COMPUTATIONALLY BASED APPROACHES TO CONSEQUENTIAL LCA: AGENT BASED AND ECONOMIC MODELLING

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INTRODUCTION
Consequential LCA of complex/large systems

- Consequential Life Cycle Assessment
  - “… activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit” (UNEP, 2011)
  - Foreground consequences modelled (over time, not only at long term market equilibrium)
  - Background consequences reflect changes of suppliers (e.g. marginal suppliers)

- Complex Systems
  - Great number of heterogeneous entities
  - Interactions among entities
  - Multiple levels of organization and structure

- Foreground CLCA modelling of complex/large systems
  - Partial/Computable General equilibrium models (economy driven)
  - Behavior modeling (behavioral rules driven)
**Hypothesis**

- “Consequential LCA using computationally based LCI modelling can effectively support (policy) decision making”

**Research objectives**

- **Energy policy:** “what are the environmental consequences of a GHG emissions policy implementation in the energy mix as compared to BAU”
  - Cut of 2.5% of GHG emissions each year following energy policy

- **Electromobility policy:** “what are the environmental consequences of policy actions (subsidies, infrastructure deployment, multi-modal scenarios) implementation on the mobility system, with special focus on commuters’ mobility ?”
  - 150k commuters per day (resident population: 537k)
  - Objective 2020: 40k electric vehicles, multimodality interconnections (tramway, trains)

- **Agricultural policy:** “what are the environmental consequences of an additional production of 145GWh of biogas from an additional demand of 80kt of maize as compared to BAU?”
  - 20/20/20 EU targets Luxembourg: 11% biofuels in final energy consumption.
  - Limited land use potential, high energy consumption rate, increasing energy imports from neighbouring nations
There were 2242 farms in Luxembourg in 2009

**METHODS**

**Bottom up (agent based) vs. Top Down (economic modelling)**

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>TOP-DOWN</th>
<th>BOTTOM-UP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives</td>
<td>Maximise Profits</td>
<td>Maximise Profits</td>
</tr>
<tr>
<td></td>
<td>Environmental Protection</td>
<td>Environmental Protection</td>
</tr>
<tr>
<td>Number of players</td>
<td>Normally 1 or few but can be 2242(*) in principle</td>
<td>2242(*) Agents or Farms</td>
</tr>
<tr>
<td>Price discovery</td>
<td>Any time-series method</td>
<td>Any time-series method</td>
</tr>
<tr>
<td>Parameters</td>
<td>Fixed, but in case of 2242 farms, random if data unavailable, else fixed</td>
<td>Random if data unavailable, else fixed</td>
</tr>
<tr>
<td>Model Structure</td>
<td>Objective function and constraints (LP/NLP) or just objective function (PMP)</td>
<td>No objective function but behavioural rules and individual responses</td>
</tr>
<tr>
<td>Shock</td>
<td>Exogenously imposed as direct change or indirect change via policy tool like subsidy, quotas...</td>
<td>Only possible via policy tool like subsidy, quotas...</td>
</tr>
<tr>
<td>Social Interaction</td>
<td>Feasible but difficult</td>
<td>Easily incorporated</td>
</tr>
</tbody>
</table>

(*) There were 2242 farms in Luxembourg in 2009
METHODS

Bottom up (ABM) vs. Top Down (economic modelling)

**ISSUE**
- Behaviour
  - Computing Δs
  - Total shock

**TOP-DOWN**
- Rooted in optimization, exhibit “rational” approach of maximising profits or minimising environmental damage
- non-stochastic and depend only on exogenous parameter
- Imposed exogenously and if a feasible solution exists one can find an optimal

**BOTTOM-UP**
- Some farmers (agents) may exhibit behaviour that appears “irrational” to the outsider, such as specific crop rotation schemes out of sync with profits
- Stochastic, even though they depend on exogenous parameters as behavioural response is random under a pre-specified distribution
- Difficult to generate the level of aggregate shock due to stochastic response of agents
Agricultural Policy Method

Soft coupling

Policy Development & Actions

# AGRICULTURAL POLICY

## Scenarios

<table>
<thead>
<tr>
<th>ID</th>
<th>Short name and acronym</th>
<th>Description</th>
<th>GC Probability density function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Greedy (NO_GC)</td>
<td>All the agents always look only at the revenue when they have to decide what crop to plant. They plant the one maximizing the revenue.</td>
<td>![Graph A]</td>
</tr>
<tr>
<td>B</td>
<td>All green (ALL_GR)</td>
<td>All the agents look at CO2 emissions when they have to decide what crop to plant. They plant the one with the lowest CO2 emissions</td>
<td>![Graph B]</td>
</tr>
<tr>
<td>C</td>
<td>Equal green consciousness (UNI_GC)</td>
<td>The GC is distributed among the agents with a uniform distribution, i.e., all the real values of GC in the interval [0,1] have the same probability to be assigned to an agent and the average of all the assigned values of GC is equal to 0.5.</td>
<td>![Graph C]</td>
</tr>
<tr>
<td>D</td>
<td>Pessimistic (PESS)</td>
<td>The GC is distributed to the agents with a Beta probability function, whose mean value is lower than 0.5. This means that the probability that an agent will be assigned a GC&lt;0.5 is higher than the probability that he will be assigned a GC&gt;0.5.</td>
<td>![Graph D]</td>
</tr>
<tr>
<td>E</td>
<td>Optimistic (OPT)</td>
<td>The GC is distributed to the agents with a Beta probability function, whose mean value is higher than 0.5. This means that the probability that an agent will be assigned a GC&gt;0.5 is higher than the probability that he will be assigned a GC&lt;0.5.</td>
<td>![Graph E]</td>
</tr>
<tr>
<td>F</td>
<td>Relative greenness (REL_GRE)</td>
<td>The green behaviour (which only looks at CO2 emissions of the crops) is implemented on the basis of the environmental performance of the agent relative to the other agents.</td>
<td>![Graph F] Based on a ranking via an index I calculated at the national level</td>
</tr>
</tbody>
</table>
ENERGY POLICY
Context and Method

ETEM: bottom-up partial equilibrium model for Luxembourg energy sector; 20 energy commodities; 650 technologies; Most cost-efficient energy system until 2030 (calibration 2006).
Inventory of energy technologies: NEEDS

LUXGEM: Dynamic multi-sector general equilibrium model for Luxembourg; 16 branches of activity, 20 commodities, 1 representative household
Response to prices: changes in consumption from elasticity of substitution

General analysis
- Increase of impacts over time due to demand growth
- Main impacts from imports (~70% HH and eco and 100% resources)
- Energy production and imports > 50% impacts

Comparison of scenarios
- GHGr impacts ~2-3% lower than BAU impacts
- Very small difference for other sectors and imports than energy
- GHGr advantage mainly due to lower energy production from natural gas (lower CO₂ emissions and extraction of natural gas)
General analysis

- Some impact categories (climate change, ozone depletion, fossil depletion) improved with GHGr
- Others not (eutrophication, ionising radiation) due to increase of nuclear energy imports (from BE)

Focus on 4 impacts:
- Net consumption’s impacts increase while energy sector intensity impacts decrease over time
- GHGr advantage ~7% on climate change, 6% on CED, 1% on land and water use.
Comparison GHGr and BAU: benefit from lower production from natural gas but counter-balanced by higher electricity imports (especially nuclear energy).

Large contribution of imports, as well as energy-related processes.

While the total net consumption shows greater impacts over years due to demand growth, the energy sector intensity shows lower impacts due to efficiency improvements.

Environmental profile of net consumption of Luxembourg: similar trends between the BAU and GHGr scenarios, with only marginal environmental benefits for the GHGr scenario (3–4% overall).

Implementation of the GHG reduction policy has low influence on the net consumption.
MOBILITY POLICY

Context and Method

*Official target:* 40,000 EVs (2020)

5,000€ CARe incentive for buying an EV *(3)*

EV internet dedicated platform *(4)*

Charging places deployment everywhere

Dynamic final demand vector
- Agents represent consumers/actors
- Models behavior in changing market vs. Dynamic technology matrix (Davis et al., 2009)
- Agents represent technologies/processes
- Models structural changes of market
MOBILITY POLICY

Results

Querini F., Benetto E. Agent-based modelling for assessing hybrid and electric cars deployment policies in Luxembourg and Lorraine. Transportation Research Part A: Policy and Practice. DOI: 10.1016/j.tra.2014.10.017
MOBILITY POLICY

Results

**MOBILITY POLICY**

Conclusions for policy makers

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Luxembourg</th>
<th>Lorraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st driver</td>
<td>Charging infrastructure</td>
<td>Charging infrastructure</td>
</tr>
<tr>
<td>2nd driver</td>
<td>EV appealing</td>
<td>Vehicle life</td>
</tr>
<tr>
<td>3rd driver</td>
<td>Vehicle life</td>
<td>Vehicle costs</td>
</tr>
</tbody>
</table>

**Recommendations**

- **Have larger infrastructure deployment.** The very uncertain nature of EV deployment leads to high uncertainties on the environmental consequences,

- **Extend the lifetime of batteries**, by for instance promoting their reuse in other applications before dismantling and recycling.

- Considering the results obtained for the German mix, we recommend to Luxembourg’s stakeholders to **keep the renewable electricity policy**
WHAT ABOUT THE RELATED UNCERTAINTIES?

Methods

Sources

- Parameter uncertainty
- Model uncertainty
- Simulation Variability
- Uncertainty due to choices
- Variability

Characterization

- Scenarios
- Relative error
- Distributions
- Stochastic modelling
- Scenario analysis

Propagation

- Stochastic modelling
- Fuzzy arithmetic
- Hybrid approaches
- Scenario analysis

How to bring both views together?
NEW METHODOLOGICAL PROPOSAL

- Uncertainty Sources:
  - Parameter uncertainty
  - Model uncertainty
  - Choice uncertainty
  - Simulation variability

- Nomenclature:
  - $\Lambda$ is one concrete instance of:
    - Parameters $P_M$ and $P_L$
    - Choices $C_M$ and $C_L$
    - Model structures $A_M$ and $A_L$
  - $r_M$ still vary due to simulation variability

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PhD Thesis Paul Baustert
First test bed case presented at SETAC Case Studies Montpellier

ABM $\xrightarrow{r_M}$ LCI $\xrightarrow{g = BA^{-1}f(r_M)}$ LCIA

Technische Universiteit Eindhoven
University of Technology

Prof. H. Timmermans
"All models are wrong, but some are useful" (Box & Draper, 1987. Empirical Model Building and Response Surfaces, Wiley & Sons, New York, NY., page 424).

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Call for abstracts: deadline 15th December 2016

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Typical winter week