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, SO₂, NOₓ)
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
- **MACRO-E** for Macroeconomic Analysis
- **PC-VALOR AGUA** for Hydro Analysis
- **WASP IV** for Expansion Analysis
- **IMPACTS** for Environmental Effects Analysis
- **GTMax** for Deregulated Market Analysis
- **DAM** for Decision Analysis
- **ICARUS** for Production Cost Analysis

Analysis was Conducted with the Energy and Power Evaluation Program (ENPEP)
ENPEP is Used by Analysts Worldwide to Study Strategic Energy and Environmental Issues

Energy and Environmental Projections

- CO_{2} EMISSIONS BY SECTOR (Reference Case)
- Analysis of Regional Power System Interconnections

Analysis of Restructured Power Markets

- Projected Hourly Electricity Prices by Location
  - Zone 1
  - Zone 2
  - Zone 3
The Model Includes all Energy Forms and All of Turkey’s Energy Sectors in an Integrated Framework.
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
Model Results Include Projections of Greenhouse Gases and Other Pollutants

- Greenhouse gases: CO₂, CH₄, N₂O, CO, NMVOC
- Local/regional pollutants: PM, PM10, PM2.5, SO₂, NOₓ, 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)

- Gas, 6896, 23.3%
- Oil, 2475, 8.4%
- Hard Coal, 300, 1.0%
- Lignite, 6387, 21.6%
- Hydro, 13504, 45.7%

2025 Projected Generation Capacity (MW)

- Gas, 93946, 67.1%
- Hydro, 33756, 24.1%
- Lignite, 8083, 5.8%
- Oil, 2475, 1.8%
- Hard Coal, 1700, 1.2%
- Imp Elec

Capacity Additions including Committed Units (MW)

- Hydro
- Gas
- Lignite
- Imp Coal
- Dom Coal
- Imp Elec

Baseline Annual CO₂ Emissions are Projected to Grow 5.8% Annually from 211 to 871 million tons

• Industrial CO₂ 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 CO₂ 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, SO₂, and NOₓ 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)
- CO₂ tax of $15 per ton of carbon
- Expanded demand side management in industry and households

- Local pollution scenarios analyze policies to reduce PM, SO₂, and NOₓ
  - Improving petroleum product quality (reducing S-content in fuel oil)
  - Upgrading existing power stations to meet EU standards on PM and SO₂ (2009) and NOₓ (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
- CO₂ 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 CO₂ emissions by 160 million tons per year or by 18.3% (23% industry, 30% households, 20% power sector)
Summary GHG Mitigation Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Incremental Cost (million $)</th>
<th>Change in Net Energy Imports (million $)</th>
<th>Cumulative MMTCE Reductions (million tons)</th>
<th>MTCE Cost Effectiveness ($/MTCE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSM</td>
<td>-23,054.2</td>
<td>-9,027.4</td>
<td>369.03</td>
<td>-62.5</td>
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<td>Technical Efficiency</td>
<td>-19.5</td>
<td>-48.2</td>
<td>12.40</td>
<td>-1.57</td>
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<td>Cogeneration</td>
<td>-63.0</td>
<td>-915.8</td>
<td>163.78</td>
<td>-0.4</td>
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<tr>
<td>Renewables</td>
<td>228.6</td>
<td>-1,493.4</td>
<td>49.75</td>
<td>4.6</td>
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<td>Nuclear</td>
<td>675.2</td>
<td>-235.5</td>
<td>25.10</td>
<td>26.9</td>
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Sub-critical Compared to Reference Case; Super-critical Compared to Sub-critical

| Constrained Gas Sub-critical | 3,151.2                      | -2,210.4                                 | -299.38                                   | na                               |
| Constrained Gas Super-critical | -182.0                      | -213.2                                   | 33.93                                     | -5.4                             |

MMTCE = million metric tons of carbon equivalent (includes CO₂, CH₄, N₂O); MTCE = metric ton of carbon equivalent
Selected Local Pollution Scenario Results

**SO₂ Emissions by Sector**
- Reference Case and EU Standards Power-Only Case

**SO₂ Emissions [1000 metric tons]**
- Historical
- Electric
- Industry
- Transport
- Residential
- Agriculture
- Supply
- Reference Case

**SO₂ Emissions**
- 1995 to 2025

**SO₂ Emissions by Sector**
- Historical
- Electric
- Industry
- Transport
- Residential
- Agriculture
- Supply
- Reference Case

**National SO₂ Emissions**
- Reference Case, EU Power-Only Case, and EU Power+Oil Case

**Reference Case, EU Standards Power-Only, EU Standards All**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Incremental Cost (million $)</th>
<th>Change in Net Energy Imports (million $)</th>
<th>Cumulative SO₂ Reductions (million tons)</th>
<th>SO₂ Cost Effectiveness ($/ton SO₂)</th>
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<tr>
<td>EU Standards Power-Only</td>
<td>637.2</td>
<td>79.8</td>
<td>3.01</td>
<td>211</td>
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<td>EU Standards Power + Oil</td>
<td>1,355.1</td>
<td>32.2</td>
<td>5.86</td>
<td>231</td>
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<tr>
<td>Petroleum Product Quality (Case1)</td>
<td>717.9</td>
<td>0</td>
<td>2.85</td>
<td>252</td>
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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, SO₂, NOₓ, 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