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ecoinvent data v2.0
Energy Supply

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Rolf Frischknecht, ESU-services Ltd.
New ecoinvent data v2.0

- US electricity sector:
  coal, natural gas & nuclear chains + PV mix
  → electricity mix

- Chinese electricity sector:
  coal & nuclear chains + PV mix
  → electricity mix

- Emerging small scale combined heat and power systems (CHP)
  (Alex Primas, Basler & Hofmann)

- Photovoltaics (Niels Jungbluth)

- Bioenergy systems (parallel session)

- Electricity mixes (Rolf Frischknecht):
  New: BR & JP, EU-27
  Updated: European countries
  (incl. emissions of coal power plants in PL, CZ, SK, HU)

Small CHP: system boundaries

Inventories include micro gas turbines, fuel cells (PEM and SOFC) and Stirling engines
Natural gas, burned in micro gas turbine 100kWe

- Natural Gas fuel and CO₂-Emissions from operation are the main impact.

Natural gas, burned in PEM fuel cell 2kWe, future

- Infrastructure of fuel cell of importance for impact on ecosystem quality.
Wood pellets, burned in stirling cogen unit 3kWe, future

- NOx and Particulate emissions from operation are of importance for total impact.

Small CHP: technical characteristics

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CHP-System</th>
<th>el. power</th>
<th>el. efficiency</th>
<th>th. efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas, biogas</td>
<td>Cogen 160kWe lambda=1</td>
<td>160 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 32%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 55%</td>
</tr>
<tr>
<td>Natural gas, biogas</td>
<td>Micro gas turbine</td>
<td>100 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 29%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 46%</td>
</tr>
<tr>
<td>Natural gas, biogas</td>
<td>SOFC-GT fuel cell</td>
<td>180 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 58%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 22%</td>
</tr>
<tr>
<td>Natural gas, biogas</td>
<td>SOFC fuel cell</td>
<td>125 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 47%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 33%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Mini-BHKW</td>
<td>5 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 25%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 65%</td>
</tr>
<tr>
<td>Natural gas, biogas</td>
<td>PEM fuel cell</td>
<td>2 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 32%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 55%</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>Stirling motor</td>
<td>3 kW&lt;sub&gt;el&lt;/sub&gt;</td>
<td>η&lt;sub&gt;el&lt;/sub&gt; = 23%</td>
<td>η&lt;sub&gt;th&lt;/sub&gt; = 67%</td>
</tr>
</tbody>
</table>
**electricity / heat from natural gas**

- Mini-BHKW
- PEM fuel cell 2kWe, future
- micro gas turbine 100kWe
- cogen 160kWe lambda=1
- SOFC fuel cell 125kWe, future
- SOFC-GT fuel cell 180kWe, future

**Ecoindicator 99 (H/A) points / kWh**

- Green: eco-indicator 99, (H,A), ecosystem quality
- Blue: eco-indicator 99, (H,A), human health
- Red: eco-indicator 99, (H,A), resources

**High electric & total efficiency leads to a low impact**

**electricity / heat from biogas**

- Mini-BHKW
- PEM fuel cell 2kWe, future
- micro gas turbine 100kWe
- cogen 160kWe lambda=1
- SOFC fuel cell 125kWe, future
- SOFC-GT fuel cell 180kWe, future

**Ecoindicator 99 (H/A) points / kWh**

- Green: eco-indicator 99, (H,A), ecosystem quality
- Blue: eco-indicator 99, (H,A), human health
- Red: eco-indicator 99, (H,A), resources

**Use of Biogas → reduction of fossil resource demand & GHG emissions**

Presentation: Christian Bauer
US electricity sector

- US specific modelling for 3 energy chains:
  - hard coal
  - natural gas
  - nuclear

- Main data sources used:
  - US National Renewable Energy Laboratory LCI database
  - Emissions & Generation Resource Integrated Database
  - Nuclear Regulatory Commission, US DOE
  - ecoinvent background data


Total US production: 4006 TWh/a

Electricity imports: 34 TWh/a

Production mix ≈ Supply mix

- hard coal 47.4%
- natural gas 17.4%
- nuclear 19.7%
- hydropower, pumped storage 6.9%
- photovoltaic 0.0%
- industrial gas 0.1%
- lignite 2.3%
- oil 3.3%
- biogas 0.2%
- nuclear 19.7%
- biomass 1.0%
- waste 0.6%
- natural gas 17.4%
- hydropower 6.9%
- photovoltaic 0.0%
- industrial gas 0.1%
- lignite 2.3%
- oil 3.3%
- biogas 0.2%
- nuclear 19.7%
- biomass 1.0%
- waste 0.6%

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Unit</th>
<th>electricity, production mix US</th>
<th>electricity, supply mix US (incl. imports)</th>
</tr>
</thead>
<tbody>
<tr>
<td>electricity, hard coal, at power plant</td>
<td>US</td>
<td>kWh</td>
<td>47.41%</td>
<td>47.05%</td>
</tr>
<tr>
<td>electricity, nuclear, at power plant</td>
<td>US</td>
<td>kWh</td>
<td>19.68%</td>
<td>19.64%</td>
</tr>
<tr>
<td>electricity, natural gas, at power plant</td>
<td>US</td>
<td>kWh</td>
<td>17.42%</td>
<td>17.32%</td>
</tr>
<tr>
<td>electricity, hydropower, at pumped storage power plant</td>
<td>US</td>
<td>kWh</td>
<td>0.88%</td>
<td>0.87%</td>
</tr>
<tr>
<td>electricity, production mix photovoltaic, at plant</td>
<td>US</td>
<td>kWh</td>
<td>0.01%</td>
<td>0.01%</td>
</tr>
<tr>
<td>electricity, hydropower, at power plant</td>
<td>SE</td>
<td>kWh</td>
<td>6.86%</td>
<td>7.28%</td>
</tr>
<tr>
<td>electricity, oil, at power plant</td>
<td>UCTE</td>
<td>kWh</td>
<td>3.31%</td>
<td>3.22%</td>
</tr>
<tr>
<td>electricity, lignite, at power plant</td>
<td>UCTE</td>
<td>kWh</td>
<td>2.26%</td>
<td>2.34%</td>
</tr>
<tr>
<td>electricity, at cogen 6400kWth, wood, allocation exergy</td>
<td>CH</td>
<td>kWh</td>
<td>0.96%</td>
<td>0.96%</td>
</tr>
<tr>
<td>electricity, at wind power plant</td>
<td>RER</td>
<td>kWh</td>
<td>0.35%</td>
<td>0.35%</td>
</tr>
<tr>
<td>electricity, at cogen with biogas engine, allocation exergy</td>
<td>CH</td>
<td>kWh</td>
<td>0.16%</td>
<td>0.16%</td>
</tr>
<tr>
<td>electricity, industrial gas, at power plant</td>
<td>UCTE</td>
<td>kWh</td>
<td>0.10%</td>
<td>0.10%</td>
</tr>
</tbody>
</table>

JS specific modeling for ~85% of electricity production
European LCA data used for ~15% of electricity production
→ small impact on cumulative LCA results

Model of the US hard coal chain

1 kWh

- **Electricity, hard coal, at power plant** *
- Hard coal, burned in power plant *
- Hard coal, supply mix, at regional storage (US)
- Hard coal, at mine (US)
- Transport, freight, rail, diesel (US)
- Transport, barge
- Transport, lorry, 32t

* specifically modeled for eight US councils following North American Electric Reliability Corporation (NERC)

Power plant (US avg.):
- $\eta = 0.32$
- US specific emissions

Presentation: Christian Bauer
Model of the US natural gas chain

NG Extraction (US) -> NG Processing (US) -> NG Transport and Distribution (US) -> Natural gas, burned in power plant* -> 1 kWh electricity

* specifically modeled for eight US councils following North American Electric Reliability Corporation (NERC)

Power plant (US avg.):
- $\eta = 0.34$
- US specific emissions

Regions considered for modeling of US coal and gas chains

ERCOT=Electric Reliability Council of Texas; FRCC=Florida Reliability Coordinating Council; MRO=Midwest Reliability Organization; NPCC=Northeast Power Coordinating Council; RFC=Reliability First Corporation; SERC=SERC Reliability Corporation; SPP=Southwest Power Pool; WECC=Western Electricity Coordinating Council

Presentation: Christian Bauer
### Key characteristics of US hard coal electricity production

<table>
<thead>
<tr>
<th></th>
<th>US total</th>
<th>ERCOT</th>
<th>FRCC</th>
<th>MRO</th>
<th>NPCC</th>
<th>RFC</th>
<th>SERC</th>
<th>SPP</th>
<th>WECC</th>
</tr>
</thead>
<tbody>
<tr>
<td>installed net capacity</td>
<td>GW&lt;sub&gt;e&lt;/sub&gt;</td>
<td>346.5</td>
<td>8.9</td>
<td>10.5</td>
<td>22.6</td>
<td>8.1</td>
<td>130.9</td>
<td>112.5</td>
<td>22.1</td>
</tr>
<tr>
<td>fuel input</td>
<td>MJ</td>
<td>2.04E+13</td>
<td>6.06E+11</td>
<td>5.81E+11</td>
<td>1.63E+12</td>
<td>4.49E+11</td>
<td>6.90E+12</td>
<td>6.46E+12</td>
<td>1.49E+12</td>
</tr>
<tr>
<td>total net generation</td>
<td>kWh</td>
<td>1.81E+12</td>
<td>5.19E+10</td>
<td>6.06E+10</td>
<td>1.18E+11</td>
<td>4.03E+10</td>
<td>6.38E+11</td>
<td>5.66E+11</td>
<td>1.10E+11</td>
</tr>
<tr>
<td>average net efficiency</td>
<td>%</td>
<td>31.8%</td>
<td>30.8%</td>
<td>37.5%</td>
<td>26.0%</td>
<td>32.3%</td>
<td>33.2%</td>
<td>32.7%</td>
<td>26.0%</td>
</tr>
</tbody>
</table>

### Model of the US nuclear chain

1 kWh electricity (at busbar)
### Origin of uranium for US reactors

<table>
<thead>
<tr>
<th>Country</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>average</th>
<th>shares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>9326</td>
<td>11660</td>
<td>9957</td>
<td>17052</td>
<td>11999</td>
<td>19%</td>
</tr>
<tr>
<td>Brazil</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>822</td>
<td>206</td>
<td>0%</td>
</tr>
<tr>
<td>Canada</td>
<td>17050</td>
<td>16468</td>
<td>22881</td>
<td>13325</td>
<td>17431</td>
<td>28%</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>4232</td>
<td>4211</td>
<td>1639</td>
<td>1628</td>
<td>2928</td>
<td>5%</td>
</tr>
<tr>
<td>Namibia</td>
<td>1034</td>
<td>2780</td>
<td>2963</td>
<td>3009</td>
<td>2447</td>
<td>4%</td>
</tr>
<tr>
<td>Russia</td>
<td>7689</td>
<td>10329</td>
<td>12959</td>
<td>15116</td>
<td>11523</td>
<td>18%</td>
</tr>
<tr>
<td>South Africa</td>
<td>1438</td>
<td>2091</td>
<td>573</td>
<td>725</td>
<td>1207</td>
<td>2%</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>3725</td>
<td>2303</td>
<td>2505</td>
<td>2020</td>
<td>2638</td>
<td>4%</td>
</tr>
<tr>
<td>Other (not specified)</td>
<td>1858</td>
<td>1918</td>
<td>1265</td>
<td>2035</td>
<td>1769</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Total Foreign</strong></td>
<td>46352</td>
<td>51760</td>
<td>54742</td>
<td>55732</td>
<td>52147</td>
<td>82%</td>
</tr>
<tr>
<td>United States</td>
<td>10200</td>
<td>12342</td>
<td>11007</td>
<td>10807</td>
<td>11089</td>
<td>18%</td>
</tr>
<tr>
<td><strong>Total Purchases</strong></td>
<td>56552</td>
<td>64102</td>
<td>65749</td>
<td>66539</td>
<td>63236</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Origin of U enrichment services

<table>
<thead>
<tr>
<th>Deliveries in Thousand Separative Work Units (SWU)</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country of Enrichment Service (SWU-origin)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>France</td>
<td>2685</td>
<td>2325</td>
<td>1831</td>
<td>2154</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>660</td>
<td>851</td>
<td>583</td>
<td>818</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>542</td>
<td>402</td>
<td>581</td>
<td>960</td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>4224</td>
<td>4563</td>
<td>5059</td>
<td>4724</td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1586</td>
<td>1379</td>
<td>1379</td>
<td>2001</td>
<td></td>
</tr>
<tr>
<td>Europe(^a)</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>Other(^b)</td>
<td>0</td>
<td>0</td>
<td>W</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td><strong>Foreign Total</strong></td>
<td>10328</td>
<td>10411</td>
<td>10343</td>
<td>11808</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>1665</td>
<td>1374</td>
<td>1052</td>
<td>1630</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>11993</td>
<td>11785</td>
<td>11394</td>
<td>13437</td>
<td></td>
</tr>
<tr>
<td><strong>Share Foreign to Total</strong></td>
<td>86%</td>
<td>88%</td>
<td>91%</td>
<td>88%</td>
<td>88%</td>
</tr>
</tbody>
</table>
Origin of U enrichment services

![Graph showing the origin of U enrichment services over time.](image)

**U.S.-Origin Enrichment Services Purchased**
**Foreign-Origin Enrichment Services Purchased**

Shares of enrichment technologies for US reactors

<table>
<thead>
<tr>
<th>Technology</th>
<th>Supplier</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrifuge</td>
<td>CNNC</td>
<td>0.074</td>
</tr>
<tr>
<td></td>
<td>Tenex</td>
<td>0.382</td>
</tr>
<tr>
<td></td>
<td>Urenco</td>
<td>0.242</td>
</tr>
<tr>
<td>Diffusion</td>
<td>Eurodif</td>
<td>0.185</td>
</tr>
<tr>
<td></td>
<td>USEC</td>
<td>0.118</td>
</tr>
</tbody>
</table>
**Characteristics of US reactors**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BWR</th>
<th>PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units in operation</td>
<td>35</td>
<td>69</td>
</tr>
<tr>
<td>Installed capacity</td>
<td>33201</td>
<td>68789</td>
</tr>
<tr>
<td>Net electricity generation of nuclear origin in 2006</td>
<td>2.64E+11</td>
<td>5.23E+11</td>
</tr>
<tr>
<td>Share to total electricity of nuclear origin in 2006</td>
<td>33.5</td>
<td>66.5</td>
</tr>
<tr>
<td>Average load factor 2004-2006</td>
<td>91.6</td>
<td>90.9</td>
</tr>
<tr>
<td>Average lifetime load factor to end of September 2006</td>
<td>72.8</td>
<td>77.8</td>
</tr>
<tr>
<td>Average lifetime load factor assumed in ecoinvent</td>
<td>80</td>
<td>85</td>
</tr>
<tr>
<td>Lifetime assumed in ecoinvent</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Lifetime net electricity generated assumed in ecoinvent</td>
<td>2.80E+11</td>
<td>2.98E+11</td>
</tr>
</tbody>
</table>

**GHG emissions, US electricity mix**

- rest of chain
- direct power plant emissions (fossil CO2; CH4 & N20)
- Electricity losses: 6.7%
Chinese electricity sector

- China specific modelling for 2 energy chains:
  - hard coal
  - nuclear

- Main data sources used:
  - China Energy Technology Program (CETP):
    reflects situation at end of the 1990’s
  - ecoinvent background data

Chinese electricity mix (2005)

- Coal 78.6%
- Hydropower 15.9%
- Wind 0.1%
- Nuclear 2.1%
- Biomass 0.1%
- Coal gas & natural gas 0.3%
- Oil 2.9%

• China specific modelling for 2 energy chains:
  - hard coal
  - nuclear
• Main data sources used:
  - China Energy Technology Program (CETP):
    reflects situation at end of the 1990’s
  - ecoinvent background data
Modelling of CN electricity mix

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Infrastructure</th>
<th>Process Unit</th>
<th>electricity mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>electricity, hard coal, at power plant</td>
<td>CN</td>
<td>0</td>
<td>kWh</td>
<td>0.7863</td>
</tr>
<tr>
<td>electricity, nuclear, at power plant</td>
<td>CN</td>
<td>0</td>
<td>kWh</td>
<td>0.0213</td>
</tr>
<tr>
<td>electricity, hydropower, at power plant</td>
<td>FI</td>
<td>0</td>
<td>kWh</td>
<td>0.1589</td>
</tr>
<tr>
<td>electricity, oil, at power plant</td>
<td>CZ</td>
<td>0</td>
<td>kWh</td>
<td>0.0287</td>
</tr>
<tr>
<td>electricity, natural gas, at power plant</td>
<td>CENTREL</td>
<td>0</td>
<td>kWh</td>
<td>0.0032</td>
</tr>
<tr>
<td>electricity, at cogen ORC 1400kWh, wood, allocation exergy</td>
<td>CH</td>
<td>0</td>
<td>kWh</td>
<td>0.0010</td>
</tr>
<tr>
<td>electricity, at wind power plant 600kW</td>
<td>CH</td>
<td>0</td>
<td>kWh</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

specific modeling for ~ 81% of electricity production
European LCA data used for ~ 19% of electricity production
→ small impact on cumulative LCA results

Presentation: Christian Bauer

Model of the Chinese coal chain

Power plant (CN avg.):
- $\eta = 0.36$
- specific NOx, SOx, PM, Rn-222 emissions

Mining:
- specific electricity supply, $\eta = 0.13$
- emissions due to coal fires
- specific Rn-222 emissions

Presentation: Christian Bauer
Nuclear chain in China

- Mostly based on the Swiss nuclear LCA model
- Centrifuge enrichment only (diffusion for military), based on Russian technology (CN electricity)
- No reprocessing
- PWR only

GHG emissions, US (CN) hard coal & natural gas in comparison

Graph showing GHG emissions in kg(CO2-eq) / kWh for US, Germany, France, Italy, Spain, and China. The graph is divided into two sections: Hard Coal and Natural Gas.
Electricity, hard coal, US & China

- USA: 45% CH₄, 38% coal fires, 14% electricity cons.
- China: 45% CH₄, 38% coal fires, 14% electricity cons.

GHG emissions: US, CN vs. European electricity production mixes

- US: 0.8 kg (CO₂-eq)/kWh
- China: 1.0 kg (CO₂-eq)/kWh
- Germany: 0.6 kg (CO₂-eq)/kWh
- France: 0.2 kg (CO₂-eq)/kWh
- GB: 0.6 kg (CO₂-eq)/kWh
- Italy: 0.6 kg (CO₂-eq)/kWh
- Spain: 0.6 kg (CO₂-eq)/kWh
- EU-27: 0.8 kg (CO₂-eq)/kWh
Composition of European electricity mixes (2004)

- Germany
- France
- GB
- Italy
- Spain

Eco-Indicator 99 (H,A): US, CN vs. EU-27 electricity mix
Conclusions

• Current modelling of US & CN electricity production covers the most important technologies (as contributors to cumulative environmental impacts) → allows better LCA modelling in these countries
• Performance of avg. fossil US & CN power plants is relatively poor, compared to European averages → high GHG emissions of electricity mix
• Due to currently high installation rate of coal power plants in CN, modelling will have to be reworked in a few years.