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

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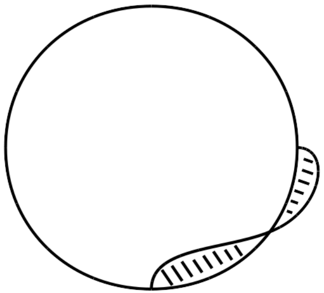
INTRODUCTION
Consequential LCA of complex/large systems

- 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)



Consequential

Adapted from Weidema, 2003

- 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)*

RESEARCH HYPOTHESIS AND OBJECTIVES

- **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

METHODS

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

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

(*)There were 2242 farms in Luxembourg in 2009

METHODS

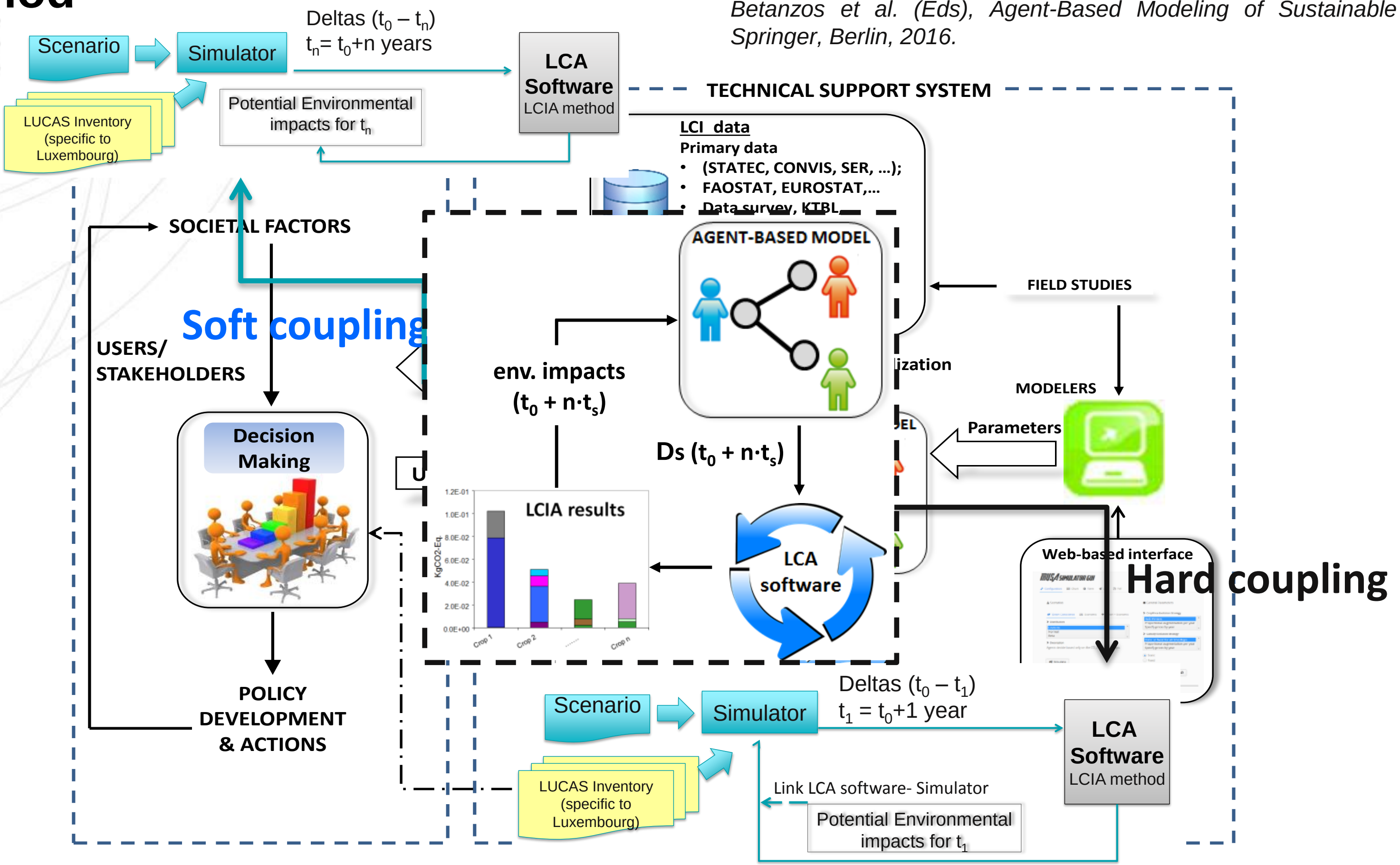
Bottom up (ABM) vs. Top Down (economic modelling)

ISSUE	TOP-DOWN	BOTTOM-UP
Behaviour	Rooted in optimization, exhibit "**rational**" approach of maximising profits or minimising environmental damage	Some farmers (agents) may exhibit behaviour that appears "**irrational**" to the outsider, such as specific crop rotation schemes out of sync with profits
Computing Δs	non-stochastic and depend only on exogenous parameter	Stochastic, even though they depend on exogenous parameters as behavioural response is random under a pre specified distribution
Total shock	Imposed exogenously and if a feasible solution exists one can find an optimal	Difficult to generate the level of aggregate shock due to stochastic response of agents

AGRICULTURAL POLICY

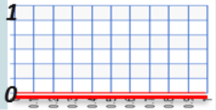
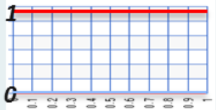
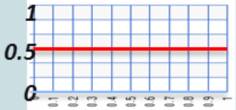
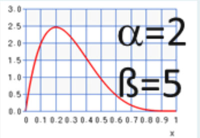
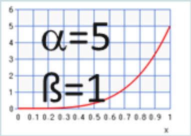
Method

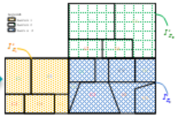
Navarrete Gutiérrez T., Rege S., Marvuglia A., Benetto E. Sustainable farming behaviours: an agent based modelling and LCA perspective. In: Alonso Betanzos et al. (Eds), Agent-Based Modeling of Sustainable Behaviors. Springer, Berlin, 2016.



AGRICULTURAL POLICY

Scenarios

ID	Short name and acronym	Description	GC Probability density function
A	Greedy (NO_GC)	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.	
B	All green (ALL_GR)	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	
C	Equal green consciousness (UNI_GC)	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.	
D	Pessimistic (PESS)	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<0.5 is higher than the probability that he will be assigned a GC>0.5.	
E	Optimistic (OPT)	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>0.5 is higher than the probability that he will be assigned a GC<0.5.	
F	Relative greenness (REL_GRE)	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.	**Based on a ranking via an index I calculated at the national level**



ENERGY POLICY
Context and Method

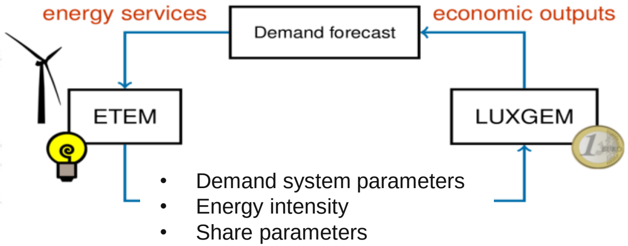
LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Intérieur et de l'Aménagement du Territoire
Direction de l'aménagement du territoire

European Union
European Regional Development Fund

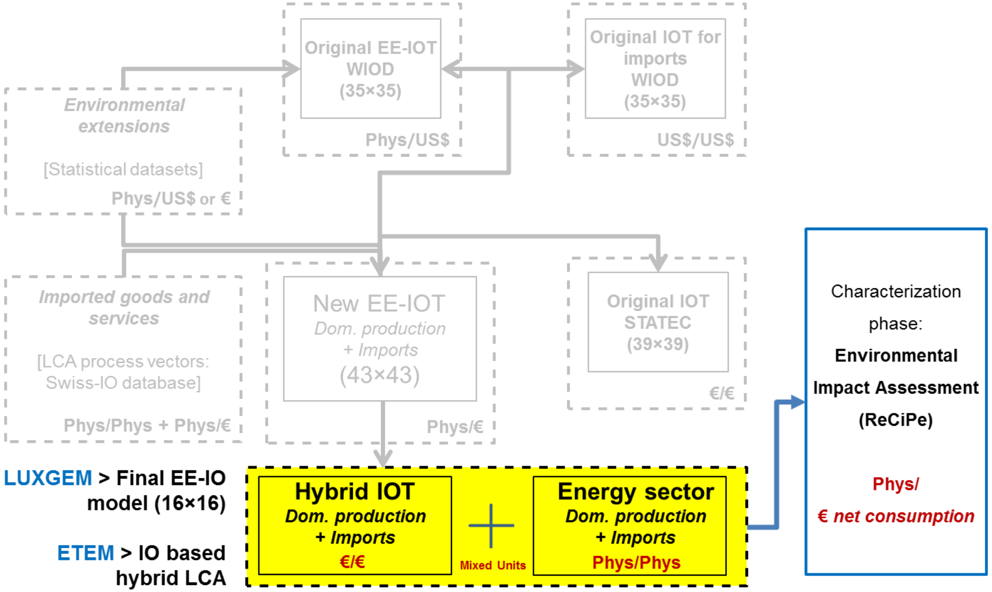
STATEC
Institut national de la statistique et des études économiques

Igos E., Rugani B., Rege S., Benetto E., Drouet L., Zachary D., 2015: Combination of equilibrium models and hybrid life cycle-input-output analysis to predict the environmental impacts of energy policy scenarios. Applied Energy 145, pp.234−245.

***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



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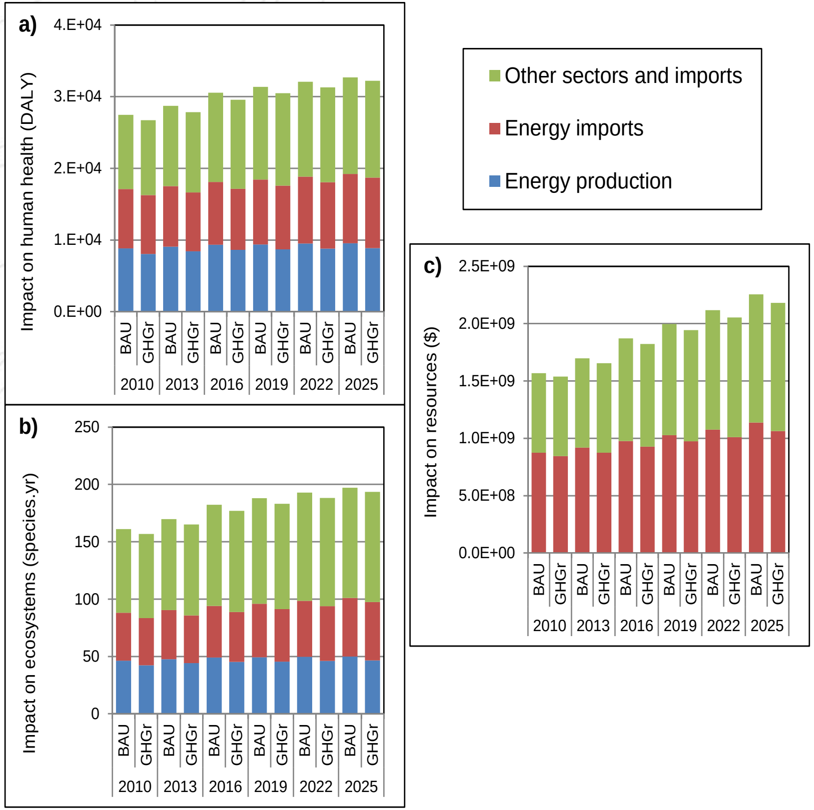
ENERGY POLICY
Results



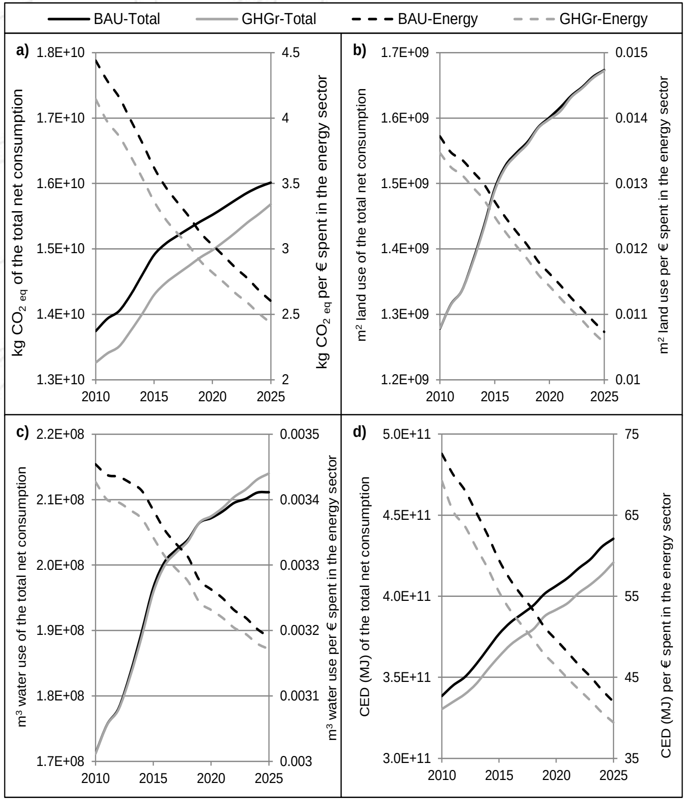
General analysis

- 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 CO_2 emissions and extraction of natural gas)

ENERGY POLICY
Results



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.

ENERGY POLICY

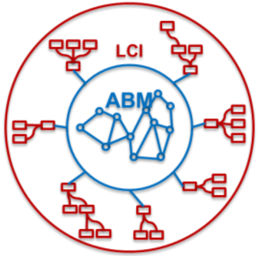
Conclusions for policy makers

- 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

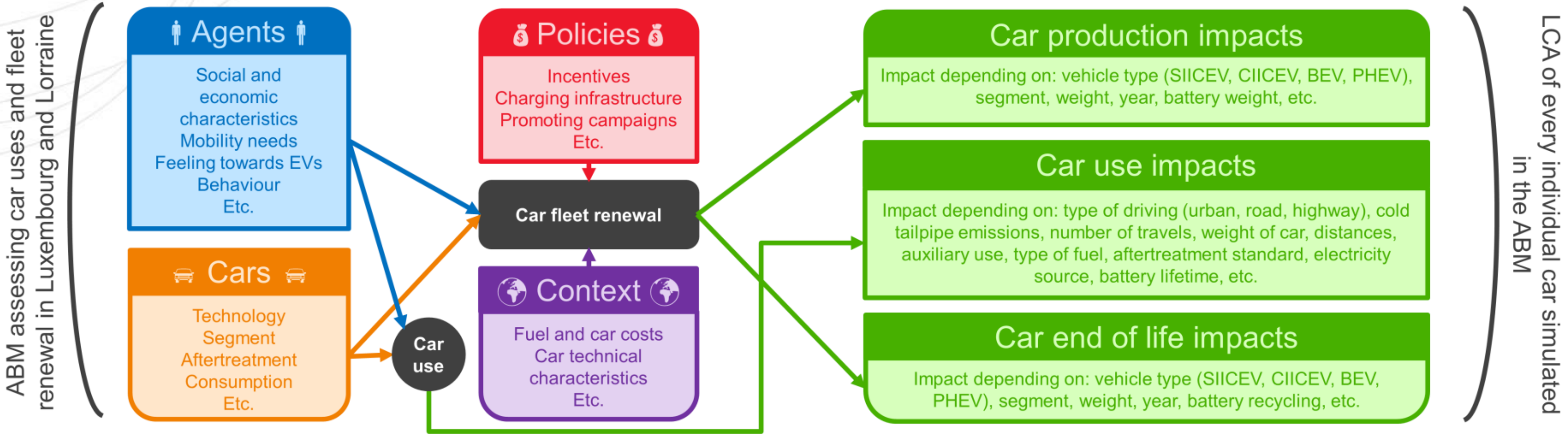


Dynamic final demand vector

- Agents represent consumers/actors
- Models behavior in changing market

vs. Dynamic technology matrix (Davis et al., 2009)

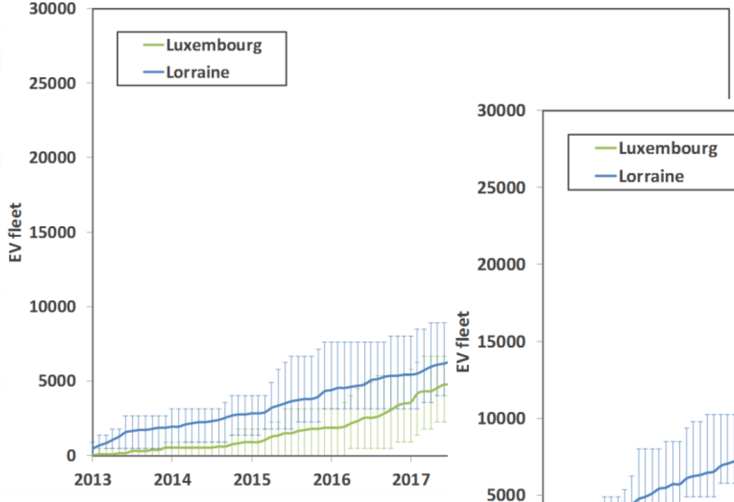
- Agents represent technologies/processes
- Models structural changes of market



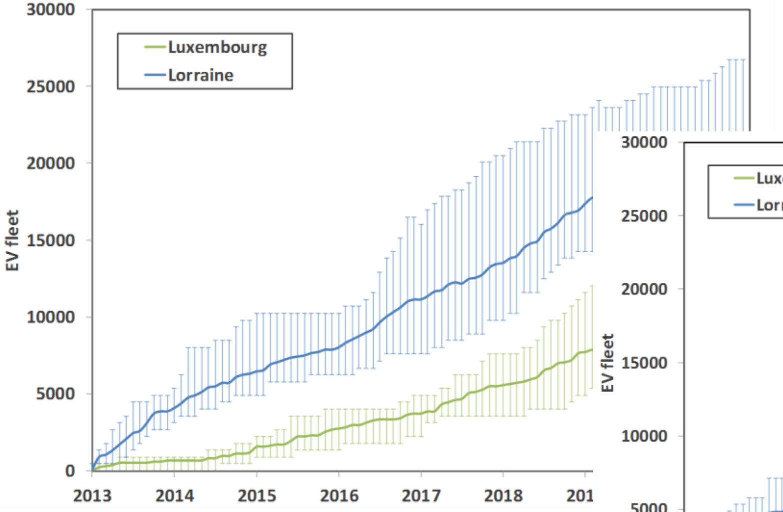
MOBILITY POLICY

Results

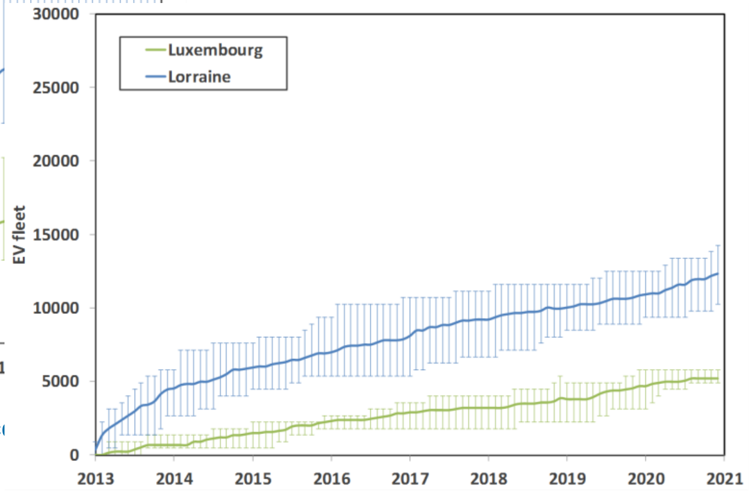
Querini F., Benetto E. Agent-based modelling for assessing hybrid and electric cars deployment policies in Luxembourg and Lorraine. Transportation Research Part A: Policy and Practice. DOI: 10.1016/j.tra.2014.10.017



deployment scenario



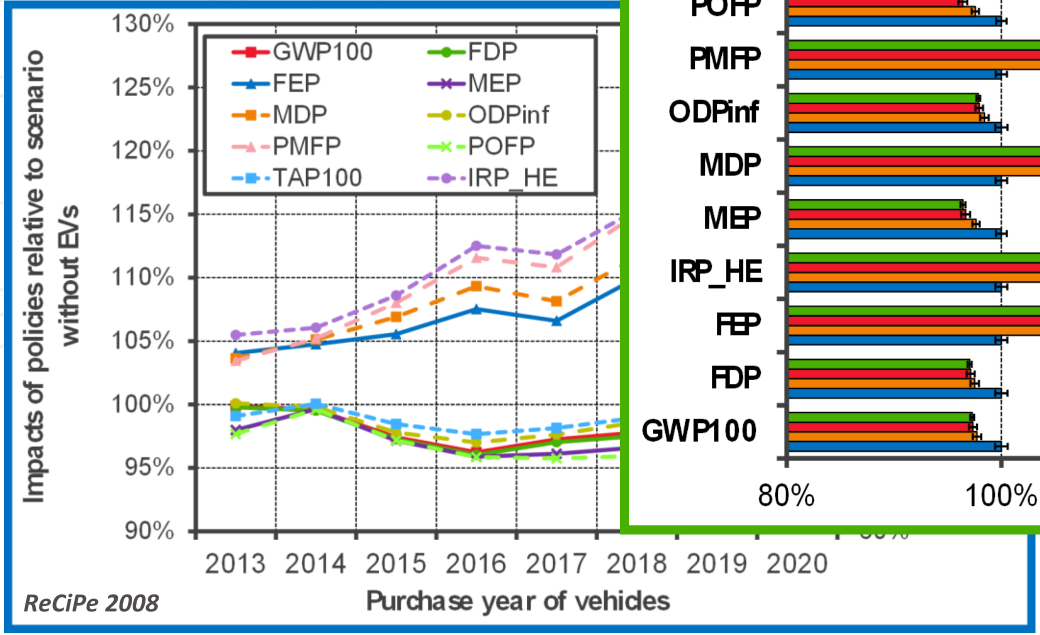
deployment scenario – inc

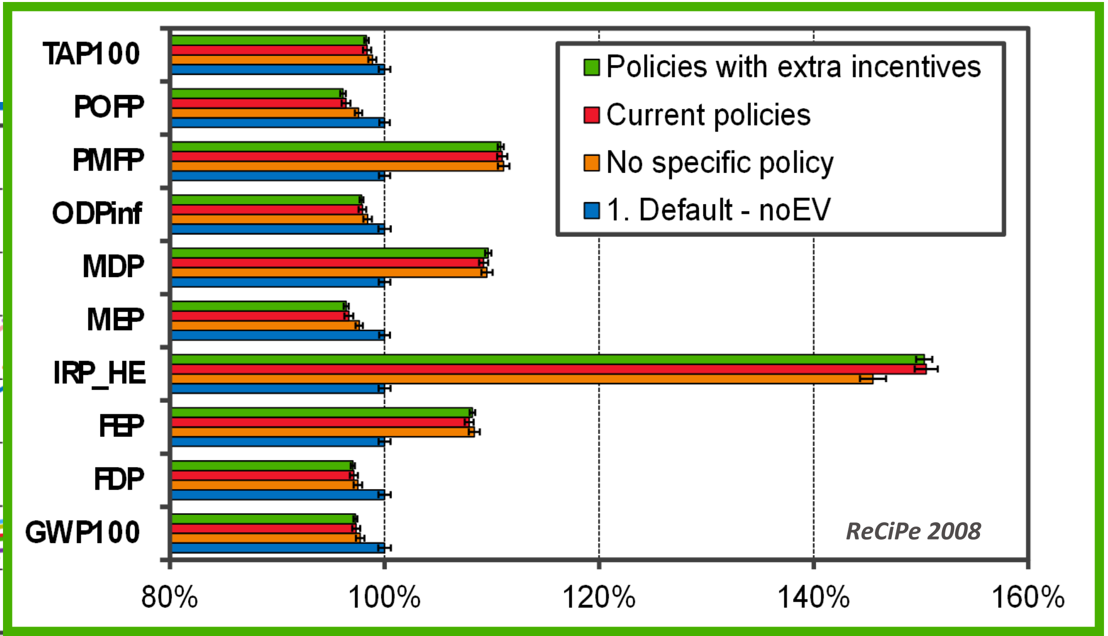


deployment scenario – no interaction

MOBILITY POLICY

Results





Querini F., Benetto E., 2015. Combining agent-based modeling and life cycle assessment for the evaluation of mobility policies. Environmental Science and Technology, 49, 1744-1751.

MOBILITY POLICY

Conclusions for policy makers

Drivers	Luxembourg	Lorraine
1st driver	Charging infrastructure	Charging infrastructure
2nd driver	EV appealing	Vehicle life
3rd driver	Vehicle life	Vehicle costs

Recommandations

- **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

ABM

LCI

Sources

ABM:
- Parameter uncertainty
- Model uncertainty
- Simulation Variability

LCI:
- Parameter uncertainty
- Model uncertainty
- Uncertainty due to choices
- Variability

Characterization

ABM:
- Scenarios
- Relative error
- Distributions

LCI:
- Scenarios
- Relative error
- Distributions
- (Fuzzy) intervals

Propagation

ABM:
- Stochastic modelling
- Scenario analysis

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

How to bring both views together?

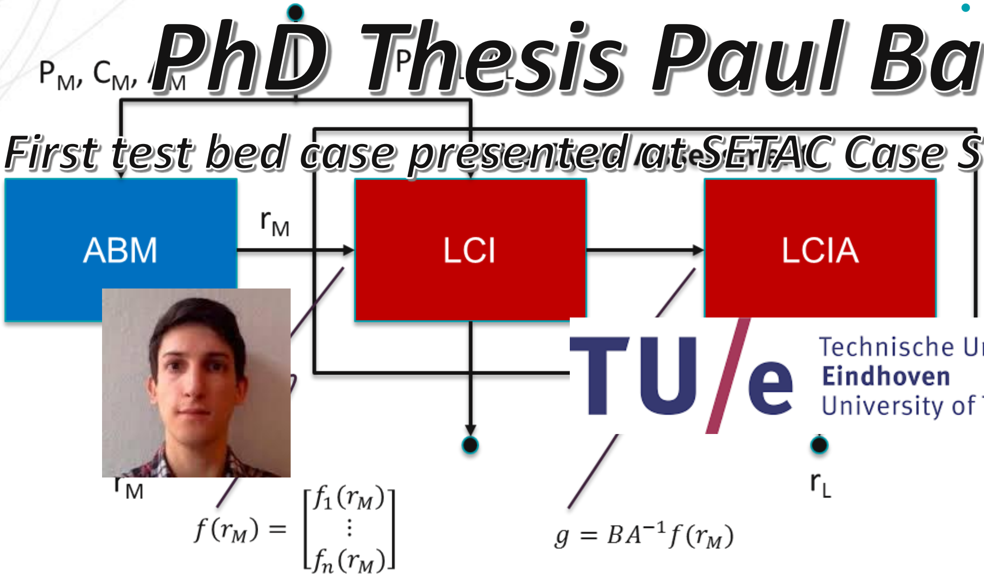
NEW METHODOLOGICAL PROPOSAL

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

- Nomenclature:
  - ʎ 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

PhD Thesis Paul Baustert

First test bed case presented at SETAC Case Studies Montpellier



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).*

THANK YOU FOR THE FINANCIAL SUPPORT:

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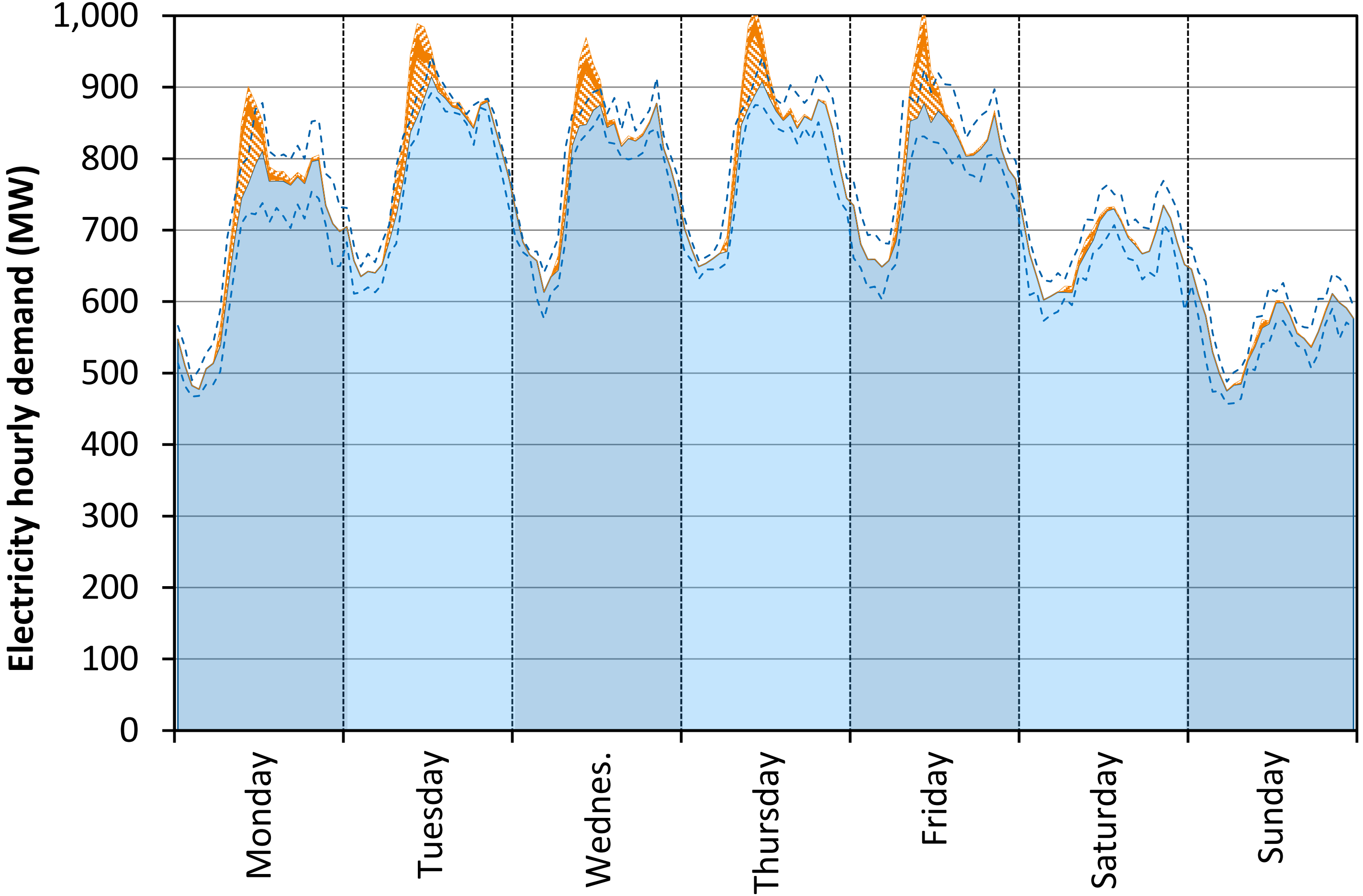
Typical winter week: 2020, with current policies

Added demand from EVs charging at work

Demand linked with crossborder commuters



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