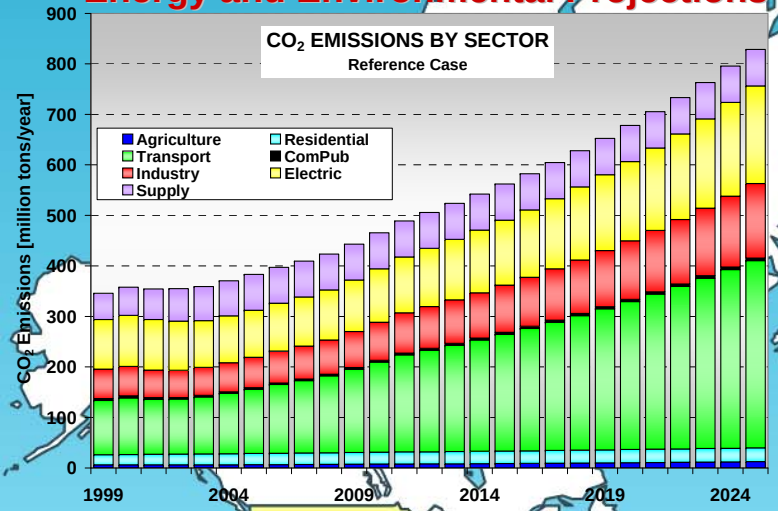
BALANCE for Integrated Overall Energy Sector Analysis, GHG Emissions, Economic Analysis

MAED for Energy Demand Projections

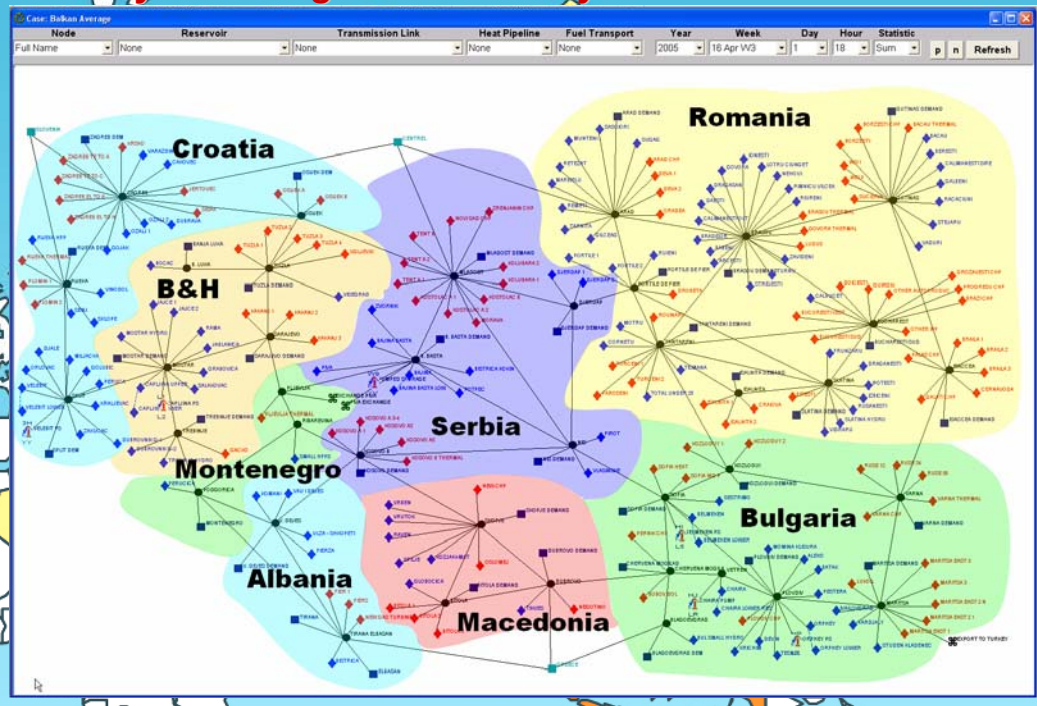


ENPEP is Used by Analysts Worldwide to Study Strategic Energy and Environmental Issues

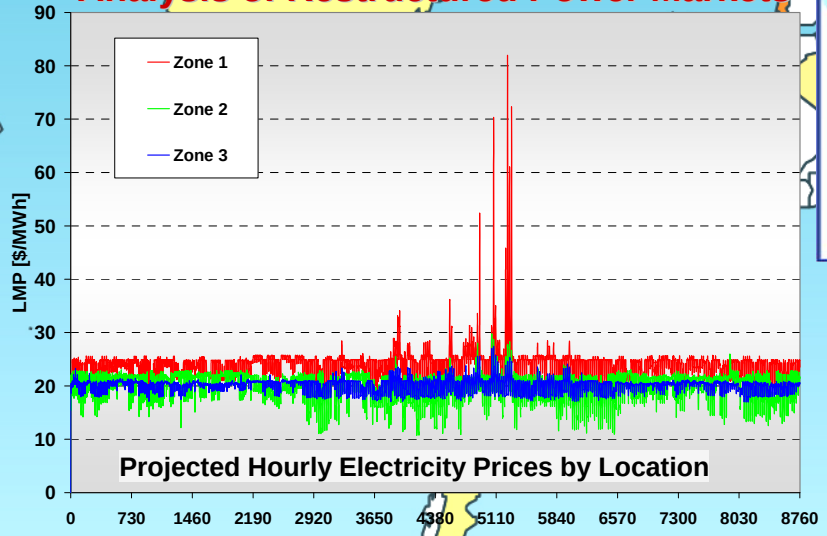
Energy and Environmental Projections



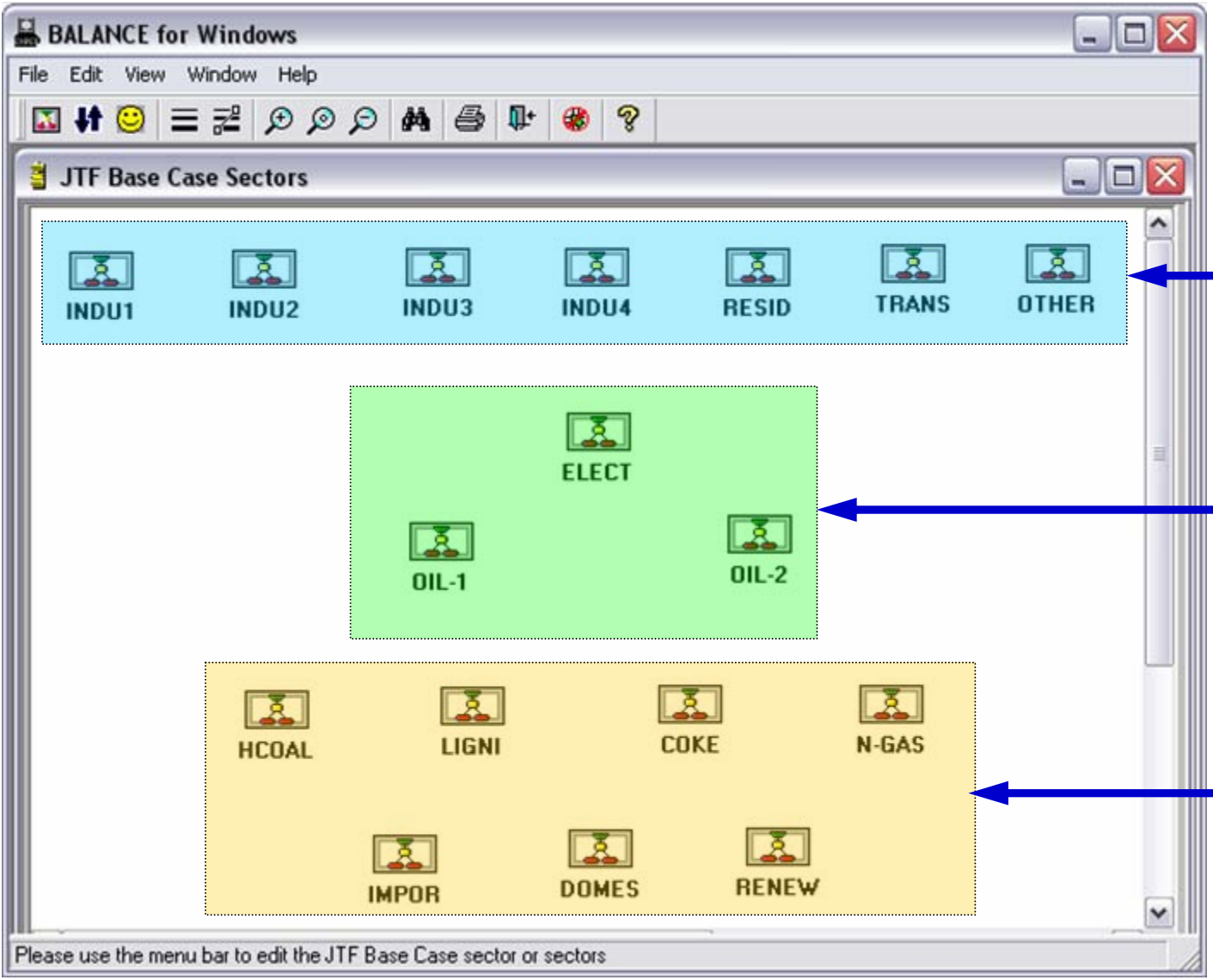
Analysis of Regional Power System Interconnections



Analysis of Restructured Power Markets



The Model Includes all Energy Forms and All of Turkey's Energy Sectors in an Integrated Framework

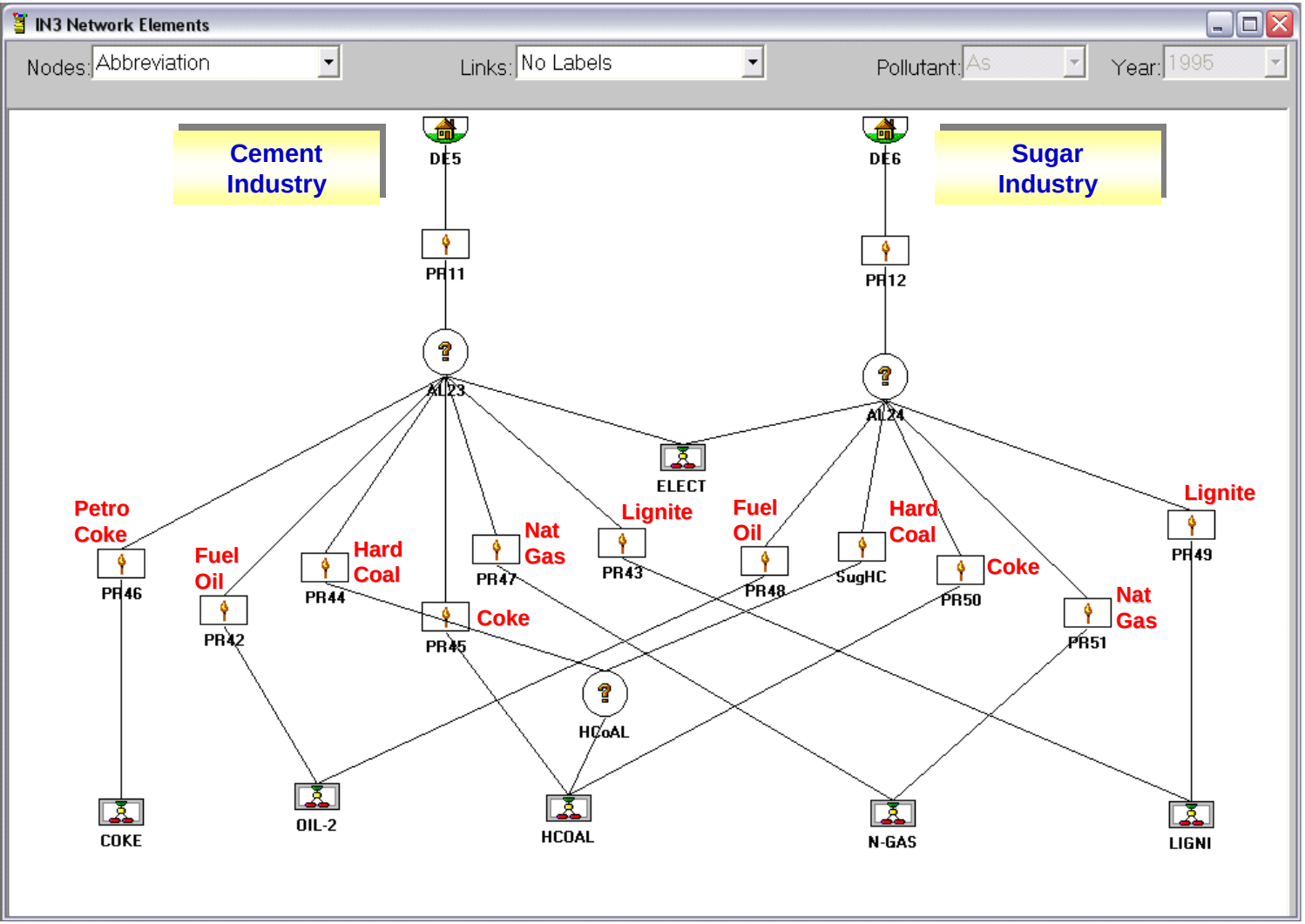


Demand Sectors

Conversion Sectors

Supply Sectors

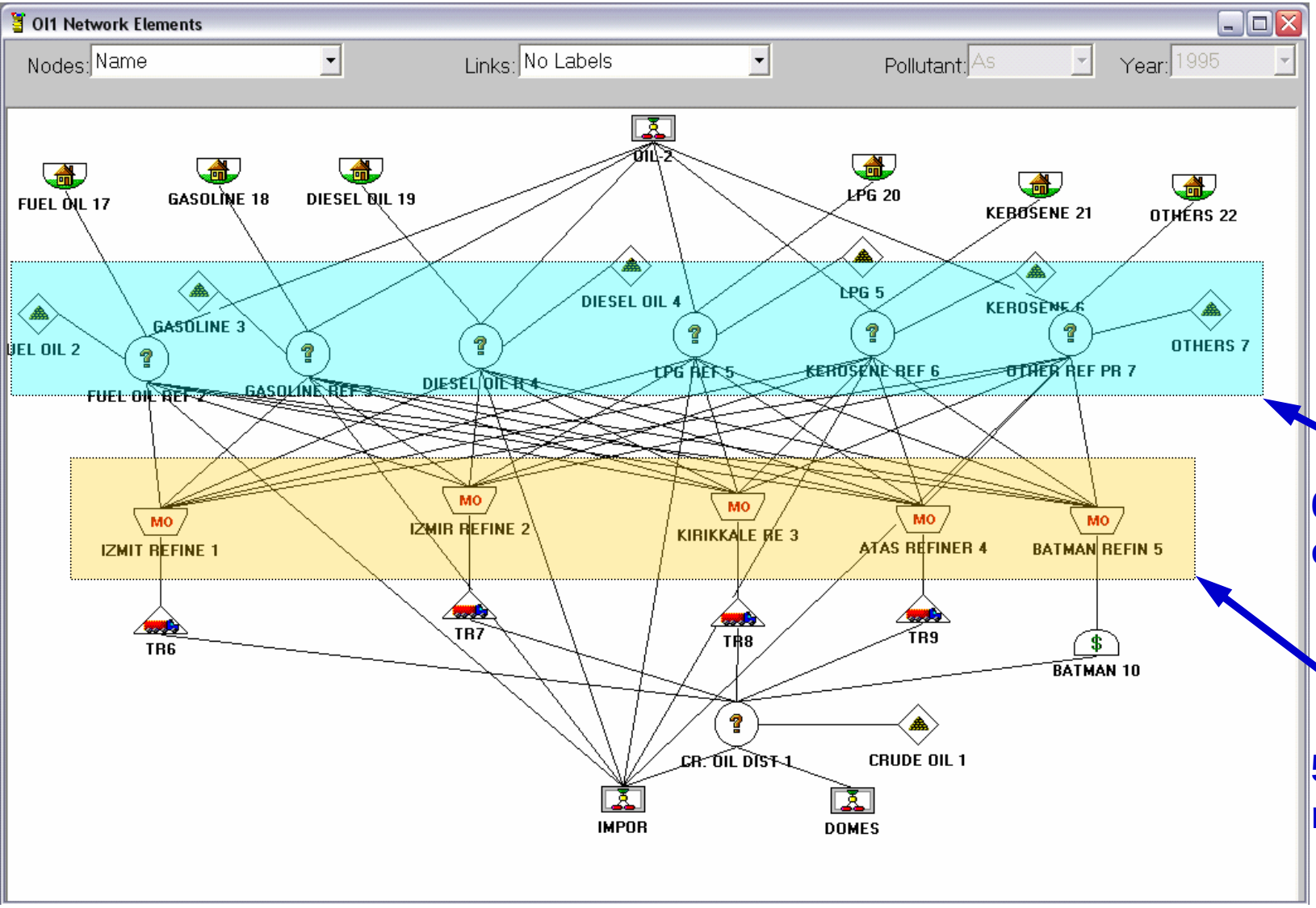
Each Sector is Modeled at Different Levels of Detail: Example of Turkish Cement and Sugar Industry



Other industries included in the Turkish model implementation:

- Iron and steel
- Chemical & petrochemical
- Petrochemical feedstocks
- Fertilizer
- Non-iron metals
- Other

Each Sector is Modeled at Different Levels of Detail: Example of Turkish Petroleum Refining



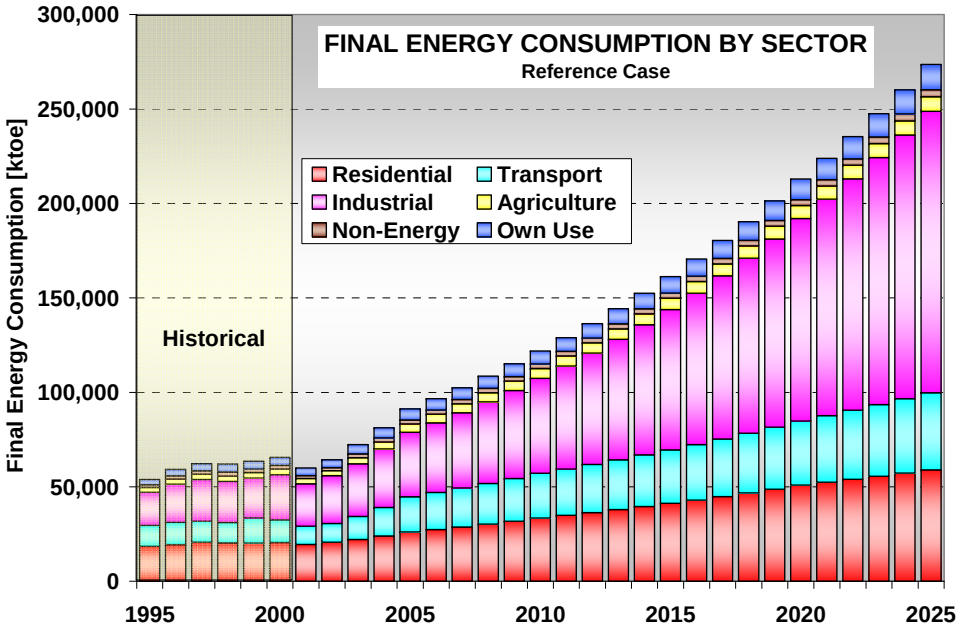
6 different oil products

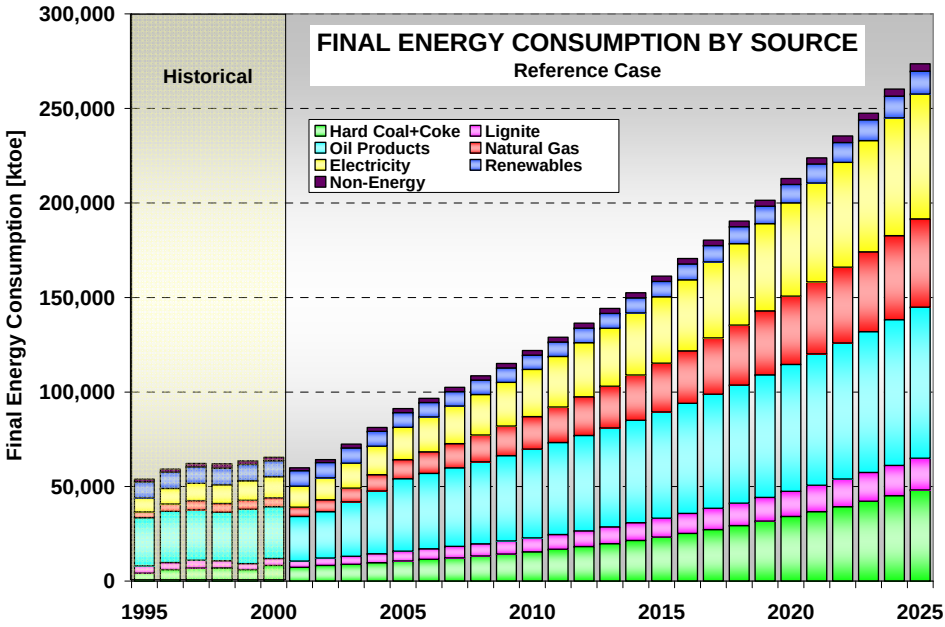
5 individual refineries

Model Results Include Projections of Greenhouse Gases and Other Pollutants

- Greenhouse gases: CO_2, CH_4, N_2O, CO, NMVOC
- Local/regional pollutants: PM, PM10, PM2.5, SO_2, NO_X, bottom ash, fly ash, total ash
- Air toxics: As, Be, Cd, Cr, Sb, Co, Pb, Mn, Hg, Ni, Se, HCl, HF

Baseline Final Energy Consumption is Projected to Grow from 65.5 mtoe (2000) to 273.5 mtoe (2025)

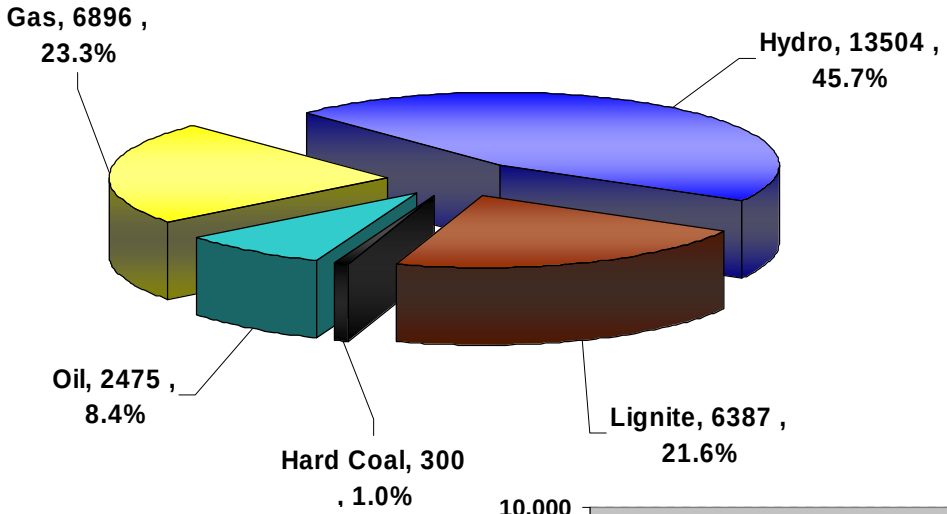




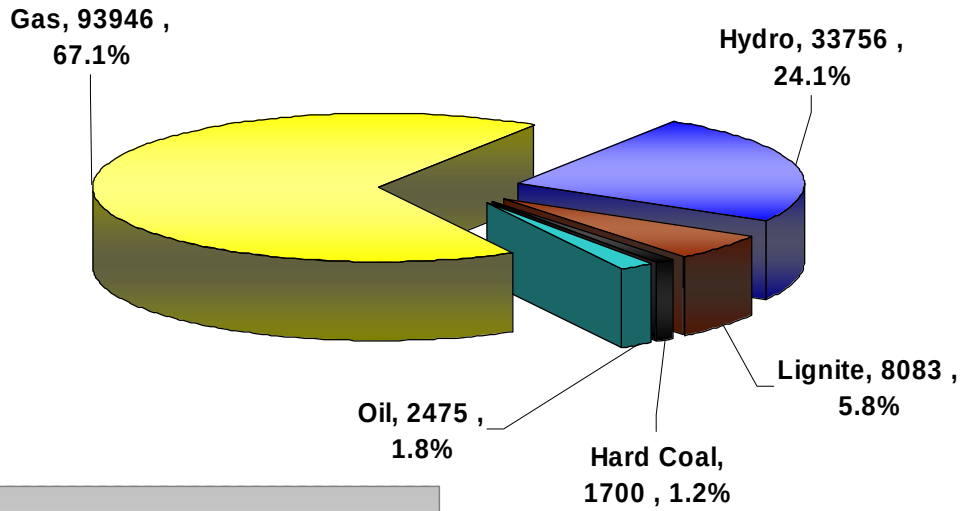
- **Average growth rate is 5.9% per year; growth rates vary by sector; e.g., industry (7.6%), transport (5.0%)**
- **Oil products continue historical decline in market share from 42% to 29% by 2025**
- **Natural gas grows at 9.6% per year from 4.7 to 46.7 mtoe and captures 17% of the market by 2025 (up from 7% in 2000)**
- **Electricity grows at 7.4% annually increasing its share from 17% to 24%**
- **Renewables grow from 8.4 to 12.1 mtoe but their share falls from 13% to 4% mostly due to the decline in non-commercial biomass (wood and wood waste); solar and geothermal energy combined increase fourfold from 2.0 mtoe (2000) to 8.3 mtoe (2025)**

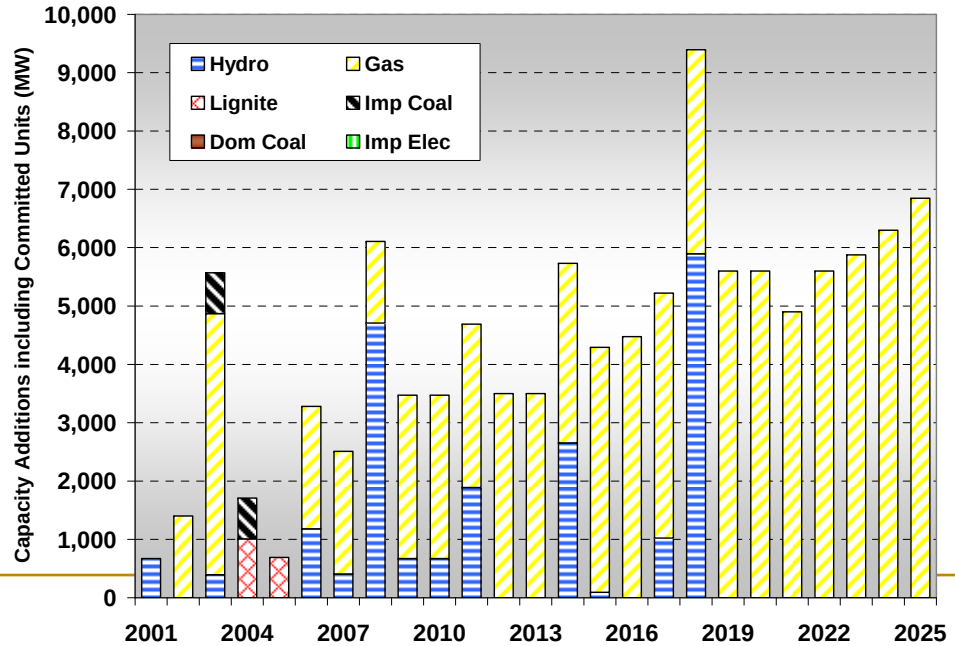
Baseline Power Sector Expansion is Dominated by Natural-Gas Fired Units

2001 Existing Generation Capacity (MW)

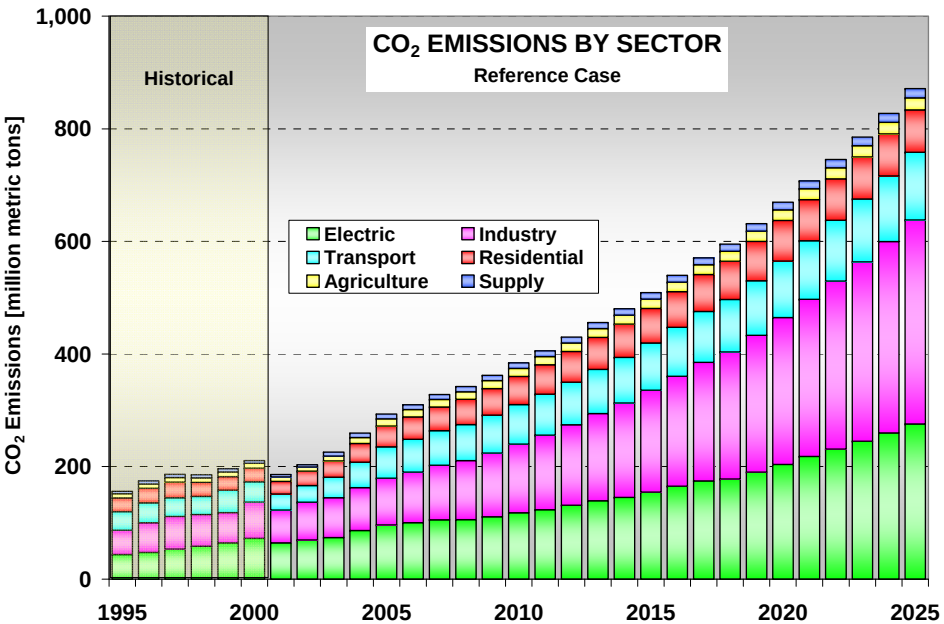


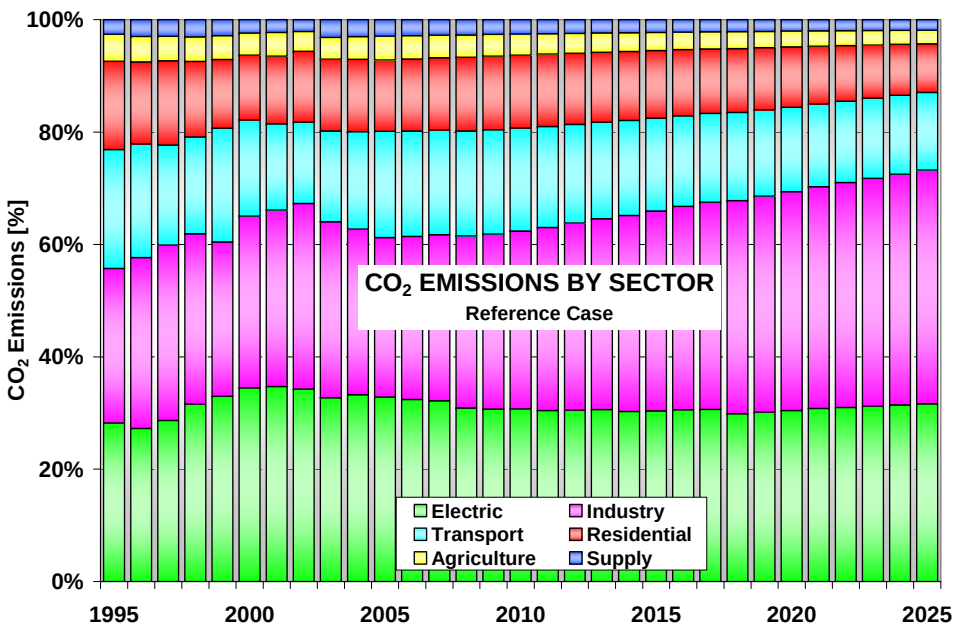
2025 Projected Generation Capacity (MW)





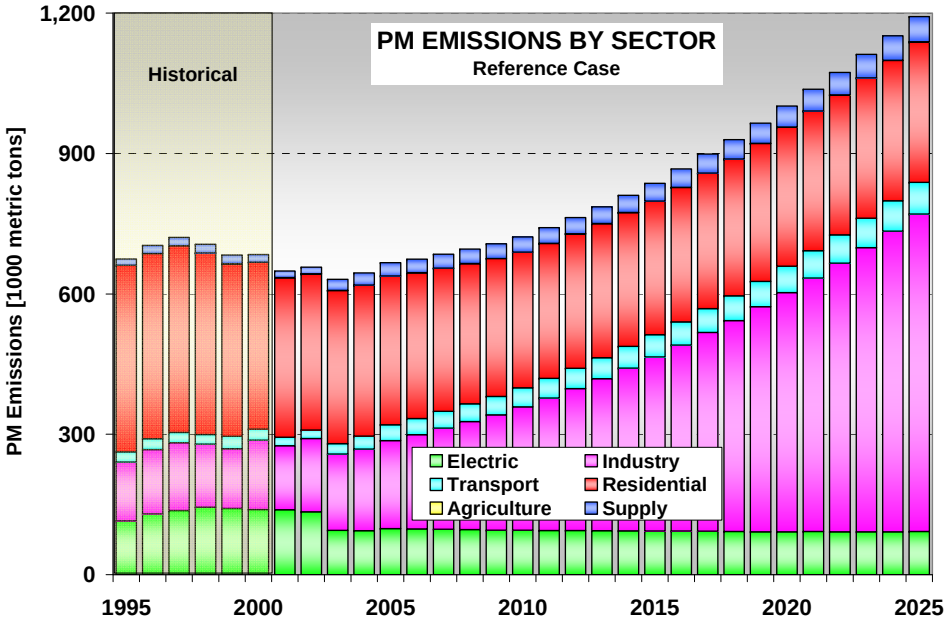
Baseline Annual CO_2 Emissions are Projected to Grow 5.8% Annually from 211 to 871 million tons

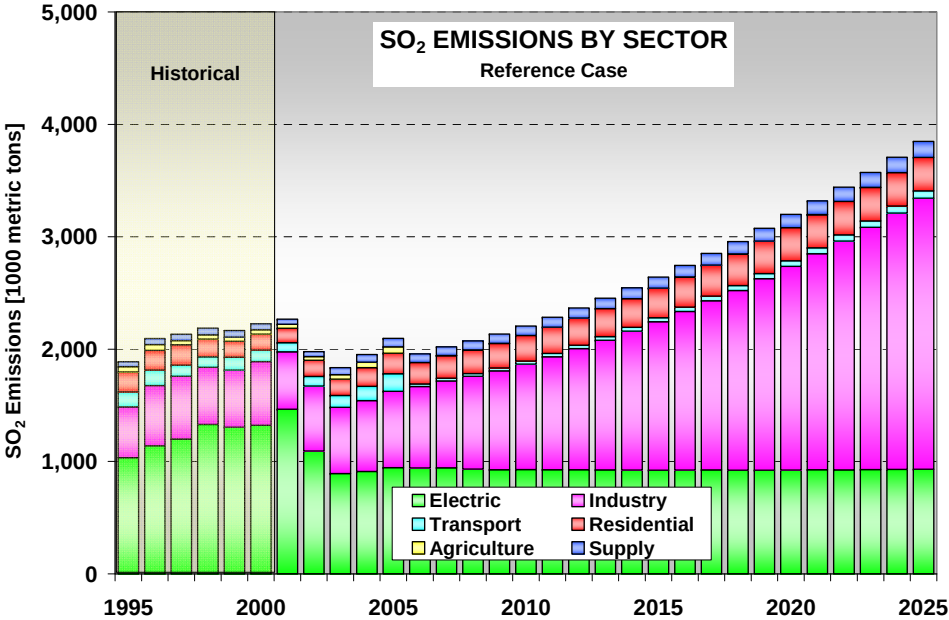


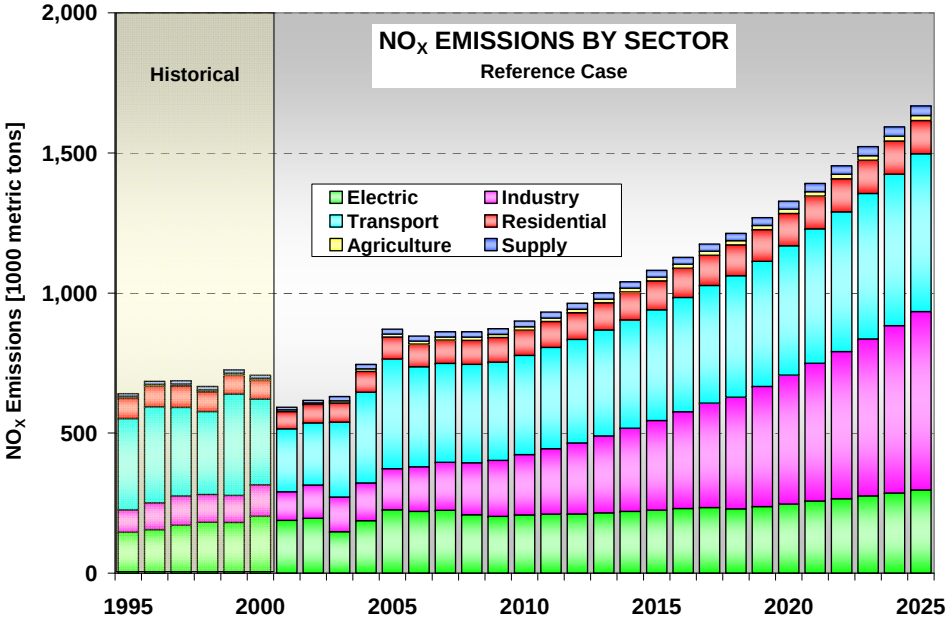


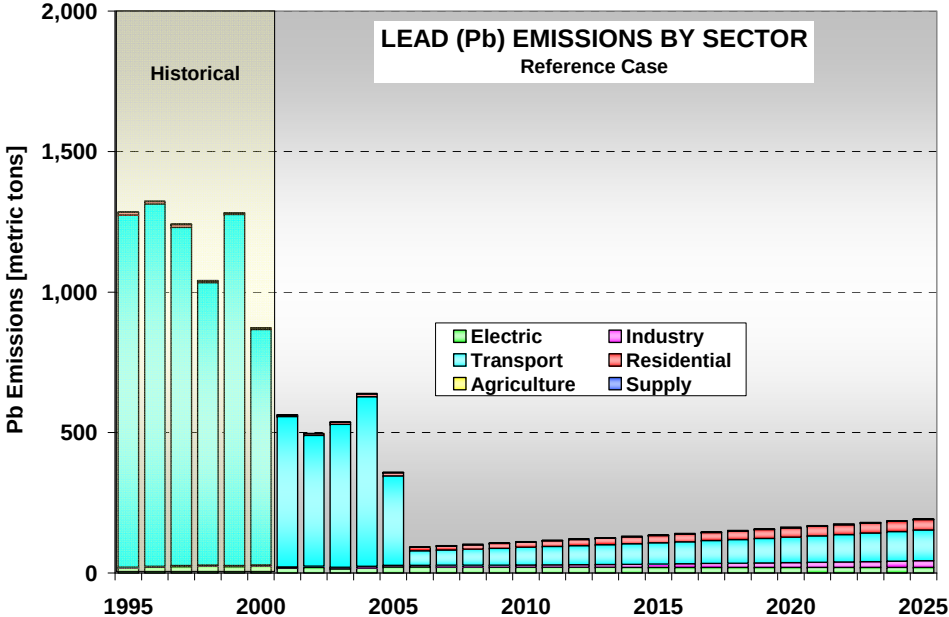
- **Industrial CO_2 emissions grow by 7.2% per year and account for 42% in 2025 (362.2 mt/yr), up from 30.5% in 2000 (64.4 mt/yr)**
  - driven by high growth in industrial final energy as well as continued reliance on solid and liquid fuels which still account for 55% of industrial final energy consumption by 2025, despite the increased penetration of natural gas
- **Power sector CO_2 emissions grow at a below average rate of 5.5% from 72.7–275.8 million tons, mostly due to increasing reliance on natural gas**

Examples for Other Emissions Results: PM, SO_2, and NO_X will Continue to Increase, Lead will Drop Substantially









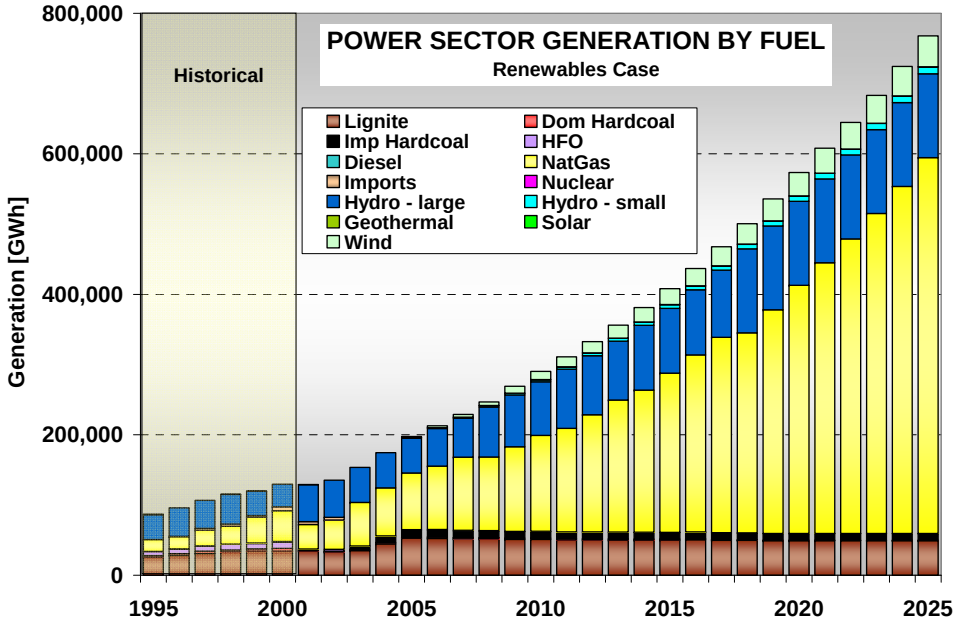
GHG Mitigation Scenarios

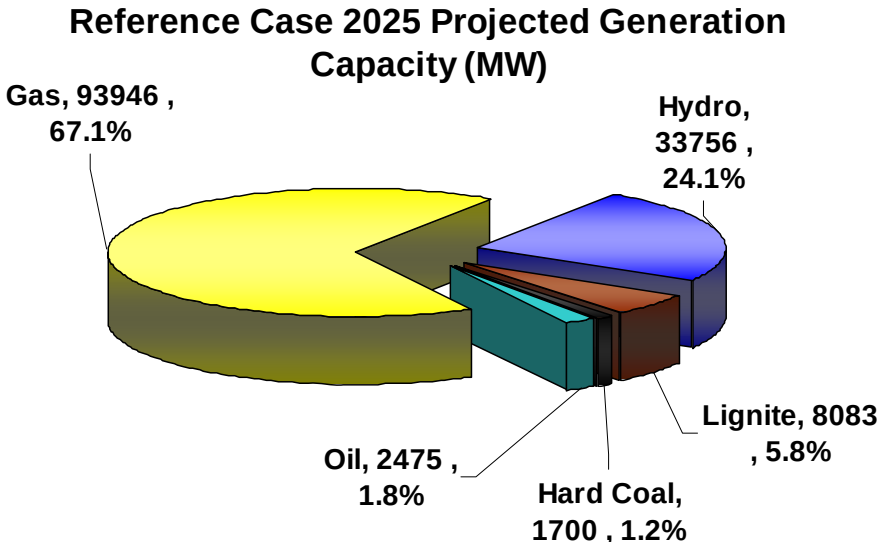
- **Technical efficiency improvements of existing power stations**
- **Clean coal technology (circulating fluidized bed combustion) for power generation**
- **Constrained gas supply combined with use of new sub-critical and super-critical coal-fired power stations**
- **Nuclear power**
- **Increased use of industrial cogeneration**
- **Expanded use of renewables (wind and mini-hydro)**
- **CO_2 tax of $15 per ton of carbon**
- **Expanded demand side management in industry and households**

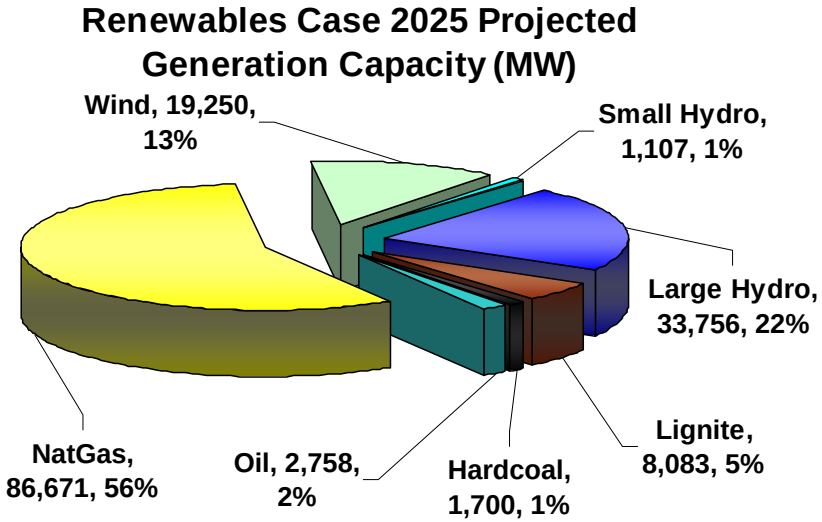
- **Local pollution scenarios analyze policies to reduce PM, SO_2, and NO_X**
  - Improving petroleum product quality (reducing S-content in fuel oil)
  - Upgrading existing power stations to meet EU standards on PM and SO_2 (2009) and NO_X (2015)
  - Combined case of improved petroleum quality and power station retrofits

Renewables Scenario

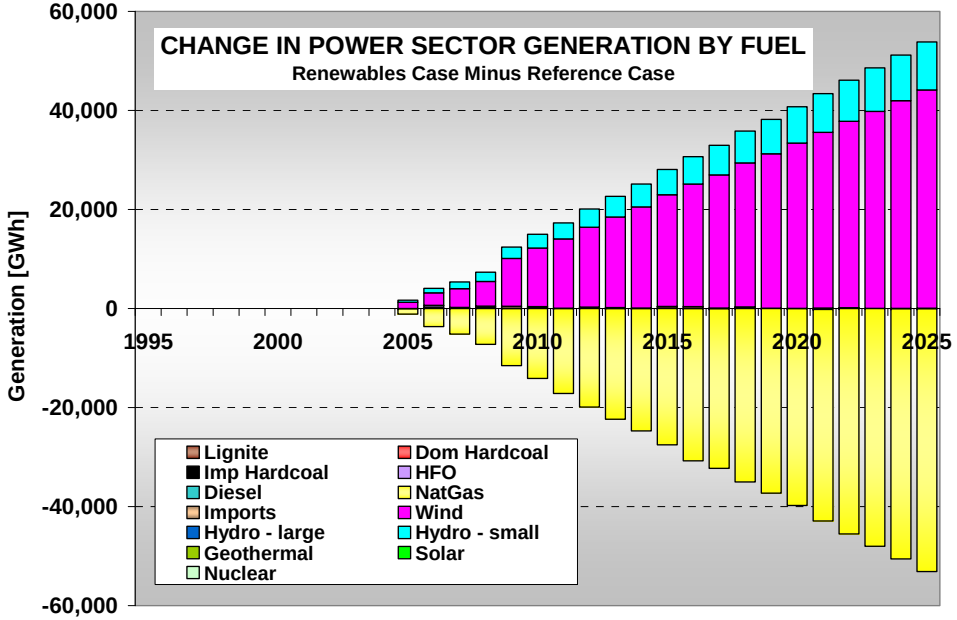
- Assumes start of more aggressive renewables program in 2005 with the goal to have 7% of total electricity production coming from mini-hydro and wind power
- 19,250 MW of wind and 1,107 MW of small hydro will be added to the system
- This replaces a total of 7,250 MW of gas-fired capacity in the power sector over 2000–2025

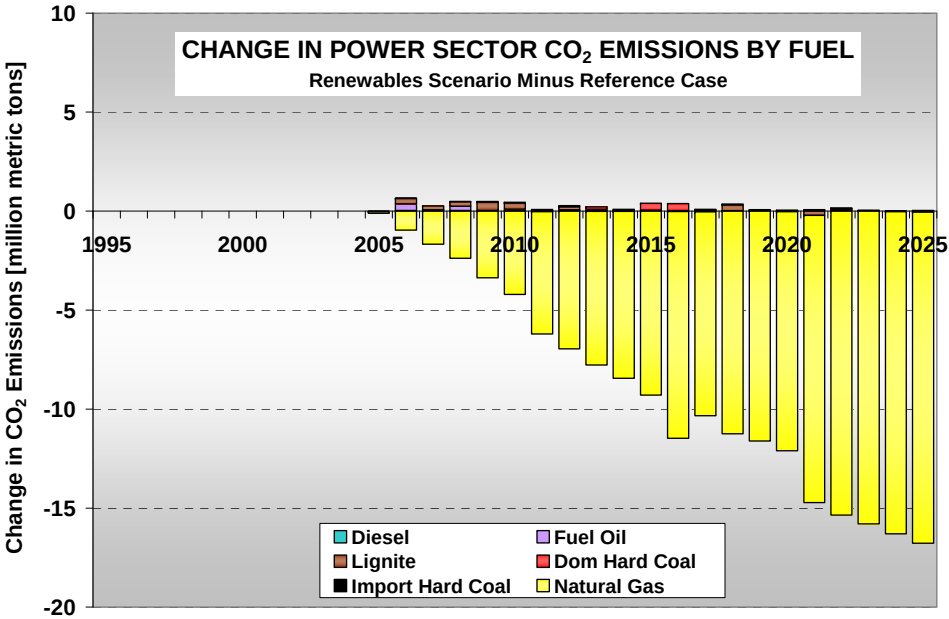






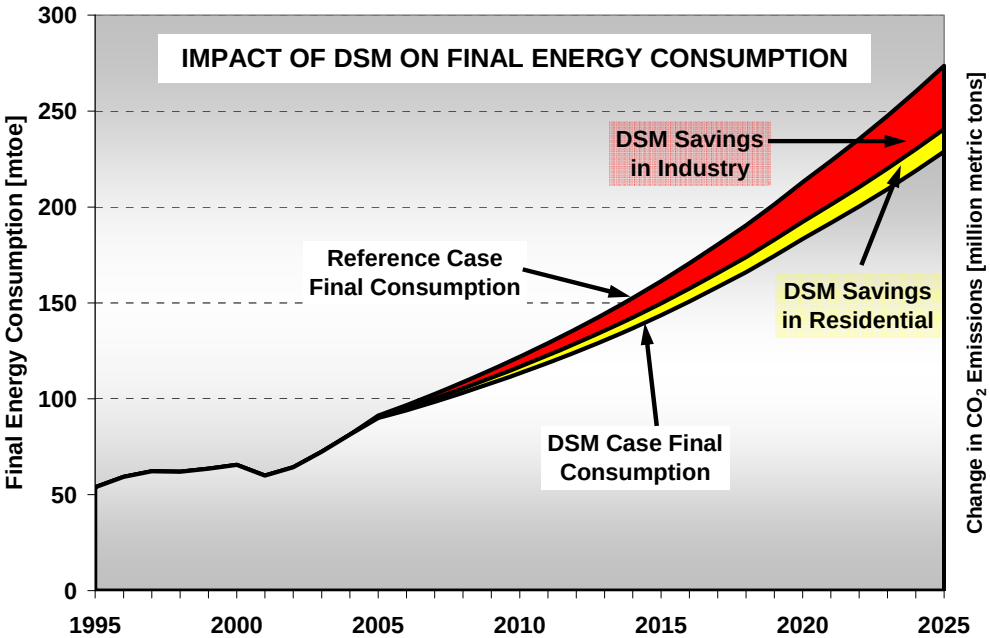
Renewables Scenario (cont'd)

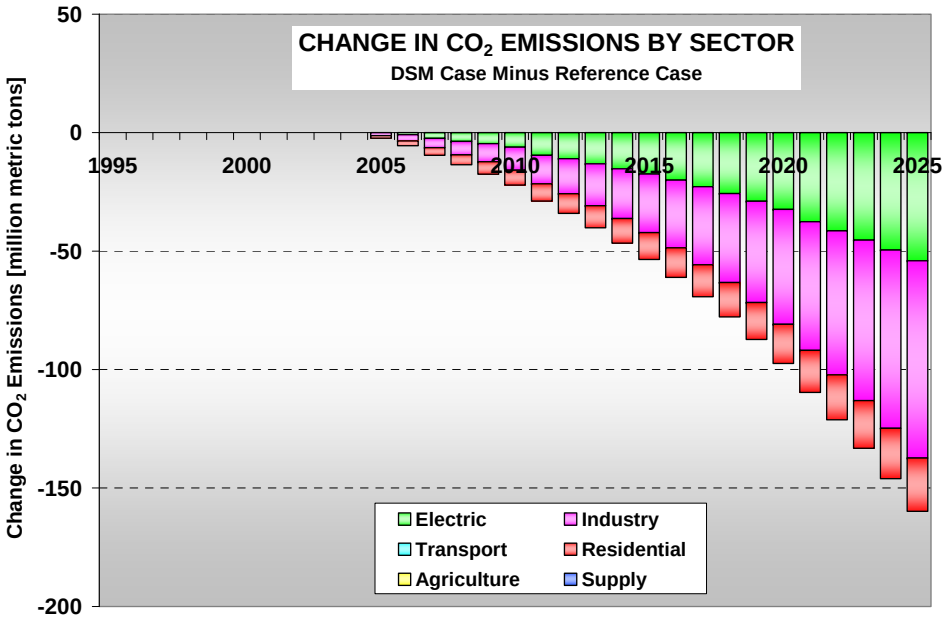




- **Wind and mini-hydro displace natural gas-fired generation which limits the emission reduction potential of renewables**
- **CO_2 emissions from power generation are reduced by 16.7 million t/yr (5.9%) by 2025 below the Baseline or Reference Case**
- **On the national level, emissions reductions are equivalent to a 1.9% cut**

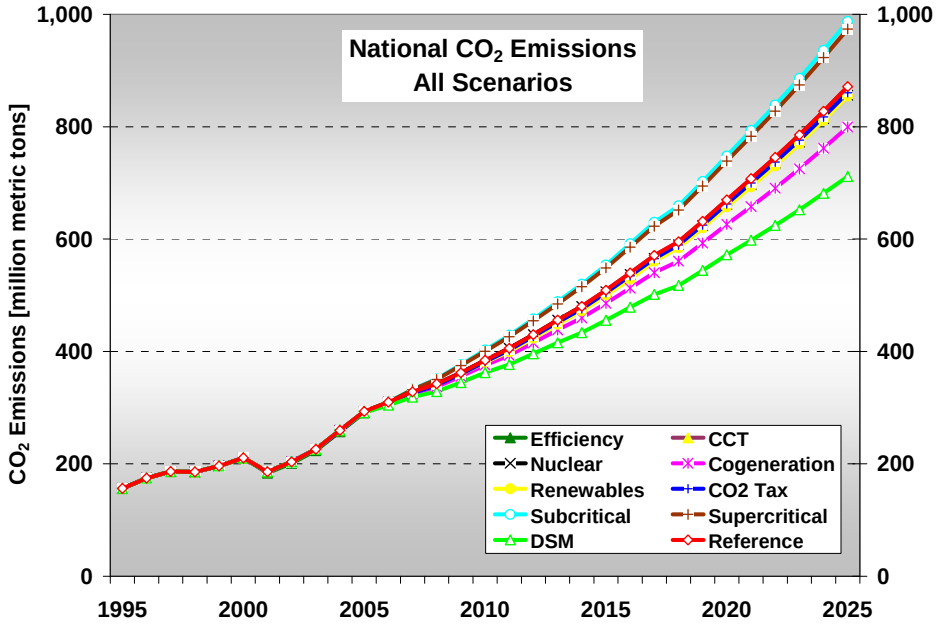
Demand Side Management (DSM) Scenario

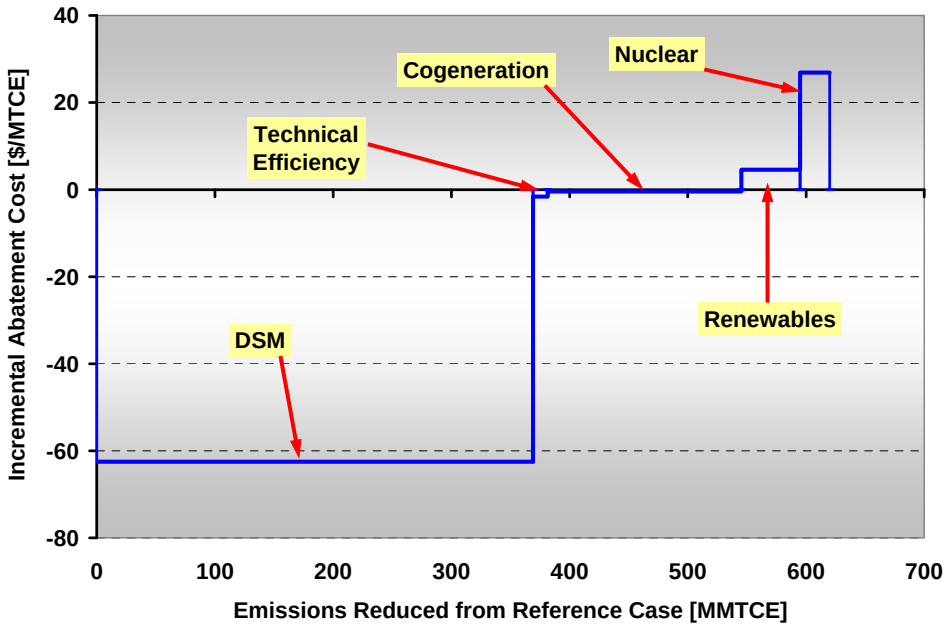




- **Total final energy consumption drops by 44.7 mtoe or 16.3%**
  - The largest declines are experienced by hard coal and coke with a drop of 24.5%, lignite of 24.3%, and natural gas of 24.2%
  - Electricity falls by 19% while oil products only drop by 6.2% as the transport sector is not affected by the DSM efforts
- **By 2025, DSM reduces national CO_2 emissions by 160 million tons per year or by 18.3% (23% industry, 30% households, 20% power sector)**

Summary GHG Mitigation Scenarios

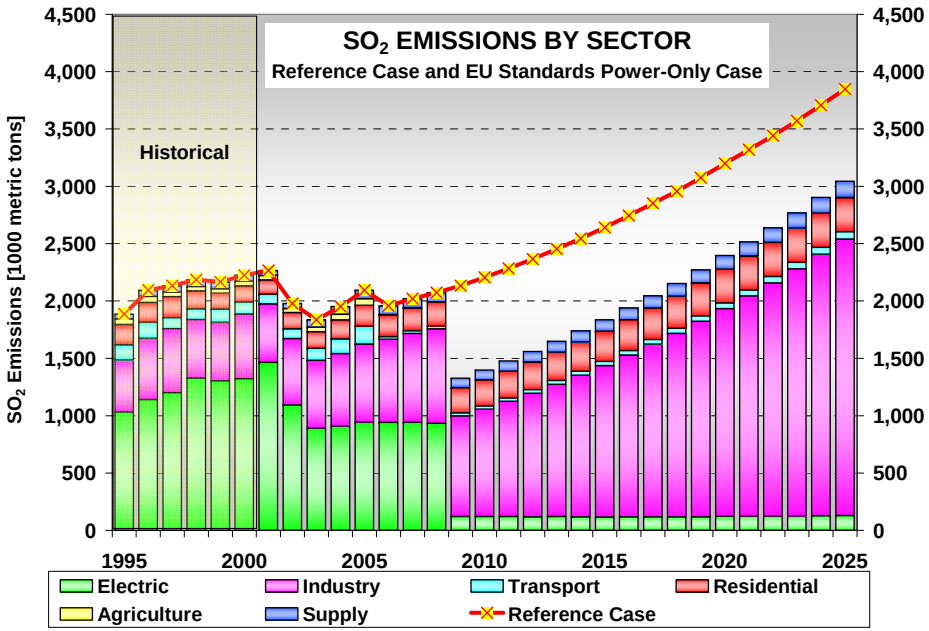


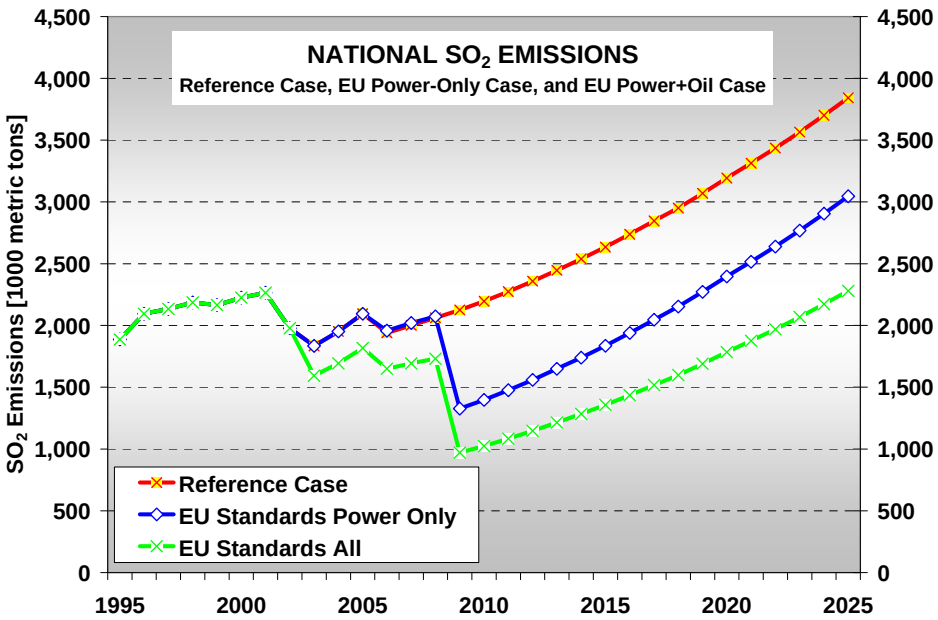


Scenario	Incremental Cost (million $)	Change in Net Energy Imports (million $)	Cumulative MMTCE Reductions (million tons)	MTCE Cost Effectiveness ($/MTCE)
DSM	-23,054.2	-9,027.4	369.03	-62.5
Technical Efficiency	-19.5	-48.2	12.40	-1.57
Cogeneration	-63.0	-915.8	163.78	-0.4
Renewables	228.6	-1,493.4	49.75	4.6
Nuclear	675.2	-235.5	25.10	26.9
Sub-critical Compared to Reference Case; Super-critical Compared to Sub-critical				
Constrained Gas Sub-critical	3,151.2	-2,218.4	-289.38	na
Constrained Gas Super-critical	-182.0	-213.2	33.93	-5.4

MMTCE = million metric tons of carbon equivalent (includes CO_2, CH_4, N_2O); MTCE = metric ton of carbon equivalent

Selected Local Pollution Scenario Results





Scenario	Incremental Cost (million $)	Change in Net Energy Imports (million $)	Cumulative SO_2 Reductions (million tons)	SO_2 Cost Effectiveness ($/ton SO_2)
EU Standards Power-Only	637.2	79.8	3.01	211
EU Standards Power + Oil	1,355.1	32.2	5.86	231
Petroleum Product Quality (Case1)	717.9	0	2.85	252

Some Conclusions and Caveats

- DSM, cogeneration in industry, and improved technical efficiency in the power sector appear to be attractive mitigation options
- Renewables have a role to play in GHG reduction policy; mini-hydro and windmills are the most promising
- Some options have noticeable ancillary benefits, that is, reductions in local pollutants (PM, SO_2, NO_X, etc.)
- Model also identified benefits in terms of lower net energy import bill
- Analysis needs to be updated, particularly given recent developments in global/regional energy markets
- If baseline natural gas dominance drops, mitigation options may become more attractive