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Task 7 Energy Sector Modeling: Executive Summary

Prepared for The World Bank
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EXECUTIVE SUMMARY

INTRODUCTION

Turkey's demand for energy and electricity is increasing rapidly. Since 1990, energy consumption has increased at an annual average rate of 4.3%. As would be expected, the rapid expansion of energy production and consumption has brought with it a wide range of environmental issues at the local, regional and global levels. With respect to global environmental issues, Turkey's carbon dioxide (CO_2) emissions have grown along with its energy consumption. Emissions in 2000 reached 211 million metric tons.

With GDP projected to grow at over 6% per year over the next 25 years, both the energy sector and the pollution associated with it are expected to increase substantially. This is expected to occur even if assuming stricter controls on lignite and hard coal-fired power generation. All energy consuming sectors, that is, power, industrial, residential, and transportation, will contribute to this increased emissions burden.

Turkish Government authorities charged with managing the fundamental problem of carrying on economic development while protecting the environment include the Ministry of Environment (MOE), the Ministry of Energy and Natural Resources (MENR), and the Ministry of Health, as well as the Turkish Electricity Generation & Transmission Company (TEAS). The World Bank, working with these agencies, is planning to assess the costs and benefits of various energy policy alternatives under an Energy and Environment Review (EER). Eight individual studies have been conducted under this activity to analyze certain key energy technology issues and use this analysis to fill in the gaps in data and technical information. This will allow the World Bank and Turkish authorities to better understand the trade-offs in costs and impacts associated with specific policy decisions.

The purpose of Task 7 – Energy Sector Modeling, is to integrate information obtained in other EER tasks and provide Turkey's policy makers with an integrated systems analysis of the various options for addressing the various energy and environmental concerns. The work presented in this report builds on earlier analyses presented at the COP 6 conference in Bonn.

ANALYTICAL METHODOLOGY

The study was carried out by Argonne National Laboratory's Center for Energy, Environmental, and Economic Systems Analysis (CEEESA) in close collaboration and support by a team from the Turkish Ministry of Energy and Natural Resources (MENR) and the Turkish Electricity Generation and Transmission Corporation (TEAS). The analytical methodology is based on the Energy and Power Evaluation Program (ENPEP), an integrated energy modeling system developed by Argonne. The MAED module of ENPEP was used for projection of energy demand, including electricity. The WASP module was used for electricity generation expansion planning. The BALANCE module projects future fossil and non-fossil energy flows in Turkey from energy extraction through end use across all sectors. BALANCE is a generalized equilibrium model that consists of a system of simultaneous linear and nonlinear relationships that specify the transformation of energy quantities and energy prices through the various stages of energy production, processing, and use. The model also calculates the environmental burdens, such as emissions of greenhouse gases and other pollutants. In addition, the VALORAGUA model was used to evaluate the operation of the hydro portion of the electric system.

The central integrating model, the BALANCE Module utilizes an energy network that was constructed to simulate the interactions among energy supply and

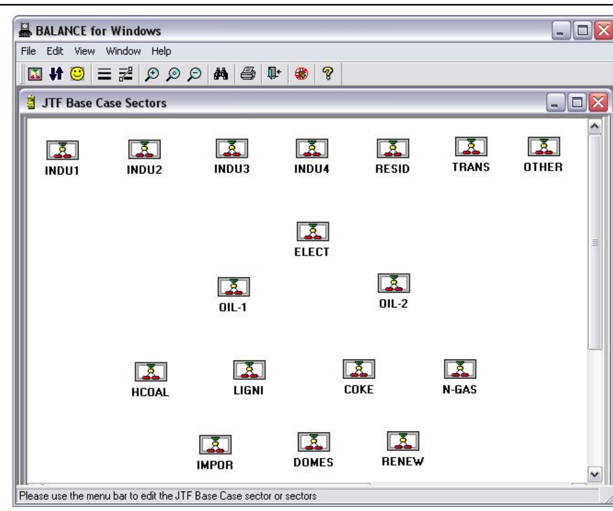

Figure S-1: Turkish ENPEP Network

demand sectors as shown in Figure S-1 (a more detailed network representation is given in the full report). The network design for the individual sectors varies, mostly depending on data availability.

ENERGY SECTOR DEVELOPMENT SCENARIOS

A Reference Case was developed to compare alternative scenarios. Scenarios are divided into two main categories: (i) Greenhouse Gas (GHG) Reduction scenarios that analyze options in form of technologies and policies that are primarily oriented toward the reduction of CO_2, CH_4, and N_2O and (ii) Local Pollution Reduction scenarios that analyze several options mostly targeting the reduction of particulate matter (PM), SO_2, NO_X, and solid waste.

GHG scenarios look at (1) technical efficiency improvements in existing power generating units, (2) clean coal technology for power generation, (3) constrained gas supply combined with the use of new sub-critical and super-critical coal-fired power stations (4) nuclear power, (5) demand-side management, (6) expanded use of cogeneration in the industrial sector, (7) expanded use of renewables for electricity generation, and (8) carbon tax.

The Local Pollution Reduction scenarios analyze the impact of (1) petroleum product quality improvements and (2) the implementation of EU Standards for the power sector and the oil sector.

MACROECONOMIC FORECASTS AND ENERGY DEMAND PROJECTIONS

The energy demand forecast by sector comes from the latest available official forecast from MENR, that is, the MAED results from December 2001. As part of Task 1 under the Turkey EER, a review of the Turkish energy demand forecast was performed. The econometric analysis found that, although the growth rates are robust over a long period of time, there are no solid grounds for rejecting the MAED forecasts in favor of lower figures.

The underlying annual population growth rate is 1.1% but declines from 1.41% for 1995–2005 to 0.8% for 2020–2025. The average GDP growth rate is 6.15% with higher rates at the beginning (7.74% during 1995–2005) and lower rates toward the end (5.6% for 2020–2025). The sectoral contributions of agriculture, mining, and construction are projected to fall while energy, manufacturing, and services increase. Given the macroeconomic assumptions, total final energy consumption is projected to grow at an average rate of 5.9% per year, while electricity demand is projected to increase on average by 7.4% per year. Growth rates vary by sector with industry growing the fastest (7.6%) and agriculture and non-energy growing the slowest (3.9% and 3.0%). Growth rates are not constant and typically fall from the beginning to the end of the planning horizon.

REFERENCE CASE PRICE PROJECTIONS

Prices drive the consumption of individual fuels as they compete for market share in the various end-use sectors. BALANCE is set up and calibrated to project consumer prices based on current and projected resource costs (crude oil, coal, and natural gas imports), conversion costs, and taxes and subsidies. For example, Figure S-2 shows projected gas prices by consumer group.

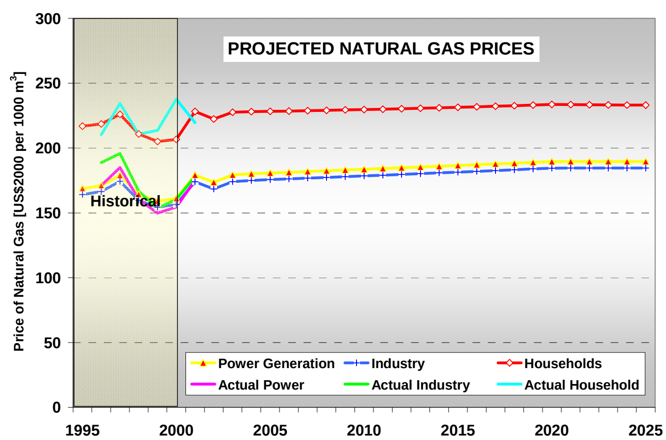

Figure S-2: Projected Consumer Gas Prices

REFERENCE CASE FINAL ENERGY CONSUMPTION

Based on the demand forecast from MAED, total final energy consumption grows at an average rate of 5.9% per year from 65.5 mtoe (2000) to 273.5 mtoe (2025).

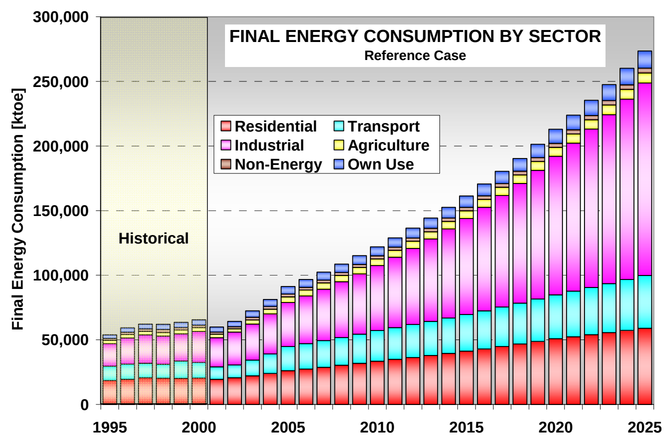

Figure S-3: Reference Case Final Energy Consumption by Sector

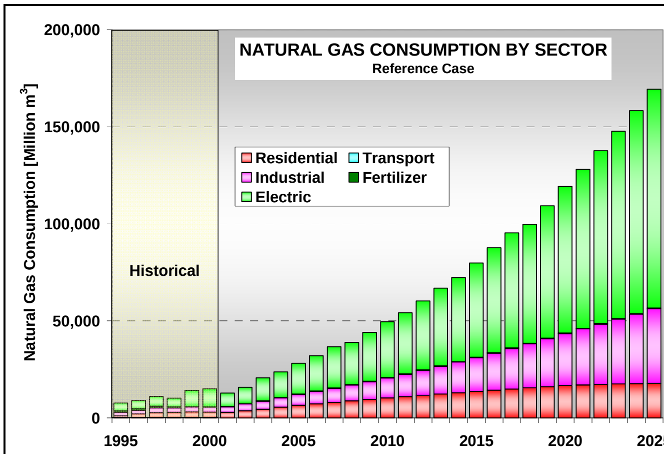

Figure S-4: Reference Case Gas Consumption by Sector

Average annual growth rates vary by sector, with industry having the highest rate at 7.6%, followed by the transportation sector with 5.0%. Over 2000–2025, industrial consumption increases from 23.9 to 148.9 mtoe increasing its share from 36% to 54% (see Figure S-3).

In terms of final energy by fuel, hard coal/coke increase their share slightly from 13–18%, lignite holds steady at 6%, electricity grows from 17–24%, oil products decline from 42–29% and natural gas increases from 7–17% between 2000 and 2025. The model also projects fuel mixes for each of the consumer groups or demand sectors.

REFERENCE CASE GAS CONSUMPTION

Total natural gas consumption is projected to increase at an annual rate of 9.6% from 15.0 to 169.4 billion m^3 (bcm) over 2000–2025. Power sector gas demand is one of the main drivers for this projected growth and will account for 112.8 bcm or 67% of total gas consumption in 2025 (up from 9.3 bcm in 2000). Industrial demand is the fastest growing market segment (11.5% annually) with gas expanding from 2.5–38.4 bcm during 2000–2025 and eventually accounting for 23% of total gas consumption (Figure S-4).

Projected natural gas consumption levels for the industrial, residential, and electric power sectors are compared with the latest forecasts by the Turkish gas company (BOTAS). For the industrial sector, ENPEP is projecting a more delayed market adoption, yet by 2015, the ENPEP projection is within 9% of the BOTAS forecast. A somewhat different picture emerges for the residential sector where up to 2012, projected ENPEP gas consumption is somewhat lower than the BOTAS values (within 1% by 2012), but then starts to be above the BOTAS values. For the electric sector, ENPEP tends to project lower values until 2008 and then higher values due to the aggressive gas-based power system expansion.

REFERENCE CASE ELECTRIC POWER GENERATION

New capacity additions are projected to total about 108 GW by 2025. WASP results indicate that the

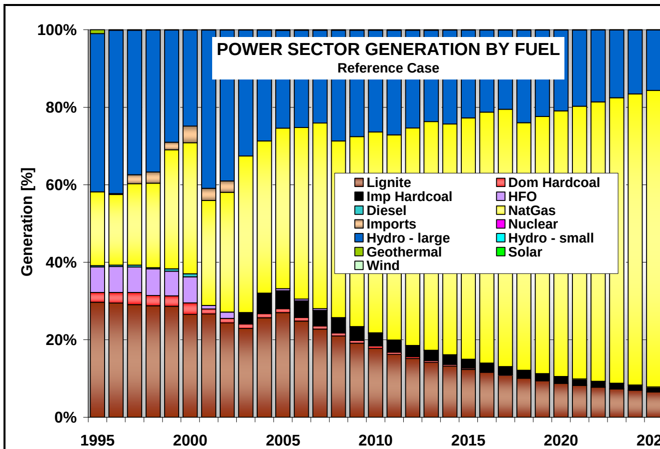

Figure S-5: Reference Case Projected Generation Mix

majority of the load growth is met with natural gas-fired generation (Figure S-5). By 2025, gas-fired units represent 67% (93 GW) of the installed generating capacity and account for 77% of total generation (588 of 768 TWh).

REFERENCE CASE PRIMARY ENERGY SUPPLY

Primary energy supply is projected to increase from 64.5 mtoe (1995) to 332.0 mtoe (2025). Crude oil imports remain constant at 33.0 mtoe after 2004 when the domestic refineries are forecast to run into their processing capacity, resulting in a drop in crude oil share from 44% to 10% of total supplies. Once the refining capacity is reached, net imports of refined products quickly grow from 2.6 to 52.3 mtoe (2000–2025), accounting for about 16% of total supplies by 2025. Natural gas quickly increases its share from 10% (6.3 mtoe) in 1995 to 42% (139.8 mtoe) of total supplies in 2025 (Figure S-6). Although renewables double over 2000–2025, their share decreases from 14% in 2000 to 7% in 2025.

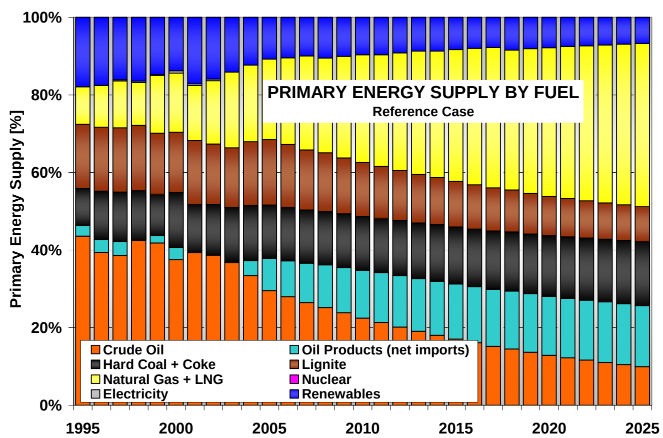

Figure S-6: Reference Case Projected Primary Energy Supply Mix

REFERENCE CASE IMPORT BILL AND ECONOMIC SYSTEM COST

Overall energy imports increase substantially from 37.1 mtoe (1995) to 275.2 mtoe (2025) and will bring Turkey's energy import dependency to 83% by the end of the study period. While in 1995, crude oil accounted for the majority of imports (67%), gas imports are slated to take this position with 51% by 2025. Turkey's total net energy import bill under the Reference Case is estimated to have a net present value over the entire study period (NPV over 2000–2025) of $155.518 billion with the total economic system cost of delivered energy estimated at US$ 372.621 billion (NPV over 2000–2025).

REFERENCE CASE PROJECTED EMISSIONS

For this analysis, the ENPEP model was configured to develop emission trajectories for 26 pollutants, including the major GHGs, pollutants of local/regional concern (PM, SO_2, NO_X, etc), as well as air toxics (e.g., heavy metals). Please see the full report as well as Annex C for more detailed emissions results.

The model projects total CO_2 emissions to increase at an average rate of 5.8%/yr and reach 871 million t/yr by 2025 (Figure S-7). The industrial contribution changes the most noticeably, rising from 31–42% driven by the high growth in industrial final energy as well as the continued reliance on solid and liquid fuels in this sector.

Total national SO_2 emissions reach their low point in 2003 with 1.83 million t/yr but then more than double to 3.85 million t/yr (2025). The majority of the emissions growth can be attributed to an increase in industrial solid fuel and fuel oil combustion and an associated rise in SO_2 emissions from 566–2,411 kt/yr over 2000–2025. By the end of the study period, industry is expected to be responsible for 63% of Turkey's SO_2 emissions. The increasing significance of the manufacturing sector goes hand in hand with a

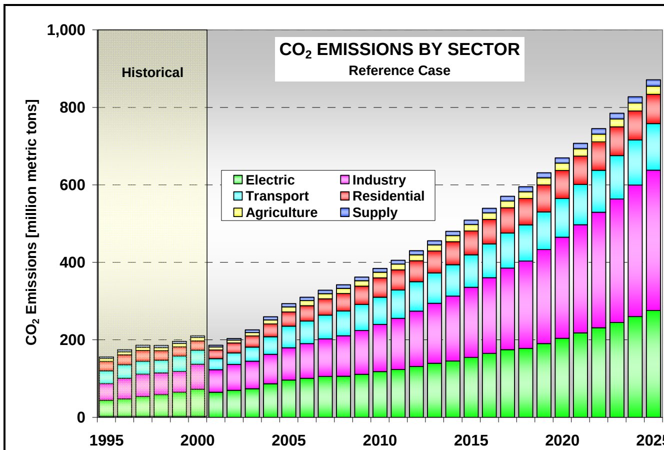

Figure S-7: Reference Case CO_2 Emissions

declining importance of the power sector. While in 2000, electricity generation accounted for 55% of national sulphur emissions, this share will be down to 24% by 2025. This is in large part because coal generation stays more or less constant while several new sulphur controls are already commissioned and expected to come on-line in the very near term.

GHG SCENARIOS

Technical Efficiency Scenario

The Technical Efficiency Scenario is designed to evaluate the environmental effectiveness of improving the heat rates of Turkey's existing power plants. The heat rate improvements vary according to generating unit, but are assumed to be in the range of 1–3%, starting in 2001.

Results show that with the exception of the domestic hard coal-fired YCTB unit, generation levels remain unchanged from the Reference Case. However, fuel consumptions are reduced but with little impact (0.1%) on primary energy supplies. As domestic coal generation is substituted for gas-fired generation, energy imports are affected to some degree, cutting the net energy import bill by $48 million (NPV over 2000–2025). Mostly emissions in the power sector (plus some CH_4 reductions in the coal supply sector) are impacted.

As shown in Figure S-8, improving the generating unit heat rates reduces power sector CO_2 emission in 2025

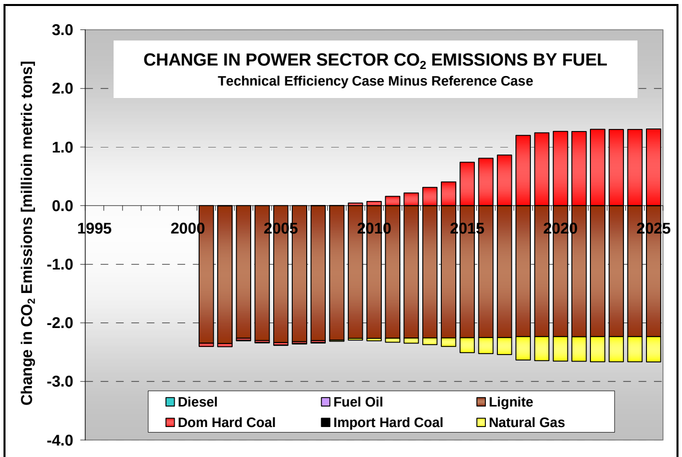

Figure S-8: Technical Efficiency Scenario Change in Power Sector CO2 Emissions

by 0.5% (0.2% effect on national emissions). The cumulative impact shows a total reduction of 48 million tons of CO_2 emissions (2000–2025) equal to a 0.4% cut. NO_X, PM, and particularly SO_2 are reduced even further (1.9% or 1.26 mt/yr for SO_2). As the incremental cost is negative (NPV of -$19.5 million) the Technical Efficiency Scenario is a "win-win" situation.

Clean Coal Technology Scenario

The purpose of the Clean Coal Technology Scenario is to evaluate the economic and environmental impact of introducing circulating fluidized bed combustion (CFBC) into the Turkish power system.

Results show that starting in 2004, the circulating fluidized bed combustion units used in this scenario replace four committed L350 units. As the combined generation level of all 6 CFBC units is somewhat larger than the output from the four L350 units, lignite generation and lignite fuel consumption generally increase except for a few years. As a result, natural gas generation falls, and so does fuel oil and domestic hard coal generation. Mostly, however, the additional output from the CFBC units replaces small portions of gas-fired generation

CO_2 emission reductions are low and vary markedly from year to year with the largest reduction occurring in 2008 (350 kt/yr or 0.31% of power sector emissions). NO_X, PM, and SO_2 emissions all decline, though they show similar but smaller variations across the years. The cumulative reduction potential of the Clean Coal Technology Case is very limited: CO_2 0.02%, SO_2 0.06%, and NO_X 0.8%. The net energy import bill drops by $82.5 million (NPV over 2000–2025) and the incremental cost is negative, that is, a cost savings of -$43.8 million. Though somewhat surprising, the cost is negative because the CFBC units replace four already committed L350 units which turn out to be less economic than the CFBC units had they been built instead, resulting in a cost savings.

Nuclear Scenario

The Nuclear Scenario assesses the impact on emissions attributable to introducing nuclear units into the Turkish power system starting in 2015, which the government now recognizes as the earliest date for nuclear power. The six nuclear units that are assumed to come on-line after 2015 essentially replace generation from gas-fired combined cycle gas turbine (CCGT) units with only very minor changes in the dispatch of the hard coal, lignite, and oil-fired generating units. By 2025, the six nuclear units generate about 42 TWh of electricity (5.5% of total).

Nuclear cuts the gas demand for power generation by 7.93 bcm (7% reduction). As a result, the net energy import bill drops by $235.5 million as the cost of imported nuclear fuel is substantially lower than that of imported natural gas.

CO_2 reductions start in 2015 with 2.65 mt/yr and reach 15.4 mt/yr by 2025 with all six nuclear units on-line. This is equivalent to a 5.4% cut in power sector emissions or a 1.7% reduction in national emissions. The carbon reduction potential is limited as nuclear is substituted for gas generation. Accordingly, PM and SO_2 reductions are negligible, with more noticeable cuts in NO_X emissions (3.6% of power sector emissions).

The incremental cost is $675.2 million (NPV over 2000–2025). As GHG mitigation option, the cost-effectiveness is about $7.3 per ton CO_2 or $26.9 per MTCE. As the cuts in other pollutants are very minor (typically less than 0.25%), nuclear does not appear to be a cost-effective way to reduce emissions of PM, SO_2, and NO_x in Turkey.

Cogeneration Scenario

The Cogeneration Scenario evaluates the economic and environmental impacts of more extensive use of cogeneration facilities in Turkish industrial plants. Results show that the projected growth in cogeneration essentially leads to a more moderate power sector gas expansion as well as a drop in gas-fired power generation. That is, a total of 23.3 GW (26%) of power sector CCGTs are avoided by cogeneration. Cogeneration reduces power sector gas-fired generation by as much as 26% by 2025.

While power sector natural gas consumption is expected to decline by 29.7 bcm (26%), industrial gas consumption is projected to grow substantially (53% over the Reference Case). Industry now accounts for 43% of total gas consumption (2025) as compared to 23% under the Reference Case. Natural gas is substituted for hard coal and coke, lignite, and oil products. The net effect of the growth in industrial gas consumption and the drop in power sector gas consumption is an overall increase by 9.4 bcm (5.5%) from 169.4 to 178.8 bcm by 2025.

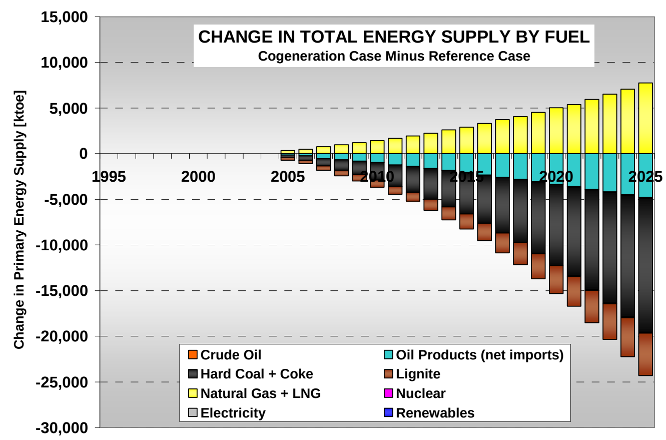

Figure S-9: Cogeneration Scenario Change in Primary Energy Supply

The supply shows the benefits of cogeneration as the higher efficiency leads to a cut in total energy supplies by 16.6 mtoe (5%) by 2025 (see Figure S-9). Despite the net increase in gas consumption, net energy imports are substantially reduced because of the drop in imported refined products and hard coal/coke. Cogeneration saves $916 million in imports (NPV over 2000–2025) while the incremental cost is negative, that is, a NPV of -$63 million.

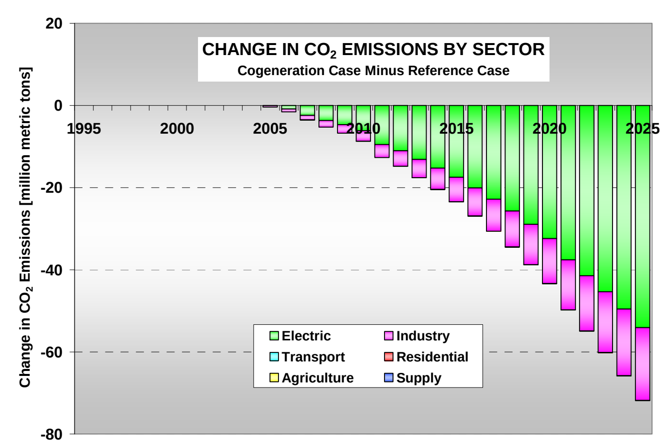

Figure S-10: Cogeneration Scenario Change in CO_2 Emissions

As shown in Figure S-10, the increased cogeneration program reduces power sector CO_2 emissions in 2025 by 54 million tons per year (20%) as a result of the drop in load and the corresponding decline in generation and fuel consumption levels; while industrial emissions drop by about 17.7 million t/y (4.9%). The overall fuel savings and the lower capital investment requirements in the power sector more than offset the costs involved in expanding industrial cogeneration. Cumulative emission reductions are substantial at 592 mt of CO_2 (4.8%). With the negative incremental cost, the cogeneration scenario is a cost-effective, “win-win” situation at -0.1 $/ton of CO_2.

Cogeneration has substantial ancillary benefits in form of cumulative reductions of PM, SO_2, and NO_X. Cumulative SO_2 emission reductions total about 6.07 million tons (9.0%), closely followed by an 8.6% reduction (1.86 million tons) in cumulative PM emissions.

Renewables Scenario

The Renewables Scenario is designed to analyze the economic and environmental impact of more extensive use of wind energy and mini-hydroelectric plants. Solar PVs were initially included in the first computer simulations but then dropped as the results showed they were not cost-effective in Turkey for grid supply. The more aggressive renewables program starts in 2005.

Results show that under the Renewables Scenario, 7,250 MW of gas-fired capacity is substituted for 19,250 MW of wind and 1,107 MW of small hydro over 2000–2025. By 2025, all renewables combined (including large hydro) amount to more than 54 GW or 35% of installed capacity. The additional generation from renewables quickly increases to 53.8 TWh (7% of total) by 2025 and essentially replaces CCGT generation with only minor changes in the dispatch of the other fossil fuel units. Combined with large hydro and geothermal, renewables generate 173.6 TWh (22.6%) of electricity by 2025.

CO_2 emissions from power generation are reduced by 16.7 mt/yr (5.9%) by 2025 as gas-fired generation is substituted for wind and small hydro which limits the emission reduction potential of renewables. Renewables can lower net energy imports by $1.49 billion (NPV over 2000–2025) at an incremental cost of $228.6 million. This leads to cost-effectiveness of $1.3 per ton CO_2 or $4.6 per MTCE. Although the total discounted economic system cost increases relative to the Reference Case, wind energy and mini-hydro appear to be cost-effective options for the mitigation of CO_2 and GHGs. Ancillary benefits in form of PM, SO_2, and NO_X emissions are very minor though (0.4% at the most).

CO_2 Tax Scenario

The purpose of the CO_2 Tax Scenario was to simulate the effects on the energy system and on emissions of imposing a tax on carbon. The tax was deemed to be initiated in 2004, using a value of $4 per ton CO_2 (equivalent to $14.7 per ton of carbon).

Results for the power sector show that the carbon tax leads to a change in the dispatch of some of the fossil fuel units. The changes are largest in 2004 and then gradually decline. The carbon tax also leads to a change in the overall fuel mix. Generally, the carbon-intensive solid fuels lose market share and are substituted for natural gas and oil. By 2025, total final consumption of hard coal/coke declines by 7%, lignite by 16%, while gas consumption increases by 13%.

The CO_2 tax actually results in an increase in the net energy import bill by $1.04 billion (NPV over 2000–2025) as the tax leads to shifts away from domestic coal resources over to imported natural gas and oil products (Figure S-11). The total cumulative CO_2 tax

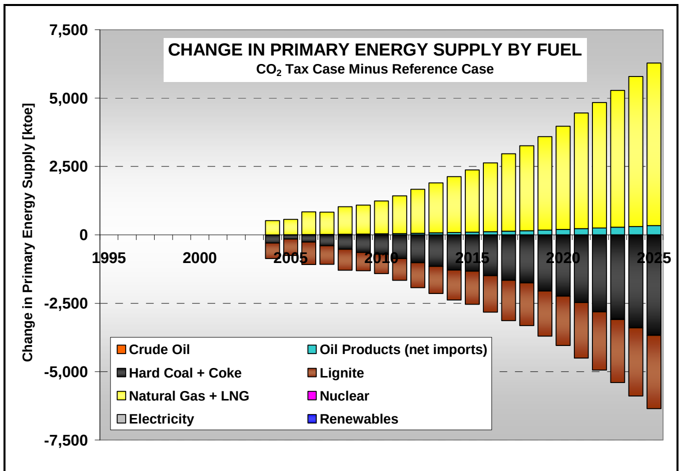

Figure S-11: CO_2 Tax Scenario Change in Primary Energy Supply

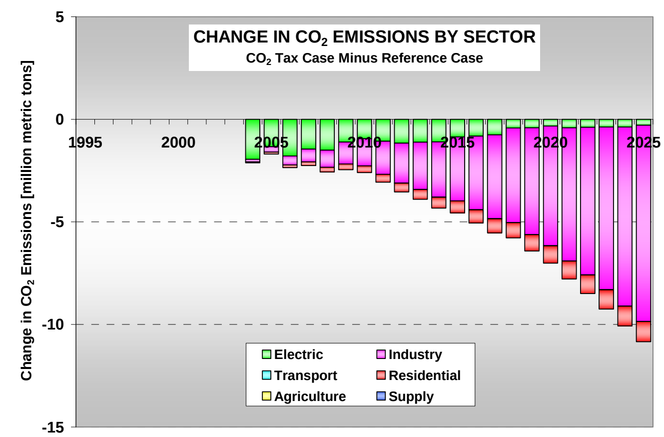

Figure S-12: CO_2 Tax Scenario Change in CO_2 Emissions

revenue (NPV) is estimated at $10.8 billion, with industry accounting for 33%, the utility sector for 32%, transport sector for 17%, households for 12%, and the other sectors for the remainder.

Although the carbon tax is successful in providing a market incentive to reduce emissions of CO_2, PM, SO_2, and NO_x, a tax of $4/t$CO_2$ is not high enough to cause a significant drop in CO_2 emissions. By 2025, national emissions are only reduced by 10.8 million t/yr (1.2%). As given in Figure S-12, CO_2 reductions are initially dominated by the power sector (up to 93% of reductions in 2004) while the majority of reductions by 2025 is projected to come from the industrial sector, (88% or 9.6 mt/yr). Over the period 2000–2025, cumulative CO_2 emissions are only 1% lower than in the Reference Case. More noticeable are ancillary benefits in form of cumulative SO_2 reductions; 2.1 million tons or 3.1% below Reference Case levels. Also, cumulative PM emissions are significantly reduced by about 3.5% (753 kt).

The market distortion via the carbon tax comes at an incremental cost of $4.82 billion (NPV over 2000–2025). This essentially is the cost of the tax-induced shifts to less economic fuels.

Constrained Gas Sub-Critical Scenario

Given that the power sector expansion under the Reference Case is dominated by natural gas, essentially reflecting recent power market trends around the world, the constrained gas scenario analyzes a situation with limited gas supply. It tries to quantify the additional costs that could be incurred if Turkey decided to constrain the power system and rely more heavily on domestic and imported coal. Compared to the Reference Case, a total of 5,500 MW of additional lignite-fired sub-critical capacity comes on line as well as 25,900 MW of imported coal-fired capacity (sub-critical).

Gas generation drops from 588 to 380 TWh while coal generation increases and now supplies 34.8% of total electricity by 2025.

Power sector CO_2 emissions in 2025 are 116 million t/yr or 42.1% above Reference Case levels, equivalent to an increase in national CO_2 emissions of 13.3% (Figure S-13). Even though gas-related CO_2 emissions drop by 76 mt/yr, the higher lignite combustion adds an additional 36 million t/yr and the higher hard coal consumption adds an additional 156 million tons with a net increase of 116 million tons. By 2025, the power sector is the largest source of CO_2 emissions (40%) followed by industry with 37%.

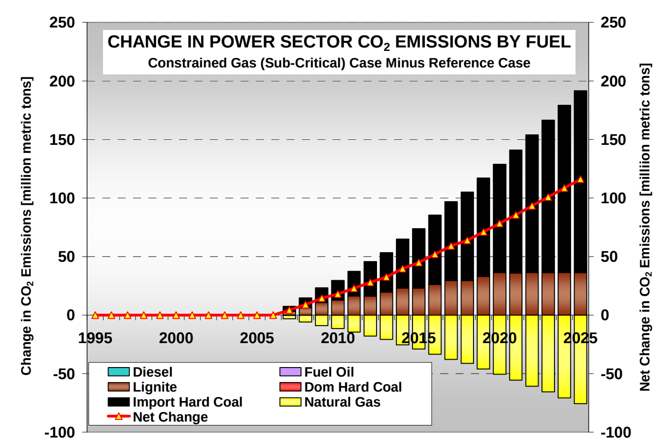

Figure S-13: Constrained Gas Sub-Critical Scenario Change in CO_2 Emissions

The Constrained Gas Sub-Critical Scenario has substantially higher emissions than the Reference Case. At the same time the incremental cost is $3.15 billion (NPV over 2000–2025). The scenario essentially illustrates the benefits of the aggressive gas-based power system expansion under the Reference Case. It shows that if Turkey encounters constraints on the gas supply, it will come at a substantial economic and environmental cost. This scenario demonstrates the

Reference Case as a "win-win" situation compared with the Constrained Gas Sub-Critical Scenario.

Constrained Gas Super-Critical Scenario

The purpose of the super-critical variation of the constrained gas scenario is to assess the advantages of using more-efficient and slightly more expensive supercritical instead of sub-critical generation technology assumed in the previous scenario. Incremental results for this scenario will be calculated using the Sub-Critical Scenario as the point of comparison.

The use of the higher-efficient super-critical units reduces fuel consumptions in the power sector. By 2025, the super-critical units result in overall power sector fuel savings of 4.01 mtoe (3.2%) as compared to the sub-critical run.

The super-critical plants lead to additional CO_2 emissions reductions of 13.7 mt/yr compared to sub-critical units, lowering power sector emissions by 3.5% (2025). All other pollutants show a similar trend.

The incremental cost compared to the Sub-critical Scenario is negative (NPV of -$182 million). Although both the sub-critical and super-critical constrained gas scenarios have higher costs and higher emissions than the Reference Case, the super-critical scenario is clearly preferable to the sub-critical scenario, given the lower total discounted economic system cost and lower emissions. The introduction of supercritical technology is highly cost-effective, especially in terms of CO_2/GHG.

DSM Scenario

The purpose of the demand-side management (DSM) scenario is to look at the potential of DSM and energy conservation measures to reduce energy consumption and national GHG emissions and to measure the impacts on total energy system costs.

Results show that by 2025, total final energy consumption drops by 44.7 mtoe or 16.3% from 273.6 to 228.9 mtoe (Figure S-14). The largest declines are experienced by hard coal and coke (24.5%), lignite (24.3%), and natural gas (24.2%).

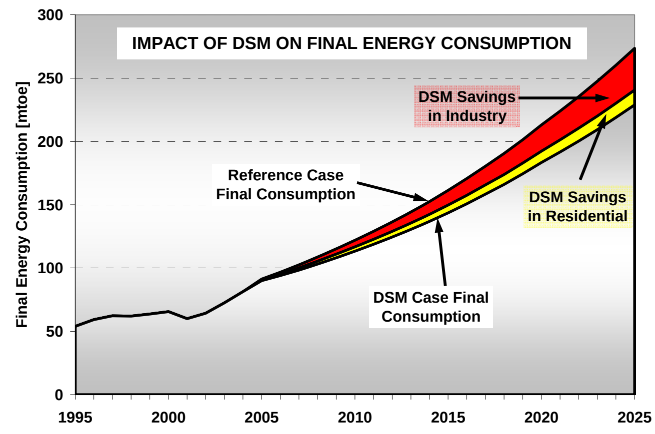

Figure S-14: DSM Scenario Final Energy Consumption

Electricity consumption falls by 19% while oil products are reduced by 6.2%.

Emission reductions in the DSM scenario are significant and take place in the industrial, residential, and power sector. DSM reduces national CO_2 emissions in 2025 by 160 million tons per year or by 18.3% (Figure S-15). Sectoral reductions are as follows:

- 83.3 mt/yr or 23.0% in industry,
- 22.5 mt/yr or 29.8% in households, and
- 54.1 mt/yr or 19.6% in the power sector.

The incremental cost is negative, that is, a NPV of -$23.05 billion. This appears to make DSM a very attractive option. The very high cost savings come with

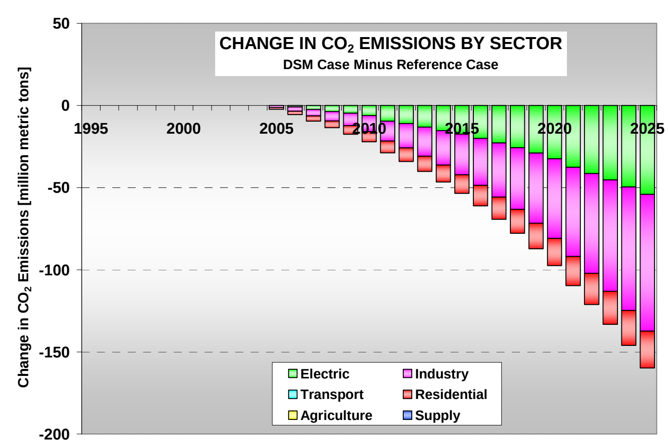

Figure S-15: DSM Scenario Change in CO_2 Emissions

the highest cumulative emissions reductions of all scenarios, that is 1.34 billion tons of CO_2 (10.8% reduction), 5.32 million tons of SO_2 (7.9% reduction), 1.77 million tons of NO_X (6.5% reduction), and 1.52 million tons of PM (7.0% reduction). Reasons why this option appears so attractive include a possible underestimation of the cost of industrial DSM efforts and the fact that we took an optimistic DSM target for the household sector of 20% at no cost.

LOCAL POLLUTION SCENARIOS

Petroleum Product Quality Scenario

The Petroleum Product Quality Scenario is designed to analyze the environmental effectiveness of reducing the sulphur content of fuel oil starting in 2003. The analysis focuses on heavy and light fuel oil used by households, industry, the utility sector, and some minor amounts in the supply and transport sectors. Reducing the fuel oil sulphur content cuts Turkey's SO_2 emissions in 2003 by 241 kt/yr (13.1%). By 2025, the cuts are even larger with 19.9% (from 3.85 to 3.08 mt/yr). The majority of emissions reductions (81%) are projected for the industrial sector (Figure S-16). This reduces industrial SO_2 emissions by 26% from 2.41 to 1.79 million t/yr.

The incremental cost is $718 million (NPV over 2000–2025). Given the large total cumulative emissions reductions of 10.95 million tons of SO_2 (a cut of 16.2%), the scenario appears to be an attractive sulphur control option with a cost-effectiveness of $252/ton (discounted). Ancillary benefits are negligible.

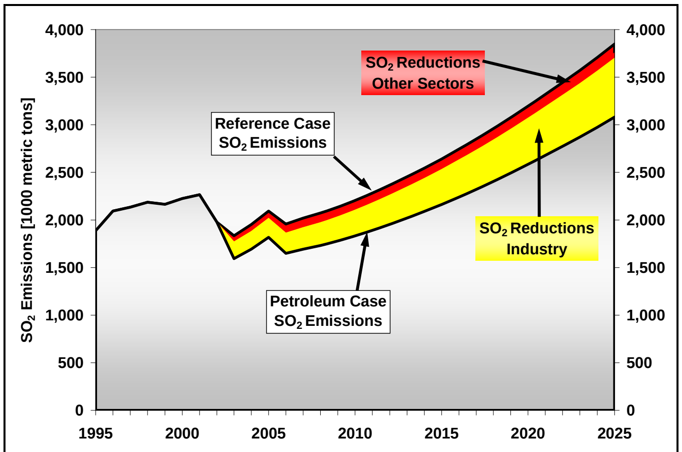

Figure S-16: Petroleum Product Quality Scenario SO_2 Emissions

EU Standards Power-Only Scenario

The EU Standards Power-Only Scenario analyzes the effects of implementing the new EU Standards for power stations. Under the scenario, existing lignite and hard-coal generating units are modified to reflect installation of new environmental control equipment or upgrade of existing equipment. Retrofits are conducted in 2 stages:

- 2009 to meet EU-2001 standards on PM and SO_2
- 2015 to meet EU-2001 standards on NO_x

In addition, all new generating stations are required to meet the EU standards.

Based on unit-level compliance information, CEEESA staff estimated the investment requirements, impacts on the O&M costs of the units/plants, and the effect on unit-level heat rates. The total capital investment requirements to comply with all EU standards for PM, SO_2, and NO_X are estimated at $375.3 million (NPV over 2000–2025).

Adding the cost of pollution control and the change in heat rates of the existing lignite and hard coal-fired units leads to a shift in the dispatch order where part of the lignite-fired and domestic hard coal-fired generation is substituted for gas-fired CCGT generation.

As given in Figure S-17, model results show a cut in power sector SO_2 emissions in 2025 of 803 kt/yr (85%). A similarly large reduction (77%) is observed for PM emissions. On a national scale, SO_2 emissions in 2025 drop by 21% (Figure S-18). The lower power sector emissions cause the industrial contribution to be more prominent, that is, industry will account for 79% of national SO_2 emission by 2025.

The NO_X standards will cut power sector emissions by 61.3 kt/yr (21%) by 2025. However, the impact on national emissions is minor, that is, a 3.7% reduction.

The incremental cost is $637 million (NPV over 2000–2025) but given the substantial total cumulative emissions reductions of 13.7 million tons of SO_2 (20.2%), the scenario appears to be an attractive

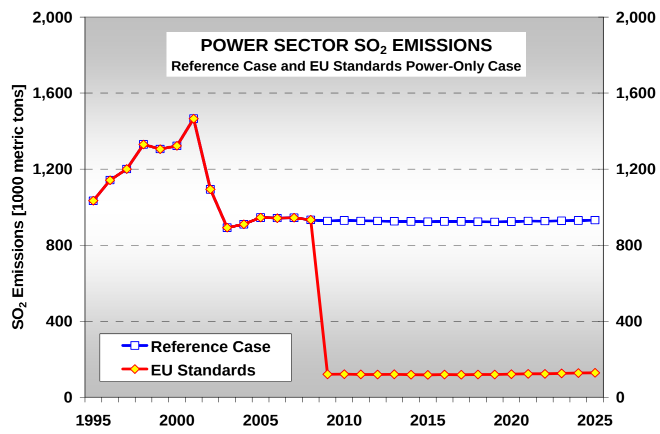

Figure S-17: EU Standards Power-Only Scenario Power Sector SO_2 Emissions

sulphur control option with a cost-effectiveness of $211 per ton (discounted). Ancillary benefits in terms of GHG reductions are negligible.

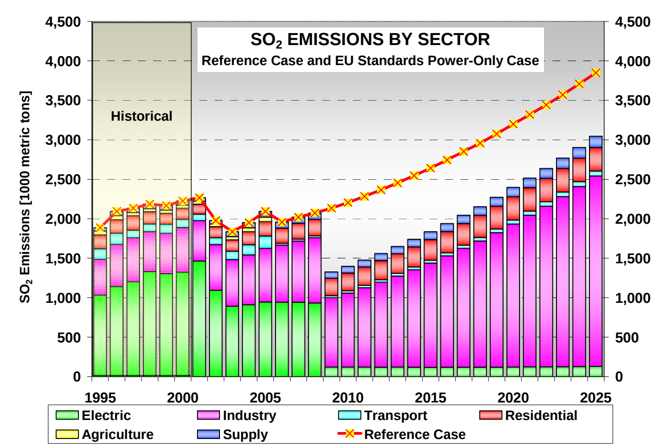

Figure S-18: EU Standards Power-Only National SO_2 Emissions by Sector

EU Standards Power + Oil Scenario

This scenario is built on the previous scenario. In addition to implementing the power sector-related EU standards, this scenario also improves the quality of petroleum products in line with EU requirements, as under the Petroleum Product Quality Scenario.

The impact on Turkey's total SO_2 emissions is substantial, that is, a 41% reduction in 2025 national emissions compared to the Reference Case. Improving the petroleum product quality contributes heavily to

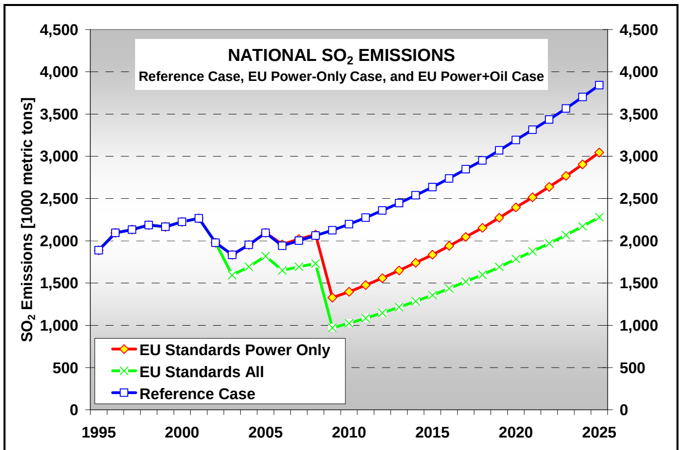

Figure S-19: EU Standards Power + Oil National SO_2 Emissions

these reductions, that is, 49% of the emission cuts in 2025 are attributable to the sulphur reduction in the fuel oil (Figure S-19).

The incremental cost is $1.365 billion (NPV over 2000–2025). Given the substantial total cumulative emissions reductions of 24.6 million tons of SO_2 (a 6.4% cut), the scenario turns out to be an attractive sulphur control option with a cost-effectiveness of $231 per ton (discounted). Ancillary benefits in terms of GHG reductions are negligible.

CONCLUSIONS

Reference Case

The Reference Case highlights the advantages of natural gas for the development of Turkey's energy supply, especially in the power sector. Given the underlying price projections of the Reference Case, more extensive gas use than at present appears to be the least-cost way of meeting growing electricity demand. At the same time, emissions of most pollutants are moderated and grow at rates below the growth of final energy demand.

The Constrained Gas Sub-critical Scenario attempts to quantify the benefits of natural gas against a greater use of coal and lignite, using conventional sub-critical generating technology. The results show that although gas imports and the import bill are higher under the Reference Case (by 23% and 1.5% respectively), the economic cost of energy supply is lower and so are all emissions, hence gas is a "win-win" option. The scenario also shows that if Turkey encounters constraints on the gas supply, they will impose substantial economic and environmental costs. In addition, the Constrained Gas Super-critical Scenario shows that if gas utilization is to be restricted, it is better to rely more on super-critical technology rather than sub-critical.

Results for a low-GDP variation of the Reference Case shows the sensitivity of national emissions to the assumed economic growth (see Appendix D). Under the low-GDP scenario, national CO_2 emissions in 2025 are about 43% lower than under the Reference Case. The impact on other pollutants is comparable, that is, NO_X 40%, PM 39%, and SO_2 32%.

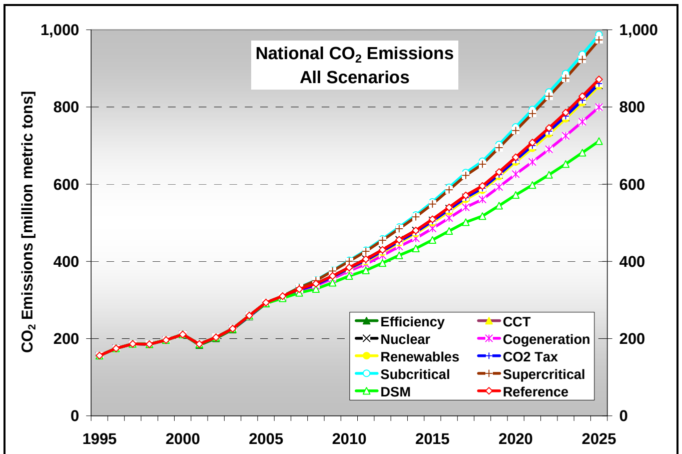

Figure S-20: CO_2 Projection to 2025 All Scenarios

GHG Scenarios

Based on results from the GHG scenarios, the following conclusions can be drawn in relation to formulating a national policy on climate change.

As Table S-1 and Figure S-20 to Figure S-22 show, DSM, cogeneration in industry, and improved technical efficiency in the power sector are clearly essential ingredients of future climate change policies. They are "win-win" options compared the Reference Case. Under all these scenarios, the economic cost of energy supply and the cost of energy imports will be lower as well as emissions of CO_2/GHG. In addition, there are substantial ancillary benefits involved in terms of PM, SO_2, NO_X, and other pollutants, particularly with regard to DSM and cogeneration.

However, it must be acknowledged that the scope for more reliance on cogeneration in industry and improved technical efficiency in the power sector is intrinsically restricted. Scenario results suggest that less than 5% and 1% reduction in CO_2/GHG emissions, respectively, can be accomplished over the period 2000–2025.

Also, the implementation costs for DSM may be underestimated while the environmental impact is the greatest in terms of projected emission reduction. The reduction in CO_2/GHG emissions exceeds 10% over the period 2000–2025 and the potential may be even more than considered as the analysis only concentrated on the residential and industrial sector but excluded the transportation sector for lack of country-specific information.

Greater natural gas utilization is clearly preferable to coal and lignite. The Constrained Gas Sub-critical and the Constrained Gas Super-critical Scenarios have CO_2/GHG emissions more than 8% and 7% above the Reference Case and the economic cost of energy

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				

Table S-1: Summary of GHG Scenario Results

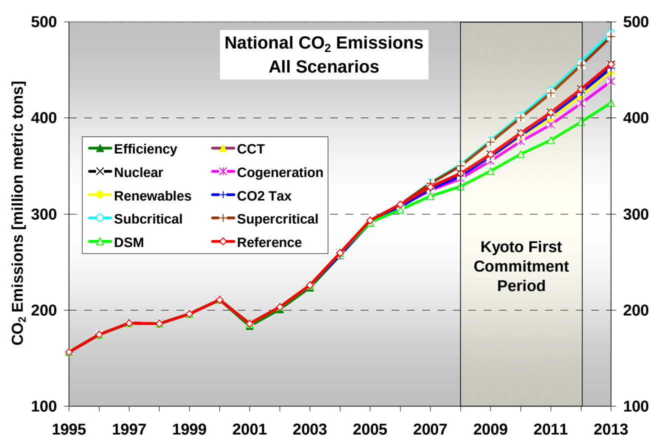

Figure S-21: CO_2 Projection to 2013 All Scenarios

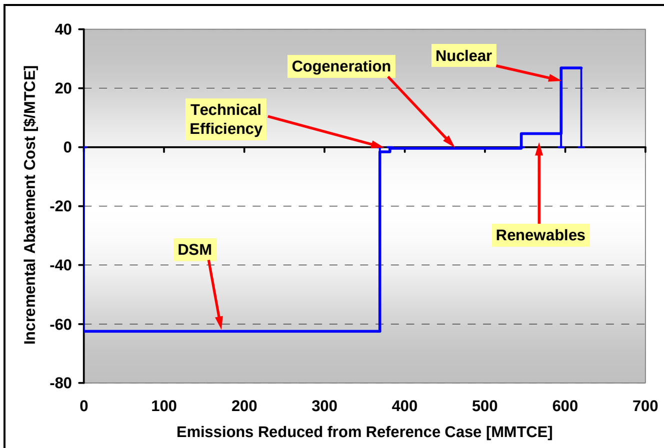

Figure S-22: GHG Abatement Cost Curve

supply is also higher, although the energy import bill is slightly lower.

Nuclear power is not attractive for GHG reduction, even though the net energy import bill drops. It is expensive as the abatement cost of $7.3 per ton CO_2 exceeds GEF guidelines and is at the top end of the range for the PCF. In addition, the scope is limited and scenario result suggests that the abatement of CO_2/GHG emissions would be less than 1% over the period 2000–2025. Although nuclear would simultaneously cut emissions of other pollutants, there are serious environmental risks associated with nuclear development.

Renewables have a role to play in GHG reduction policy, but development of renewables will need to be selective. Mini-hydro and windmills are the most promising and offer an attractive cost for the reduction of CO_2/GHG at an estimated $1.3 per undiscounted ton of CO_2 and $4.6 per ton of undiscounted carbon equivalent. Solar PV installations appear to be unattractive on cost grounds except perhaps for particular applications, such as off-grid supply or in low-temperature heating applications. The scope for mini-hydro and windmills is limited and scenario results suggest that total abatement of CO_2/GHG emissions would be less than 2% over the period 2000–2025.

A carbon tax will bring about some beneficial inter-fuel substitution, inducing consumers to use less carbon intensive gas in preference to coal and lignite. However, the result of these fuel shifts is an increase in the economic cost of energy supply. Also, at the tax rate considered ($4/ton CO_2), not much change occurs in the level of carbon emissions (less than 1% drop over planning horizon) so much higher tax rates are likely to be required to bring about substantial reductions.

Each of the options applied individually does not have a major impact on CO_2/GHG emissions: an effective national policy on climate change will have to rely on the aggressive application of a combination of options, e.g. DSM, cogeneration in industry, improved technical efficiency in the power sector, greater natural gas utilization and investment in mini-hydro plants and windmills.

Local Pollution Scenarios

Based on results from the Local Pollution Scenarios, the following conclusions can be drawn in relation to formulating national policies aimed at improving local air quality. As in the case of GHG reduction policies, any strategy to control local pollution should consider the following (see Table S-2 and Figure S-23):

Improving the petroleum product quality would cut sulphur emissions by more than 16% over the period 2000–2025 at a cost of $252/tonne (discounted).

The introduction of EU Standards and the improvement of petroleum product quality would be cost-effective options to reduce emissions of sulphur. EU standards would result in sulphur emissions 36% lower than under the Reference Case over the period 2000–2025. The cost of abatement is estimated to be

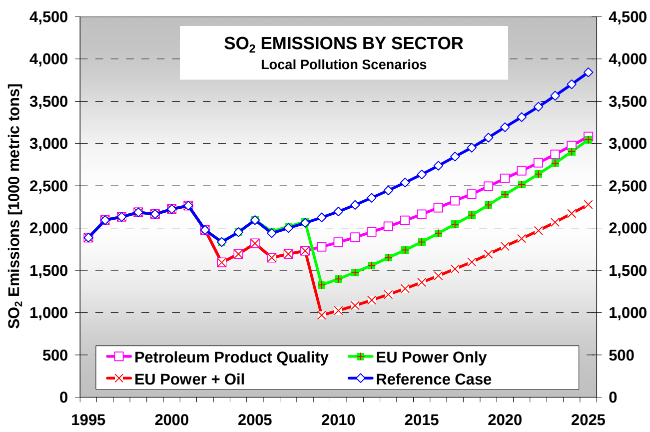

Figure S-23: Summary of Local Pollution Scenario Results

about \$231/tonne (discounted), and there would also be moderately lower emissions of PM and NO_x.

DSM, cogeneration in industry, and improved technical efficiency in the power sector, can all contribute to local pollution control because the economic cost of energy supply and the cost of energy imports will be lower as well as emissions of PM, SO_2, NO_x and ash.

The use of natural gas in preference to coal and lignite, because emissions of PM, SO_2, NO_x and ash are all higher in the Constrained Gas Sub-critical and Super-critical Scenarios, as well as the economic cost of energy supply, although at a lower net energy import bill.

The nuclear power scenario showed little impact on local pollutants and, in addition, the analysis makes no allowance for the potentially major environmental risks associated with handling nuclear fuel, disposing of nuclear waste and nuclear accidents.

Although a carbon tax is normally regarded as an economic instrument for the control of GHG emissions, it would also yield as a by-product or ancillary benefit, useful reductions in local pollution.

In contrast with GHG reduction policies, windmills and mini-hydro showed little promise for local pollution reduction policy relative to the Reference Case, because they had a negligible or no impact on PM, ash, NO_x and SO_2. It should be noted, though, that the results are greatly influenced by comparison with the high preponderance of natural gas in the Reference Case.

As with the design of policies for GHG mitigation, it is clear that no one single policy option will have a major impact on all emissions causing local pollution. An effective national policy for the reduction of local pollution will have to rely on the application of a mix of options, e.g. DSM, cogeneration in industry, improved technical efficiency in the power sector, greater natural gas utilization and tighter emissions standards.

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

Table S-2: Summary of Local Pollution Scenario Results