e-SAGE

Energy-extended South African General Equilibrium model

James Thurlow, UNU-WIDER
Core model structure
Demand and supply linkages

- **Warehouse**
  - Domestic supply
  - Supplier 1
  - Supplier n
  - Output 1
  - Output n

- **Freight transport**
  - CET
  - Exports
  - Imports
  - CES

- **Consumption linkages**
  - CES
  - LES
  - LEO
  - Households
  - Investment
  - Government
  - Traders

- **Production linkages**
  - Factory
  - Office
  - Supermarket
  - Freight transport

- **Inputs**
  - Capital
  - Labor
  - Intermediates

- **Demand and supply linkages**
  - CES
  - LEO
  - CET

- **Exports**
  - Imports
  - Total supply
e-SAGE model structure

- 2007 social accounting matrix (SAM)
  - 61 activities and 49 commodities
    - 4 × agriculture, 49 × industry, 8 × services
  - 9 factors of production
    - 4 × education-based labor groups
    - 1 × non-energy capital
    - 3 × energy capital: ESKOM, PetroSA, SASOL
    - 1 × agricultural crop land
  - 14 household groups based on per capita expenditures
    - 10 deciles with top decile divided in 5 sub-groups
## 2007 energy balance (native units)

<table>
<thead>
<tr>
<th></th>
<th>Coal (kt)</th>
<th>Crude oil (kt)</th>
<th>Natural gas (TJ)</th>
<th>Electricity (GWh)</th>
<th>Petroleum (MI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>247,666</td>
<td></td>
<td>128,033</td>
<td>247,587</td>
<td>25,528</td>
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<tr>
<td>Imports</td>
<td>1,783</td>
<td>19,042</td>
<td>45,383</td>
<td>10,624</td>
<td>4,859</td>
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<tr>
<td>Exports</td>
<td>66,964</td>
<td></td>
<td></td>
<td>13,589</td>
<td>4,743</td>
</tr>
<tr>
<td>Stocks</td>
<td>7,324</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>175,162</strong></td>
<td><strong>19,042</strong></td>
<td><strong>173,417</strong></td>
<td><strong>244,622</strong></td>
<td><strong>25,645</strong></td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19,113</td>
</tr>
<tr>
<td>Petroleum</td>
<td>45,437</td>
<td>19,042</td>
<td>67,732</td>
<td>7,133</td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>22,486</td>
<td></td>
<td>104,821</td>
<td>122,400</td>
<td>1,209</td>
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<tr>
<td>Transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,501</td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td>32</td>
<td>5,998</td>
<td>1,433</td>
<td></td>
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<tr>
<td>Commerce</td>
<td>3,201</td>
<td></td>
<td>864</td>
<td>32,705</td>
<td>704</td>
</tr>
<tr>
<td>Residential</td>
<td>1,135</td>
<td></td>
<td>53,771</td>
<td>754</td>
<td></td>
</tr>
</tbody>
</table>
Differential electricity prices

Rand per MWh in 2005
Energy as an intermediate input

- Inputs
  - Capital
  - Labor

- Inputs
  - Input 1
  - Input n

- Energy

- Sector output

- LEO

- CES
Energy-saving investment behavior

- Change in energy inputs per unit of output based on energy prices

- Energy product input coefficient \((i_\omega_{ij})\) falls when...
  - Energy prices \((p_i)\) rise (provided there is some new investment)
  - New investment share \((s_j)\) is positive (provided the price rises)

- Governed by a response elasticity \((\rho)\)

\[
\frac{i_\omega_{ij,t+1}}{i_\omega_{ij,t}} = 1 - (1 - \frac{P_{jt}}{P_{jt,t-1} \uparrow \rho}) \cdot s_{\downarrow i}
\]
Macro closure rules

• Upward sloping labor supply curves for less-educated workers

• “Putty clay” capital and endogenous capital accumulation

• Fixed current account with flexible real exchange rate

• Savings-driven investment
  – Distinguish between electricity and non-electricity sector investment
  – Electricity investment differentiated by subsector (esp. import content and job creation)
  – Government borrows abroad to pay for investment (gradual interest and principal repayment)
Carbon tax scenarios
with e-SAGE model
Carbon tax simulations

• Domestic carbon tax
  – Applied to all fossil fuels burned in South Africa
  – Starts at US$3 per ton CO2 in 2012 and rises gradually to US$30 in 2022
  – Uniform reduction in indirect sales tax rates (distribution neutral)

• Domestic border tax adjustment on embodied carbon
  – As above, but rebate exporters and tax imports at same carbon tax rate

• Foreign border tax adjustment
  – South African exports are taxed at foreign border
  – Starts at US$1.5 per ton CO2 in 2012 - rises gradually to US$15 in 2022

• Recycling revenues
  – Instead of sales taxes, reduce corporate taxes or increase social transfers
Electricity sector

- Future electricity generation mix is predetermined by IRP2
  - Baseline scenario includes the Policy-Adjusted investment plan

**Base Case (BAU)**

**Policy-Adjusted**
Cost: ???
Emissions: -19% of BAU by 2025

**Emissions 3**
Cost: US$171 bil.
Emissions: -42% of BAU by 2030
Emissions reductions

• A US$30 per ton CO2 carbon tax is enough to reach national emissions reduction targets (using sectoral measures)

• “Ring-fencing” of electricity means large reduction in other sectors

Changes in GHG emissions, 2010-2025

<table>
<thead>
<tr>
<th></th>
<th>Business-as-usual, 2010</th>
<th>Deviation from “business-as-usual” scenario, 2025 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Policy-Adjusted</td>
</tr>
<tr>
<td>CO₂ emissions (mil.mt) using the reference approach</td>
<td>447.5</td>
<td>-8.6</td>
</tr>
<tr>
<td>Electricity generation</td>
<td>237.0</td>
<td>-19.0</td>
</tr>
<tr>
<td>Other sectors/households</td>
<td>210.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Total CO₂ emissions (mil.mt) using the sectoral approach</td>
<td>397.4</td>
<td>n.a.</td>
</tr>
</tbody>
</table>
GDP and employment losses

Economywide abatement costs

Sectoral sources of losses

Decline in GDP or employment, 2025 (%)

Decline in GHG emissions, 2025 (%)

Decline in GDP, 2025 (%)

Carbon tax (US$/mt)

Services
Construction
Manufacturing
Mining
Agriculture

Economywide abatement costs

Sectoral sources of losses

Decline in GDP or employment, 2025 (%)

Decline in GHG emissions, 2025 (%)

Decline in GDP, 2025 (%)

Carbon tax (US$/mt)
Income distribution

Consumption growth incidence curves

Deviation in consumption, 2025 (%)

Ranked population per capita expenditure percentiles

Corporate tax
Sales tax
Retaliatory tax
Social transfers
Our conclusions

• Carbon taxes reduce national welfare and employment
  – Absorption and employment fall by 1.2 and 0.6 percent by 2025
  – Effects are small in annual growth rate terms (less than 0.1 %-points)

• Welfare and employment losses are larger if RSA’s trading partners unilaterally impose BTAs on South African exports

• Domestic BTAs cushion welfare and employment losses while maintaining the same emissions reductions

• Mode of revenue recycling strong influences growth and distributional outcomes (i.e., trade-offs)
SATIM-SAGE
Linked CGE and TIMES models
Endogenizing the energy sector

- Would economywide marginal abatement costs be lower if the electricity sector is not “ring fenced”?
  - Cheaper regional energy options? (e.g., INGA, Zambezi, Mozambique gas)
  - Might mean lower carbon taxes are needed for non-electricity sectors

- One option is to allow the CGE model to pick energy profile (e.g., share of electricity from coal, nuclear or renewables)
  - BUT build plans involve discrete changes and non-economic decisions

- Alternative is to embed an energy model within the CGE model (or vice versa)
  - SATIM: Inter-temporal optimization energy model
  - SAGE: Recursive dynamic CGE model
Simulating the energy planning process

- **2007**: SATIM
- **2010**: SAGE, SATIM
- **2020**: SAGE, SATIM
- **2030**: SAGE
- **2070**: SATIM

**Iterative coupled runs**

- **Sector energy demands**
- **Fossil fuel prices**
- **Committed build plan**
- **Labor costs**
- **Electricity subsector supplies**
- **Investment costs**
- **Final electricity price**

**Committed** **Forecast**
Projections from SAGE model

• Energy demand forecasts
  – Sector level: Agriculture, Commerce, Industry, Residential, Transport

• Fuel prices
  – Imported: World prices, import tariffs, exchange rates, transaction costs
  – Domestic: Production costs, including labor and imported inputs

• Committed build plan
  – Historical investments cannot be undone
  – Includes future plants under construction (due to long lead times)
Build plans from SATIM

- TIMES forecasts build plans and detailed energy supplies
  - Aggregate energy sectors in the CGE model are a weighted combination of subsector supplies

- For periods until next IRP...
  - Impose level and composition of energy supply on CGE model

- For periods beyond next IRP...
  - Impose supply composition in CGE model, but allow demand/supply level to vary based on economic conditions
Electricity price from SATIM

- TIMES estimate price inclusive of debt amortization
  - i.e., the price needed to meet O&M and long-run capital investment costs

- Electricity price projection imposed on CGE model
  - Government taxes or subsidizes the equilibrium market price to maintain the fixed TIMES price