Integrated modelling to assess land use change impacts on ecosystem service provision – Prospects for LCIA

Benedetto RUGANI & Benoit OTHONIEL

RDI Unit on Life Cycle Sustainability and Risk Assessment (LiSRA)
Environmental Research & Innovation (ERIN) department

67th LCA Discussion Forum
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AGENDA

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- Background

  State-of-the-art on LCIA of land use (change) on ecosystem services

- Scope

  Motivation and objectives

- Methodological approach

  Multi-scale integrated and dynamic framework of “VALUES”

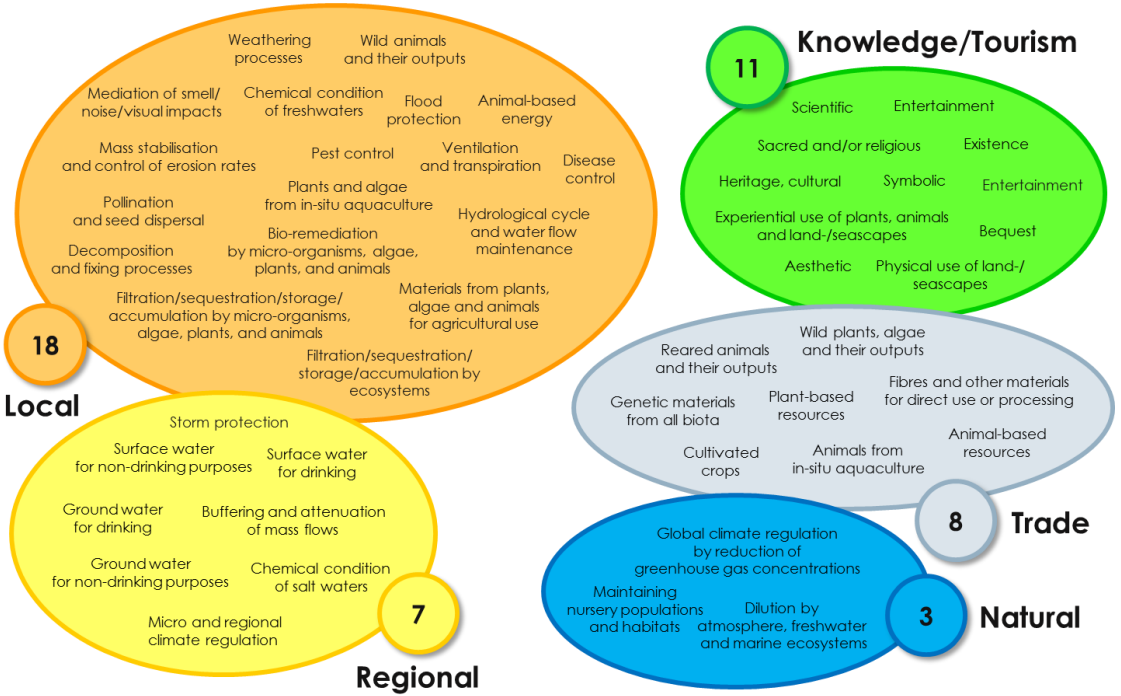
- Results

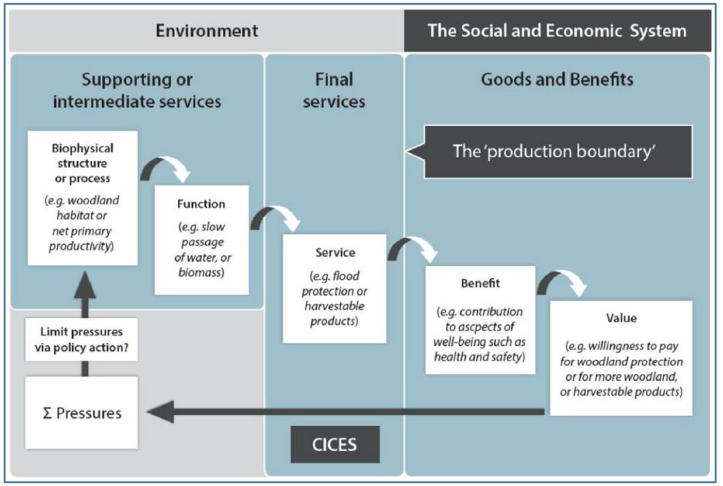
  Calculation routine and preliminary outcomes

- Conclusions

  Lesson learnt and outlook

Ecosystem Services: concept, typologies, scales

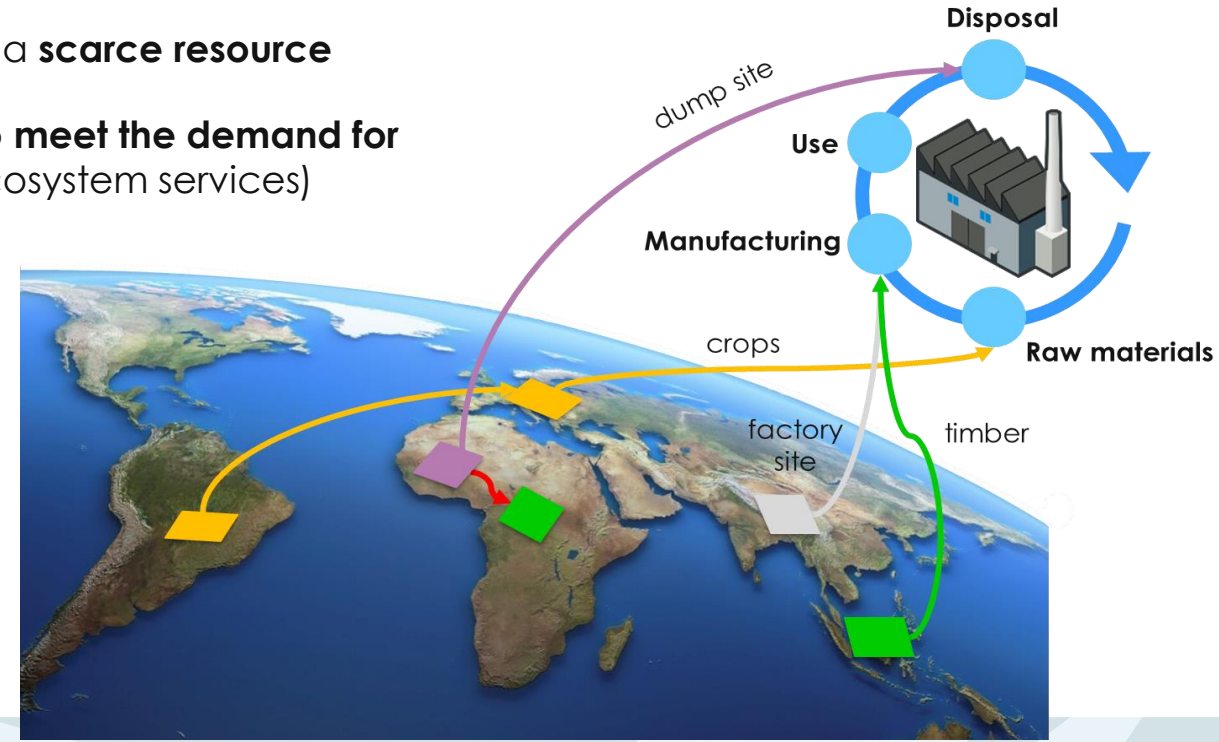




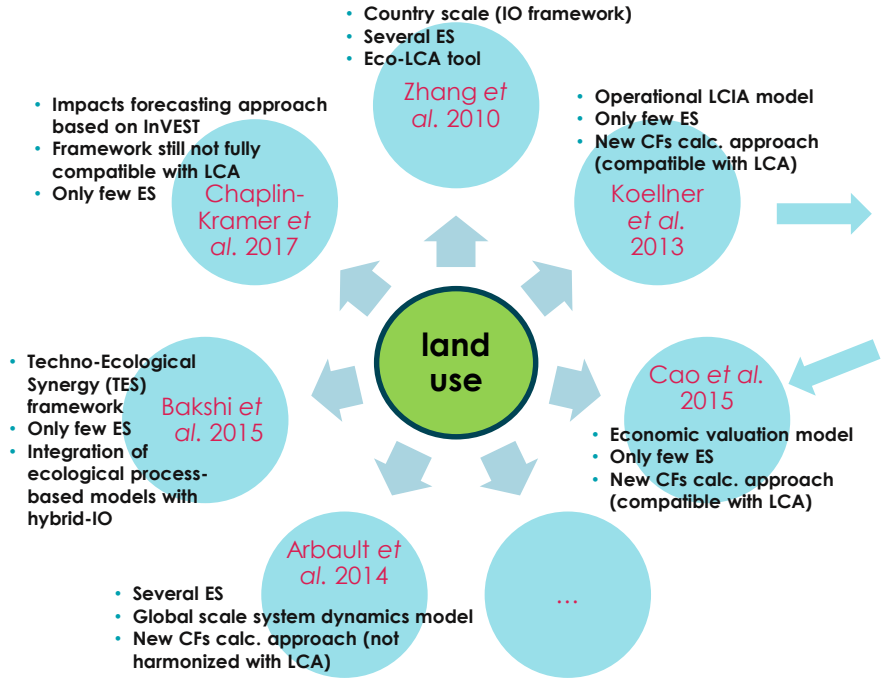
Costanza *et al.* **2017**

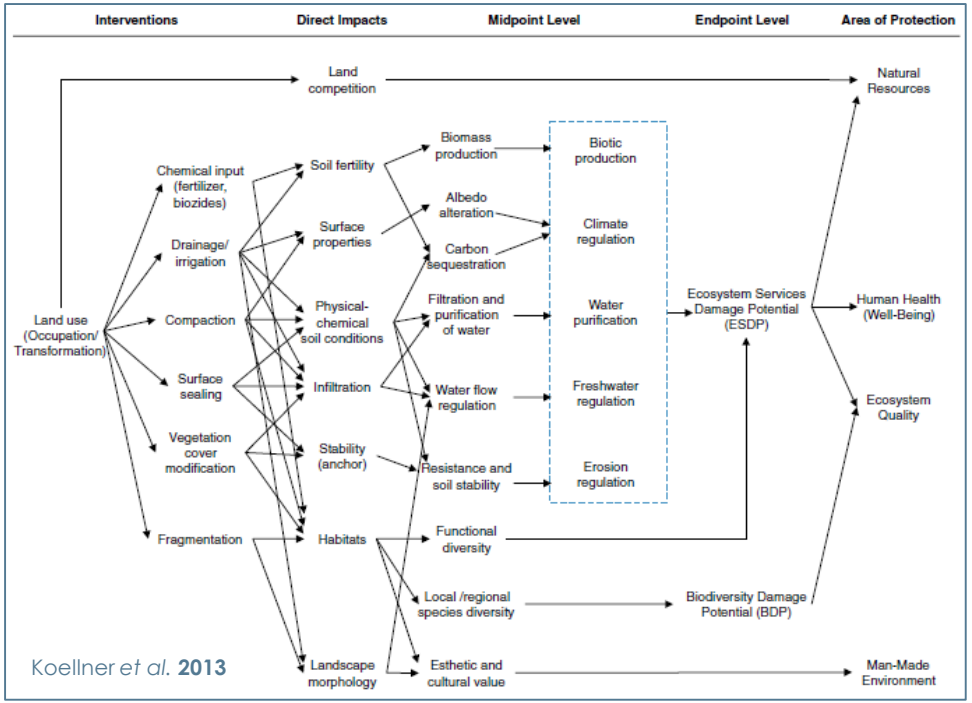
Ecosystem Services and their relationship with land use

- (productive) **land** is globally a **scarce resource**
- Land is managed in order to **meet the demand for "benefits"** (among which ecosystem services)
- Land use (and cover) changes **can generate trade-offs**
- Land is an **input to production** systems and its use a **source of impacts**



State-of-the-Art on LCA and Ecosystem Services

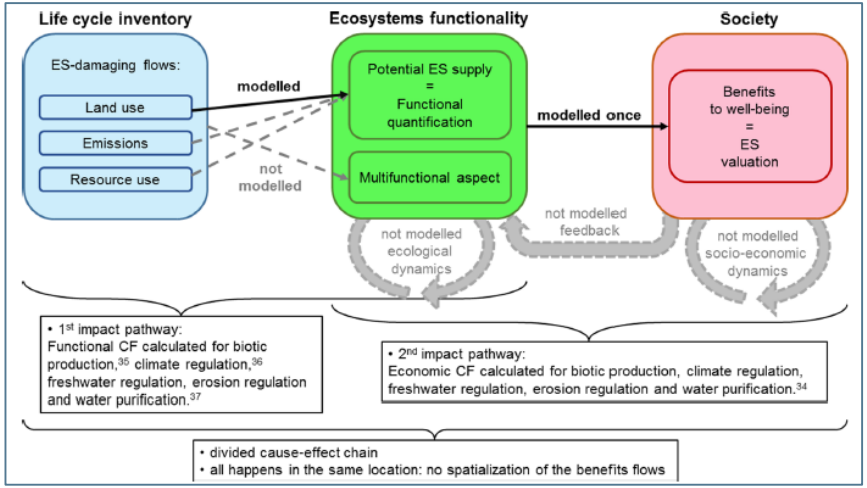




Motivation & research questions

- The **ES concept not sufficiently encompassed in LCA**: lack of interconnections among socio-ecological systems, which **demand and supply ES**
- **Feedback processes and non-linear effects** generating synergies and trade-offs are not considered in cause-effect chains: CFs needs to **incorporate both harmful and beneficial aspects underlying ES**
- **Integrated modelling as a possible solution** to calculate a new generation of spatially-explicit and scenario-dependent CFs

Othoniel *et al.* **2016**



VALUing Ecosystem Services for environmental assessment

2014 → 2018

Fonds National de la Recherche Luxembourg

Rationale and objectives

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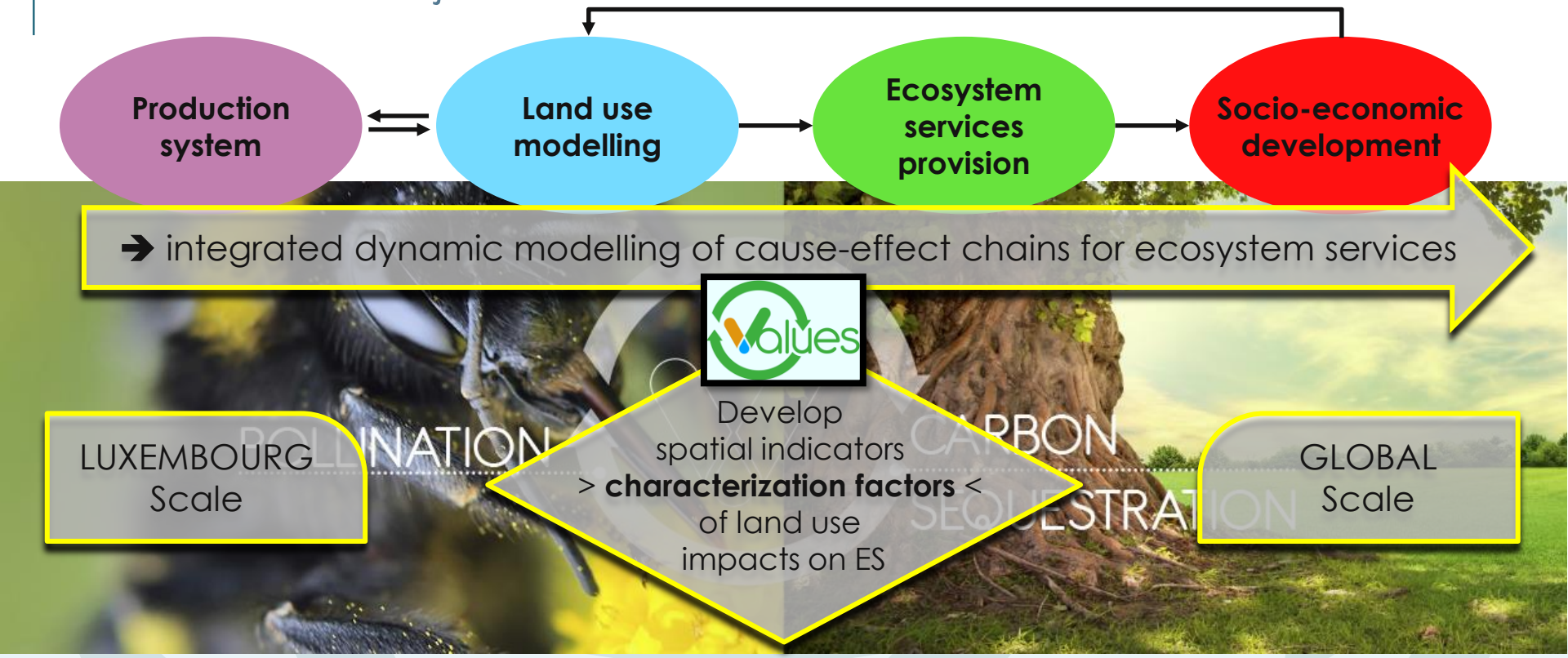
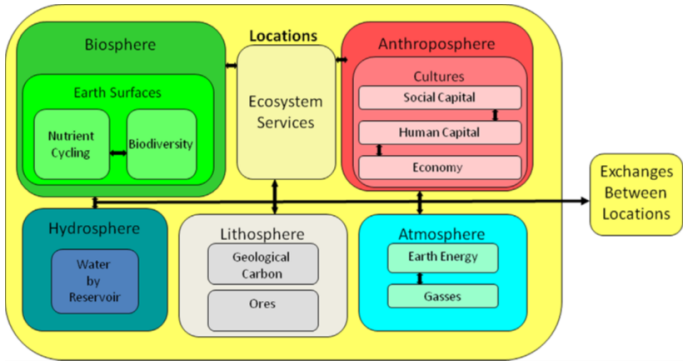
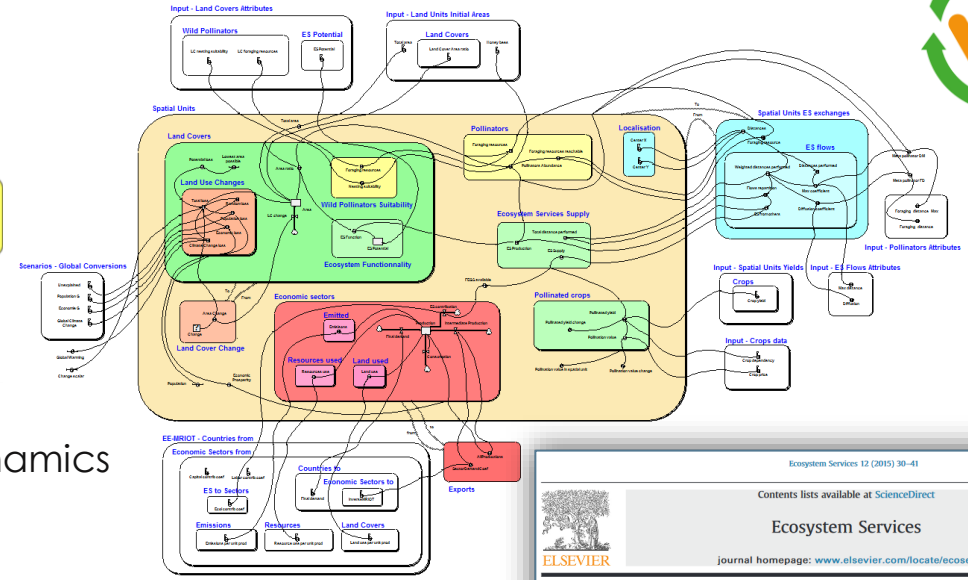
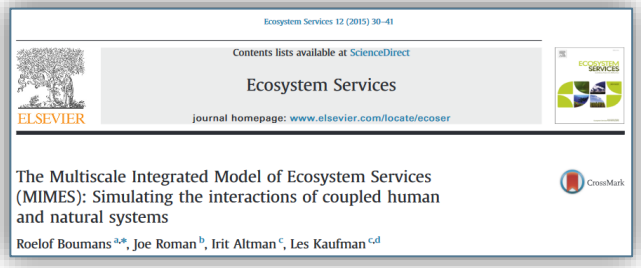


Multiscale integrated framework: MIMES





- Coupling of models in system dynamics (stock and flow model)
- Spatialized
- Multi-scalar
- Flexible programming



Ecosystem Services 12 (2015) 30–41

Contents lists available at ScienceDirect

Ecosystem Services

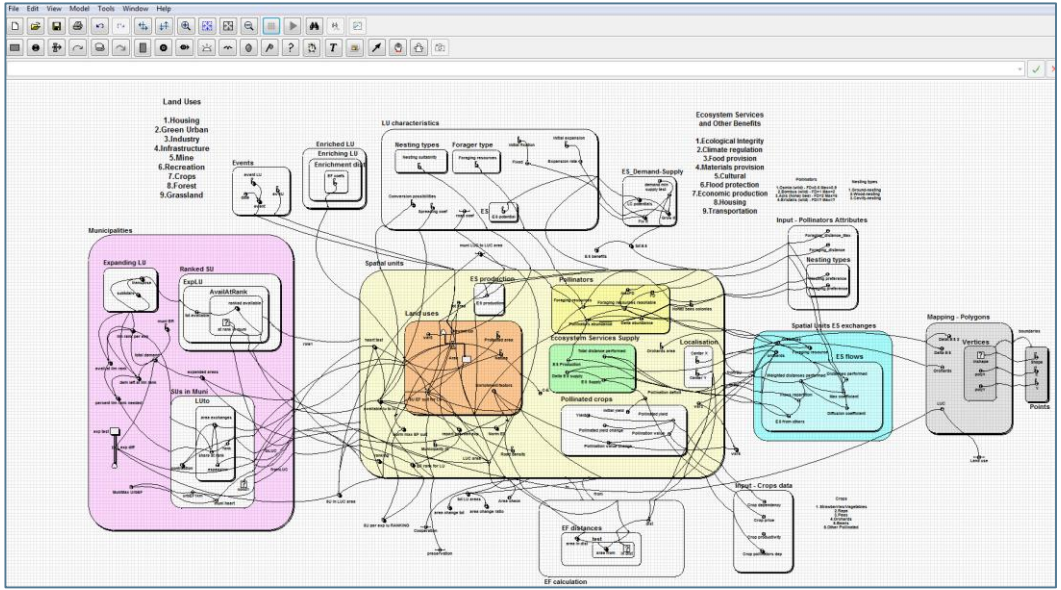
journal homepage: www.elsevier.com/locate/ecoser

The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems

Roelof Boumans [a,*], Joe Roman [b], Irit Altman [c], Les Kaufman [c,d]

Modelling steps

- ↓ Goal & Scope
- ↓ Creation of the model



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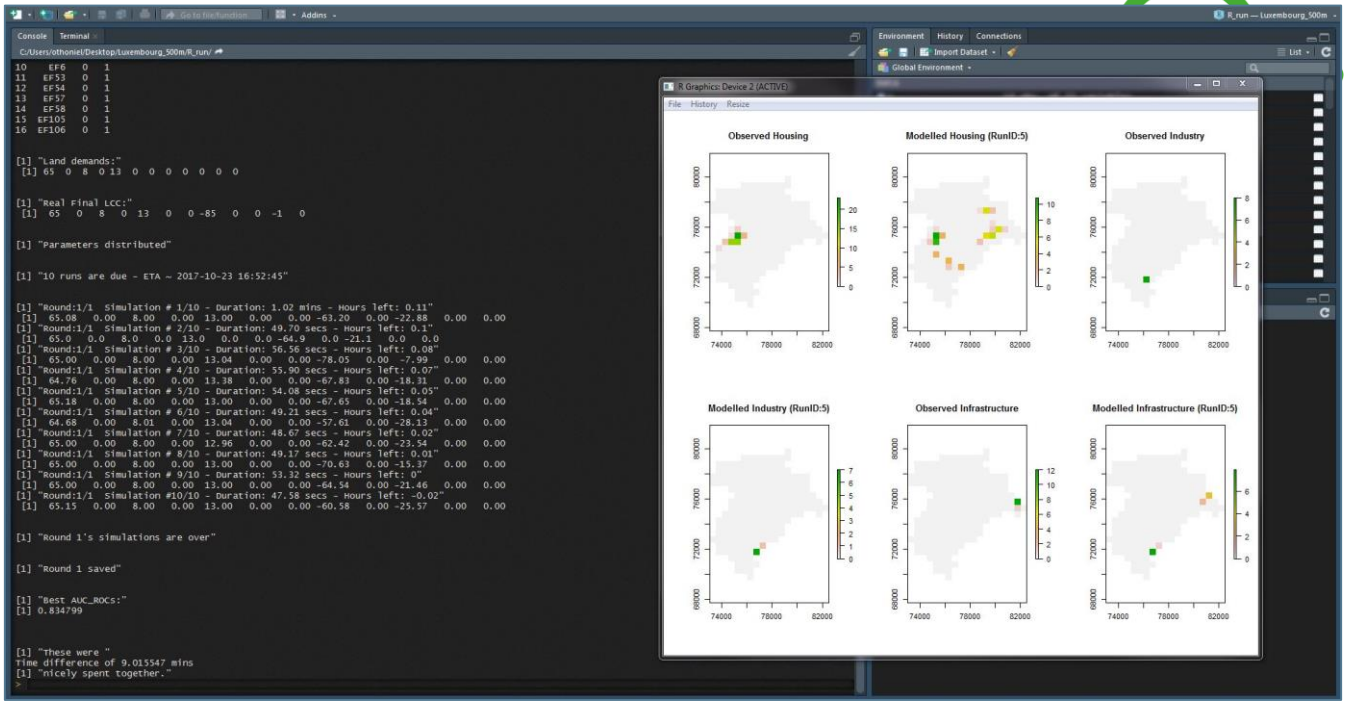
Modelling steps

- ↓ Goal & Scope
- ↓ Creation of the model
- ↓ Calibration



Modelling steps

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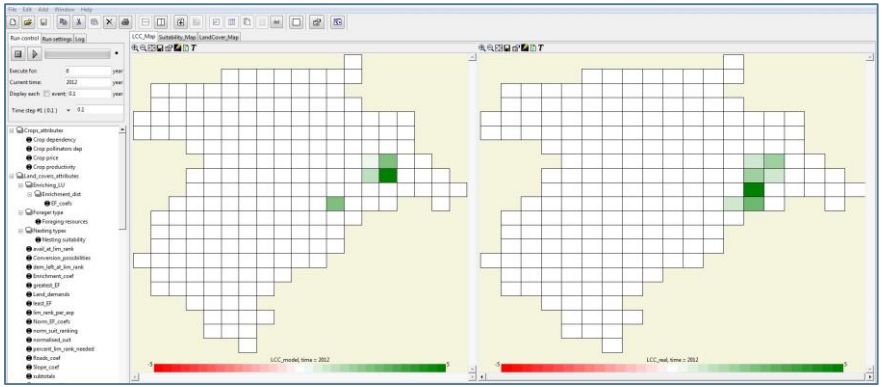

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Modelling steps

- ↓ Goal & Scope
- ↓ Creation of the model
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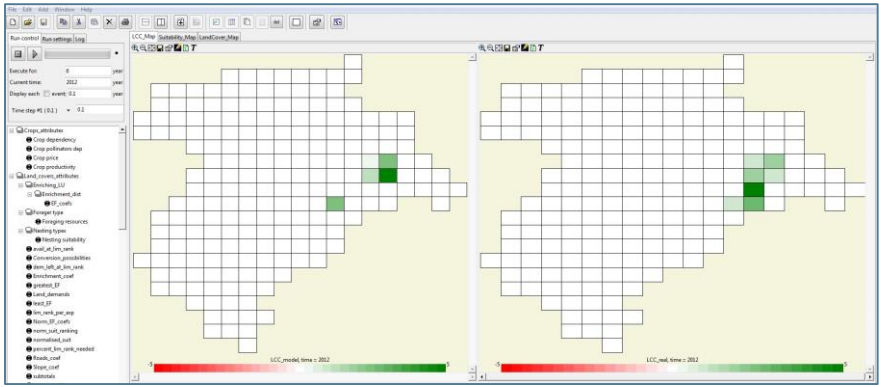
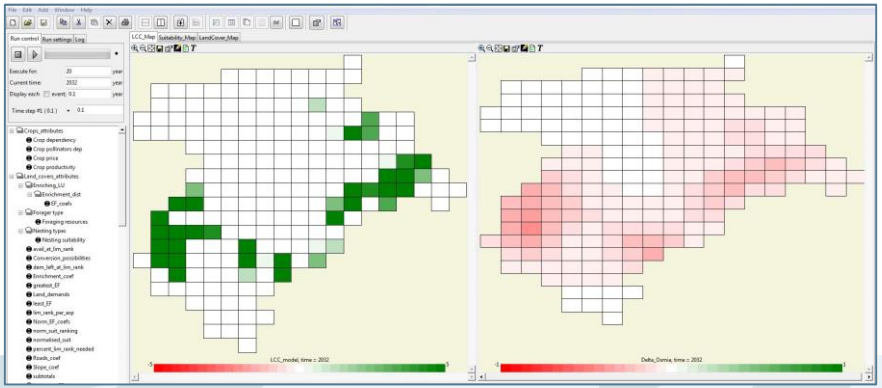
- ↓ Validation
- ↓ Simulation





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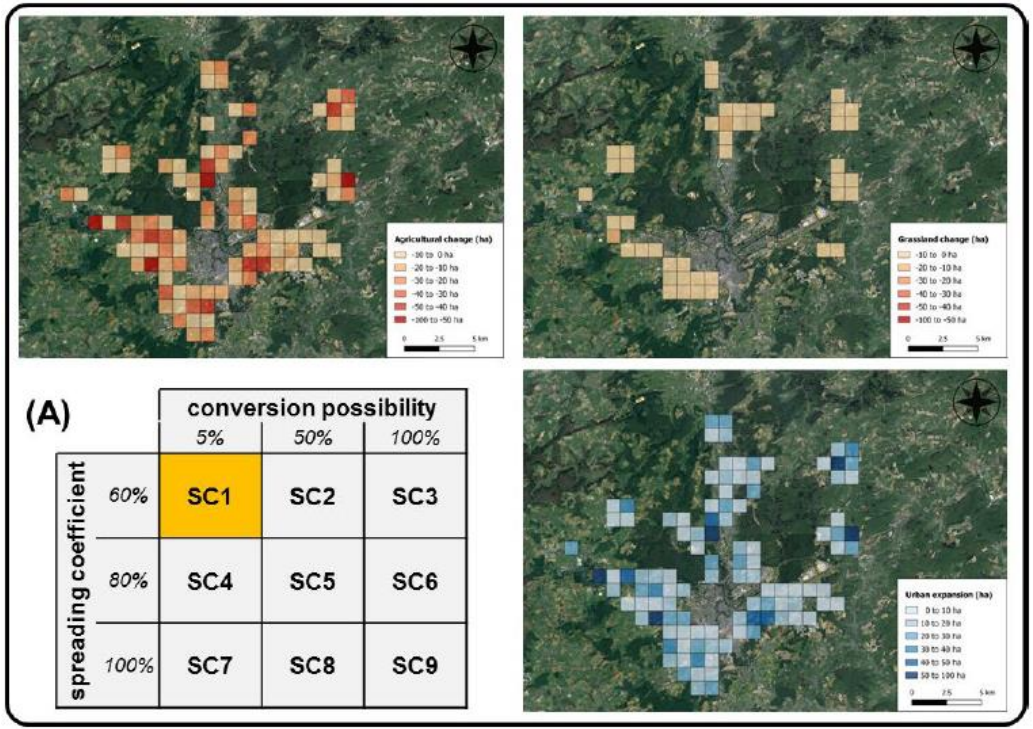
Modelling steps

- ↓ Goal & Scope
- ↓ Creation of the model
- ↓ Calibration
- ↓ Validation
- ↓ Simulation
- ↓ Scenario analysis and assessment



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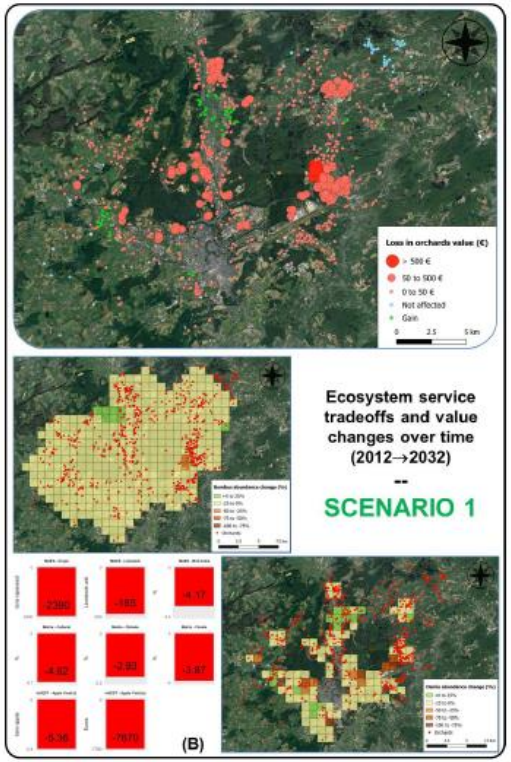
Modelling steps

- ↓ Goal & Scope
- ↓ Creation of the model
- ↓ Calibration
- ↓ Validation
- ↓ Simulation
- ↓ Scenario analysis and assessment
- ↓ Calculation of CFs
- ▪ Application in LCA



$$(\Delta E_C^+)_I = CF_{mid,C}^{2,1} \times (\Delta d^{2,1})_I + CF_{mid,C}^{2,3} \times (\Delta d^{2,3})_I = \begin{bmatrix} -20 \\ -10 \\ +20 \\ -3 \\ 0 \\ -15 \end{bmatrix} \begin{matrix} m^3.yr^{-1}.ha^{-1} \text{ of timber} \\ t.yr^{-1}.ha^{-1} \text{ of } CO_2 \text{ seq.} \\ t.yr^{-1}.ha^{-1} \text{ of seeds} \\ yr^{-1}.ha^{-1} \text{ of pollination} \\ t.yr^{-1}.ha^{-1} \text{ of apples} \\ LSU.yr^{-1}.ha^{-1} \end{matrix}$$

$$(\Delta W_C)_I = CF_{end,C}^{2,1} \times (\Delta d^{2,1})_I + CF_{end,C}^{2,3} \times (\Delta d^{2,3})_I = \begin{bmatrix} -24000 \\ -3000 \\ -150 \\ -28500 \end{bmatrix} \begin{matrix} €.yr^{-1}.ha^{-1} \text{ worth of material} \\ €.yr^{-1}.ha^{-1} \text{ worth of biomass} \\ €.yr^{-1}.ha^{-1} \text{ worth of climate reg.} \\ €.yr^{-1}.ha^{-1} \text{ worth of food} \end{matrix}$$

Othoniel et al.: Methodological framework for the impact assessment of land cover changes on ecosystem services in global supply chain models - **SUBMITTED**

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Rationale and objectives

Production system → Land use modelling → Ecosystem services provision → Socio-economic development

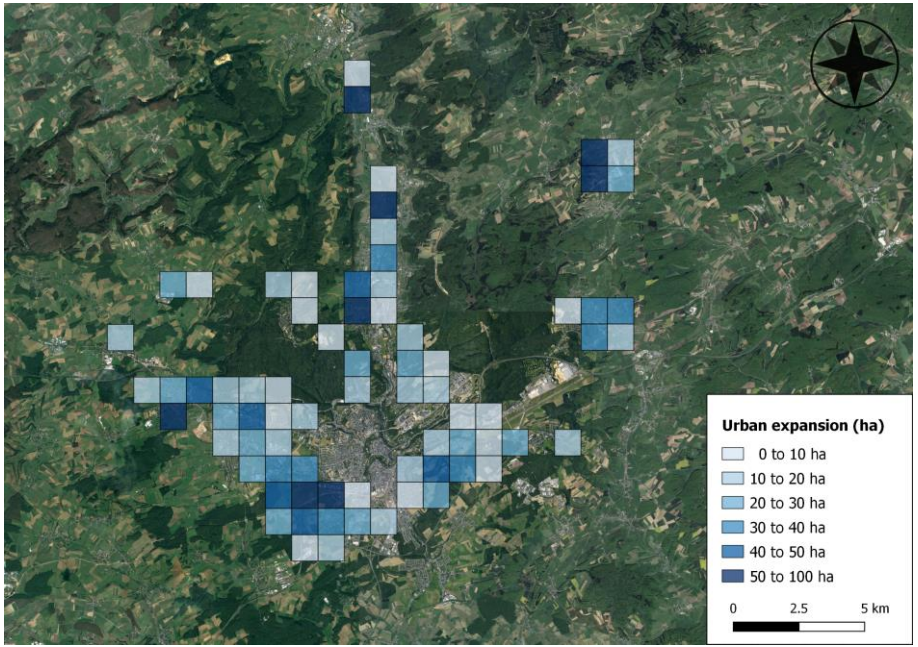
➔ integrated dynamic modelling of cause-effect chains for ecosystem services

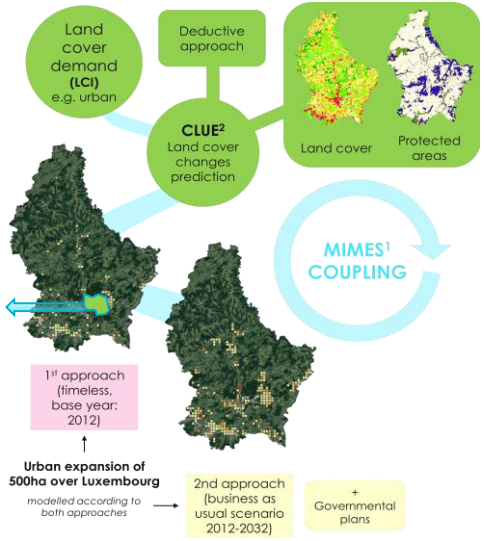
LUXEMBOURG Scale

Develop spatial indicators > **characterization factors** < of land use impacts on ES

GLOBAL Scale

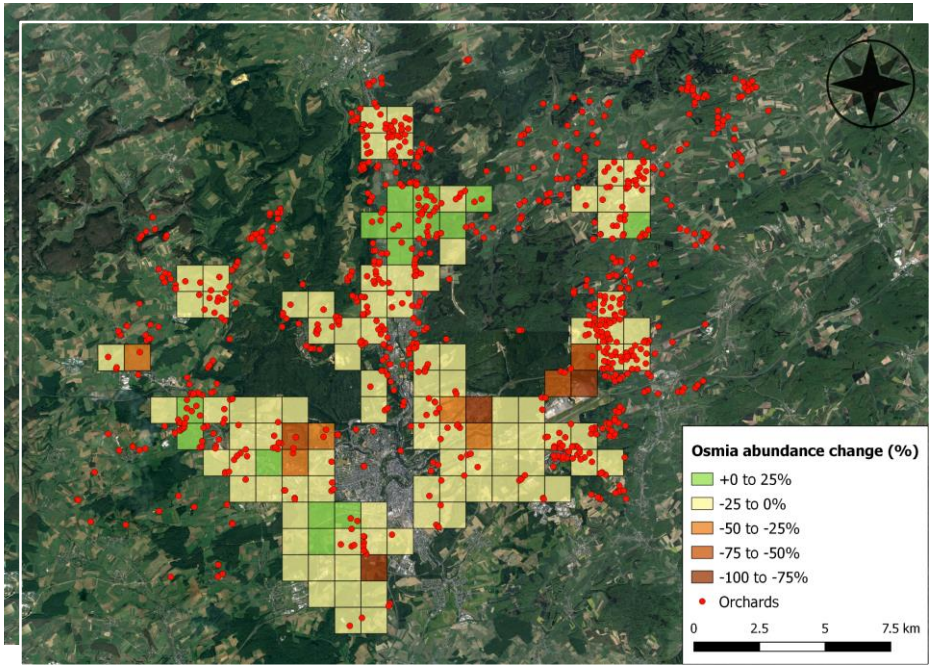
Preliminary outcomes for Luxembourg

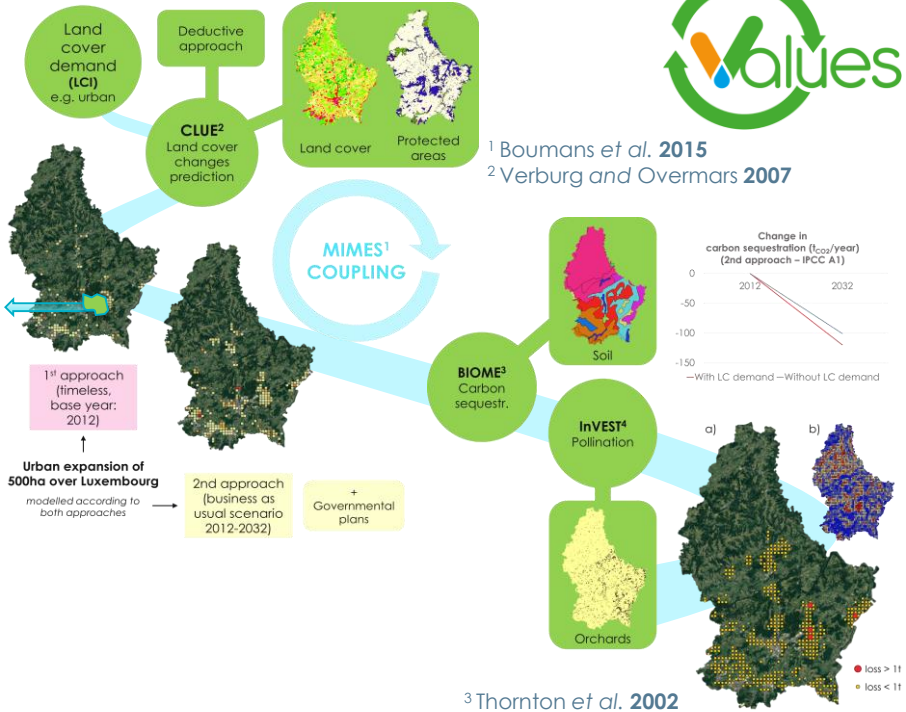




[1] Boumans *et al.* **2015**
[2] Verburg *and* Overmars **2007**

Preliminary outcomes for Luxembourg





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[4] Lonsdorf *et al.* **2011**

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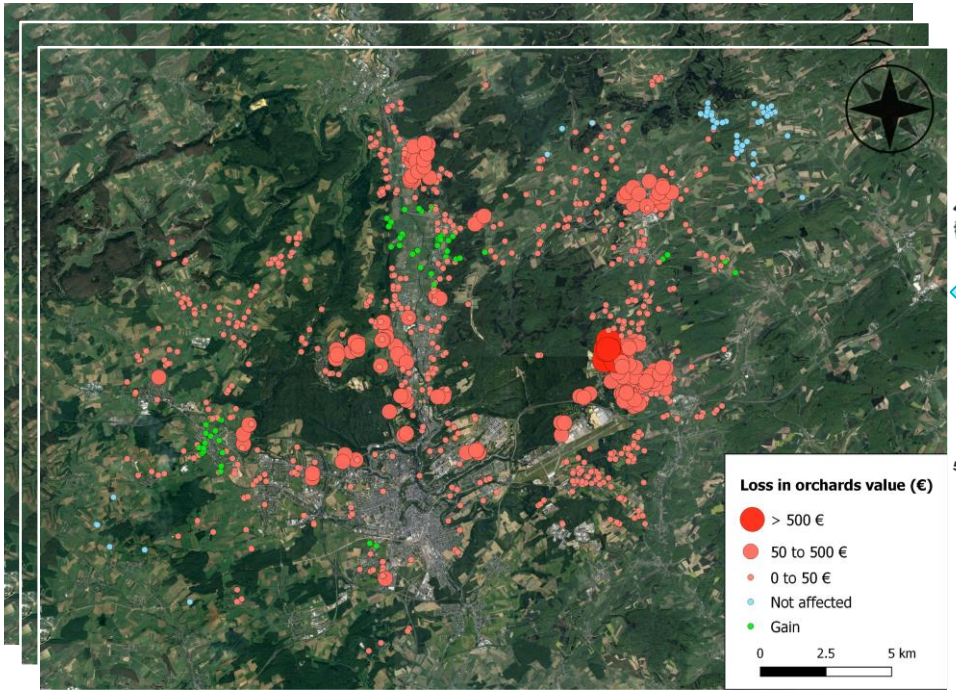

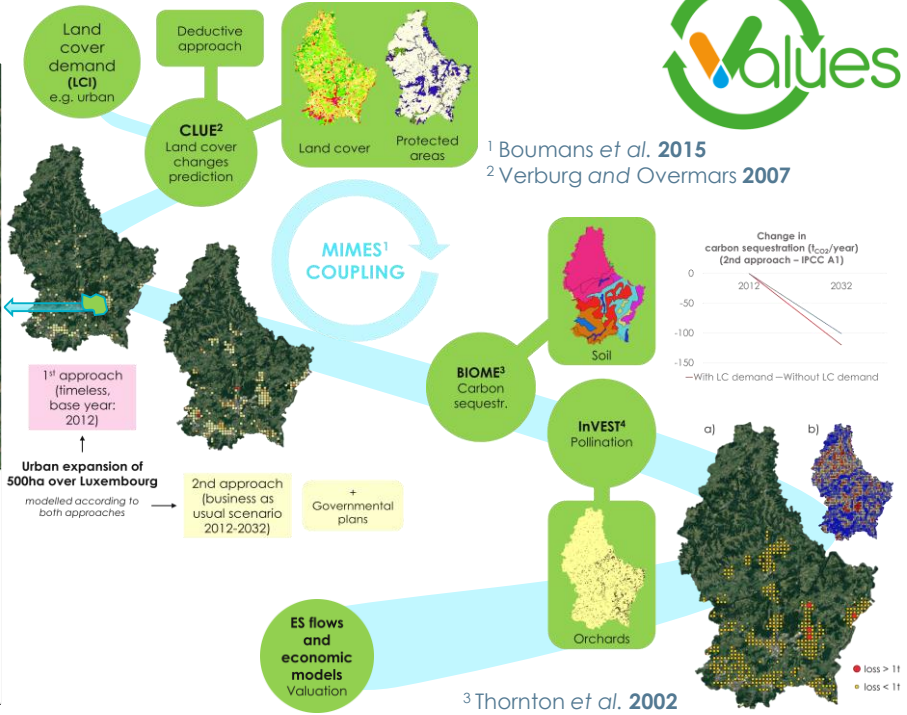

[1] Boumans *et al.* **2015**
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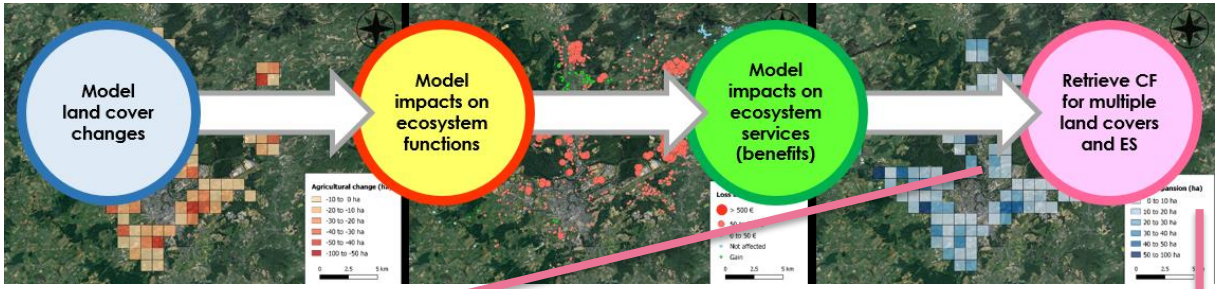
a) Change in apple orchards yield and b) pollination supply
1st approach : +500ha in 2012

Preliminary outcomes for Luxembourg



e.g.

$$CF^{s,p}_{mid,C} = \frac{\partial F^{p}_{mid,C}(d^{1,p}_C, d^{2,p}_C, \ldots, d^{S,p}_C)}{\partial d^{s,p}_C} \qquad CF^{2,1}_{mid,C} = \begin{bmatrix} 0 \\ 0 \\ +4 \\ 0 \\ 0 \\ -5 \end{bmatrix} \quad CF^{2,2}_{mid,C} = \begin{bmatrix} -10 \\ -5 \\ +4 \\ -1 \\ -8.4 \\ 0 \end{bmatrix} \quad CF^{2,3}_{mid,C} = \begin{bmatrix} -10 \\ -5 \\ +4 \\ -1 \\ 0 \\ 0 \end{bmatrix} \begin{array}{l} m^3.yr^{-1}.ha^{-1} \text{ of timber} \\ t.yr^{-1}.ha^{-1} \text{ of } CO_2 \text{ seq.} \\ t.yr^{-1}.ha^{-1} \text{ of seeds} \\ yr^{-1}.ha^{-1} \text{ of pollination} \\ t.yr^{-1}.ha^{-1} \text{ of apples} \\ LSU.yr^{-1}.ha^{-1} \end{array}$$

$$CF^{s,p}_{end,C} = \frac{\partial F^{p}_{end,C}(d^{1,p}_C, d^{2,p}_C, \ldots, d^{S,p}_C)}{\partial d^{s,p}_C} \qquad CF^{2,1}_{end,C} = \begin{bmatrix} 0 \\ +200 \\ 0 \\ -9700 \end{bmatrix} \quad CF^{2,2}_{end,C} = \begin{bmatrix} -12000 \\ -1800 \\ -75 \\ -12300 \end{bmatrix} \quad CF^{2,3}_{end,C} = \begin{bmatrix} -12000 \\ -1800 \\ -75 \\ 300 \end{bmatrix} \begin{array}{l} €.yr^{-1}.ha^{-1} \text{ worth of material} \\ €.yr^{-1}.ha^{-1} \text{ worth of biomass} \\ €.yr^{-1}.ha^{-1} \text{ worth of climate reg.} \\ €.yr^{-1}.ha^{-1} \text{ worth of food} \end{array}$$

Othoniel et al.: Methodological framework for the impact assessment of land cover changes on ecosystem services in global supply chain models - **SUBMITTED**

e.g.

CF for Luxembourg	Urban Land	Infrastructure
Pollination (€ change per ha in 2012)	-0.02t_{apple}/ha +/- 0.01 -28€/ha	+0.001t_{apple}/ha +/-0.005 +14€/ha
C-sequestration (t_{CO2} change per ha in 2012)	-0.2t_{CO2}/ha +/- 0.07	X
Pollination (€ change per ha by 2032)	-0.008t_{apple}/ha +/- 0.007 -11€/ha	+0.0005t_{apple}/ha +/-0.005 +7€/ha
C-sequestration (t_{CO2} change per ha by 2032)	-0.04t_{CO2}/ha	X

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LUXEMBOURG Scale

Develop spatial indicators > **characterization factors** < of land use impacts on ES

GLOBAL Scale

Global scale: modelling framework

Production function: $P = K^{b_1} L^{b_2} \prod ECS^{b_{3\to i}} \prod ES^{b_{i+1\to j}}$

Boumans *et al.* **2015**

e.g.

World Input-Output Database (43 countries + rest of the world)

Land use tables (FAO data)

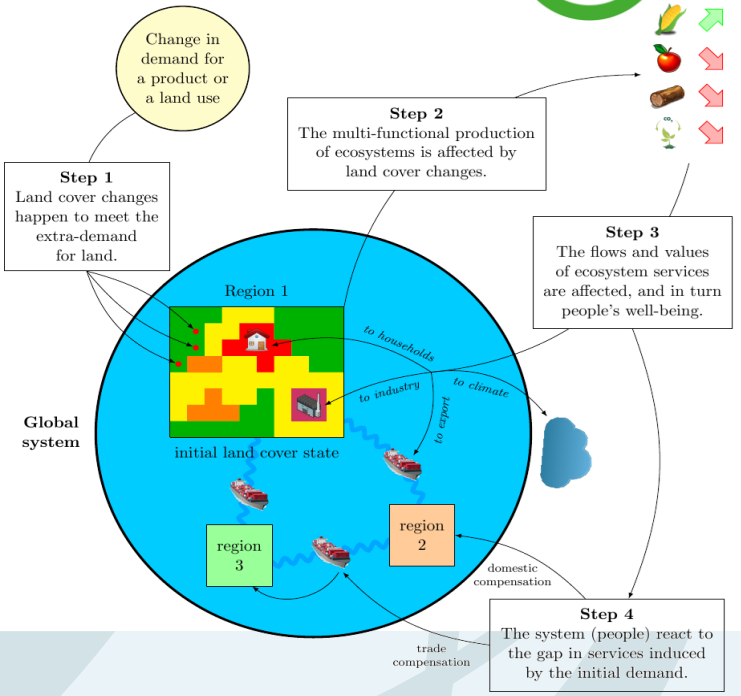
Global Matrix[1] Ecosystem services valuation model

TEEB/CICES accounting framework

K: built capital
L: labour force
ECS: intermediate production
ES: ecosystem services

The role of ES in economic development is **explicit** and a **limiting factor**

- Demand is met under supply constraints (imperfect market)
- Economic development assessed inside the planet's bio-physical boundaries



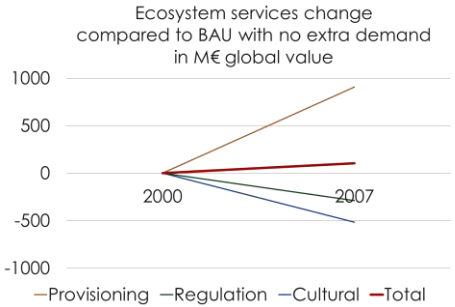
[1] De Groot *et al.* **2012**

Global scale: preliminary outcomes

- Interpretation:

CF for life-cycle commodity productions under scenario of Business-As-Usual (BAU) ➔ calculated as marginal monetary variation over time (from 2000 to 2007) of ecosystem services (ΔES) per hectare of agricultural land transformed in Switzerland and compensated for…

e.g.



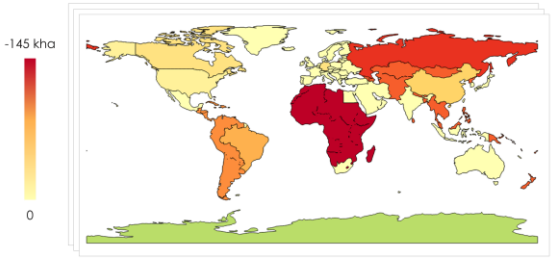
$$CF_{agric,CH,BAU} = \begin{pmatrix} +0.907\ M€_{prov} \\ -0.287\ M€_{reg} \\ -0.517\ M€_{cult} \end{pmatrix}$$

per M€ → to be converted in $ha_{agric,CH,BAU}$

Services: provisioning, regulation & maintenance, cultural

e.g. **Characterization Factors**

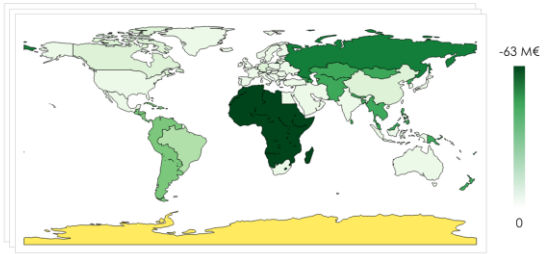
e.g. Forest loss due to increasing demand for agricultural sector by 100M€ in Germany over BAU scenario – Period: 2000-2007



Land cover changes are a driver of impacts on ecosystem services. Their dynamics over space (countries) depend on multiple identified factors (e.g. climate, population, technological development, legislations).

Yearly dynamic feedback loop in System Dynamics

The provision of ecosystem services is a criteria that influences more or less land use changes, depending on the context (country). For instance, the conservation of forests, sources of many services, seems much more efficient in "developed countries", where land cover changes are overall more constrained.



Changes in the potential provision of ES due to land use changes
e.g. Regulation & Maintenance ES – Time: 2007

Outlook on the final steps with VALUES

- **Model developments, application, and work in progress**

Local model (2 papers in preparation):

- Calculation of CFs for pollination and C seq. in Luxembourg, associated with land use changes from 2012 to 2032 (current situation and national land management plans are used as reference)
- Sensitivity analysis and characterization of uncertainty propagation across spatial units
- Application to LCA case study on bioenergy production in Luxembourg

Global model (paper in preparation):

- Calibration and validation to allow forecasting and scenarios simulation
- Disaggregation of land uses by economic sectors of influence + Nesting with Luxembourg
- Improvement of trades modelling and demographic dynamics

- **Comparison with state-of-the-art practice** in land use-based assessment of ES values

Key opportunities and limitations for decision-making

- **Library of characterization factors**: under construction for multiple settings
  ➔ expected delivery (March 2018 via @ www.lifecycle-values.lu)

  First-generation of CFs developed at multiple (spatial and temporal) scales to assess the impact of land use-based activities on the provision of ecosystem services:

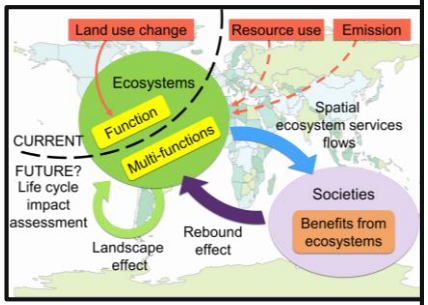
  - **Luxembourg scale**: example of high-resolution (500m pixel) integration of different models (land use, ES, …)
  - **Global scale**: adjustment on the Burkhard et al.'s look-up table / De Groot et al.' $scores

- **Follow-up of VALUES for decision-making**: basis for ES monitoring and assessment in Luxembourg, complementary to **MAES** (Mapping and Assessment of Ecosystems and their Services), and benchmark for **TEEB** (The Economics of Ecosystems and Biodiversity) country study (Rugani *and* Othoniel 2017)

  - **VALUES tool**: potential to develop a **decision support system**
  - Work in progress on the **uncertainty** associated with modelling framework, indicators and the definition of scenarios, in collaboration with **local stakeholders and authorities in Luxembourg**

Further research directions and take-home message(s)

- **Alignment of spatial and temporal scope** of LCIs with the ES assessment framework
- Definition of substantiated and transparent indicators that can clearly communicate the **costs and benefits to society induced by life-cycle interventions** on ecosystems.
- **Land use is not the only driver**: better consideration of the characterization of impacts due to other LCI flows
- A parallel between cause-effect chains: the **cascade model** in the assessment of **"cross-cutting issues"**



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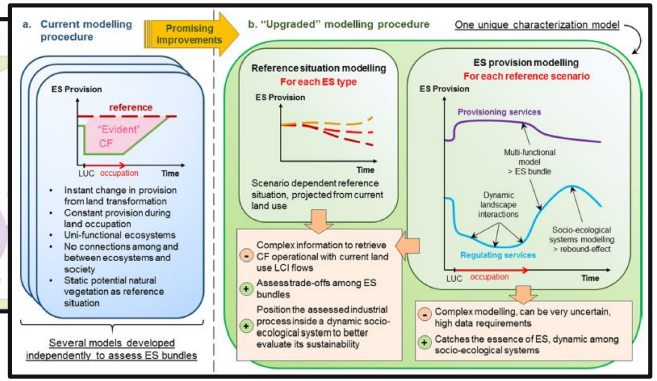

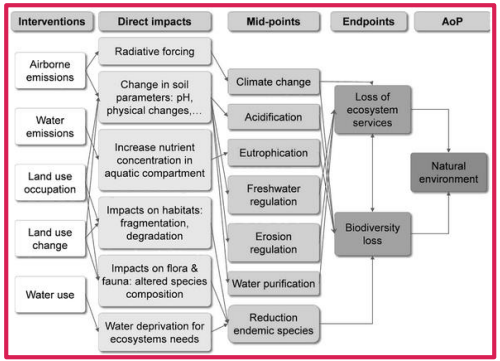

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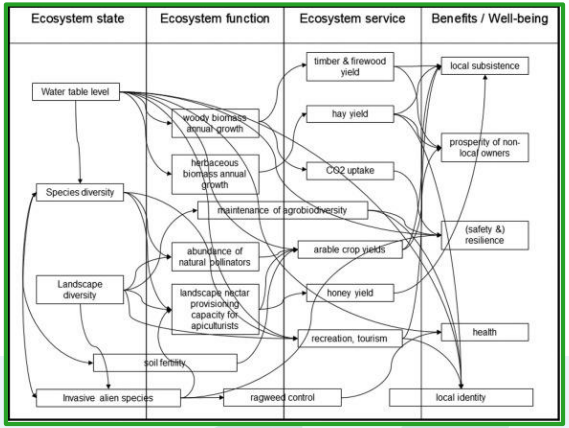

Potschin-Young *et al.* **2017**

Life Cycle Initiative

Acknowledgments

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C13/SR/5903117

VALUing Ecosystem Services for environmental assessment

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Reinout **Heijungs**

Cees A.A.M. **Withagen**

AFORDable Futures LLC

Roelof **Boumans**

E-mail contacts: info@lifecycle-values.lu
benedetto.rugani@list.lu
benoit.othoniel@list.lu

Website: www.lifecycle-values.lu

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