Transport and Power System Scenarios for Northern Europe in 2030

Juul, Nina; Meibom, Peter

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Transport and power system scenarios for Denmark in 2030

Nina Juul, Risoe DTU – Technical University of Denmark
njua@risoe.dtu.dk

Peter Meibom, Risoe DTU – Technical University of Denmark
peme@risoe.dtu.dk
Overview

• Purpose

• Balmorel and Transport – the model

• Cases

• Results
Adding transport to a power system model (Balmorel) enables analysis of:

• consequences of possibility of using electric power in transport sector

• consequences of adding vehicle-to-grid technologies

• competition between different vehicle technologies
Balmorel (www.balmorel.com)

- Developed by Hans Ravn, RAM-løse edb
- Further development and usage: Risø DTU, EA Energianalyse, Cowi, Energinet.dk
- Investment model: calculates optimal future configurations of power systems
- Time resolution: from hourly to more aggregated time steps
- Deterministic assuming perfect foresight
- Power plants, CHP plants, boilers, heat pumps, electricity and heat storages, transmission lines
- Lately:
  - hydrogen storage, production (electrolysis, steam reforming), consumption
  - plug-in electric vehicles
Sketch of the Balmorel model including transport

**Input data**
- Present power and transport system (e.g. capacities, storages, transmission lines, plants, consumption)
- Scenario data (e.g. prices, demands, technology data)

**Model run**
- maximizing social surplus
- Restrictions for transport and power system

**Model output**
Configuration and operation of power and transport system
The transport model

- Modelling assumptions
- Input data (e.g., demand, prices, technical data, driving pattern)

Costs

- Configuration and operation of the transport system (and energy system)
- The energy system (Balmorel)

Power flows
Power flow

Propulsion system configuration of electric drive vehicles

Grid connection

Storage

Accessory loads

Power Bus

Electric motor

Transmission

Driving Wheels

Generator

Engine

Only applicable for the plug-in serial propulsion systems
Power flow model of electric drive vehicles

a) vehicles plugged in       b) vehicles not plugged in

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Applicable for PHEVs propulsion systems

- Replaced with output from fuel cell for FCEVs

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a) From grid

b) To grid

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Storage

Unload

Power Bus

Output from engine to generator

---

Storage

Unload

Power Bus

Braking energy

Consumption propulsion

Consumption accessory loads

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b) vehicles not plugged in
Model formulation

• Objective function: investments in vehicles

• Vehicle restrictions: balancing of on board storage (plugged in)
  balancing of the power bus (plugged in)
  supply and demand must meet
  minimum and maximum capacities

• Electricity balance equation: power to grid - power from grid
Assumptions

- Communication system in place
- Vehicles are aggregated in vehicle groups
- Loading and unloading depending on vehicles plugged in (cannot exceed max storage level)
- Average driving patterns (forcing specific patterns for use of diesel)
- All vehicles leave grid with predefined storage level
- Energy consumption of accessory loads and propulsion power proportional to vehicle kilometre driven
- PHEVs and FCEVs are assumed to use the electric motor until storage is depleted
Case description

- Denmark without transmission possibilities to neighbouring countries
- 1.2 GW transmission capacity between Western and Eastern Denmark
- 26 selected weeks with hourly resolution (26 X 168 time steps)
- Year 2030
- Oil prices $100/barrel
- CO₂ prices 40€/ton
- Road transport
- Including ICE, BEV, PHEV for persons transport
### Demand input data year 2030

<table>
<thead>
<tr>
<th></th>
<th>Denmark East</th>
<th>Denmark West</th>
<th>Total demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity demand (TWh/yr)</td>
<td>15</td>
<td>23</td>
<td>38</td>
</tr>
<tr>
<td>District heat demand (TWh/yr)</td>
<td>16</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td>Transport demand (b. persons km/yr)</td>
<td>32</td>
<td>42</td>
<td>74</td>
</tr>
</tbody>
</table>
Case description

- Investment options in power system:
  - Onshore wind
  - Offshore wind
  - CHP plant biomass
  - Open cycle gas turbine
  - Heat storage
  - Solid oxide electrolysis
  - Heat pump
  - Electric boiler
  - Combined cycle natural gas
  - Hydrogen storage, cavern
Scenarios

- No usage of electricity in road transport
- Integrated power and transport system with V2G facilities
- Integrated power and transport system without V2G facilities
<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Inv. costs (€) (yearly cost)</th>
<th>O &amp; M costs (€/year)</th>
<th>Electric storage cap. (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>1,573</td>
<td>1,168</td>
<td>0</td>
</tr>
<tr>
<td>BEV</td>
<td>2,520</td>
<td>1,101</td>
<td>50</td>
</tr>
<tr>
<td>PHEV</td>
<td>2,133</td>
<td>1,168</td>
<td>10</td>
</tr>
</tbody>
</table>
Investments in vehicles 2030

- **ICE**
- **BEV**
- **PHEV**

- Incl transport
- NoV2G
- No transport
Investments in power plants and heat boilers 2030

GW

Electric boiler  Combined cycle, natural gas  CHP plant, biomass  Onshore wind  Offshore wind

Incl transport  NoV2G  No transport
## Results

Total costs of running the integrated power and transport system

<table>
<thead>
<tr>
<th>Billion</th>
<th>Incl. transport</th>
<th>No V2G</th>
<th>No transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>10.271</td>
<td>10.273</td>
<td>10.345</td>
</tr>
</tbody>
</table>
## Results

### Power exchange between vehicles and electricity grid

<table>
<thead>
<tr>
<th>Region</th>
<th>From grid (GWh)</th>
<th>To grid (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Denmark</td>
<td>2,941</td>
<td>45</td>
</tr>
<tr>
<td>Western Denmark</td>
<td>3,911</td>
<td>82</td>
</tr>
<tr>
<td>Total</td>
<td>6,853</td>
<td>127</td>
</tr>
</tbody>
</table>
Week 16: Power exchange between grid and vehicles vs. electricity prices (western Denmark)
Conclusions

• Optimisation model developed for configuring and operating the integrated power and transport system.

• Using electricity for transport incorporates more wind – more than what is used by the electric drive vehicles in the transport sector.

• Adding V2G facilities incorporates more wind even though the usage is small.

• Electric drive vehicles will have a daily charging cycle.