Evaluation of electricity related impacts using a dynamic LCA model

Grégory HERFRAY, Bruno PEUPORTIER
Chair Eco-design of Buildings and Infrastructures
ParisTech-Vinci
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MODELLING OF TEMPORAL ASPECTS
Principles

- Modelling of french electricity production curves, regarding the type of energy used, and based on time and temperature-dependant functions
- Choice of a year supposed to be representative
- Analyse of production dynamics, identification of specific evolution morphologies, supposed to be linked with electricity uses categories in the building sector
- Differentiated determination, regarding uses and function of time, of production mix for every category
Climatic aspects: definition of a representative value

Available RTE data

\[ T_{av} = \frac{T_1 \cdot n_1 + T_2 \cdot n_2 + T_3 \cdot n_3}{n_1 + n_2 + n_3} \]
Climatic aspects: definition of a representative value

Available RTE data

\[ T_{av} = \frac{T_1 * n_1 + T_2 * n_2 + T_3 * n_3}{n_1 + n_2 + n_3} \]
Electricity production: data

- Telemetric hourly production measurement, for installations of more than 20 MW, given by RTE since 2007
- Available for the main means of production (nuclear, hydro-electricity, fuel+peak production, coal+natural gas, others)
- Choice of data for 2008, supposed to be representative on a first step
- Modelling: analysis of frequencies aspects
### i values  
Corresponding period (hours)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>168</td>
</tr>
<tr>
<td>5</td>
<td>8784</td>
</tr>
<tr>
<td>6</td>
<td>672</td>
</tr>
<tr>
<td>7</td>
<td>4392</td>
</tr>
</tbody>
</table>
Methodology

- Modelling of the production with functions of sinusoidal form:

\[ P(t, T_{av}) = \sum_{i=1}^{n} (X_i(T_{av}) \cdot \cos (w_i \cdot t + Y_i)) + Z(T_{av}) \]

In the case of nuclear and hydro power production:

\[ X_i(T_{av}) = A_i \cdot T_{av} + B_i \]

\[ Z(T_{av}) = C \cdot T_{av} + D \]

In the case of thermal production:

\[ X_i(T_{av}) = A_i \cdot T_{av}^2 + B_i \cdot T_{av} + C_i \cdot \bar{T}_{48} + D \]

\[ Z(T_{av}) = E \cdot T_{av}^2 + F \cdot T_{av} + G \cdot \bar{T}_{48} + H \]
Results:

\[
\sigma_{2008} = \frac{\sum_{n=1}^{8784} \left( (Prod(h)_{RTE\ 2008} - Prod(h)_{corr\&\ 2008}) \right)}{Prod(h)_{RTE\ 2008}}
\]

<table>
<thead>
<tr>
<th>Breakdown</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{2008}) (nuclear)</td>
<td>0.03</td>
</tr>
<tr>
<td>(\sigma_{2008}) (hydro)</td>
<td>0.24</td>
</tr>
<tr>
<td>(\sigma_{2008}) (thermal)</td>
<td>1.03</td>
</tr>
<tr>
<td>(\sigma_{2008}) (total)</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Validation: comparison of GHG emissions

<table>
<thead>
<tr>
<th>Production mean</th>
<th>kg CO2 eq/kWh according to EDF [EDF, 2009]</th>
<th>kg CO2 eq/kWh according to Ecoinvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>4</td>
<td>7.9</td>
</tr>
<tr>
<td>Hydro production</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Natural gas</td>
<td>1329</td>
<td>640.8</td>
</tr>
<tr>
<td>Coal</td>
<td>1030</td>
<td>1065.6</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>1067</td>
<td>882</td>
</tr>
<tr>
<td>Thermal production</td>
<td>1200</td>
<td>854.5</td>
</tr>
</tbody>
</table>

Year 2008

Year 2009
Curves exploitation: annual balance for each use type

Definition of uses categories:

- Base uses, which absolute importance doesn’t vary during the year
- Seasonal uses, varying on one year
- Specific uses during working days (professional uses)
- Daily uses (domestic uses)

\[
\begin{align*}
Th_{TOT}(h) &= Th_B(h) + Th_H(h) + Th_C(h) + Th_D(h) + Th_P(h) \\
H_{TOT}(h) &= H_B(h) + H_H(h) + H_C(h) + H_D(h) + H_P(h) \\
N_{TOT}(h) &= N_B(h) + N_H(h) + N_C(h) + N_D(h) + N_P(h)
\end{align*}
\]
Curves exploitation: annual balance for each use type

Détermination of « base » mix
Curves exploitation: annual balance for each use type

Détermination of « base » mix
Curves exploitation: annual balance for each use type

Détermination of « base » mix: curves correction
Curves exploitation: annual balance for each use type

Determination of professionnal and domestic mix
Import-Export of electricity

- Taking into account trans-border exchanges of electricity, with neighbor countries
- Exploitation of RTE data giving exchanges by hour
- Taking into account the production means concerned by the exchanges, using different alternatives (average production mix for each country, European mix, hypothesis)
Curves exploitation: annual balance for each use type

- Base
- Heating
- Cooling
- Domestic ADEME: usages intermittents
- Professional ADEME: éclairage

Graph showing GWP100, fCO2 eq/kWh for different use types.
Limits, conclusions, perspectives

- Only one year used: need of a more wide sample of data
- Simplifying hypothesis: limited number of variable considered for production modelling: \( \text{prod} = f(\text{time}, \text{temperature}) \)
- Sensitivity to temperature problematic: time and temperature partially correlated
- Modelled data built on restrictive bases (infrastructures > 20 MW)
- No consideration for holidays
DYNAMIC LCA IMPLEMENTATION
Modelling of thermal comportment of buildings

- Thermal Dynamic Simulation
- Data available on an hourly time base:
  - Heating needs
  - Cooling needs
  - Specific electricity consumption
  - Occupation scenarios
  - Needs of hot water
Hourly LCA: methodology

- Articulation with existing tools of the hourly differentiation of electricity production and consumption
- Use of models already developed
- Dynamic calculation, on an hourly time basis, of the inventories linked to electricity production and consumption
Hourly LCA: common mix method

- Heating and/or cooling needs
- Hot water needs
- Domestic or professional uses
- Localized electricity production

\[
I_{\text{use}}(h) = \left( \frac{N(h)}{N(h) + H(h) + Th(h)} \right) I_N + \left( \frac{H(h)}{N(h) + H(h) + Th(h)} \right) I_H + \left( \frac{Th(h)}{N(h) + H(h) + Th(h)} \right) I_{Th}
\]

\[
\frac{B_{\text{use}}(h)}{\eta_{\text{network}}}
\]
Hourly LCA: specific mix method

- Allocation question for impacts, uses of electricity considered as co-products
- Differentiated approach regarding uses, as the one developed before, but on an hourly base:
  - definition of a « base » mix, related to hot water production, constant
  - definition of mix related to seasonal uses, depending of time and temperature
  - « domestic » and « professional » mix, depending of time
Application: INCAS plus energy house

- DTS results: 18 kWh/m²/year
- Alternative I: « all electricity »
- Alternative II: « all electricity », PV and solar hot water production
Methodology comparison for the two alternatives

- **Solar passive house**
- **Passive house**
Conclusions

- The case study is not decisive for LCA results
- Needs for a sensitivity analysis regarding production and consumption volumes
- Dynamic aspects of production and consumption of electricity are taken into account, this can permit a better comparison of technological options (particularly for local electricity production)
- Interesting for peak consumption limitation strategies
Perspectives

- Needs for sensitivity analysis
- Production analysis: use of a wider set of data (more years), better modelling (other aspects, variables), integration of infrastructures of less than 20 MW (cogeneration)
- Other dynamic aspects to consider: evolution of components characteristics (insulation, technological systems), consequential LCA, probabilistic evolution of energetical context