Exploring future environmental impacts of vertical farming and emerging agricultural technologies

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ICTA Institute of Environmental Science and Technology ICTA-UAB

Introduction: urban agriculture

- Emerged as an alternative way to **produce food near cities**
- **Gained attention and popularity** after COVID, with large capital investments
- Aims to improve **food security, resilience and sustainability**
- Uses technologies & management practices that are still at their **infancy**, where **increased maturity levels are expected** in the future

Introduction: urban agriculture

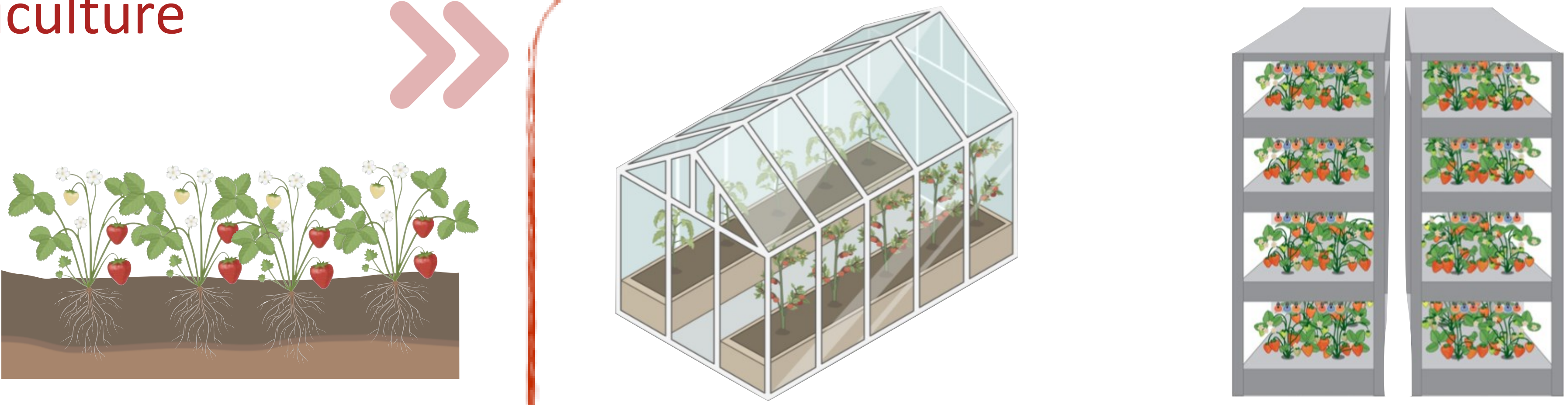
But why UA?

- Close to people = potential to provide more **ecosystem services**
- Close availability (< 30km) of **unconstrained waste stream resources** from cities
- Closed controlled environments = facilitates **resource recirculation & revaloritzation**

» they have more potential to improve in the future!

Controlled Environment Agriculture

images from biorender.com, van Delden et al., 2021



	Open field	Greenhouses	Vertical Farms
Total material + energy use	—	++	+++
Plant-use efficiency	—	++	+++
urban waste circularity	—	++	+++
technological improvements	—	++	+++

The ecofarm—city project

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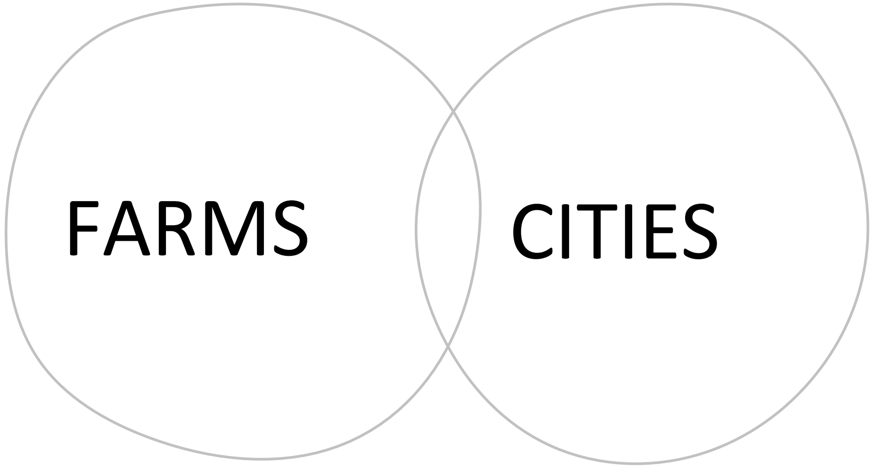
- Objective ➔ To assess the potential of future developments in vertical farms (VFs) to mitigate future environmental impacts of agricultural production in comparison to conventional (CA) systems.

ECOFARM-CITY
vertical farms for circular cities

A research project
funded by:

FORMAS
A SWEDISH RESEARCH COUNCIL
FOR SUSTAINABLE DEVELOPMENT



- Shift the product-oriented focus of VFs to include the benefits that VFs can provide to cities when integrated!

The ecofarm—city project

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3 Partner institutions

370 k€ of public funding

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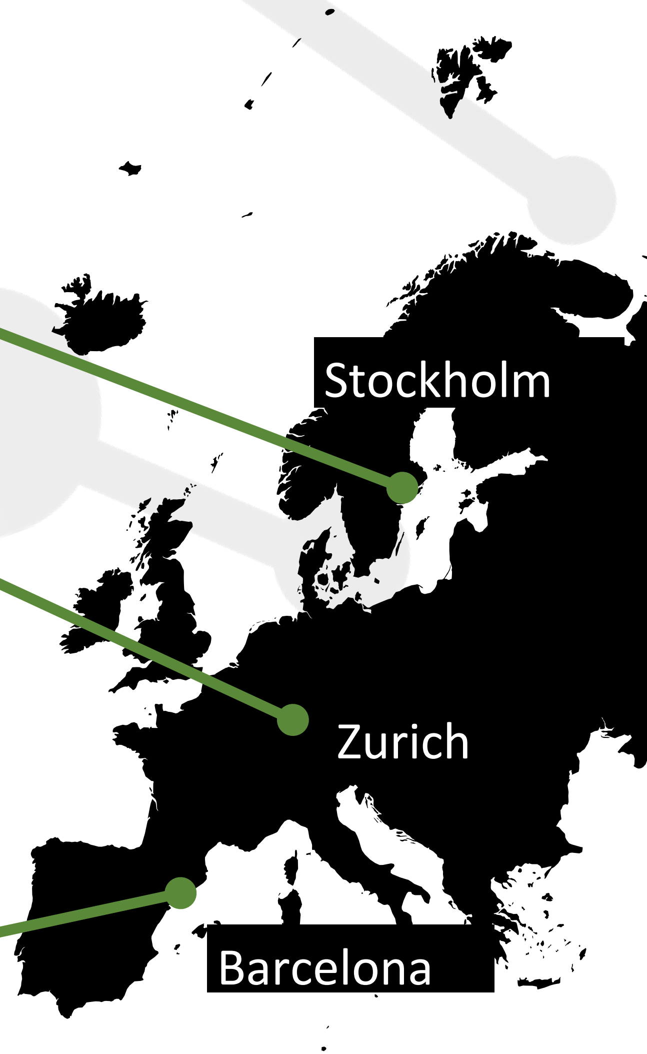

The ecofarm—city project

ECOFARM-CITY
vertical farms for circular cities

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NÄRA

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YASAI
GROW MORE WITH LESS

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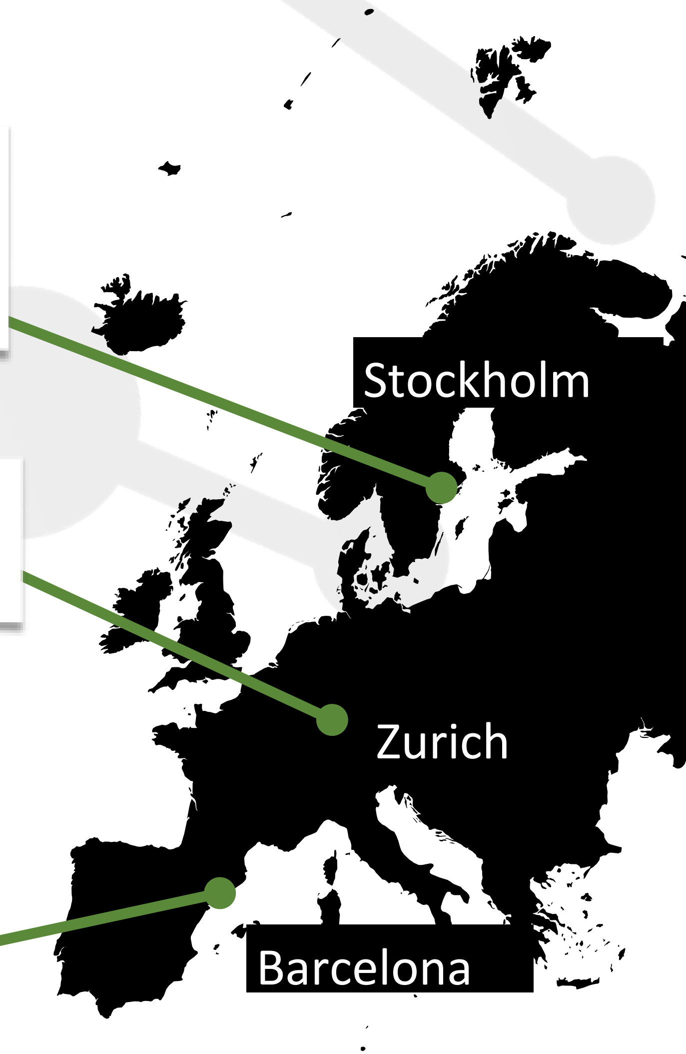

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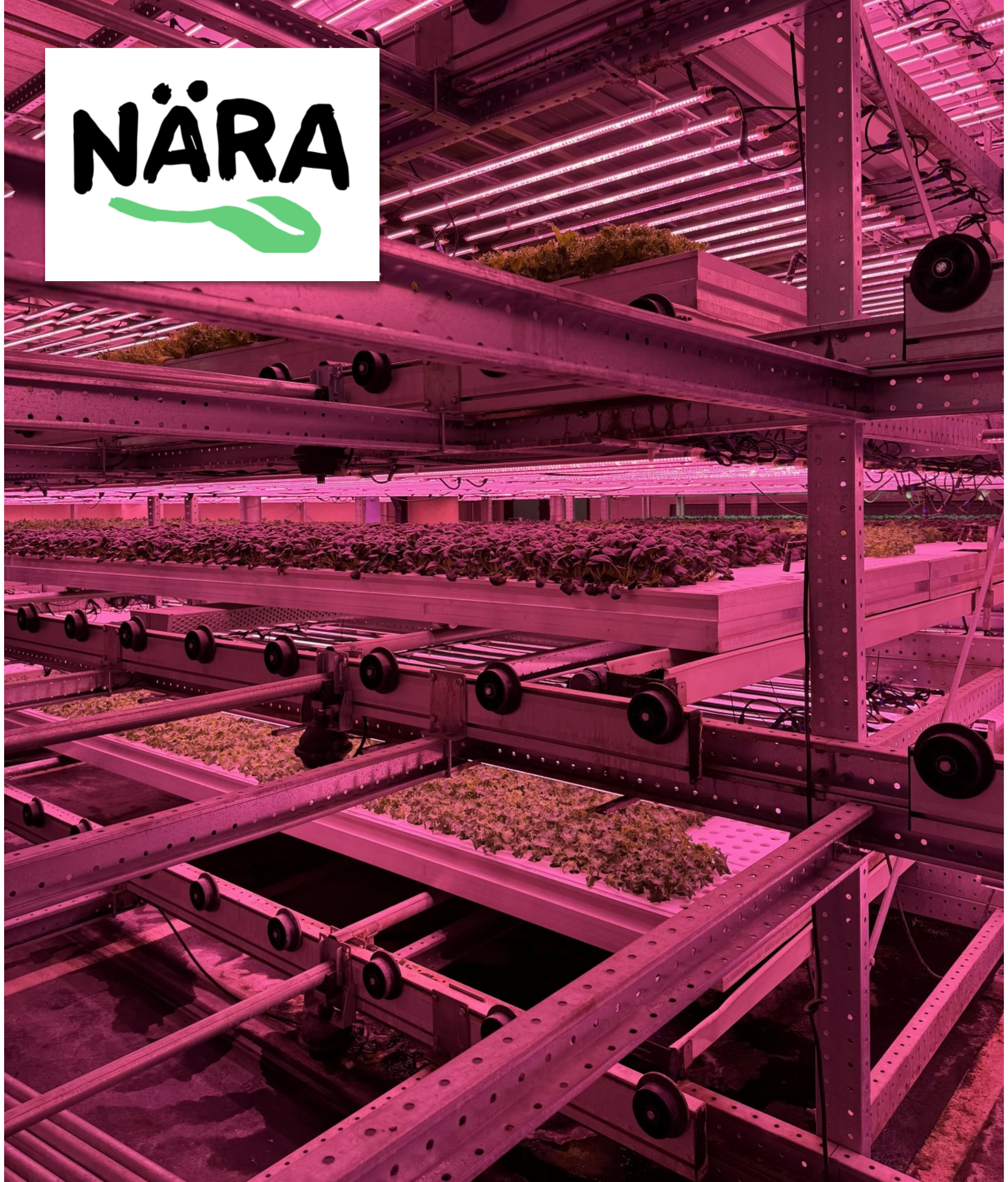

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The ecofarm—city project

Steps to reach project objectives:

1

Setting-up tools, harmonizing data, improving consistency for pLCA

2

Understanding current environmental impacts of VFs

+

identify and assess common improvement technologies

3

Comparing current and future environmental impacts of vertical farms with conventional agricultural systems

LCA impacts of VFs vs CA: challenges

1

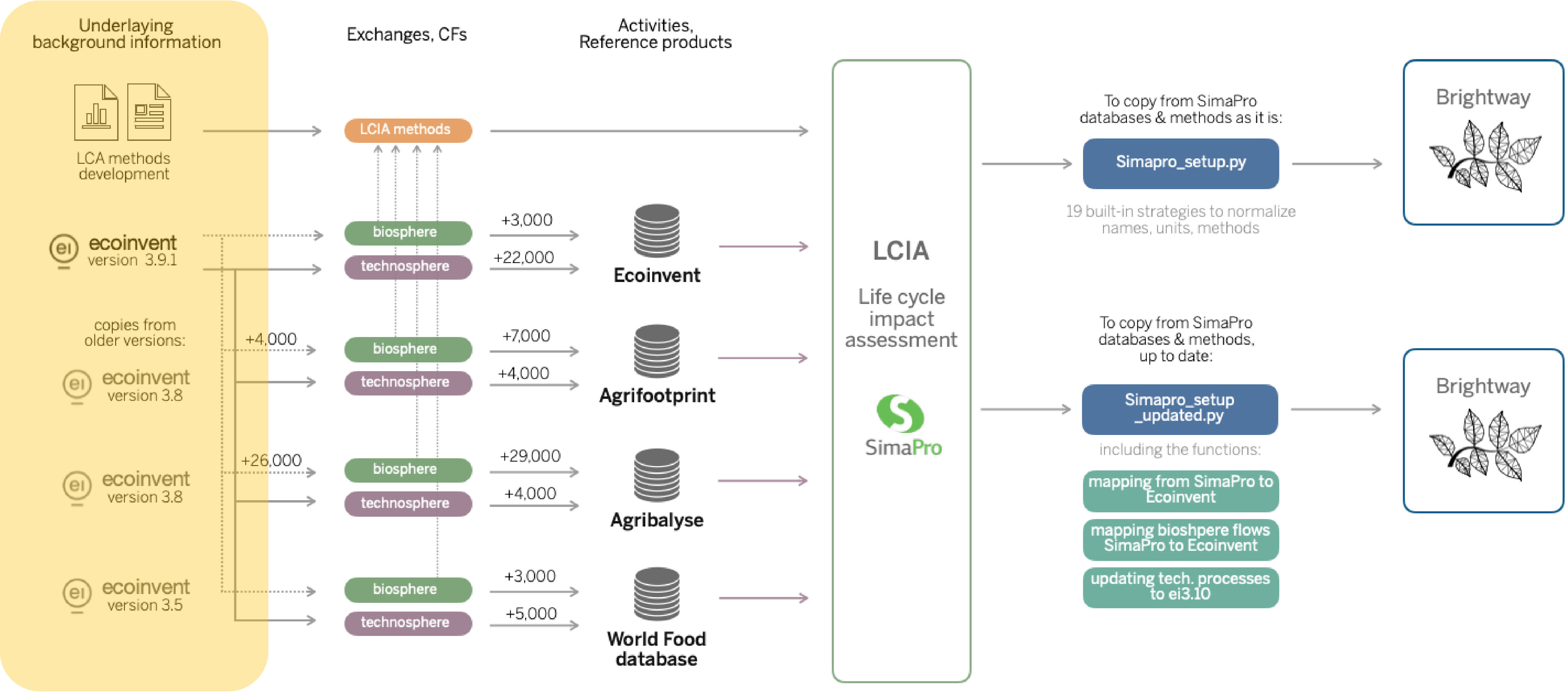
#1 LCI data consistency from current agri-food databases

- LCI data formats, background versions

1

Increasing the consistency of agrifood databases: a python library using Brightway2 framework

Cédric Furrer



Underlaying background information

LCA methods development

ecoinvent version 3.9.1

copies from older versions:

ecoinvent version 3.8

ecoinvent version 3.8

ecoinvent version 3.5

+4,000

+26,000

Exchanges, CFs

LCIA methods

biosphere

technosphere

biosphere

technosphere

biosphere

technosphere

biosphere

technosphere

Activities, Reference products

+3,000

+22,000

Ecoinvent

+7,000

+4,000

Agrifootprint

+29,000

+4,000

Agribalyse

+3,000

+5,000

World Food database

LCIA

Life cycle impact assessment

SimaPro

To copy from SimaPro databases & methods as it is:

Simapro_setup.py

19 built-in strategies to normalize names, units, methods

To copy from SimaPro databases & methods, up to date:

Simapro_setup_updated.py

including the functions:

- mapping from SimaPro to Ecoinvent
- mapping bioshpere flows SimaPro to Ecoinvent
- updating tech. processes to ei3.10

Brightway

Brightway

1

LCA impacts of VFs vs CA: challenges

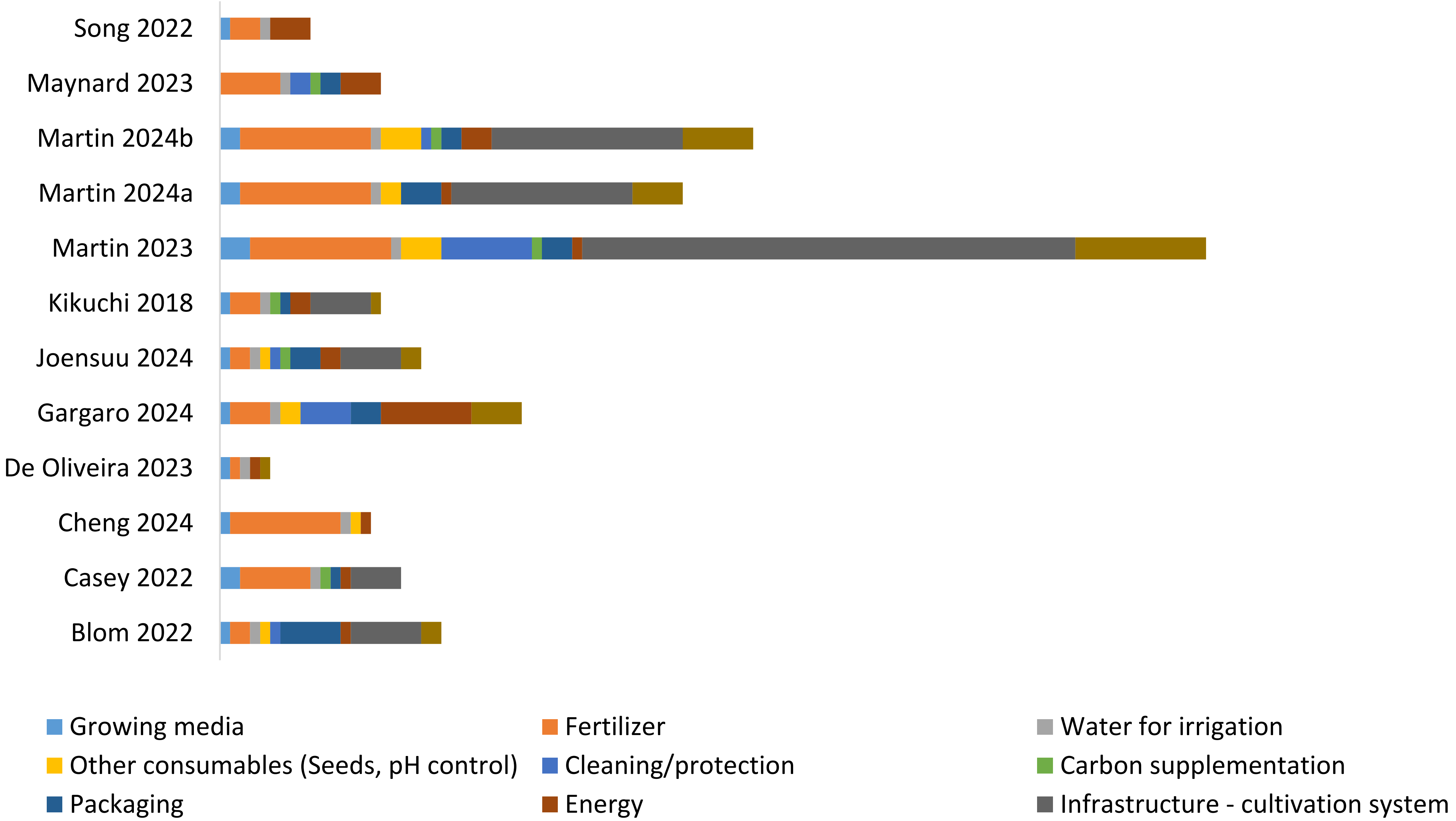
#1 LCI data consistency from current agri-food databases

- LCI data formats, background versions

#2 System completeness

- Different system boundaries
- Different assumptions: building envelopes of VFs
- LCA practitioner modelling decisions

Number of assessed inventory items per category



1 LCA impacts of VFs vs CA: challenges

#1 LCI data consistency from current agri-food databases

- LCI data formats, background versions

#2 System completeness

- Different system boundaries
- Different assumptions: building envelopes of VFs
- LCA practitioner modelling decisions

#3 Data representativeness

- Lack of data to increase representativeness
- Temporal gaps in VFs operation
- Different products, different regions, different maturity levels

2.1

Assessing LCA impacts of lettuce and basil from 3 VFs

ReCiPe method, Ecoinvent 3.10

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Ljusgårda
Supernormal Greens®

Select syst.. (Multiple values)

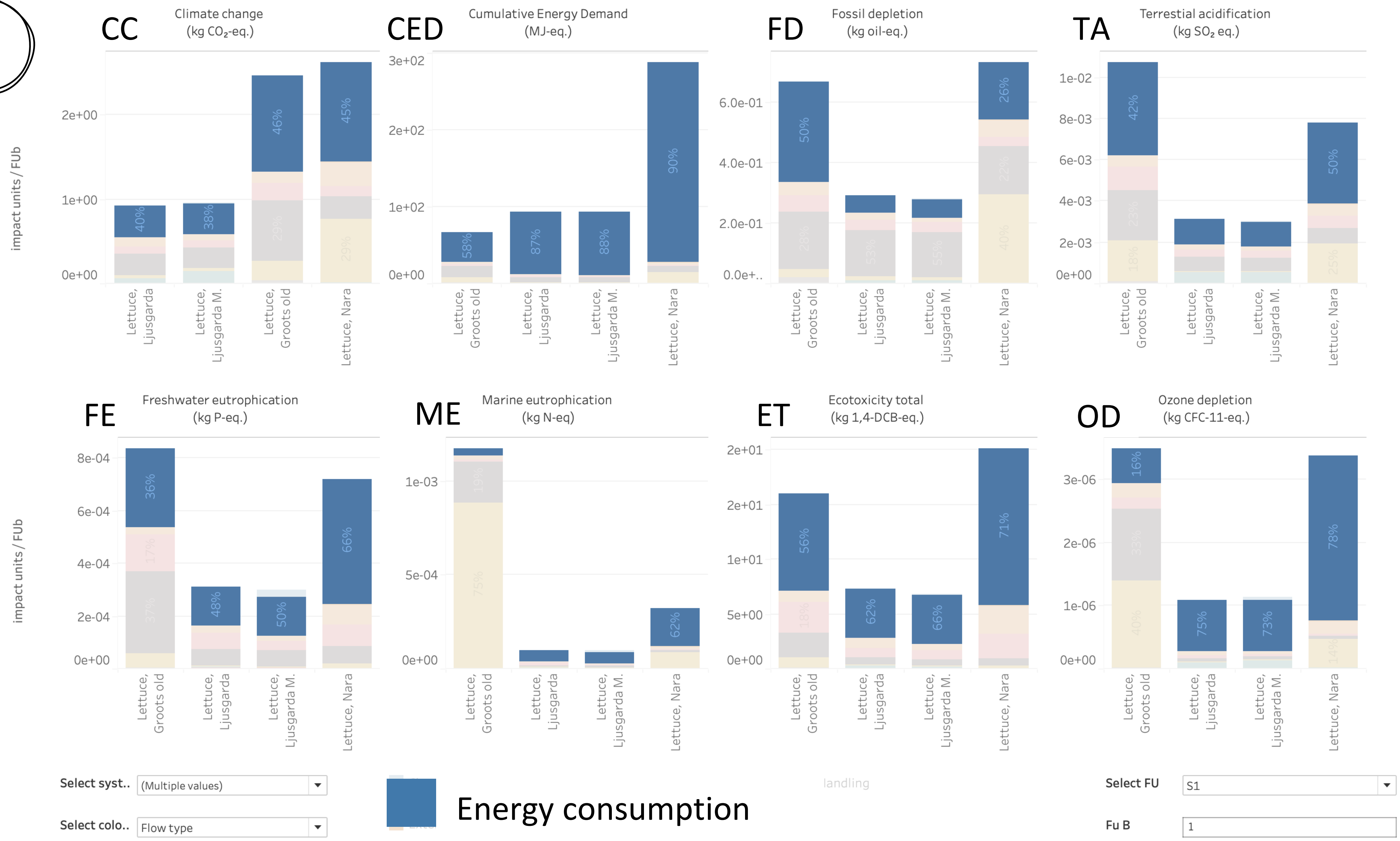
Select colo.. Flow type

Select FU S1

Fu B 1

Agroscope

A



Select syst.. (Multiple values)

Select colo.. Flow type

Select FU S1

Fu B 1

🟦 Energy consumption

Select syst.. (Multiple values)

Select colo.. Flow type

Select FU S1

Fu B 1

🟥 Infrastructure

Agroscope

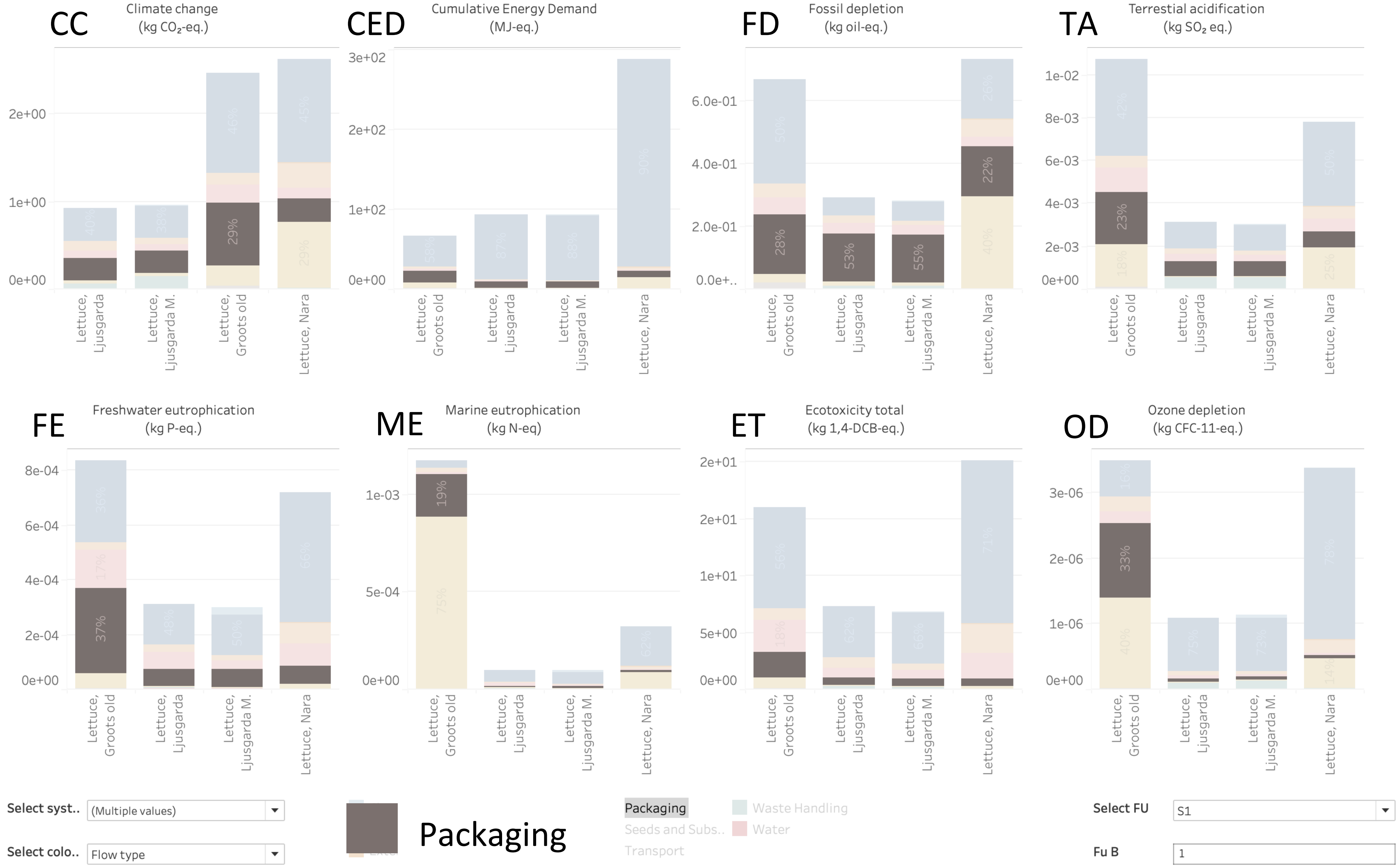
Select syst.. (Multiple values)

Select colo.. Flow type

Select FU S1

Fu B 1

D



Select syst.. (Multiple values)

Select colo.. Flow type

Select FU S1

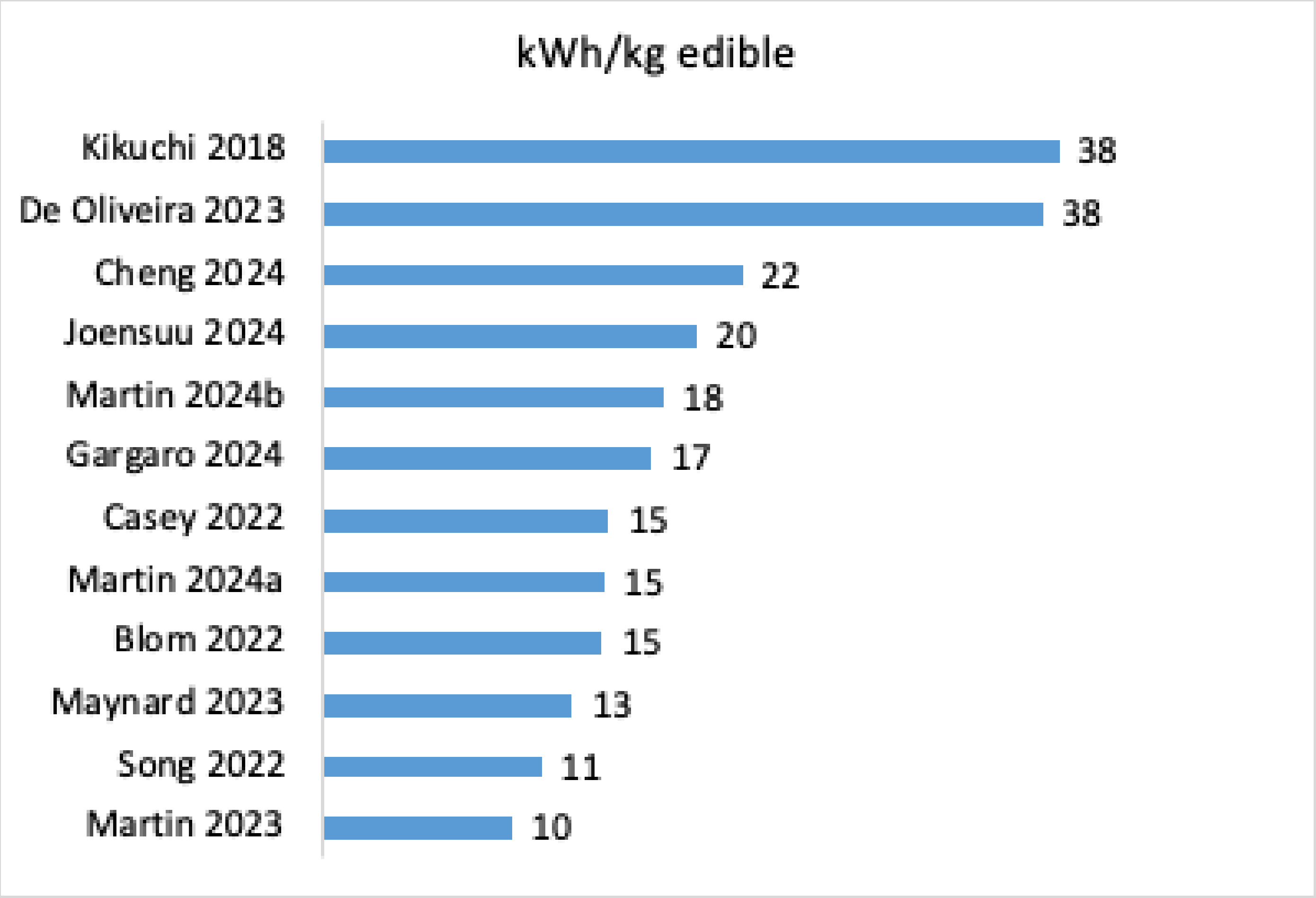
Fu B 1

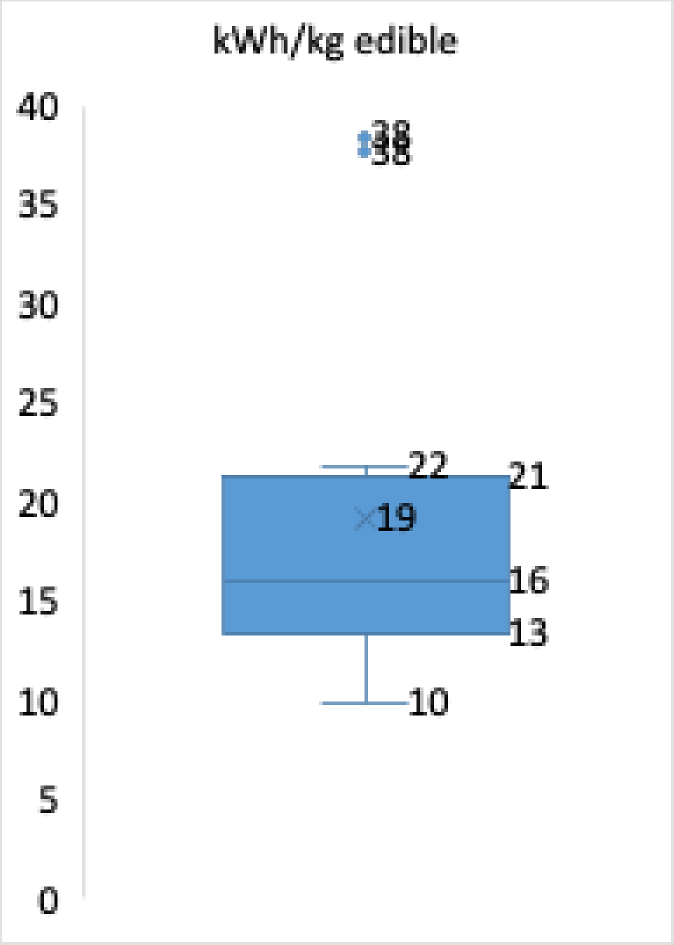
Packaging

Agroscope

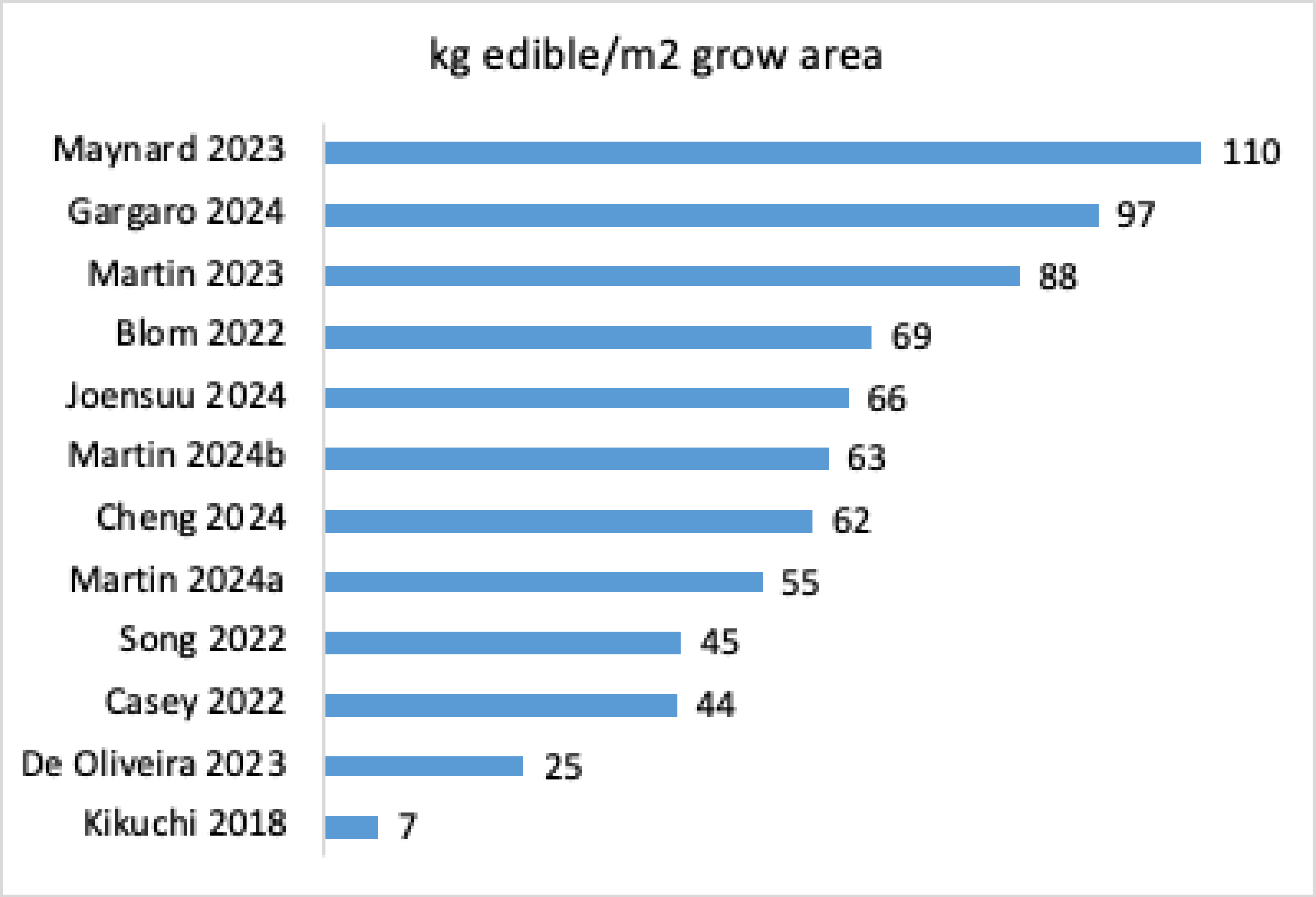
②

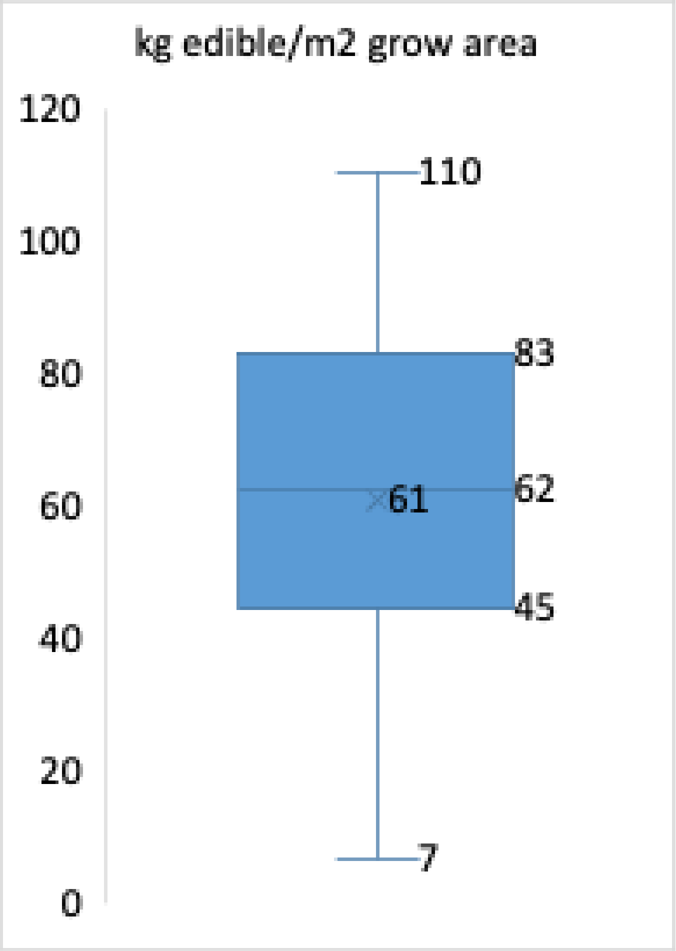
LCA impacts of VFs: energy use



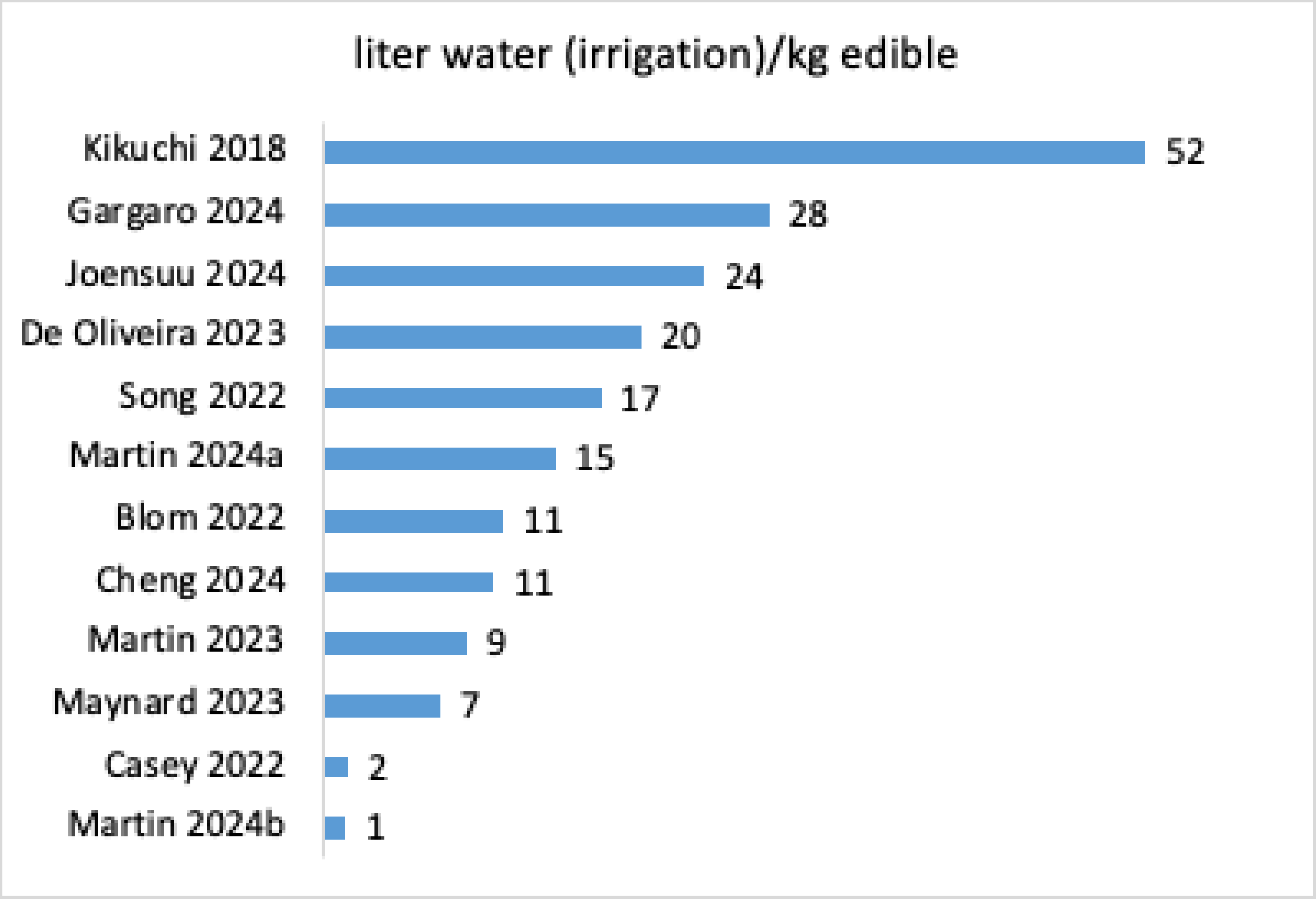


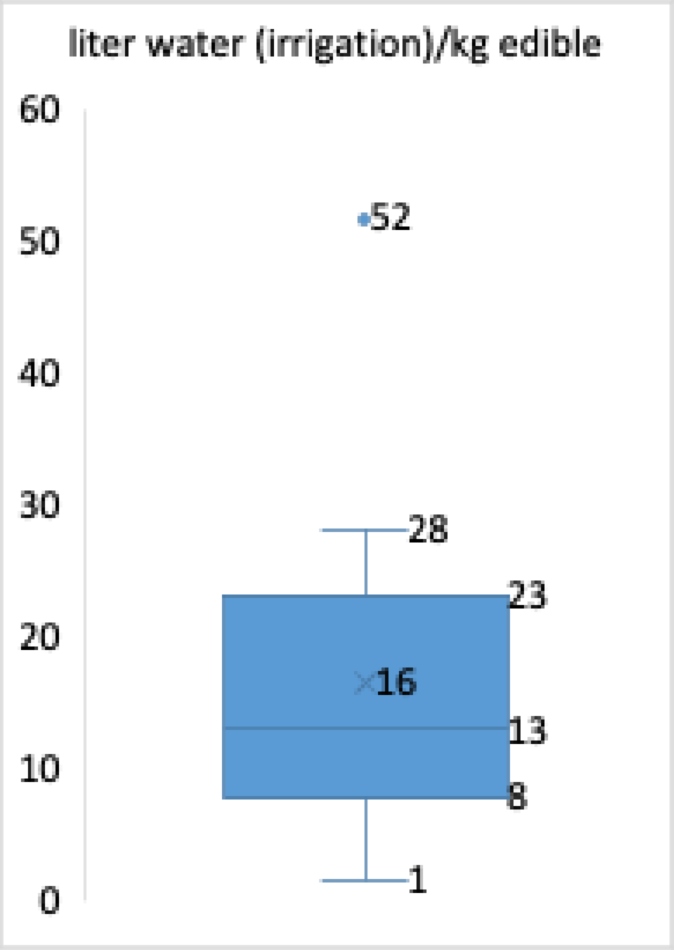
② LCA impacts of VFs: land use





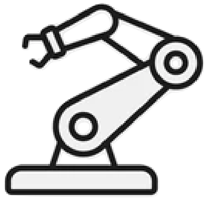
② LCA impacts of VFs: water use



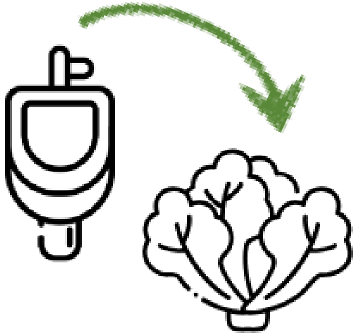


2.2

Assessing LCA impacts of novel agricultural technologies



Automatized production systems



On-site lab-scale aerobic reactor for nitrogen recovery

Alternative nitrogen sources, other circular strategies

Ljusgårda
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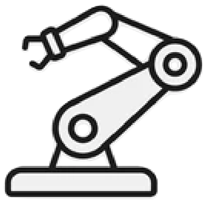
2.2

Assessing LCA impacts of novel agricultural technologies

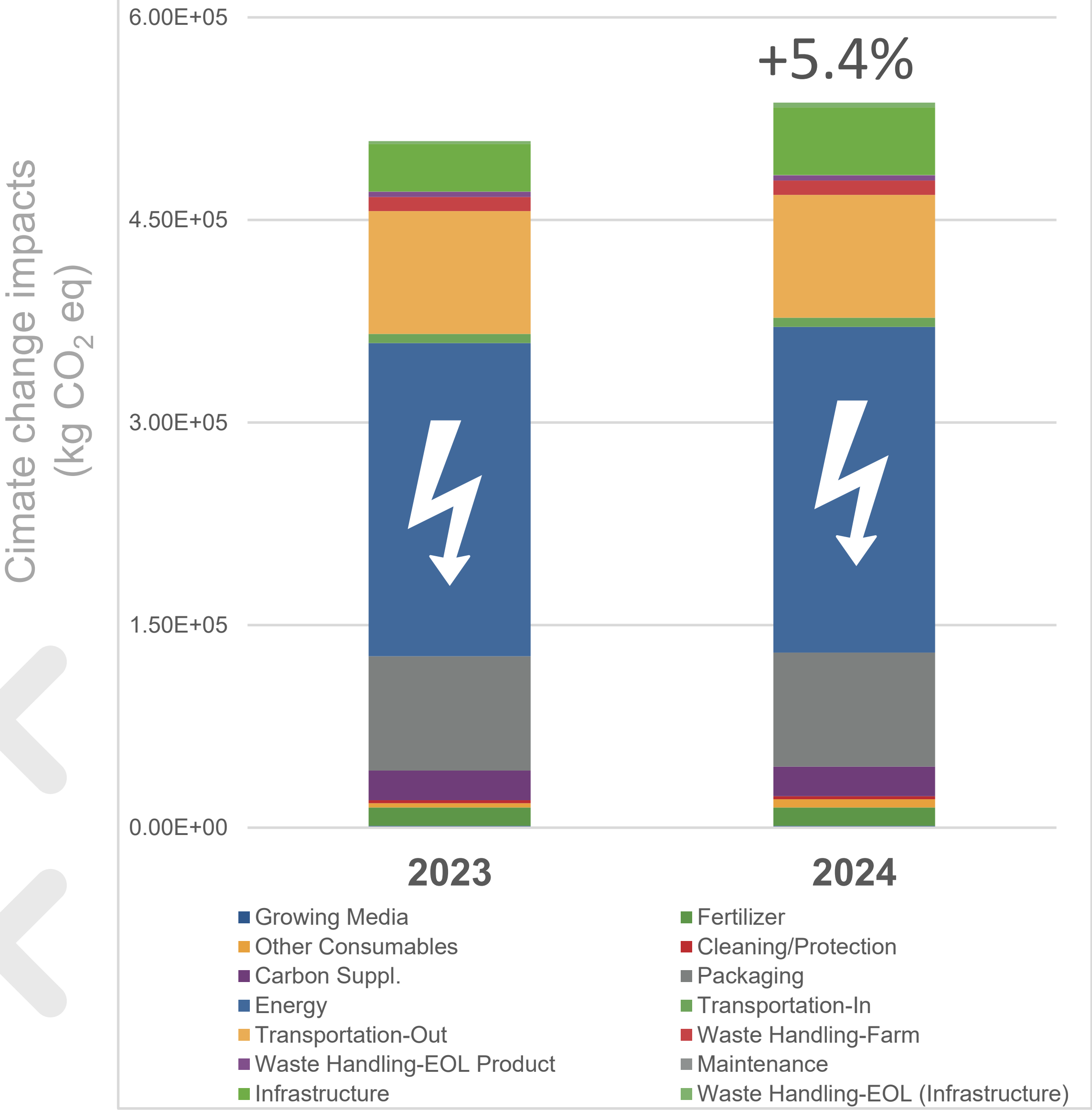
Loris Mazzaferro, MSc.



Automatized production systems

Increased infrastructure impacts!

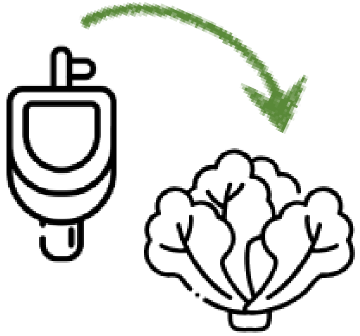
Highly dependent on the energy consumption and electricity grid sources!



2.2

Assessing LCA impacts of novel agricultural technologies

Maiza et al., 2025

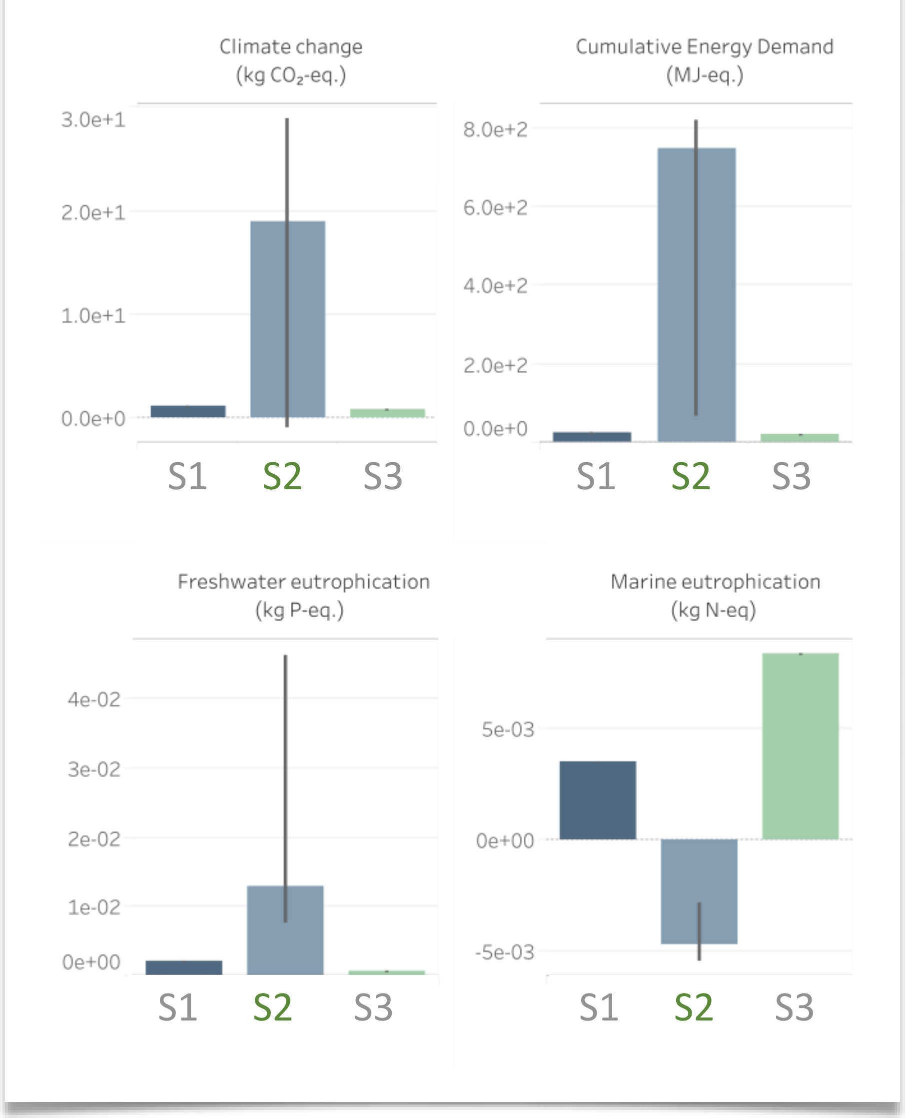


On-site lab-scale aerobic reactor for nitrogen recovery

Different alternative scenarios assessed:

S1 = Artificial wetland
S2 = Aerobic reactor
S3 = WWTP (Waste water treatment plant)

Highly dependent on the energy consumption and electricity grid sources!



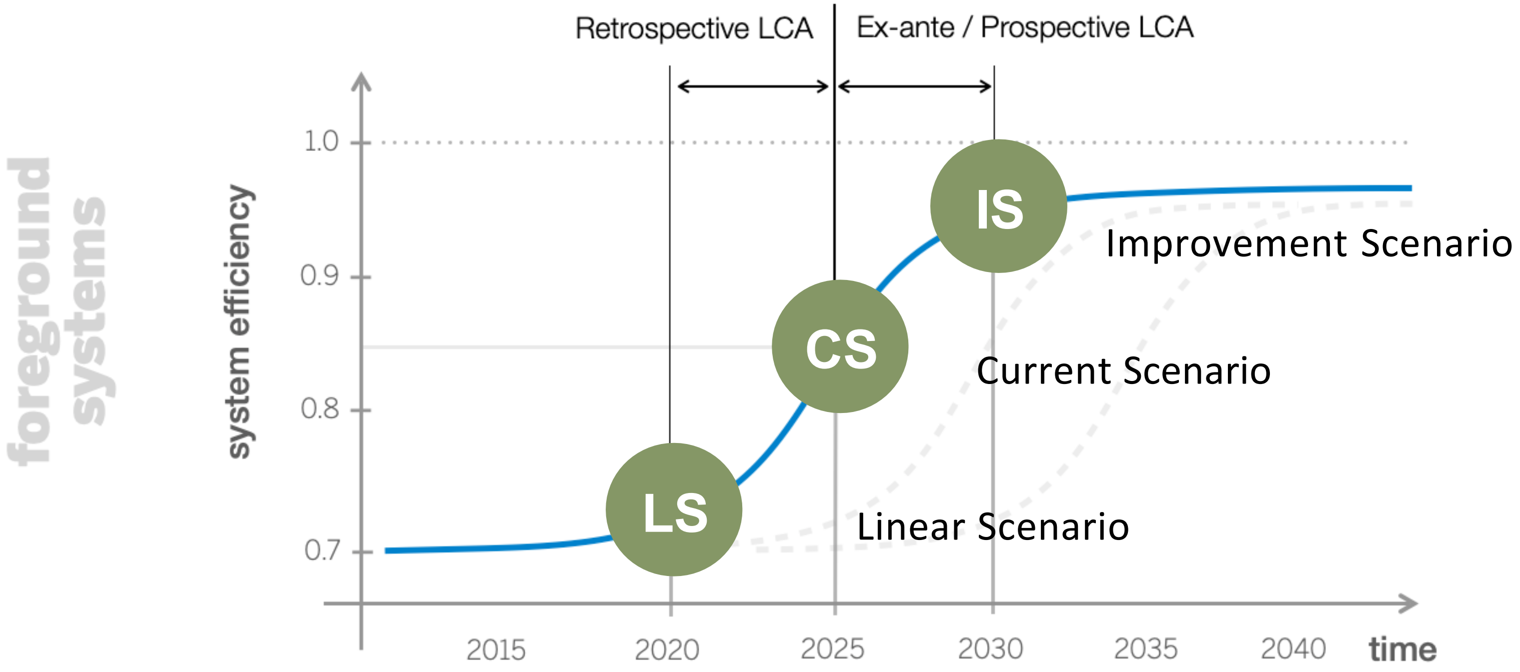
2.2

Assessing LCA impacts of novel agricultural technologies

Alicia
Invernón,
MSc

Objective

To assess the extent to which a set of **circular strategies** can improve the **environmental sustainability** of two European **VFs**, considering their different **maturity level and regional contexts**



➔ compare system environmental efficiency

Improvements & scenarios considered

LS Linear Scenario

No circular strategies.

CS Current Scenario

VF1 → Strategies 3, 4, 7, 8

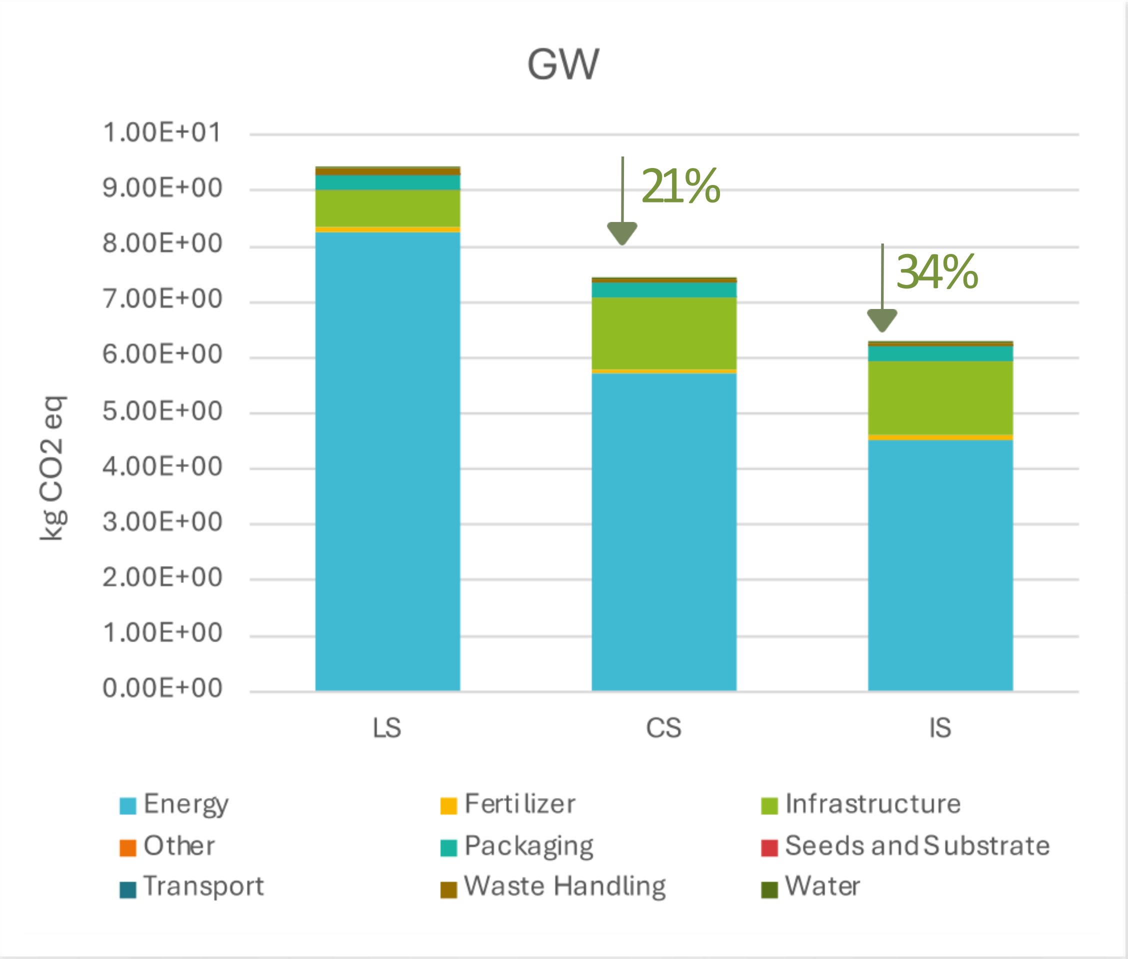
VF2 → Strategies 3, 4, 7

IS Improvement Scenario

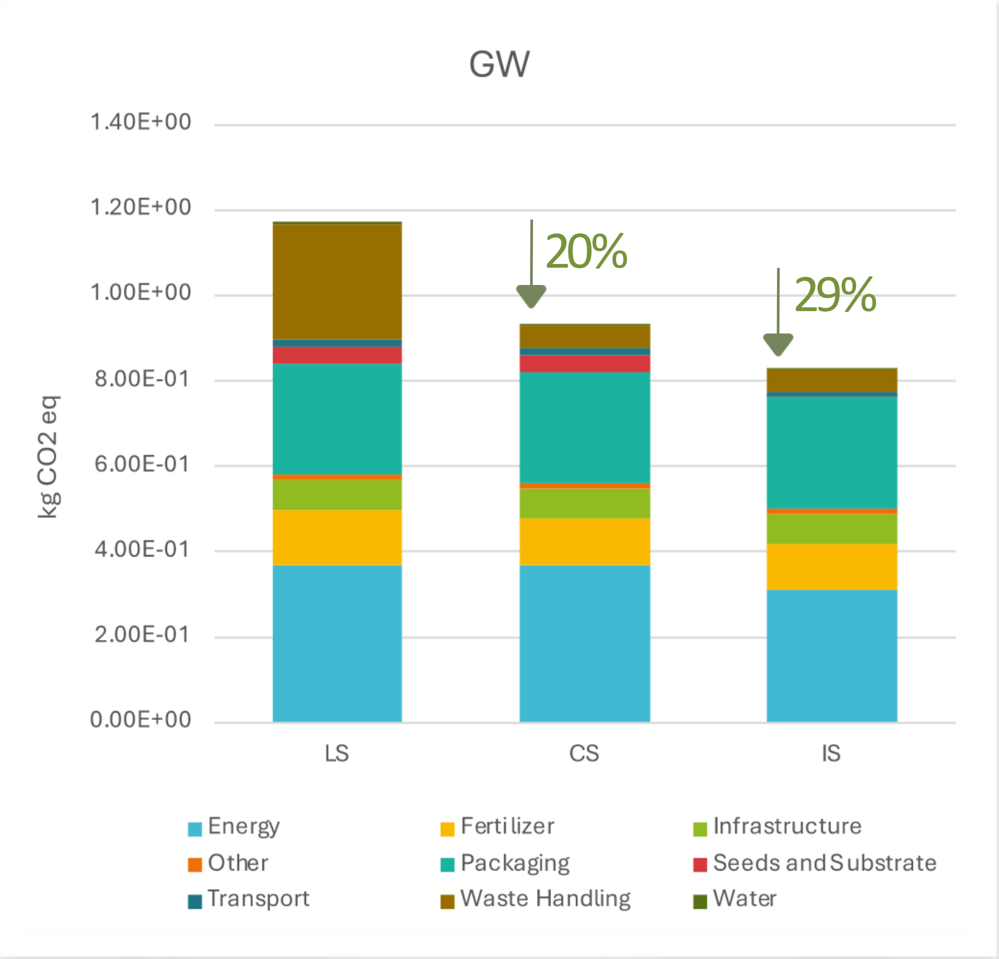
All circular strategies.

S1 Compost
S2 Rainwater harvesting system
S3 Closed-loop irrigation system
S4 Condensed water recovery
S5 Struvite
S6 Reuse waste heat
S7 Recycling of materials
S8 PV panels

Comparative analysis of 2 VFs



VF1 Barcelona



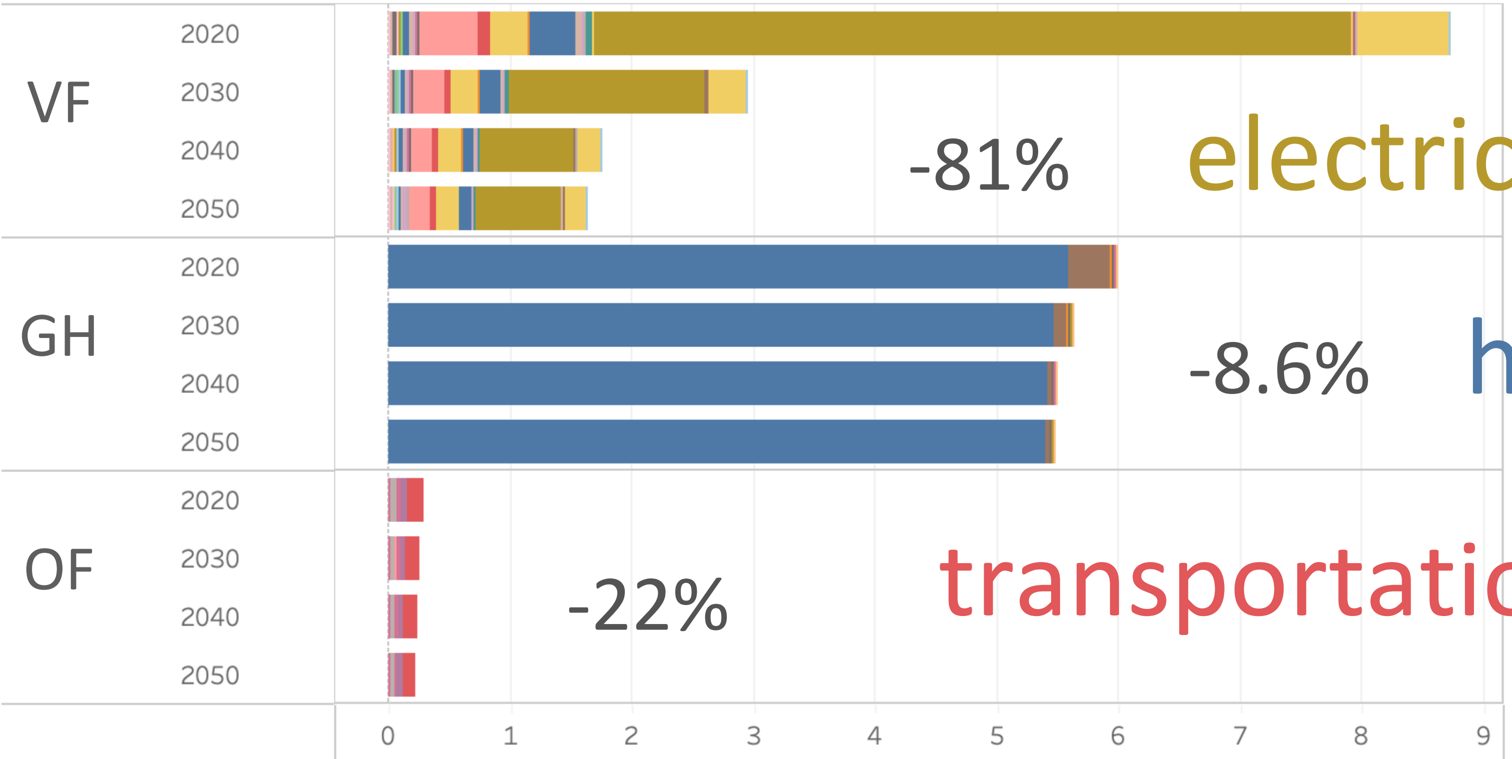
VF2 Stockholm

3 Assessing LCA impacts of VFs in the future

- Climate change impacts according to the agricultural system and the energy source:

1kg of lettuce

VF = vertical farm
GH = greenhouse
OF = open field

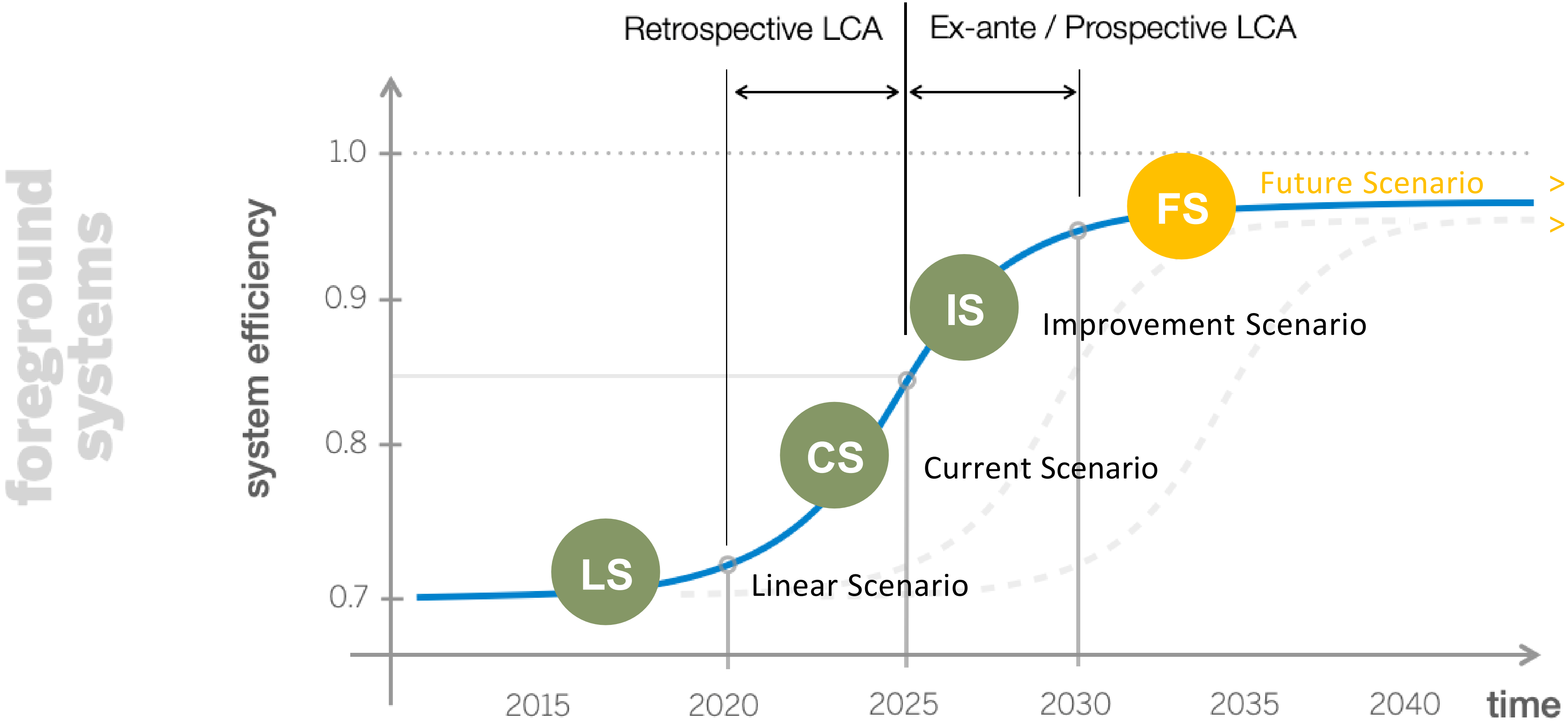


ecoinvent
premise

IMAGE
PBL Netherlands Environmental Assessment Agency

IMAGE SSP2-RCP19 pathway, EF v3.1 climate change

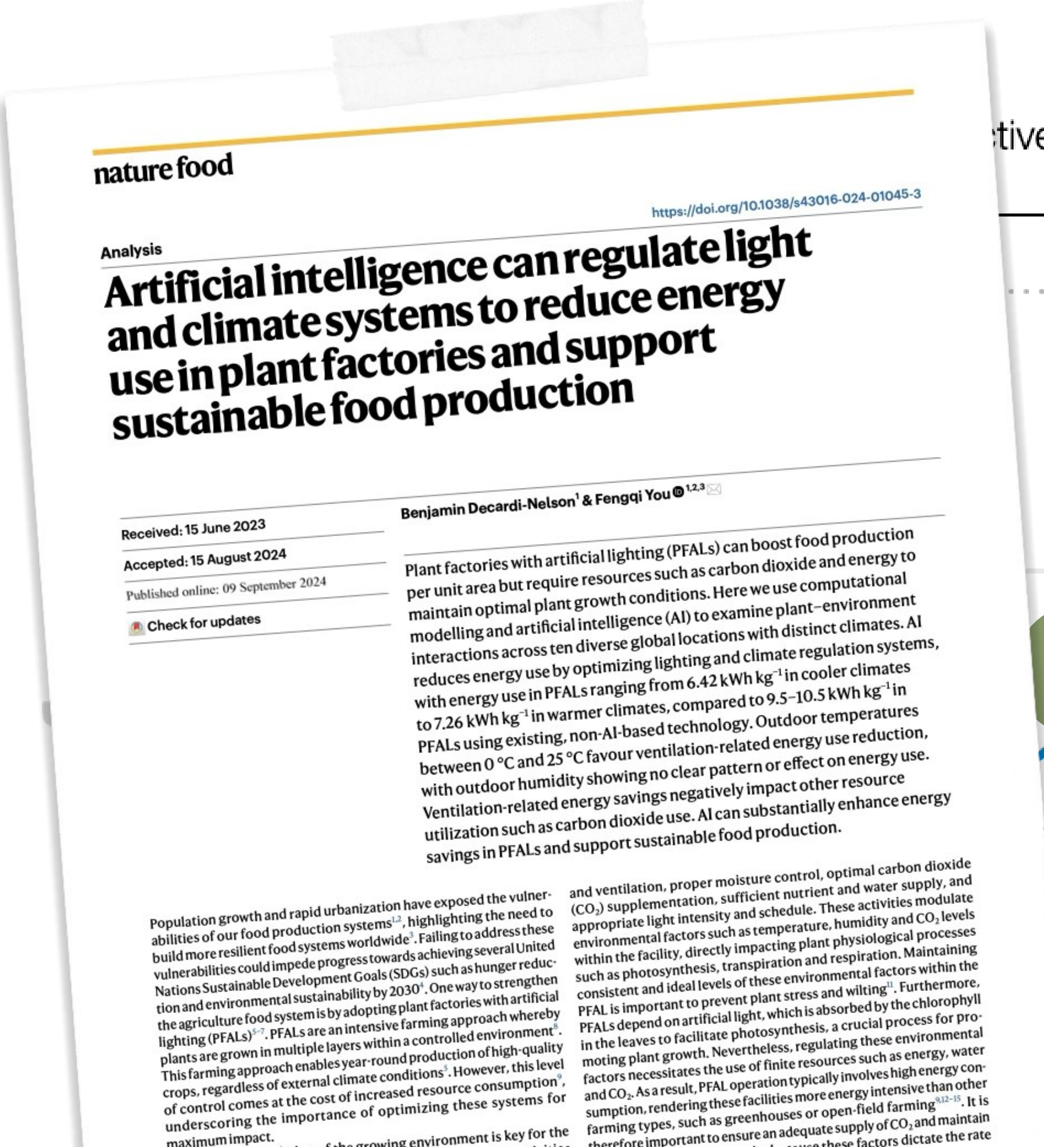
3 Assessing LCA impacts of VFs in the future



> LEDs efficiency

> IA improvements

Assessing the environmental impacts of different circular strategies in 2 VFs



nature food

https://doi.org/10.1038/s43016-024-01045-3

Analysis

Artificial intelligence can regulate light and climate systems to reduce energy use in plant factories and support sustainable food production

Received: 15 June 2023

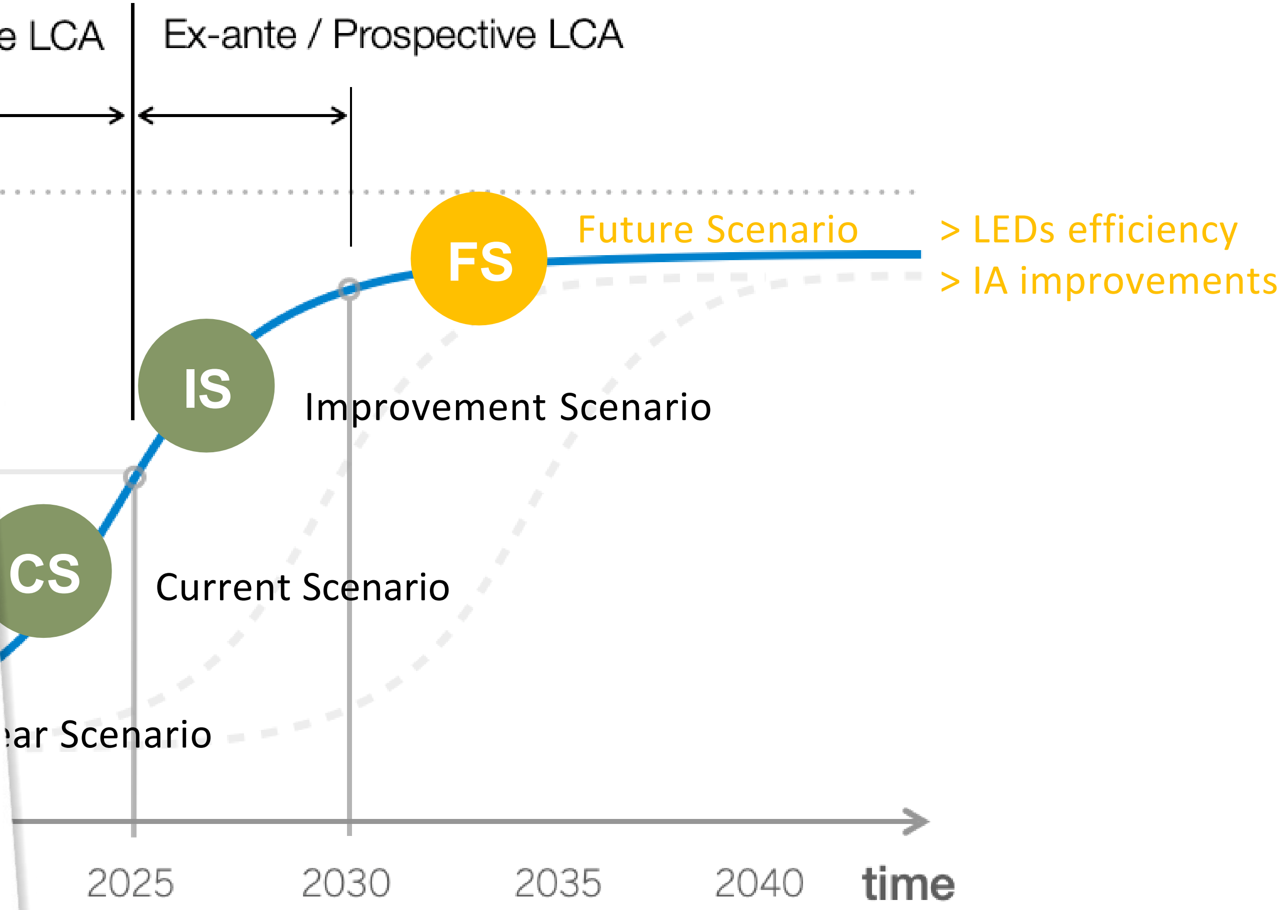
Accepted: 15 August 2024

Benjamin Decardi-Nelson[1] & Fengqi You[1,2,3]

Plant factories with artificial lighting (PFALs) can boost food production per unit area but require resources such as carbon dioxide and energy to maintain optimal plant growth conditions. Here we use computational modelling and artificial intelligence (AI) to examine plant–environment interactions across ten diverse global locations with distinct climates. AI reduces energy use by optimizing lighting and climate regulation systems, with energy use in PFALs ranging from 6.42 kWh kg^{-1} in cooler climates to 7.26 kWh kg^{-1} in warmer climates, compared to 9.5–10.5 kWh kg^{-1} in PFALs using existing, non-AI-based technology. Outdoor temperatures between 0 °C and 25 °C favour ventilation-related energy use reduction, with outdoor humidity showing no clear pattern or effect on energy use. Ventilation-related energy savings negatively impact other resource utilization such as carbon dioxide use. AI can substantially enhance energy savings in PFALs and support sustainable food production.

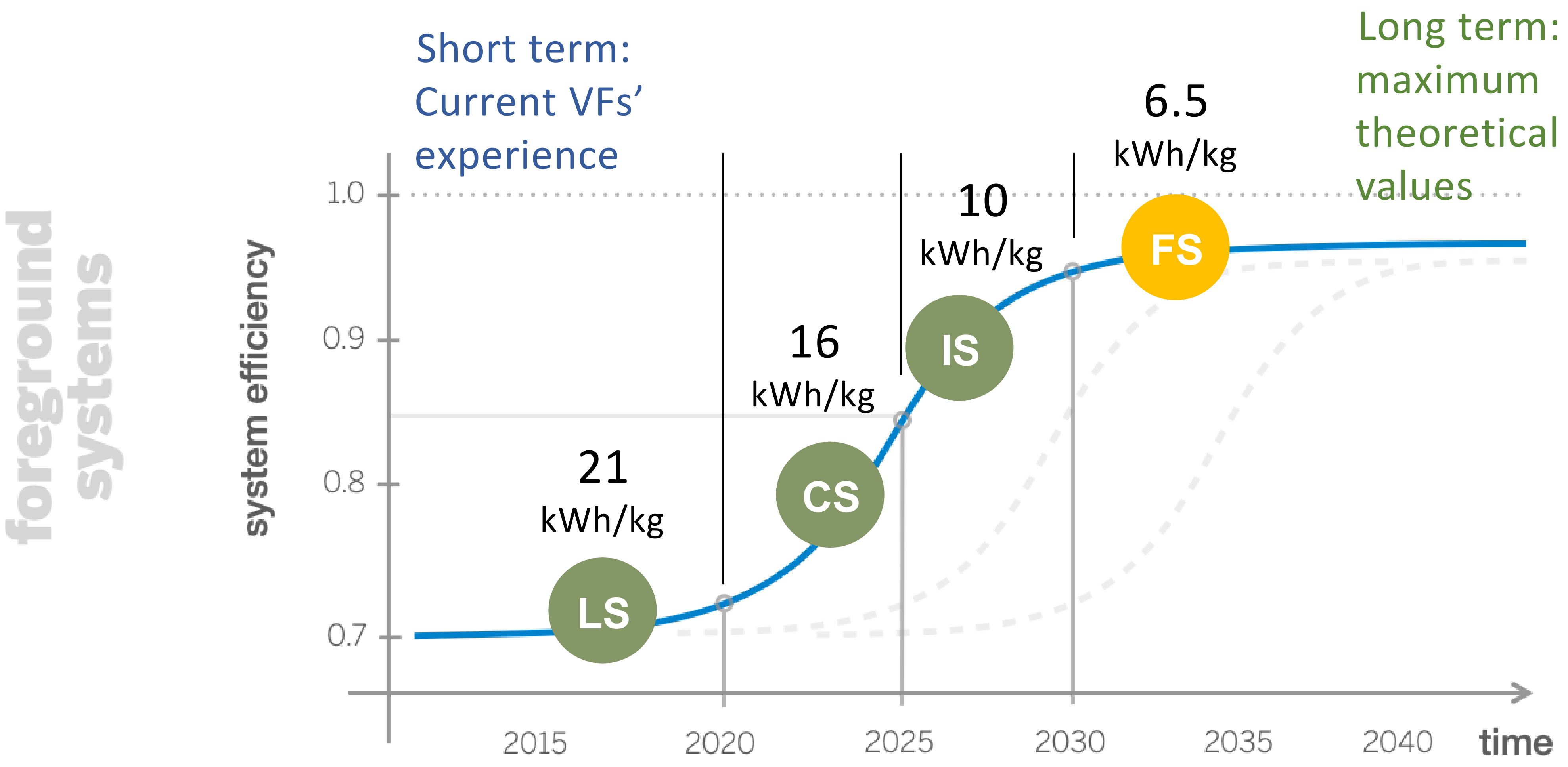
Population growth and rapid urbanization have exposed the vulnerabilities of our food production systems[1,2], highlighting the need to build more resilient food systems worldwide[3]. Failing to address these vulnerabilities could impede progress towards achieving several United Nations Sustainable Development Goals (SDGs) such as hunger reduction and environmental sustainability by 2030[4]. One way to strengthen the agriculture food system is by adopting plant factories with artificial lighting (PFALs)[5–7]. PFALs are an intensive farming approach whereby plants are grown in multiple layers within a controlled environment[8]. This farming approach enables year-round production of high-quality crops, regardless of external climate conditions[5]. However, this level of control comes at the cost of increased resource consumption[9], underscoring the importance of optimizing these systems for maximum impact.

and ventilation, proper moisture control, optimal carbon dioxide (CO_2) supplementation, sufficient nutrient and water supply, and appropriate light intensity and schedule. These activities modulate environmental factors such as temperature, humidity and CO_2 levels within the facility, directly impacting plant physiological processes such as photosynthesis, transpiration and respiration. Maintaining consistent and ideal levels of these environmental factors within the PFAL is important to prevent plant stress and wilting[11]. Furthermore, PFALs depend on artificial light, which is absorbed by the chlorophyll in the leaves to facilitate photosynthesis, a crucial process for promoting plant growth. Nevertheless, regulating these environmental factors necessitates the use of finite resources such as energy, water and CO_2. As a result, PFAL operation typically involves high energy consumption, rendering these facilities more energy intensive than other farming types, such as greenhouses or open-field farming[9,12–15]. It is therefore important to ensure an adequate supply of CO_2 and maintain



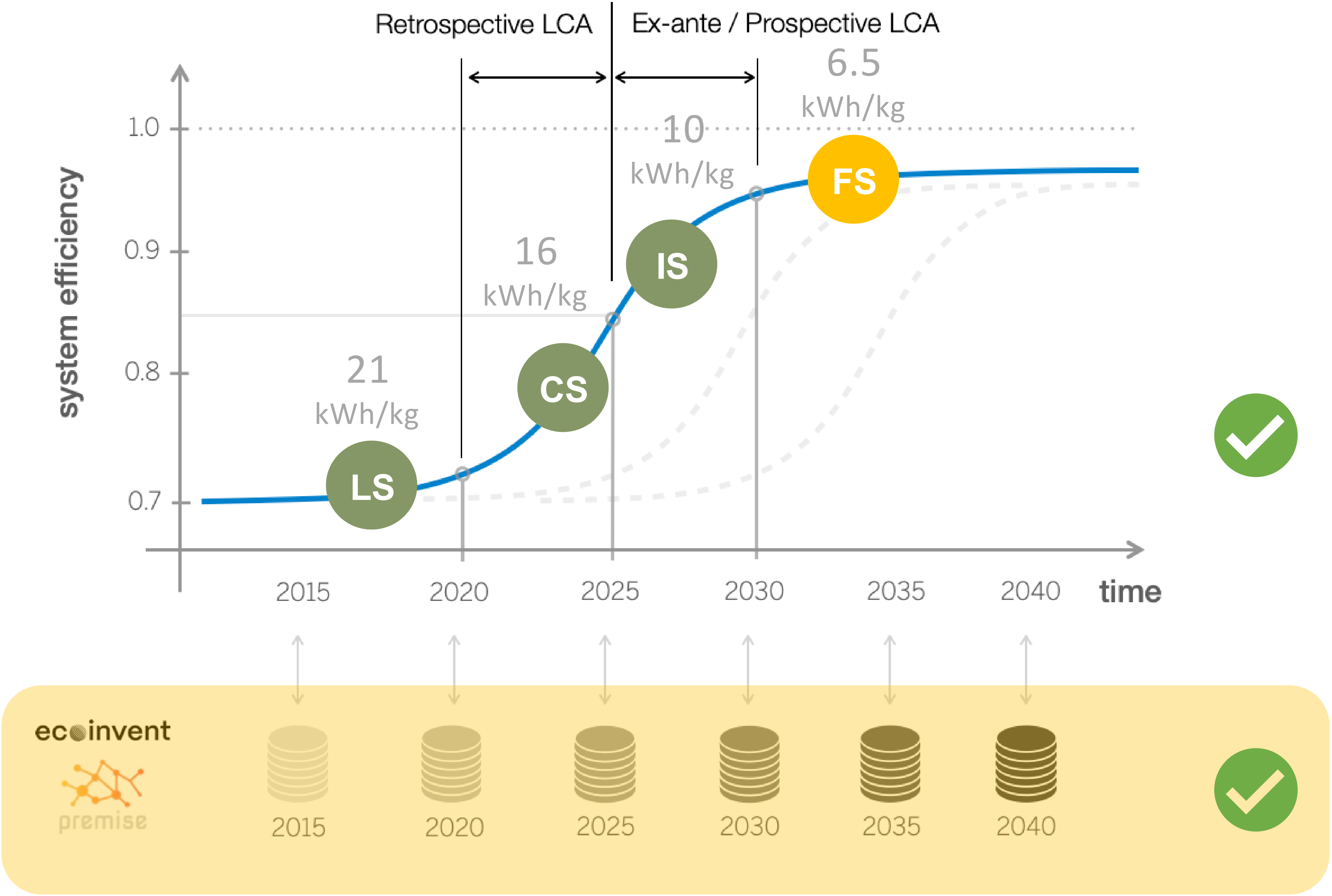
> LEDs efficiency
> IA improvements

Assessing the environmental impacts of different circular strategies in 2 VFs



foreground systems

background systems



Conclusions

1

- **Electricity consumption** dominates the environmental impacts of vertical farms ranging from **39-87%** (Stockholm) to **51-88%** (Barcelona).
  - Following, **infrastructure, fertilizers** and **packaging** sum up **> 80-90%** of all impact categories analyzed.

2

- **VF have been evolving** during the last years to reduce their environmental impacts around **20%** compared to the first linear vertical farming systems.
  - By implementing **improvement / circular strategies,** VFs' environmental impacts could be further decreased by up to **29-34%.**

3

- Vertical farming systems have the potential to **improve resource-use efficiency of plant growth and its related environmental impacts in the future** due to changes at the foreground and background systems.

Thank you!

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