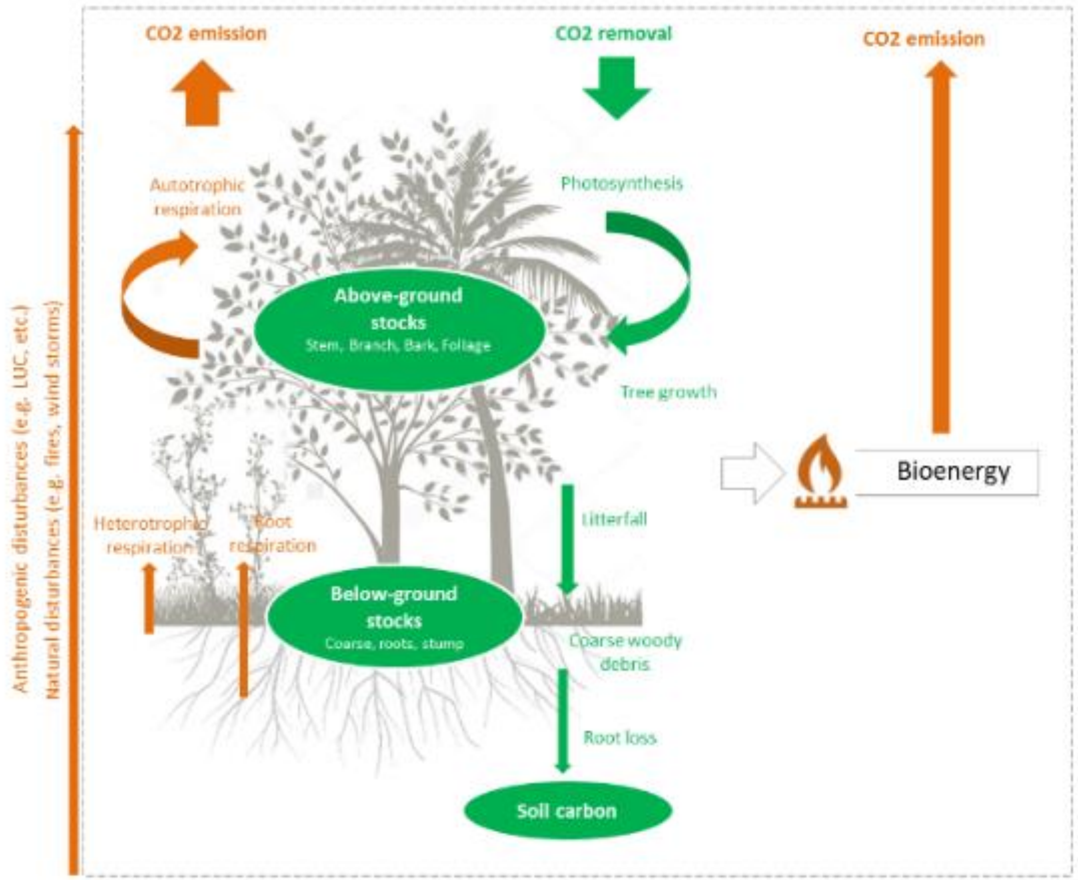
INRAE-BETA Workshop 10 May 2021

Extending the boundaries of environmental assessments: coupling LCA with economic modelling

Integration of carbon dynamics within LCA



Prepared by Ariane Albers
Post Doc INSA Toulouse Biotechnology Institute
albers@insa-toulouse.fr

INSA TOULOUSE
tbi Toulouse Biotechnology Institute Bio & Chemical Engineering

Outline

Introduction & rationale

- Why does dynamic LCA matter?
- Current methodological developments

Modelling approaches

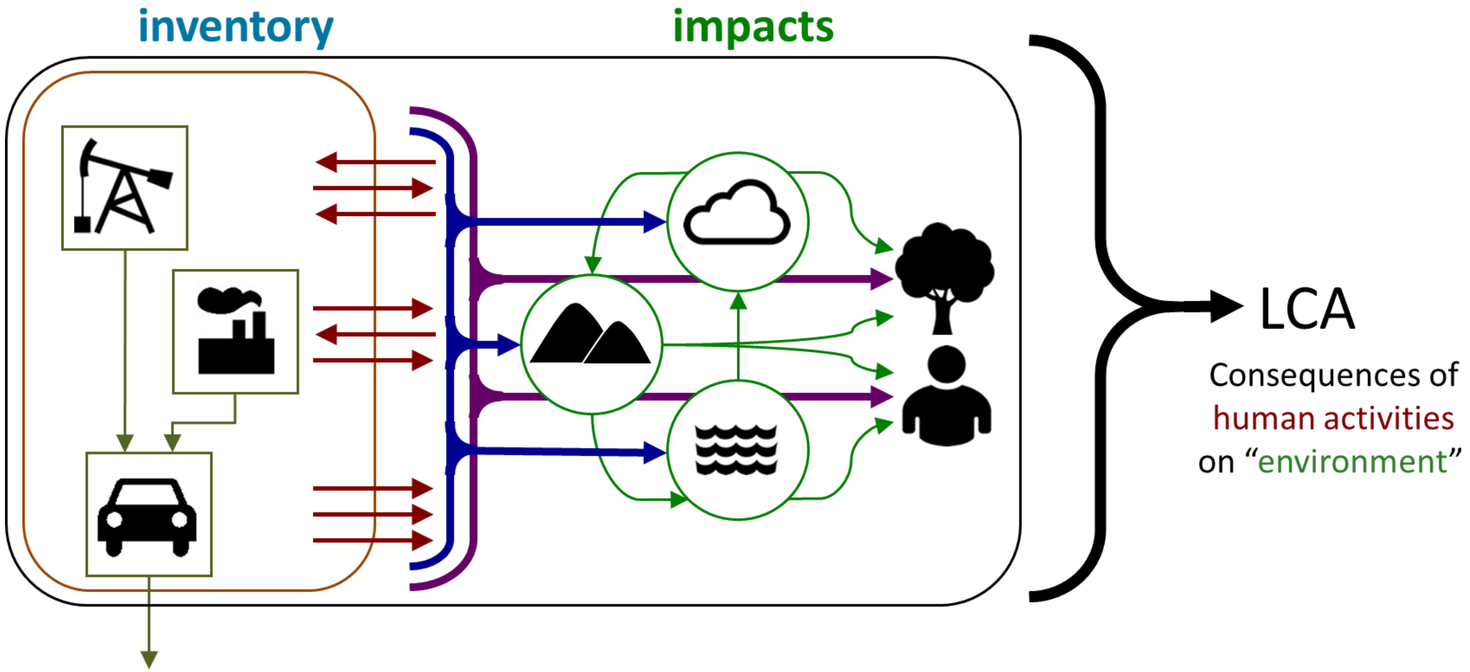
- How to model biomass/carbon dynamic?
- Bottom-up
- Top-down

Conclusions

- When to use what?
- To achieve what?

Introduction

- LCA framework under continuous developed in the last 30 years
- There are still challenges, such as, the lack of consideration of **dynamic features**:
  - **Temporal scope** (when does an emission occur?) → temporal profiles
  - **Spatial scope** (where does an emission occur?) → local environmental uniqueness



Refs.: Figure Arnaud Hélias (2019), ELSA Montpellier

Temporal dynamics: static carbon characterisation

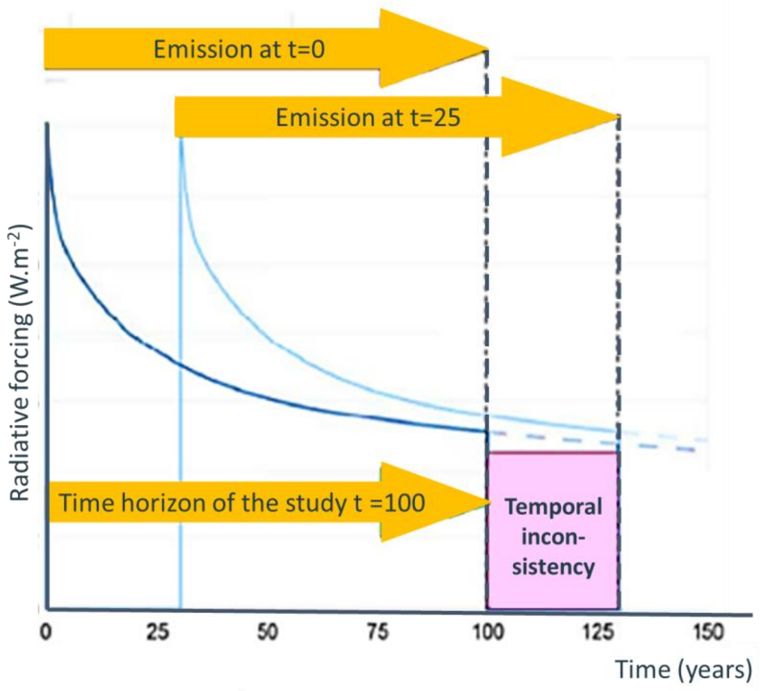
Example: IPCC Global Warming Potential (GWP) metric

$$\text{Climate Change}_{\text{impact}} = \sum_i m(i) \times GWP_{100}(i)$$

$[\text{kg } CO_{2,eq}]$ $[\text{kg}]$ $[\text{kg } CO_{2,eq} \cdot \text{kg}^{-1}]$

Limitations in the characterisation:

- **Time preferences**: temporal cut-offs beyond the fixed TH
- **Inconsistent** temporal boundaries



Ref.: Benoist, 2009; O'Hare, 2009; Levasseur, 2010

Temporal dynamics: static carbon inventories

Example: IPCC Global Warming Potential (GWP) metric

$$\text{Climate Change}_{\text{impact}} = \sum_i \text{m(i)} \times \text{GWP}_{100}\text{(i)}$$

$[\text{kg } CO_{2,eq}]$ $[\text{kg}]$ $[\text{kg } CO_{2,eq} \cdot \text{kg}^{-1}]$

Accounting limitation:

- **Aggregation** of all C flows at t=0
- **No temporal differentiation** of elementary flows

Why is this an issue?

Ref.: Collet et al. 2011, Albers et al. 2019

Example of the (static) aggregation of carbon flows

Missing temporal biogenic C profiles due to aggregation of C flows

Fossil-based economy

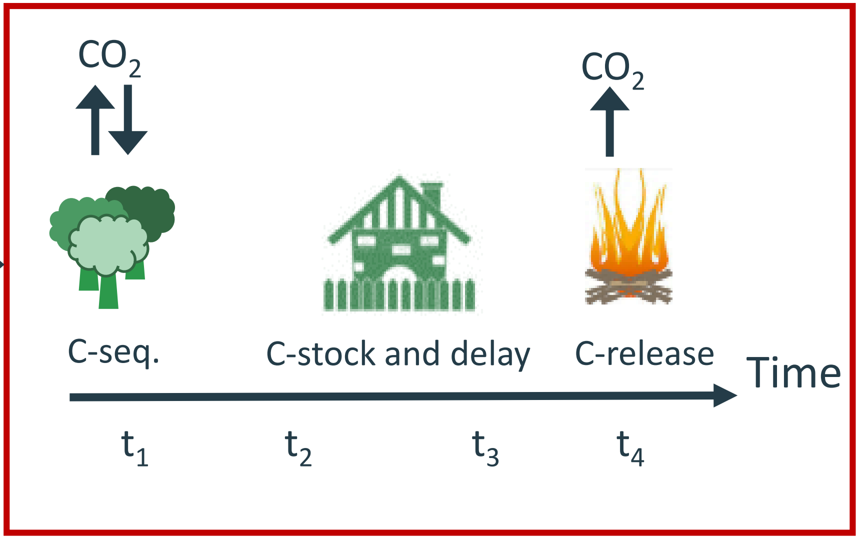
Fossil CO_2

Carbon source
(Fossil CO_2 = release)

Bioeconomy

Biogenic CO_2

Carbon neutral
(Biogenic CO_2 = release – sequestration)



Zero impact promotes carbon neutrality

Modelling approaches rely on this hypothesis, so does policy

Biogenic carbon does have an impact!

The time lag matters!

Permanent C losses!

Non-CO_2 emissions (e.g. CH_4)!

The **point it time** the C is emitted it increases the atmospheric concentration of GHGs

→The energy balance of the Earth climate system does **not make a difference on the origin of C** (biogenic- or fossil-sourced)

→ **Temporary releases** contribute to climate change

CO_{2bio} ≠ climate neutral

↑

In the atmosphere

1 unit of $CO_{2\,bio}$ = 1 unit of $CO_{2\,fossil}$

↑

1 unit $CO_{2\,bio}$ emitted

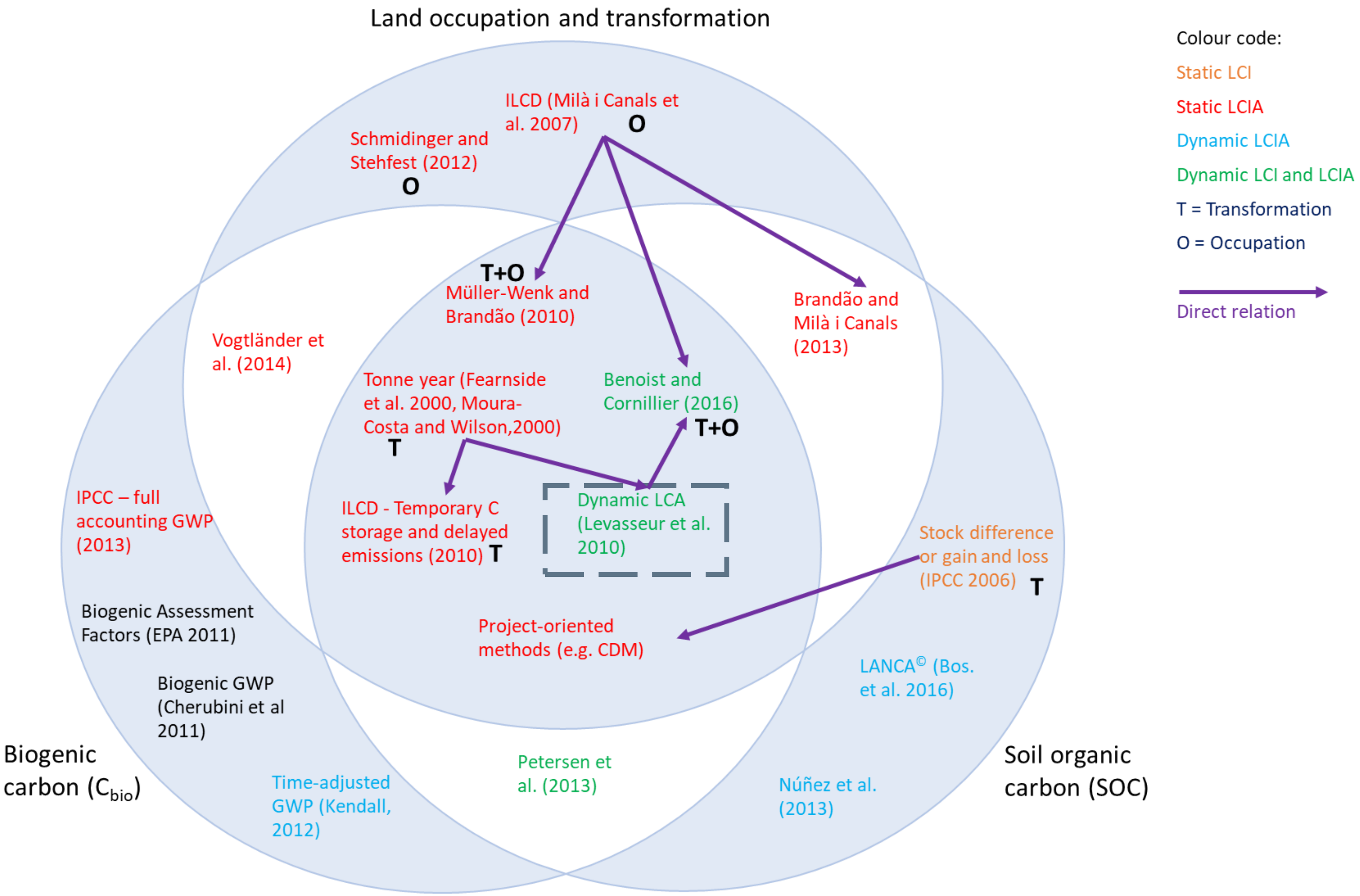
↑

Conversion of biomass into energy

$CH_nO_n + nO_2 \rightarrow nH_2O + CO_{2\,bio}$ + energy

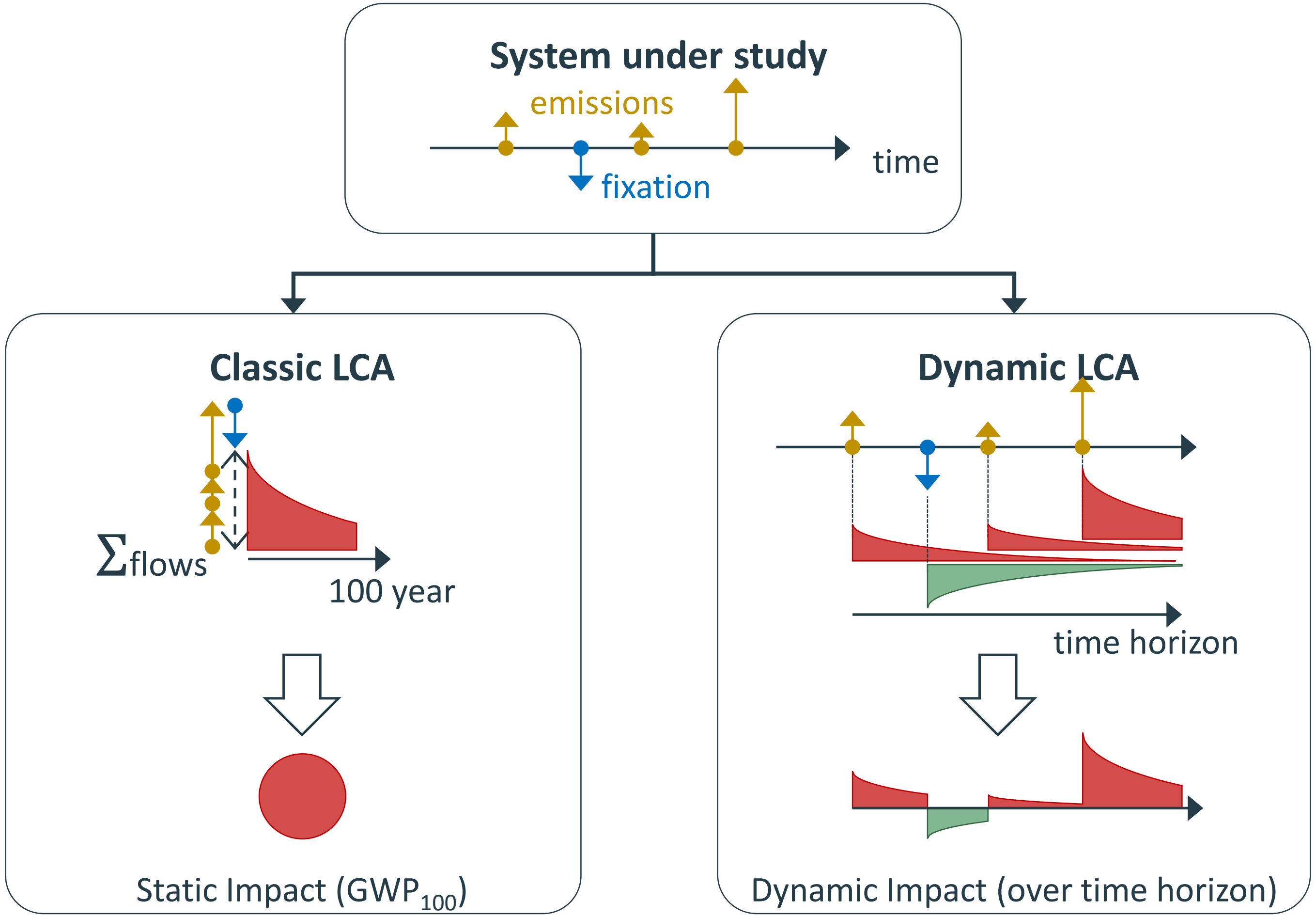
Cherubini et al. 2011

Methods in LCA linking LULUC, biogenic C and SOC



Ref.: adapted from Benoist and Bessou (2018), SOCLE project; evaluation in progress

Dynamic LCA approach compared to static GWP



Albers et al. (2019)
De Rosa et al. (2018)

- Build biogenic carbon profiles
- Dynamic emission may provide a more accurate picture of "real" climate change mitigation potentials, for instance towards climate targets

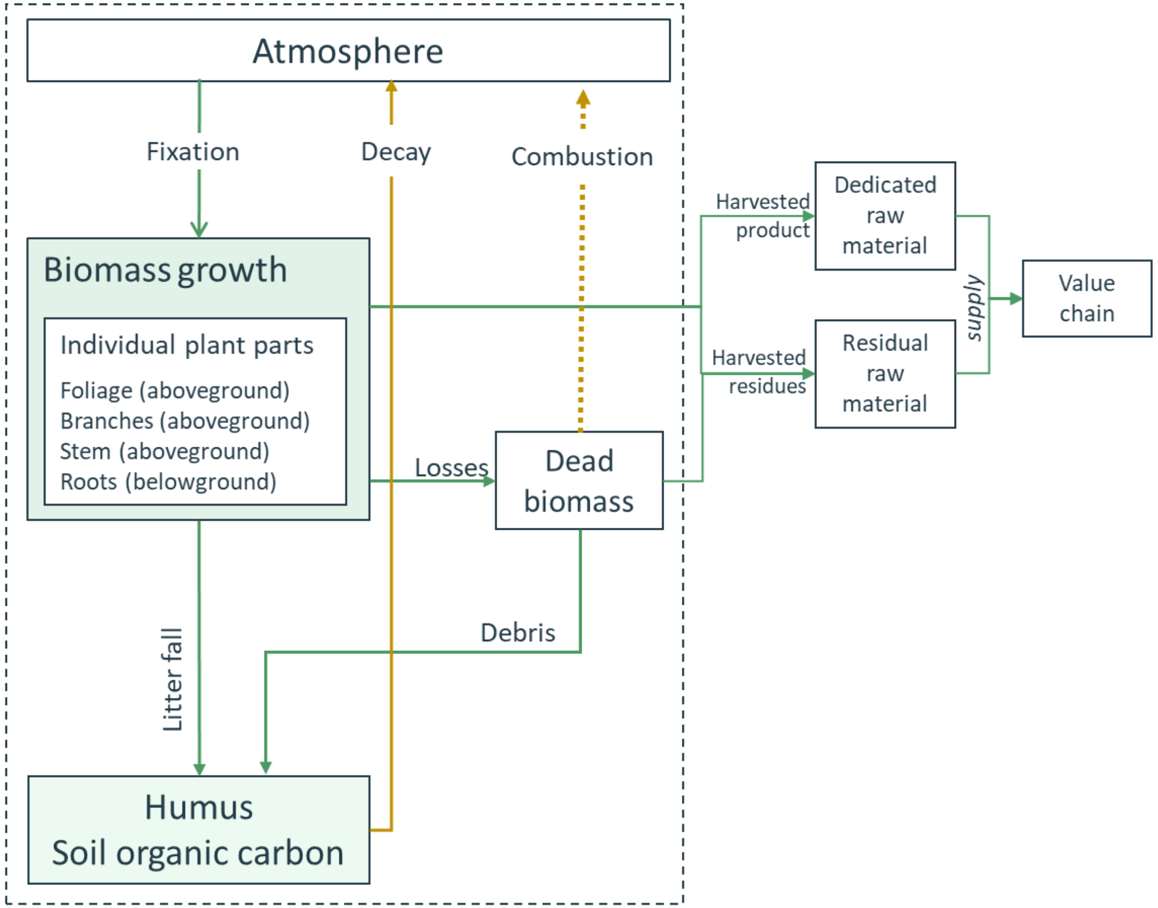
Refs.: Figure Arnaud Hélias (2019), ELSA Montpellier

Dynamic modelling of feedstock resources

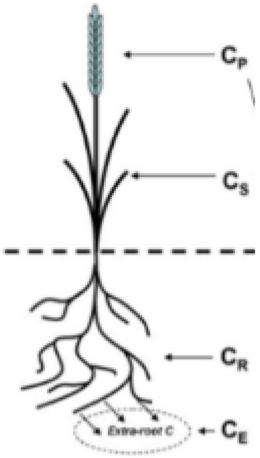
Modelling

Dynamic carbon accounting: $\mathbf{C_{bio} + SOC + LU(C)}$

Upstream modelling

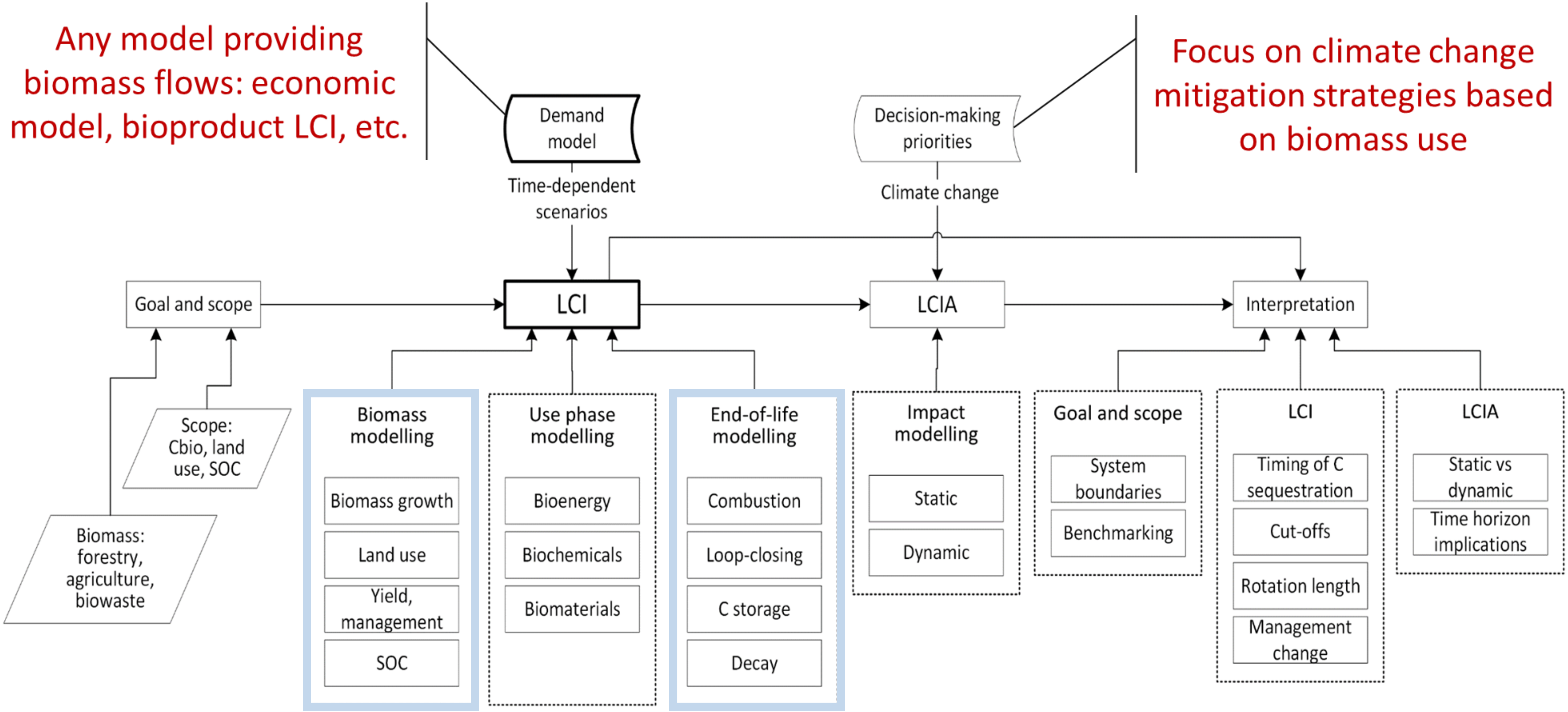


- ○ **Carbon sequestration** in the living biomass
  - Plant growth (non-linear)
  - Allometric relation btw. e.g. age and height or diameter
  - C partitioning among plant organs (e.g. leaf, stem, root)
- ○ **Soil organic carbon**: dead biomass
- ○ **Land use management (change)**: rotations, thinning, nutrient supply, residue removals, tillage, etc.
- **Land use change**
- **Climatic and edaphic conditions and changes**



Ref.: Fig. (left) Albers, 2019 (PhD thesis), Fig. (right): Bolinder, et al., 2007 (https://doi.org/10.1016/j.agee.2006.05.013)

Modelling: a framework for dynamic LCA of biomass

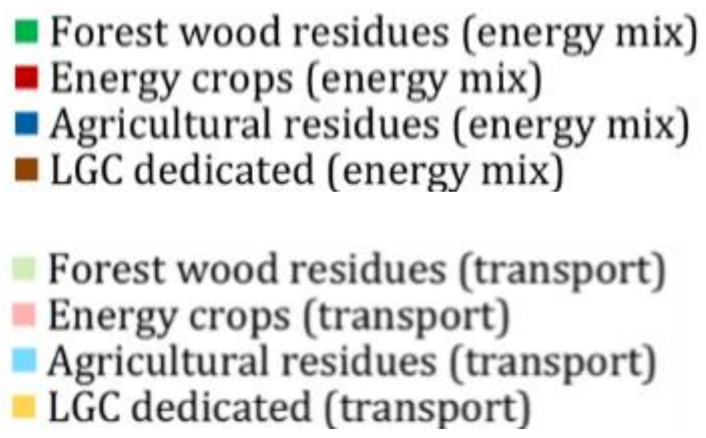


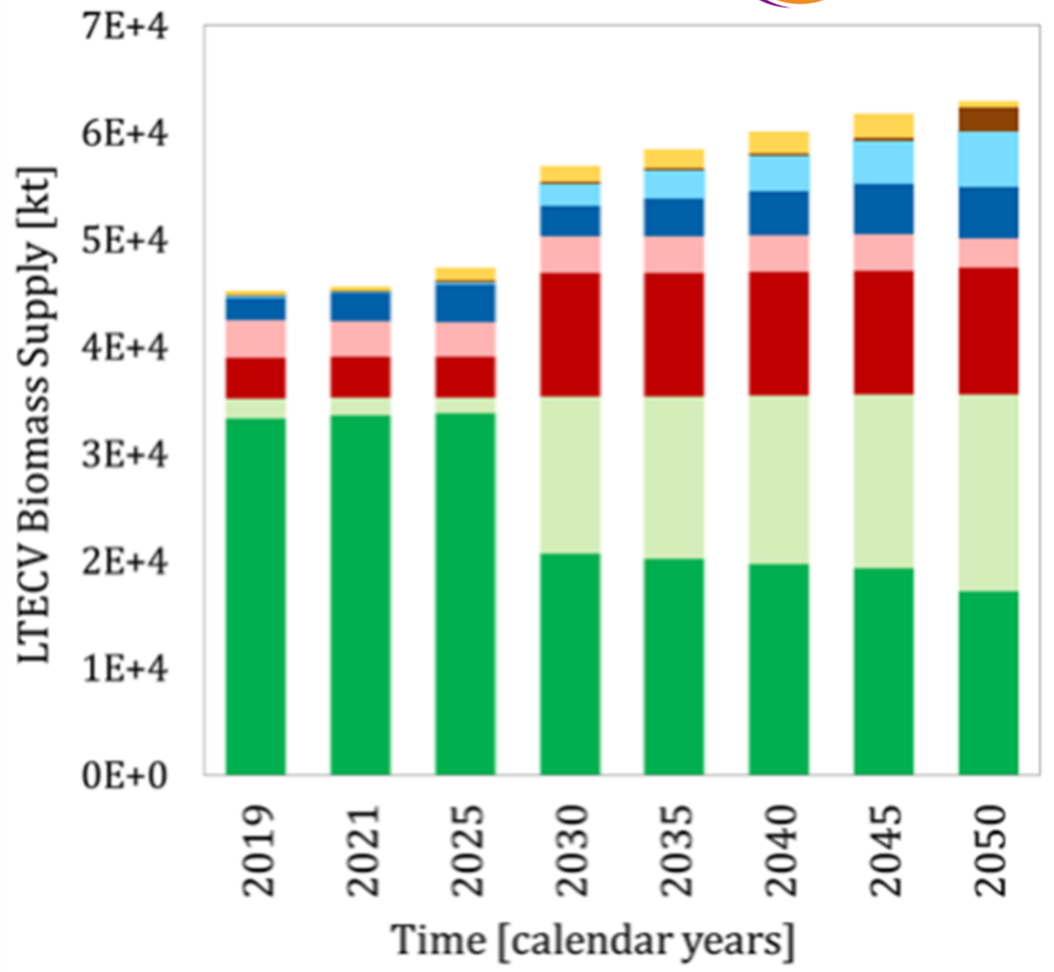
Albers, 2019 (PhD thesis)

Bottom-up: IFPEN TIMES-MIRET partial-equilibrium

Modelling

Example of prospective **biomass demand in France** up to the year 2050 under policy constraints (LTECV: “loi de transition energetique”)



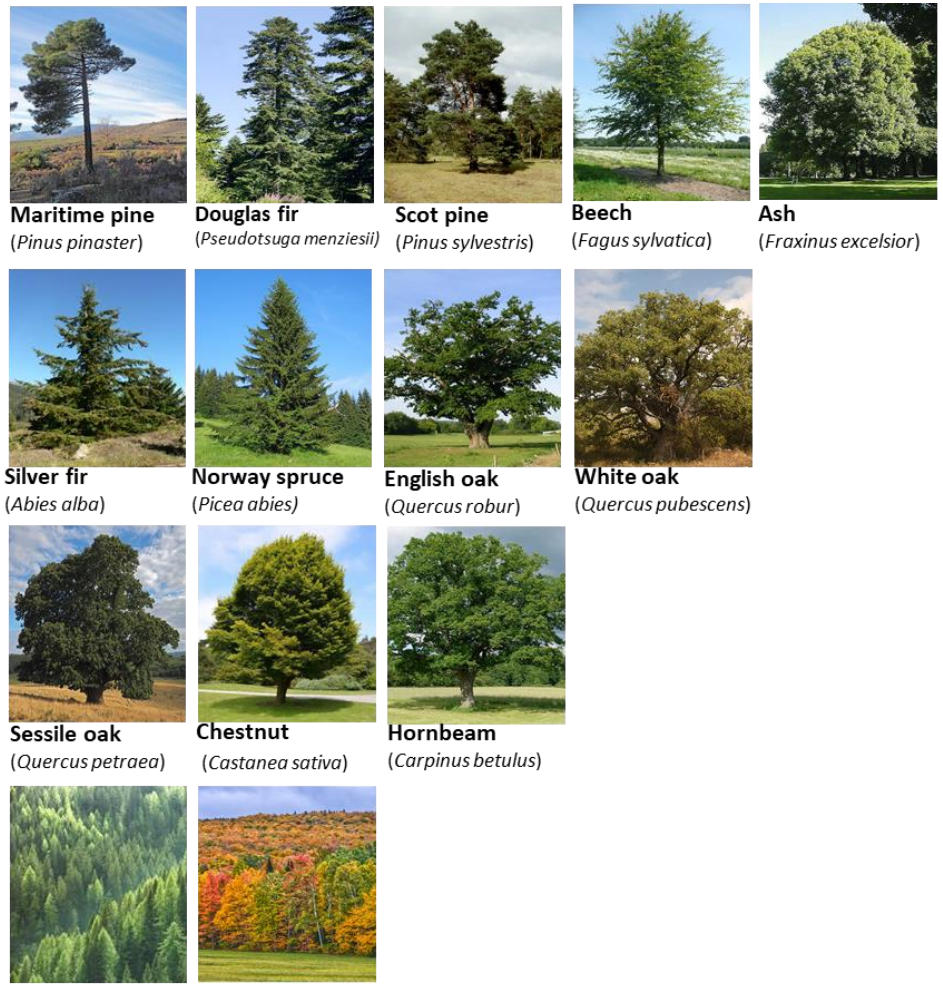


LGC: Lignocellulosic matter

A. Albers, P. Collet, D. Lorne, A. Benoist, A. Hélias, Coupling partial-equilibrium and dynamic biogenic carbon models to assess future transport scenarios in France, Appl. Energy. 239 (2019) 316–330. https://doi.org/10.1016/j.apenergy.2019.01.186.

Modelling forest trees of the French wood supply-chain

Modelling

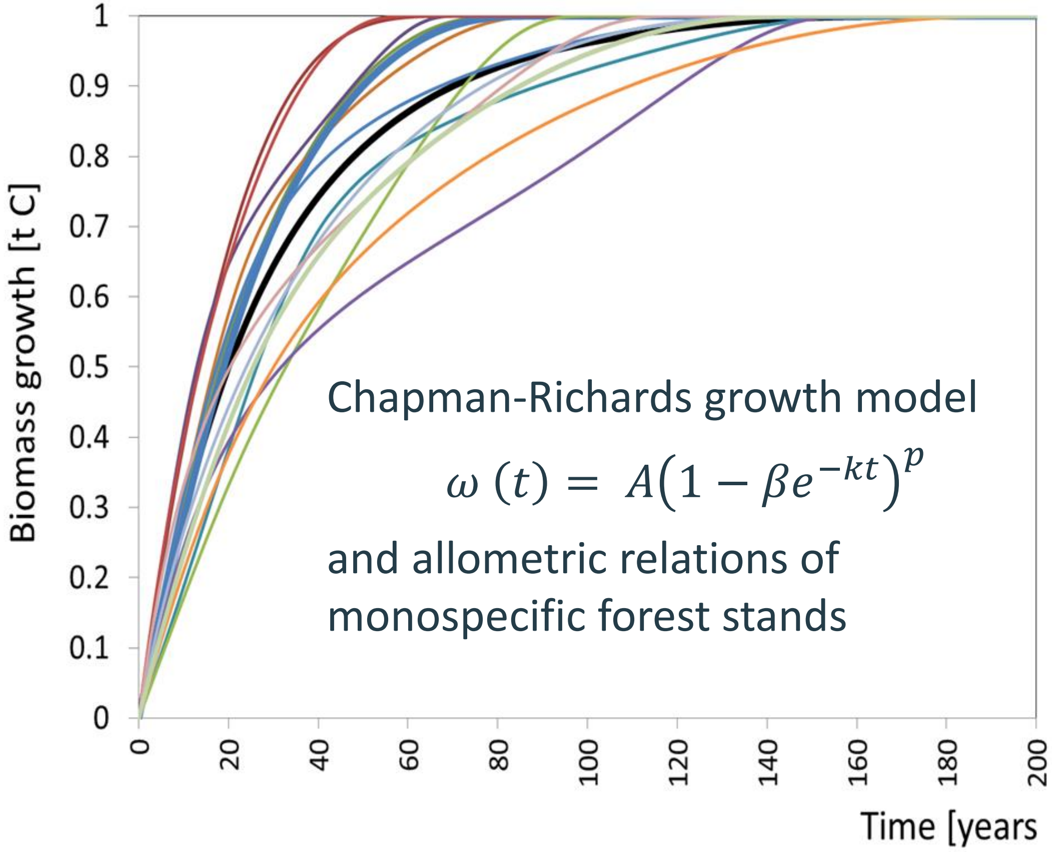


Maritime pine (*Pinus pinaster*) · Douglas fir (*Pseudotsuga menziesii*) · Scot pine (*Pinus sylvestris*) · Beech (*Fagus sylvatica*) · Ash (*Fraxinus excelsior*)

Silver fir (*Abies alba*) · Norway spruce (*Picea abies*) · English oak (*Quercus robur*) · White oak (*Quercus pubescens*)

Sessile oak (*Quercus petraea*) · Chestnut (*Castanea sativa*) · Hornbeam (*Carpinus betulus*)

Other conifers · Other broadleaved



Chapman-Richards growth model

$$\omega\,(t) = A\left(1-\beta e^{-kt}\right)^{p}$$

and allometric relations of monospecific forest stands

A. Albers, P. Collet, A. Benoist, A. Hélias, Data and non-linear models for the estimation of biomass growth and carbon fixation in managed forests, Data Br. 23 (2019) 1–8. https://doi.org/10.1016/j.dib.2019.103841.

The “chicken-egg-causality-dilemma”

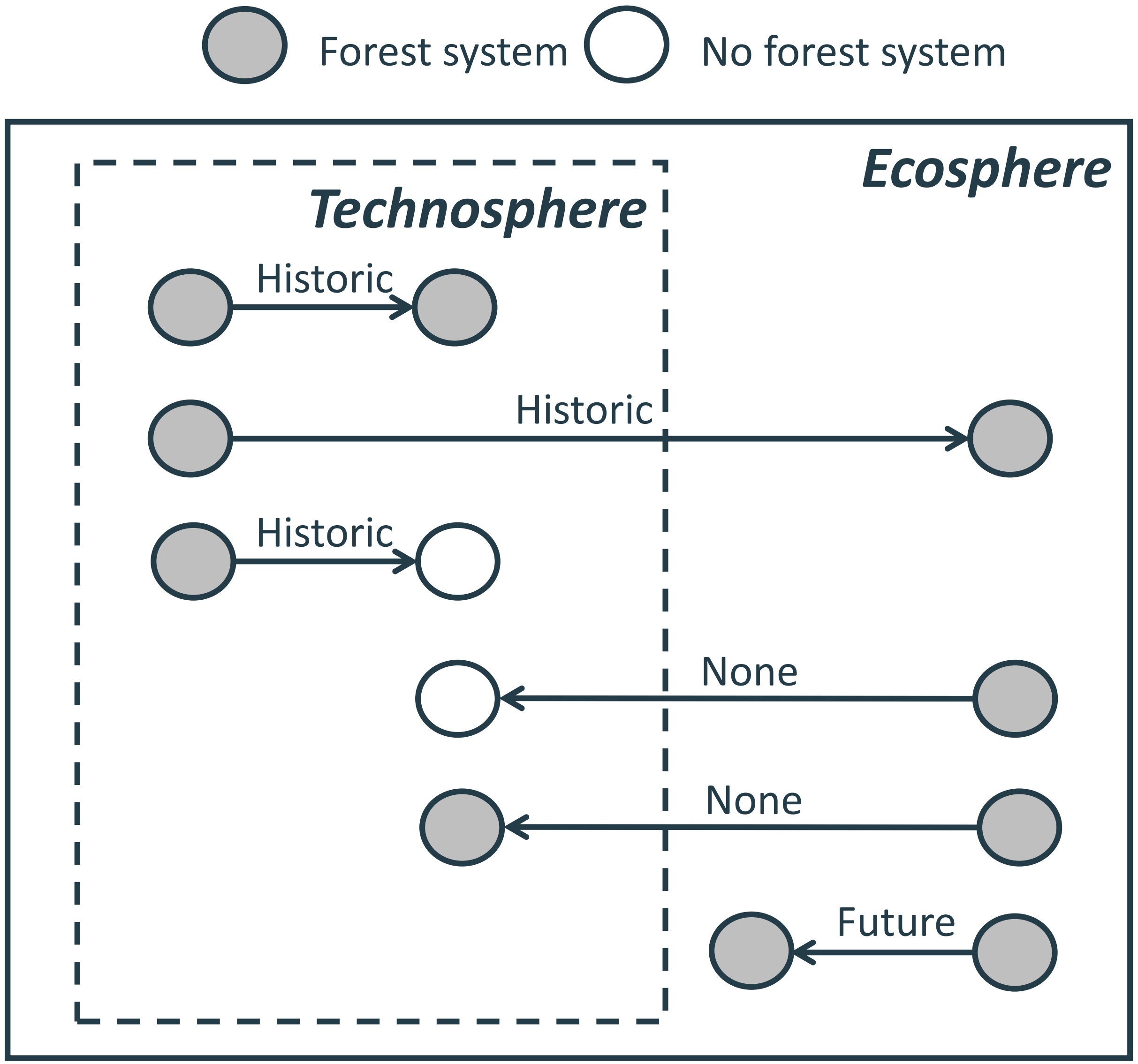
Historic approach generates **C benefits**, while the future one **C debt**.

Historic < C-neutral < Future

Historic approach for attributional LCA, unless new biomass sources, or substitution is modelled

Key criteria:

- Previous state of the **land use**
- **If from ecosphere**, does it remain unmanaged forest or is it converted into a managed system?

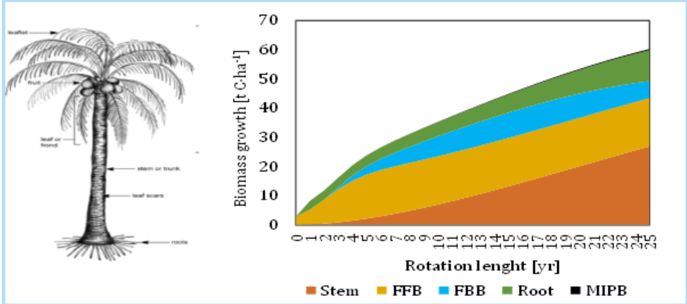


A. Albers, P. Collet, A. Benoist, A. Hélias, Back to the future: dynamic full carbon accounting applied to prospective bioenergy scenarios, Int. J. Life Cycle Assess. 25 (2020) 1242–1258. https://doi.org/10.1007/s11367-019-01695-7.

Bottom-up: dynamic model integration coupled with LCA

Demand model: a static LCA of a palm oil-based bioproduct

Non-linear growth per crop fraction

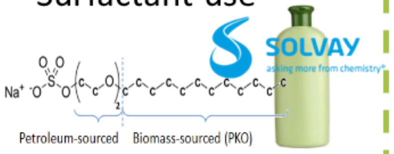


SOC modelling

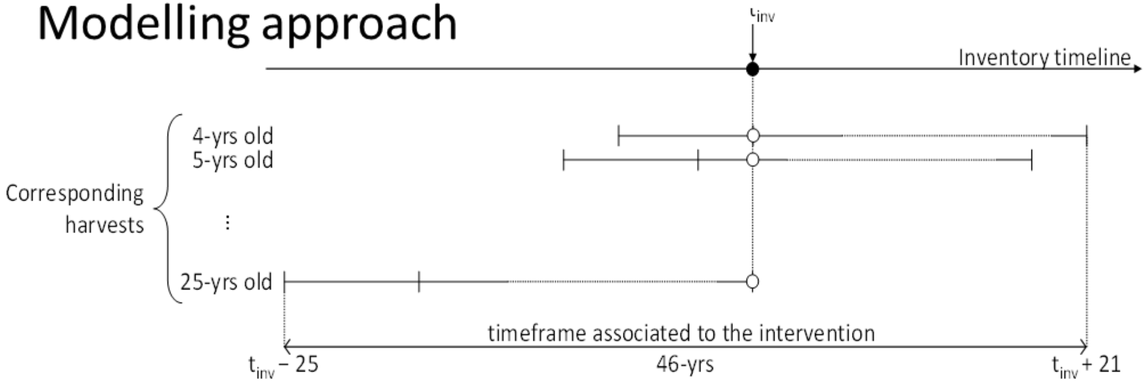
Other emissions

Shell incineration

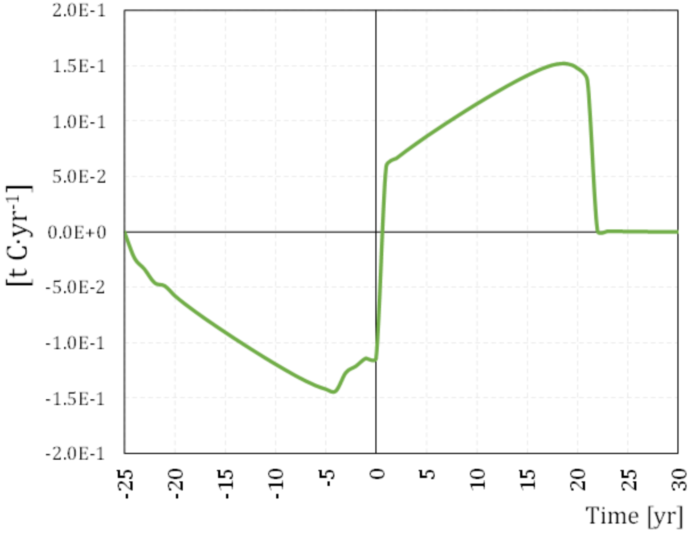
Surfactant use



Modelling approach



Dynamic C flows of a whole lifecvcle

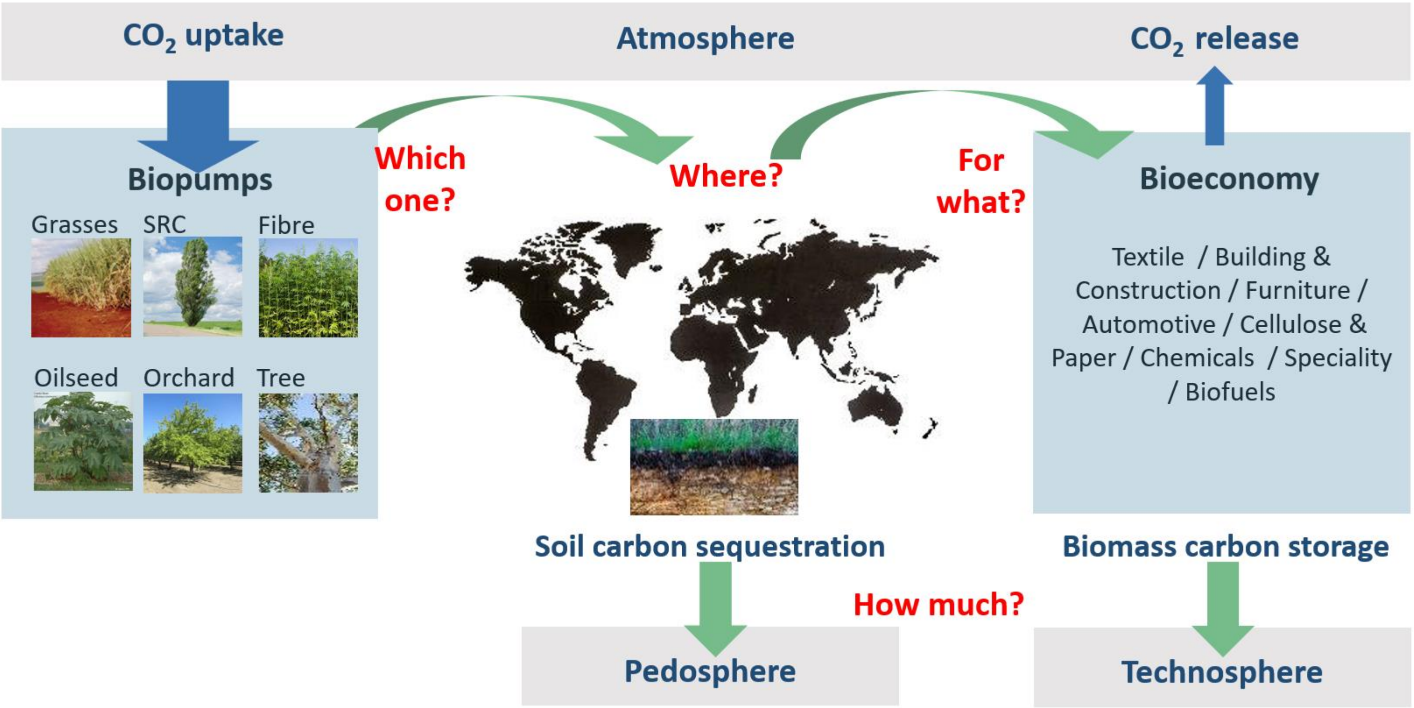


Ref.: Albers, 2019 (PhD thesis)

Top down: negative land-based emissions

Modelling

- We want to identify **global SOC-deficient sinks (< 50 t C/ha)** to sequester CO_2 trough the biomass to the soil
- Apply it on **marginal land** (non-agricultural, non-forestry land cover)
- Rely on the use of **georeferenced products** corresponding to the needs of macro-level global models



1st phase (top-down): Identify global negative SOC-CO_2 emissions

2nd phase (bottom-up): Conduct LCA of biomass C scenarios

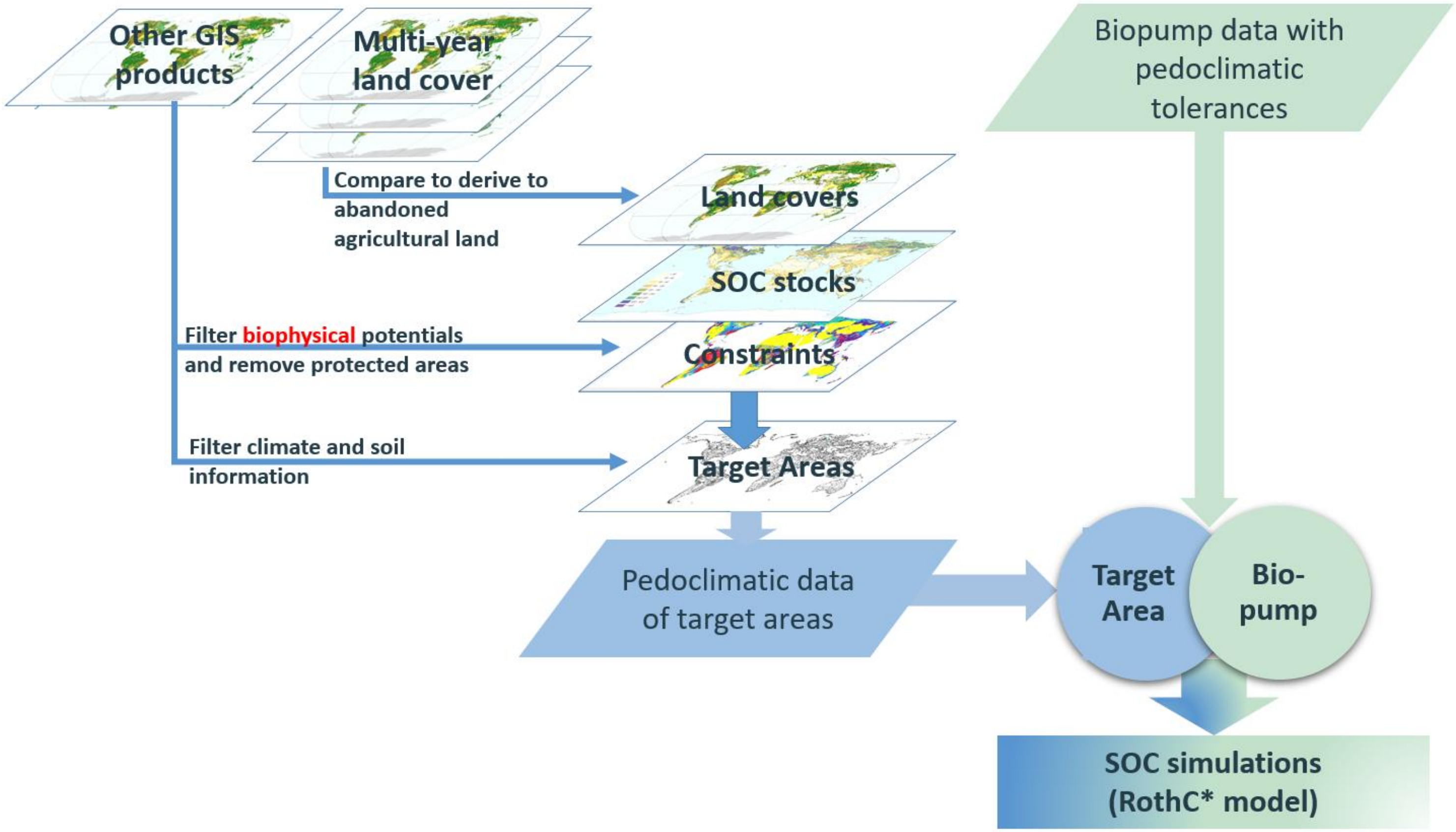
NEGEM

Overview of the framework and strategy

Framework structure in four main steps:

1. Identify global marginal land, while considering **biophysical constraints** for biomass production
2. **Characterise** target areas by pedoclimatic and terrain conditions
3. Identify **plant species** determining their **environmental tolerances**
4. **Model long-term Soil C flows** (2020-2100) of target areas/biopumps matches:

SOC + erosion dynamics

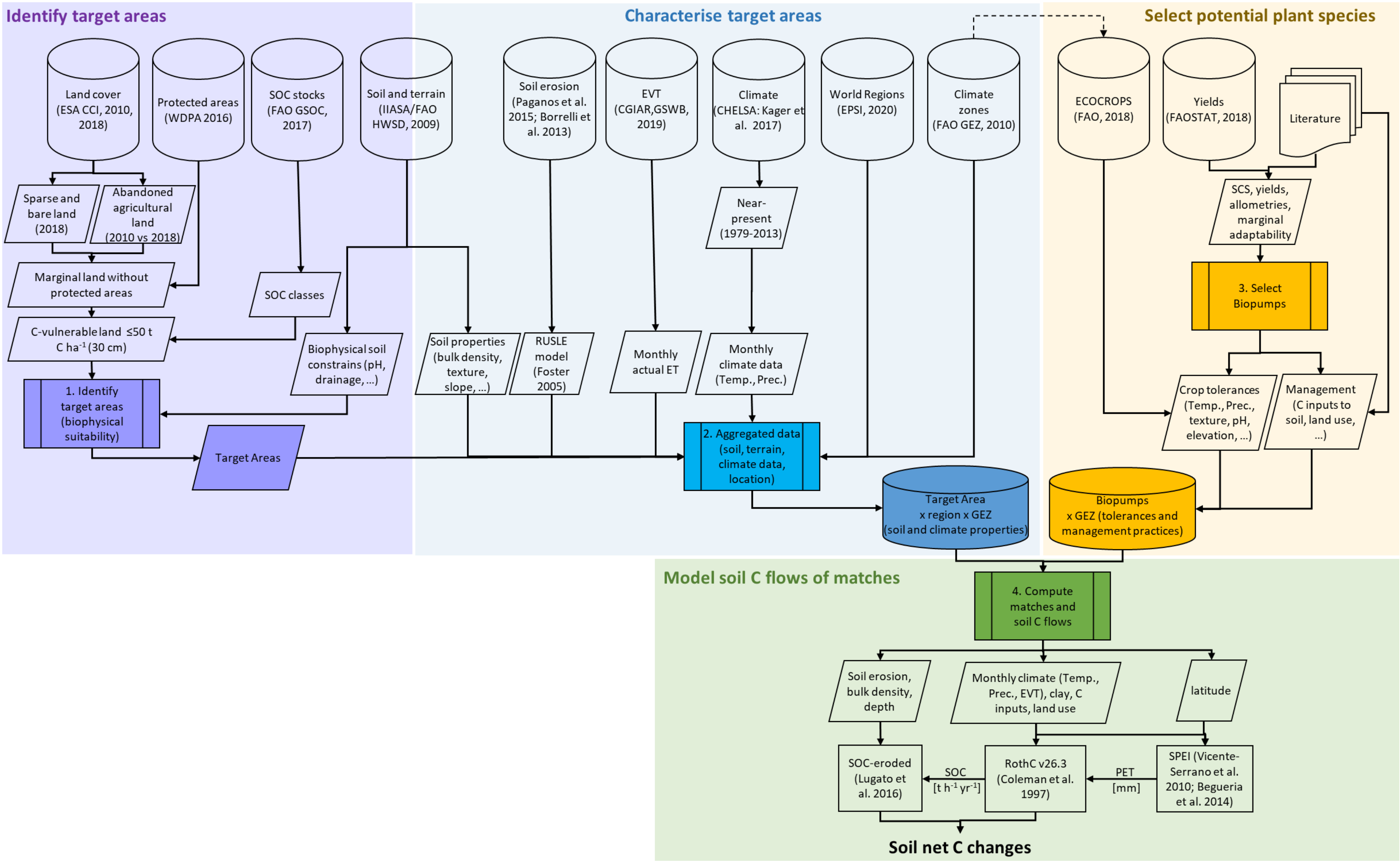


*Coleman & Jenkinson (1996)

NEGEM

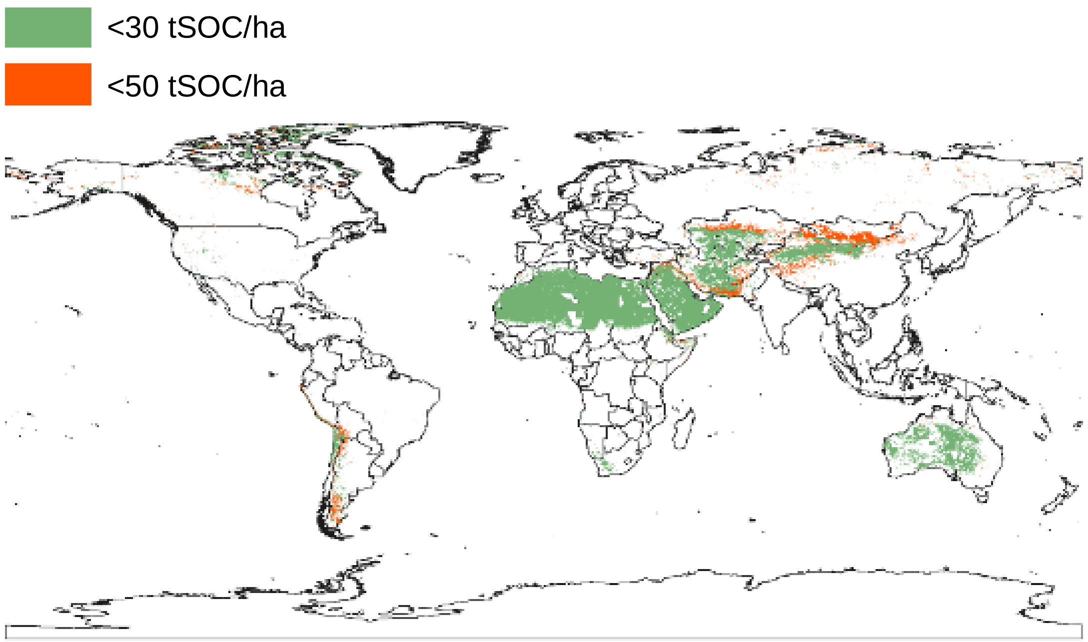
Methods and data sources of the Framework

Modelling



NEGEM

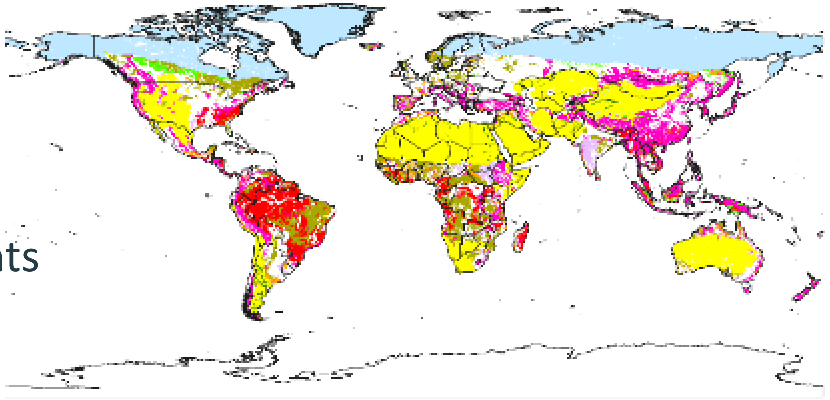
Preliminary result: marginal lands



Sparse vegetation	690 Mha
Bare areas	2 020 Mha
Abandoned agricultural land (2010-2018)	4 Mha

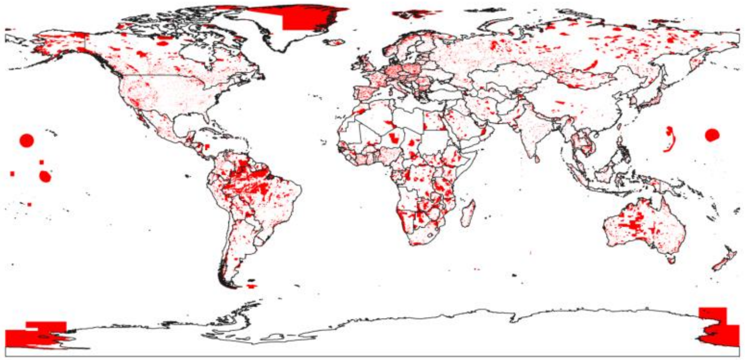
Filter out

Soil constraints



World Harmonised Soil Database (FAO/IISA, 2009)

Protected areas



World database for protected areas (WDPA, 2016)

Target areas by Regions and Global Ecological Zones

Modelling

Land covers (<50 t SOC/ha)

8 067 Mha

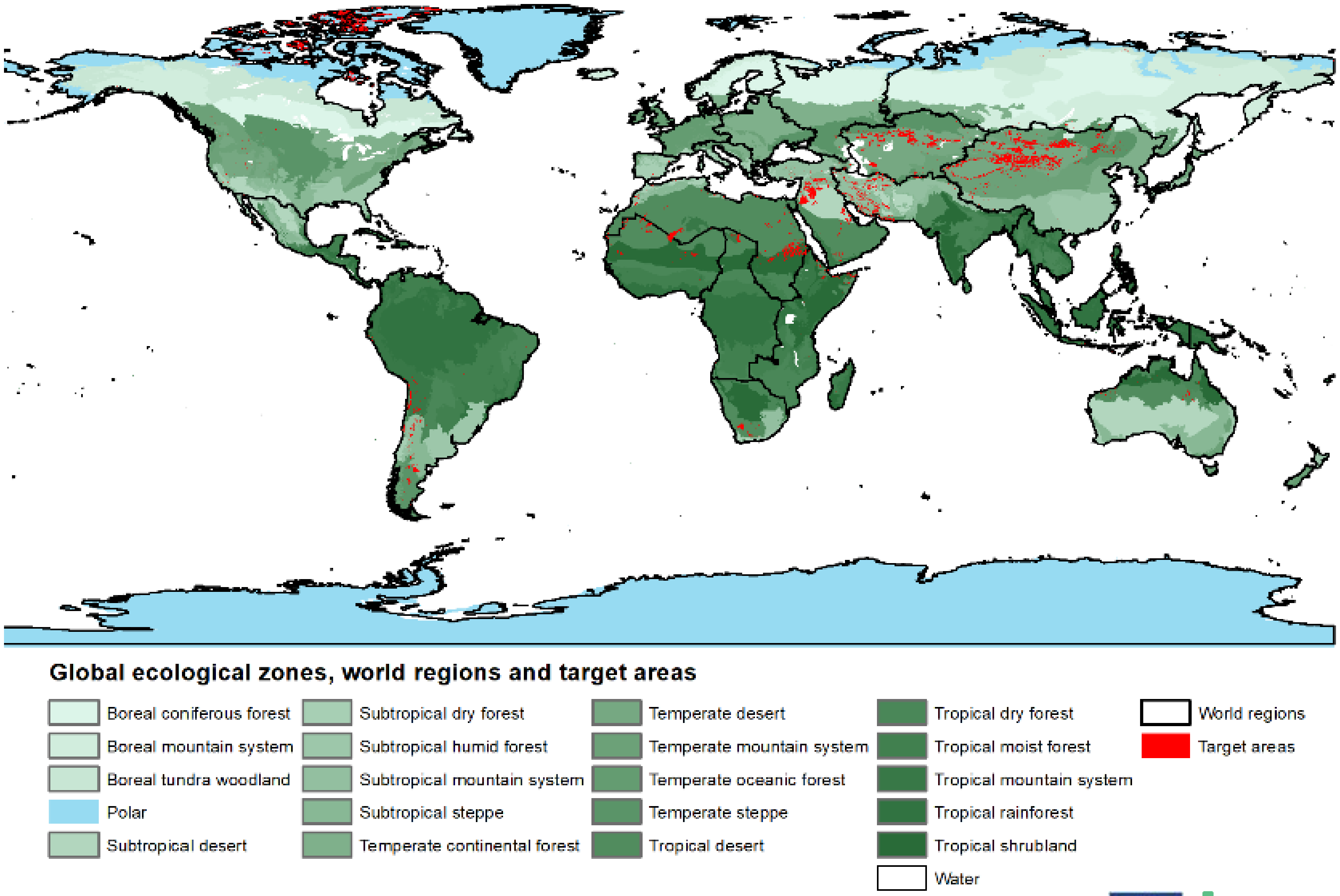
Marginal land (bare + sparse + abandoned)

2 714 Mha (34%)

Target Areas (biophysical suitable)

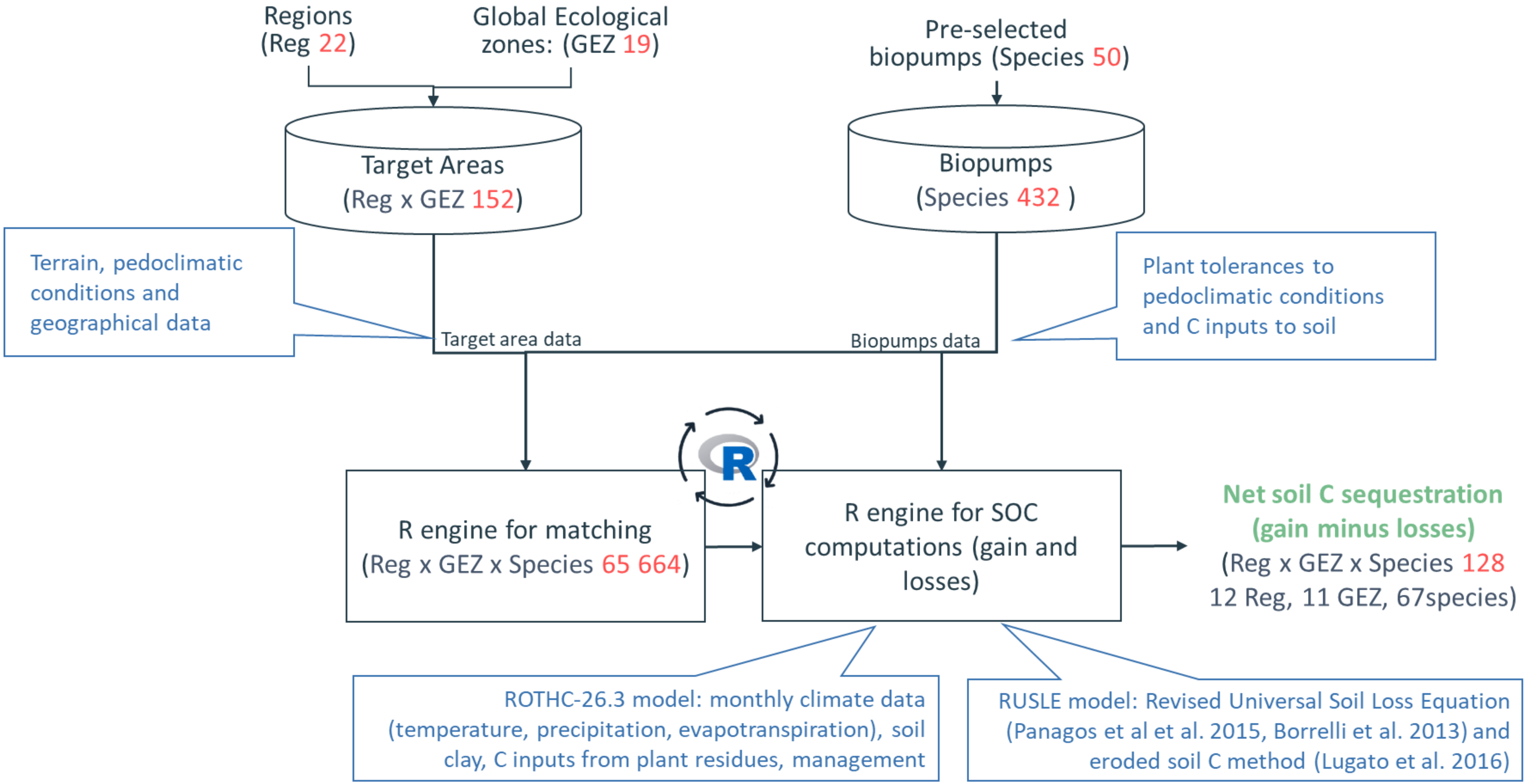
28 Mha (1%)

About the size of Ecuador

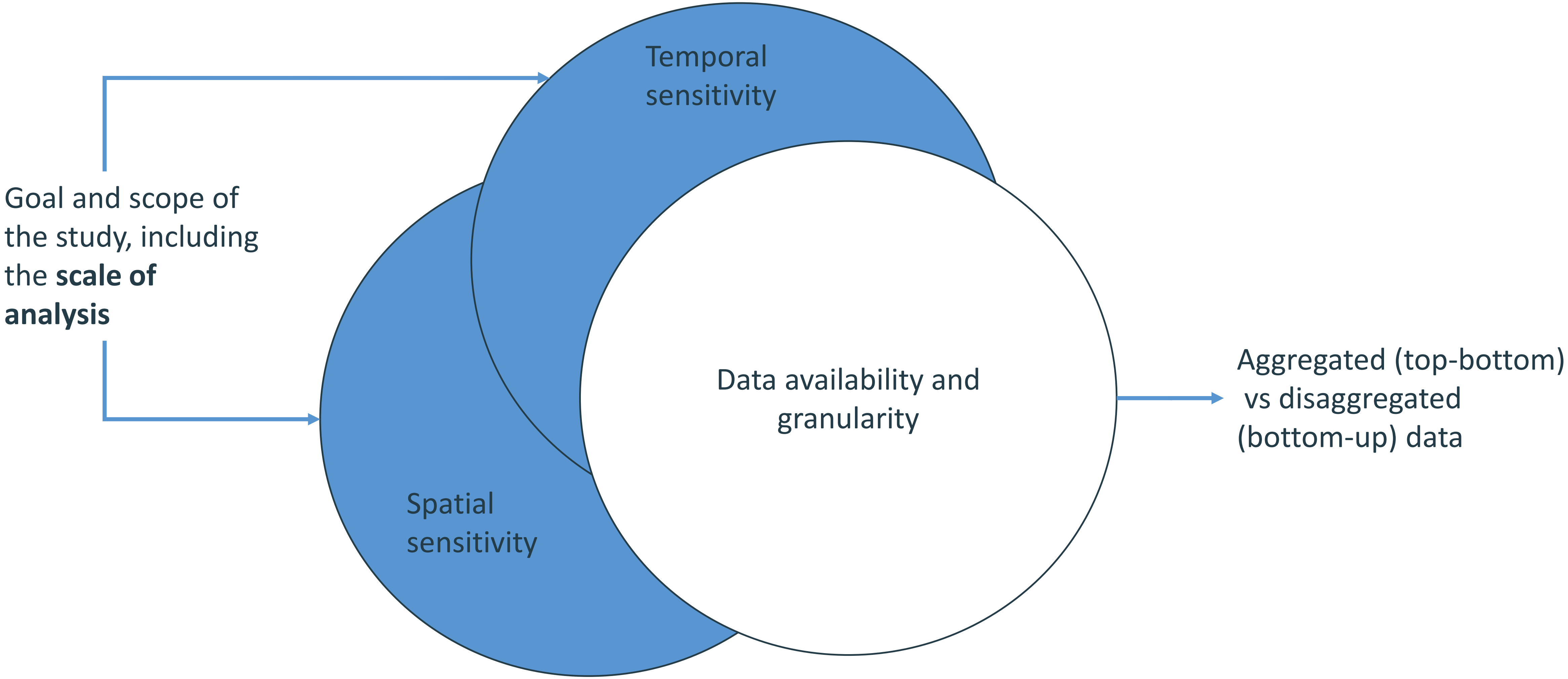


NEGEM

Matching and soil C modelling



Overall conclusion: determinants of data and modelling approaches



Conclusions and perspectives

Bottom-up

- From particular to general
- E.g.: Assess (prospective) **biomass demand**
- What biomass resources are required for more sustainable transport?
- Involve land use management (change)

Top-down

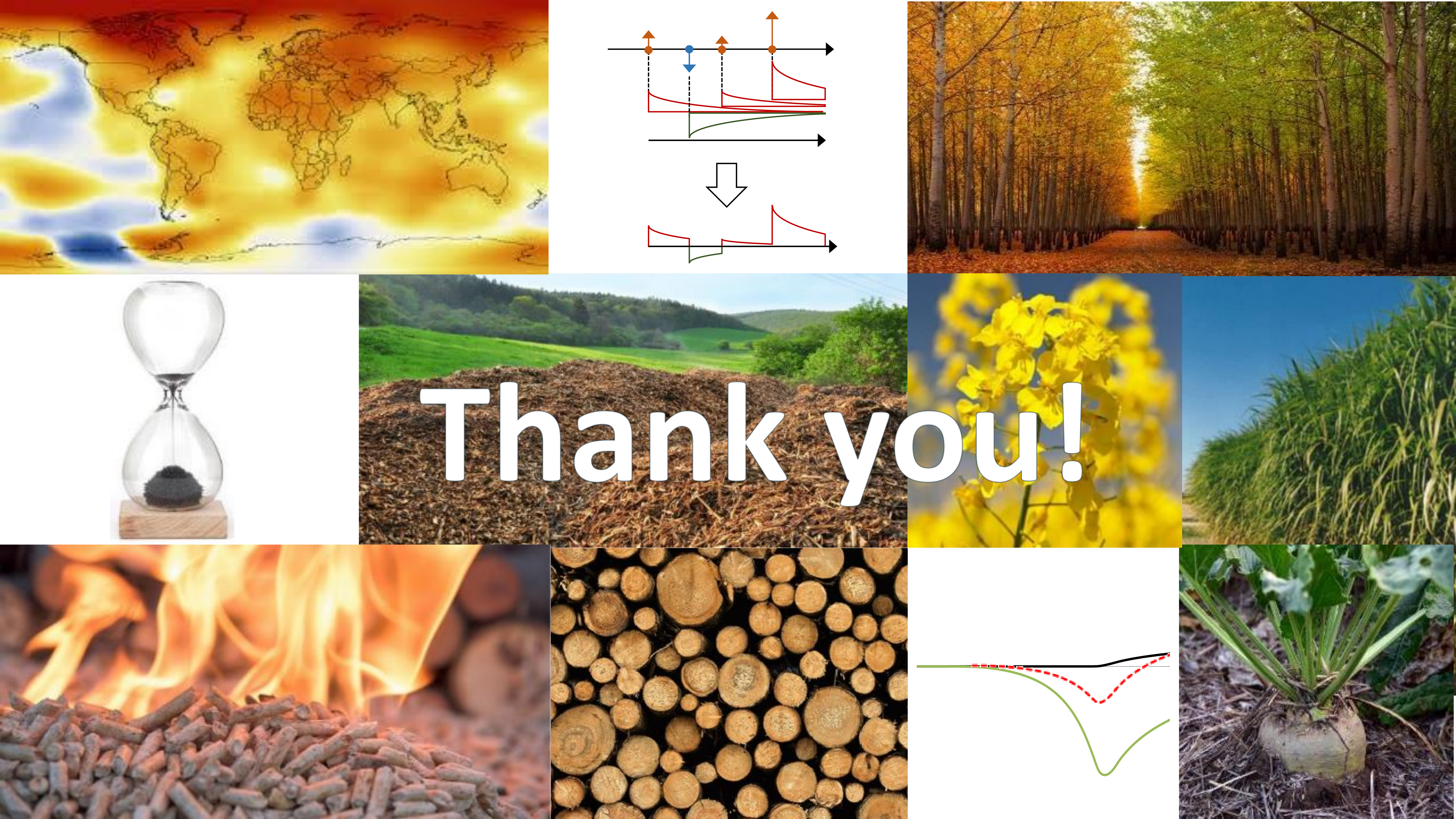
- From general to particular
- E.g.: Assess (prospective) **biomass supply**
- How to model available resources (land, plant species, soil) to estimate global SOC sequestration?
- Include environmental constraints (climate, soil properties, topography)

Hybrid

- Use national statistics for yields or primary data for LCA, biomass distribution
- Tend to be more suitable for intermediate geographical scales (e.g. a region/landscape/territory in contrast with a site or a whole country)

Conclusions and perspectives

- Considering temporal and spatial dynamics alters the results
- The “dynamic” approaches are not standardised, so there is considerable uncertainty/variation associated with choices (e.g. chicken-egg-dilemma, temporal boundaries, geographical boundaries and aggregation levels, modelling of even-or un-even-aged stands)
- **Scale matters** for temporal and spatial dynamics:
  - At the landscape level, stocks are rather constant, but not at the stand/farm/project level (e.g. SOC dynamics depend in the long term on management practices and climate change)
  - Contribution to climate change (a global impact) is uneven among regions


Thank you!