The ETP model
Developments and Preliminary Results
Dolf Gielen
Fridtjof Unander

ETSAP meeting 29/10/2002

Topics

- Model approach
- Database
- Results: the electricity sector
- Results: ETL
- Next steps
ETP1 demand

- Final demand from WEO 2002 (until 2030)
- Extrapolated to 2050
- Load curve, based on sector electricity demand
- At least 10% decentralized supply
- Transmission losses region-specific
- No distribution cost
ETP database 1

- 70% of model development time is for data collection
- One global technology database
- Region-specific constraints
- Region-specific cost index
- Region and sector specific discount rate

ETP database II

- Existing technologies + new technologies
- Vintage approach
- Resource/technology supply curves
- Minimize the use of adratios
ETP database III
Supply curves

Technology/ fuel cost
[$/kW] or
[$/GJ]

Option 1
Option 2
Option 3

Q [GW] or [PJ]

ETP database IV
Electricity sector

- Renewables
- Fossil fuels
- Fossil fuels + CO₂ capture
- Nuclear (constrained)
- No “negawatts” in ETP1 (but in ETP2)
ETP database V
Renewables

- Wind onshore (10) offshore (5)
- Hydro (3)
- Solar PV (2)
- Solar thermal (1)
- Biomass (9)
- Waste (6)
- Geothermal (3)
- Tidal (1)

Renewables are intra-regionally diverse
(example wind)
Renewables potential conceptual assessment

Renewables assessment method

- Start from technological potential (WEC)
- Estimate socially acceptable potential from economic potential (WEC) + maximum annual investment growth
- Stepped supply curve (economics)
- Significant cost reductions in time (exogenous assumptions, later ETL)
Renewables key assumptions

- Wind onshore socially constrained
- Wind offshore cost/location constrained
- Solar PV cost constrained
- Biomass cost/availability constrained
- Hydro socially constrained
- Waste socially constrained

Fossil fuels continued progress

<table>
<thead>
<tr>
<th>Power plant type</th>
<th>Efficiency 2005</th>
<th>Efficiency 2020</th>
<th>Power cost 2015 [mills/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGCC</td>
<td>53</td>
<td>58</td>
<td>29</td>
</tr>
<tr>
<td>IGCC</td>
<td>48</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>USCSC</td>
<td>44</td>
<td>44</td>
<td>37</td>
</tr>
<tr>
<td>SOFC</td>
<td></td>
<td>68</td>
<td>48</td>
</tr>
<tr>
<td>FBC</td>
<td>37</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>PFBC</td>
<td>41</td>
<td>41</td>
<td>28</td>
</tr>
<tr>
<td>Decentralized</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas CHP 100 MW</td>
<td>E+H 80</td>
<td>E+H 80</td>
<td>30</td>
</tr>
<tr>
<td>SOFC (decentralized)</td>
<td></td>
<td>56</td>
<td>70</td>
</tr>
</tbody>
</table>
CO2 capture & sequestration I

- “CO2-free fossil fuels”
- Technologically feasible
- Costs are coming down (hopefully)
- Not yet applied in electricity sector
- Probably only with new power plants
- Especially important for coal

ETP database

CO2 capture & sequestration II

- Retrofit existing SCSC
- USCSC, CO2 removal flue gas
- USCSC, Oxyfuel combustion
- IGCC, CO2 removal flue gas
- IGCC, CO2 removal input gas
- NGCC, CO2 removal flue gas
- SOFC, gas fired
- IGCC-SOFC, coal fired

Pipeline transportation

- Onshore EOR
- Depleted oil fields onshore
- Depleted oil fields offshore
- Offshore EGR
- Onshore EGR
- ECBM <1km depth
- ECBM >1km depth
- Onshore aquifers
- Offshore aquifers
- Methanol/DME production
ETP database
CO₂ capture & sequestration III

<table>
<thead>
<tr>
<th>Fuel + type</th>
<th>Starting year</th>
<th>INV  [$/kW]</th>
<th>FIX  [$/kW.yr]</th>
<th>Eff [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal steam cycle – MEA scrubbing</td>
<td>2005</td>
<td>1976</td>
<td>80</td>
<td>30.9</td>
</tr>
<tr>
<td>Coal steam cycle – membranes + MEA scrubbing</td>
<td>2015</td>
<td>1718</td>
<td>75</td>
<td>36.1</td>
</tr>
<tr>
<td>Coal IGCC – Selexol</td>
<td>2005</td>
<td>1909</td>
<td>100</td>
<td>36.1</td>
</tr>
<tr>
<td>Coal IGCC – Selexol + MEA scrubbing</td>
<td>2015</td>
<td>1459</td>
<td>75</td>
<td>47.5</td>
</tr>
<tr>
<td>Coal IGCC – SOFC</td>
<td>2030</td>
<td>2000</td>
<td>100</td>
<td>57.1</td>
</tr>
<tr>
<td>Gas CC – MEA scrubbing</td>
<td>2005</td>
<td>1120</td>
<td>50</td>
<td>46.8</td>
</tr>
<tr>
<td>Gas CC – membranes + MEA scrubbing</td>
<td>2015</td>
<td>894</td>
<td>40</td>
<td>54.1</td>
</tr>
<tr>
<td>Gas turbine + SOFC</td>
<td>2020</td>
<td>1500</td>
<td>75</td>
<td>66.7</td>
</tr>
</tbody>
</table>

Database quality

- New coal/gas technologies: data quality ++++, main uncertainty fuel cell prospects
- ZETs: +, main uncertainty costs and efficiency future CO₂ capture technology for coal
- Renewables: +/-, main uncertainty regional characteristics + potentials
ETP results: the electricity sector

- CO2 valued at $50/t CO₂ from 2010 onward
- 3 runs: WEO Reference scenario (no new policy), CO₂ tax with and without CO₂ capture and sequestration (TAX50 and TAX50NZ)

ETP preliminary results ELE sector: Fuel use, IEA region
ETP preliminary results:
Electricity production
TAX50, IEA region

ETP preliminary results:
CO₂ capture and storage
TAX50, IEA region
ETP preliminary results
CO₂ capture and sequestration
regional patterns

ETP preliminary results: the
impact of capture on renewables
ETP preliminary results: CO2 emissions

ETP preliminary results: the impacts on investment costs

Global Investment costs

[Graphs showing CO2 emissions and investment costs over different scenarios.]
Endogenous Technology Learning (ETL)

- Algorithm works
- A number of MARKAL bugs solved (Gary)
- Run time 1 1/2 hr for a global model with 4 learning technologies
- Unfortunately major calculation pitfalls

ETL - Learning characteristics

- Clustering/technology selection
- Maximum production growth rate
- Progress ratios
ETL - Software issues

- Maximum cumulative capacity
- Model time horizon
- Regional discount rate
- Regional investment costs
- No. of steps
- Step-wise approximation of LC

ETL - Parameter sensitivity I
PV [GW]

<table>
<thead>
<tr>
<th>Steps</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>CC_max</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>35</td>
<td>212</td>
<td>462</td>
<td>1505</td>
<td>5756</td>
<td>9010</td>
<td>10000</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>3</td>
<td>32</td>
<td>176</td>
<td>788</td>
<td>952</td>
<td>10000</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10000</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10000</td>
</tr>
</tbody>
</table>
### ETL - parameter sensitivity II PV [GW]

<table>
<thead>
<tr>
<th>Steps</th>
<th>CCmax</th>
<th>Time horizon</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1,000</td>
<td>2050</td>
<td>1</td>
<td>24</td>
<td>147</td>
<td>298</td>
<td>298</td>
<td>303</td>
</tr>
<tr>
<td>5</td>
<td>10,000</td>
<td>2050</td>
<td>35</td>
<td>212</td>
<td>462</td>
<td>1505</td>
<td>5756</td>
<td>9010</td>
</tr>
<tr>
<td>5</td>
<td>50,000</td>
<td>2050</td>
<td>1</td>
<td>51</td>
<td>154</td>
<td>154</td>
<td>154</td>
<td>154</td>
</tr>
<tr>
<td>10</td>
<td>10,000</td>
<td>2050</td>
<td>1</td>
<td>3</td>
<td>32</td>
<td>176</td>
<td>788</td>
<td>952</td>
</tr>
<tr>
<td>10</td>
<td>50,000</td>
<td>2050</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>10,000</td>
<td>2095</td>
<td>129</td>
<td>952</td>
<td>218</td>
<td>2908</td>
<td>3025</td>
<td>3076</td>
</tr>
</tbody>
</table>

---

### Next steps: ETP2

- **First version of a global model (“ETP2”) covering the entire energy system is expected to be operational in November 2002.**

- **Things to do:**
  - More details for renewables, ZETs and upstream oil and gas production.
  - Adding demand side technologies to the model.
  - Representation of ETL.
  - Review of all 15 regions (ETSAP).