Environmental impacts of vertical farming across Europe: outlook and future perspectives

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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**

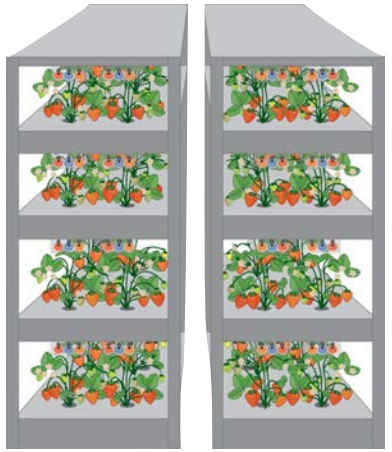
» they have more potential to improve in the future!

Controlled Environment Agriculture

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

Open field

Greenhouses



Vertical Farms

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

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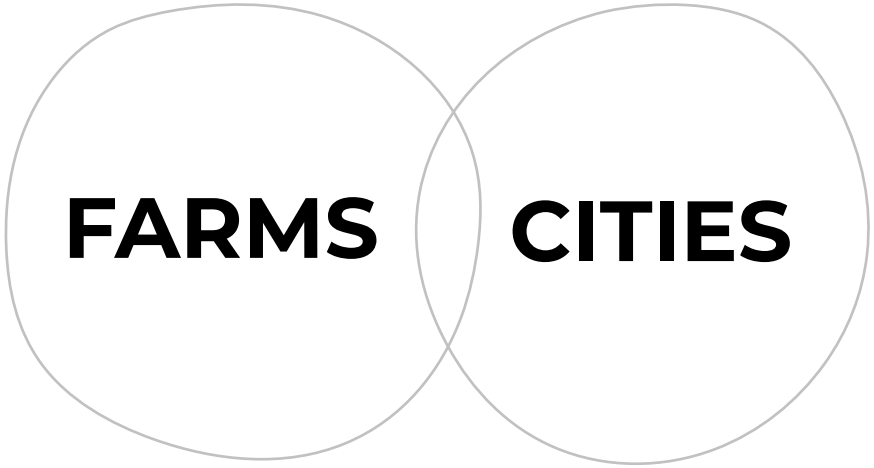
The ecofarm—city project

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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vertical farms for circular cities

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3 Partner institutions

370 k€ of public funding

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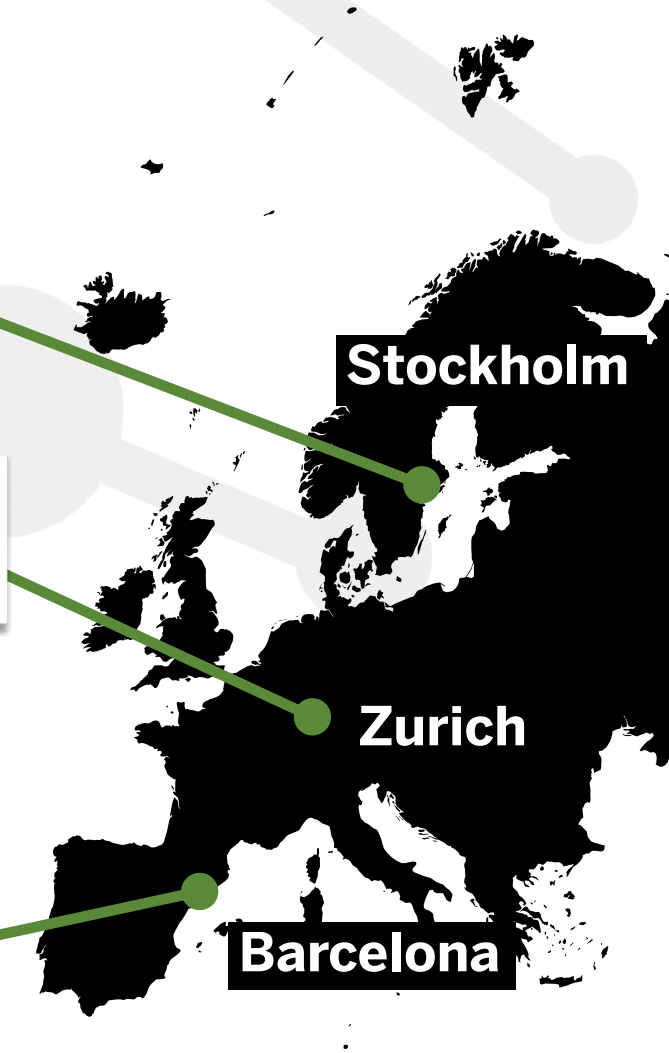

The ecofarm—city project

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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GROOTS

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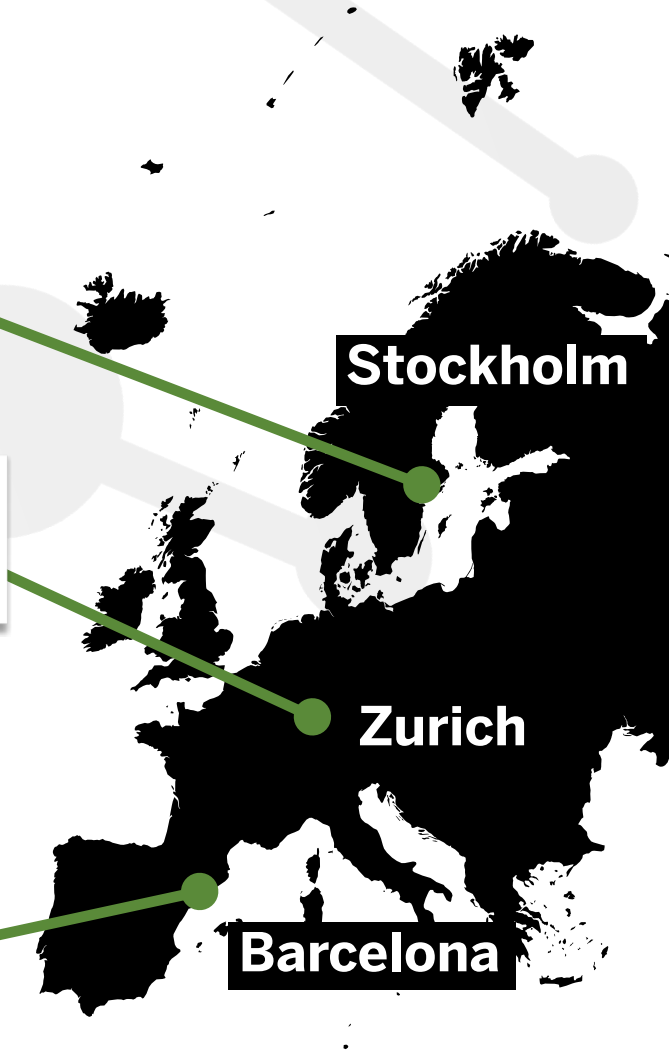

NÄRA

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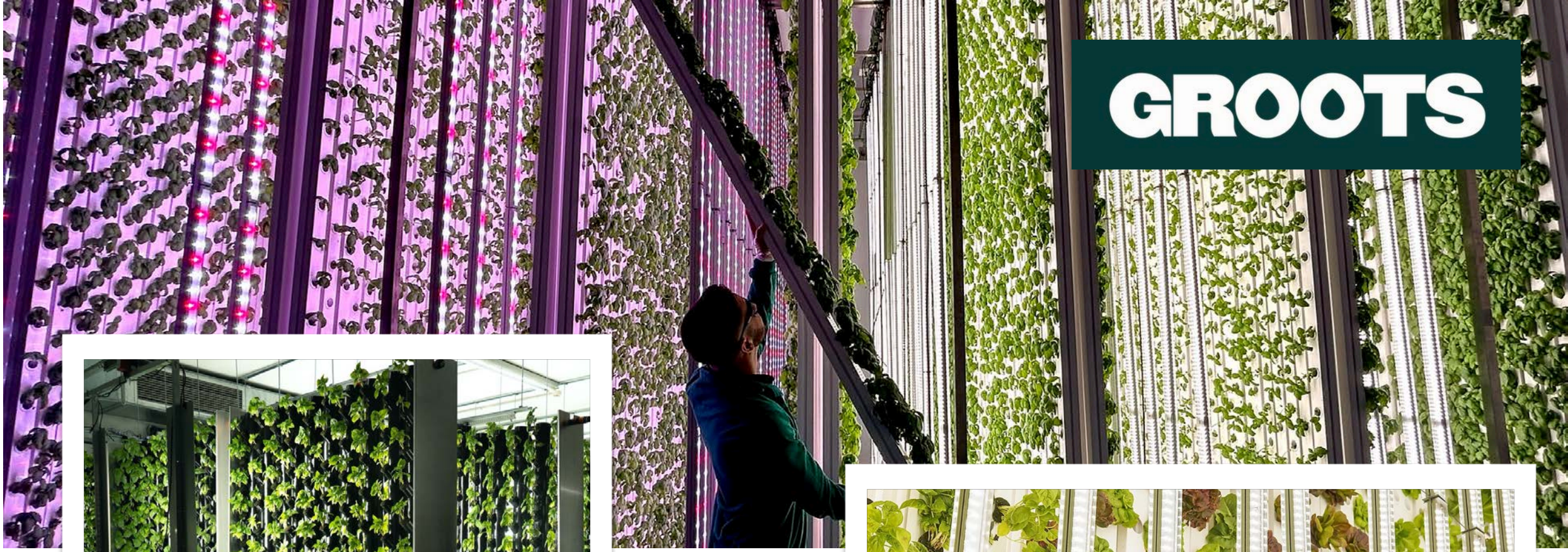

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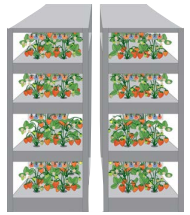
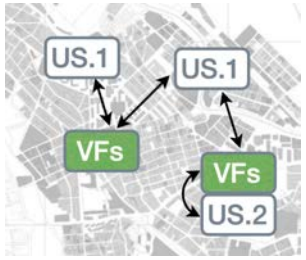
The ecofarm—city project

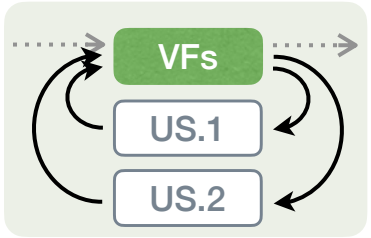
Steps to reach project objectives:



1

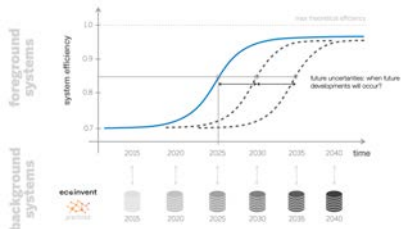
To understand **current life-cycle environmental impacts** of vertical farms + conventional agricultural systems





2

To identify and model **common circular strategies and future improvement technologies** within vertical farms



3

To **compare current and future environmental impacts of vertical farms** with conventional agricultural systems

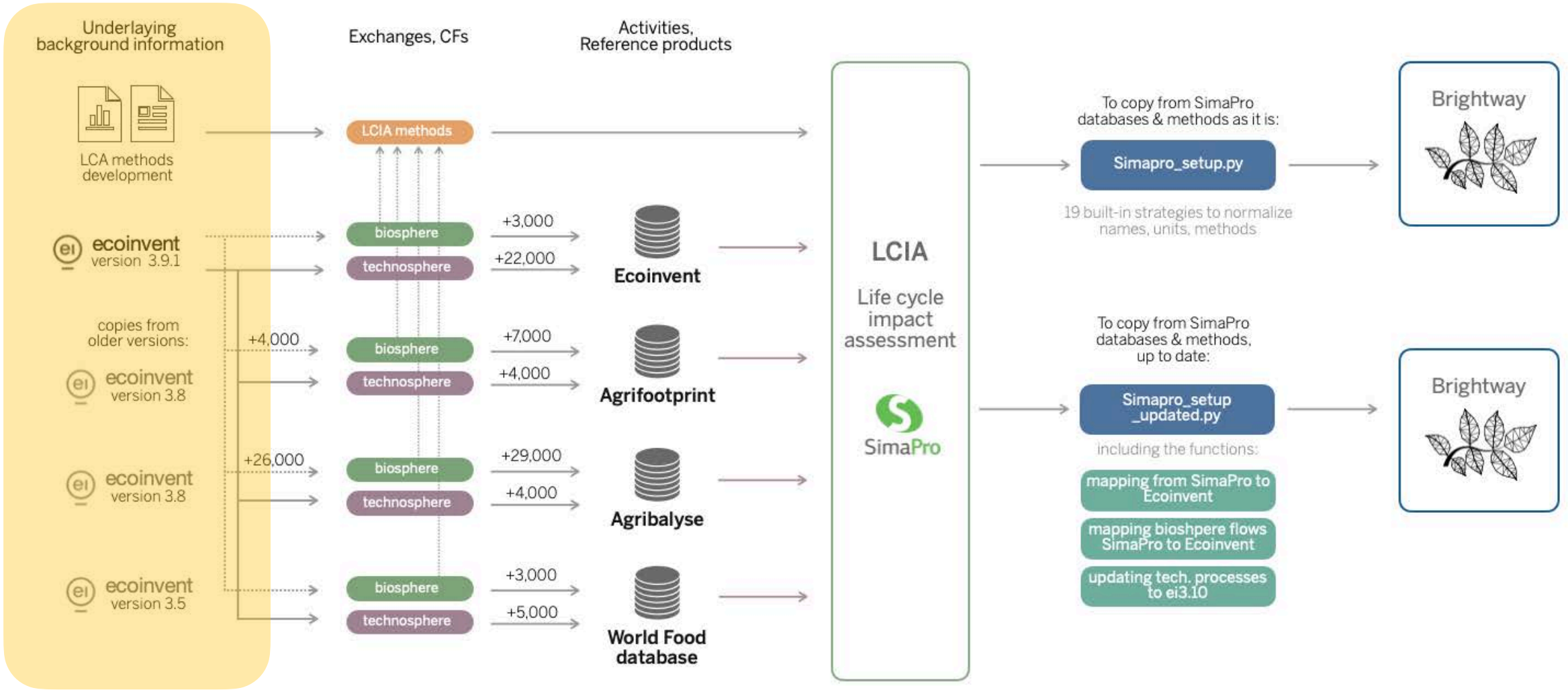
1 LCA impacts of VFs vs CA: challenges

#1 LCI data consistency from current agri-food databases

- LCI data formats, background versions

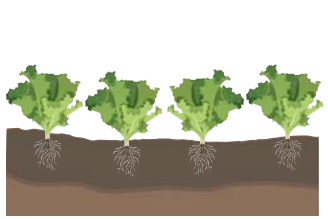
1 Increasing the consistency of agrifood databases: a python library using Brightway2 framework

Cedric Furrer



1 LCA impacts of VFs vs CA

Current and future objectives for LCI data:



+64 **life cycle inventories** from conventional agricultural systems

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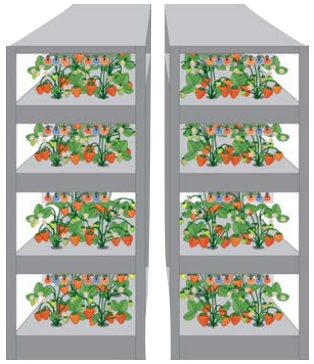


3 original **life cycle inventories** from vertical farms

+10 **life cycle inventories** from other studies in vertical farms

1 LCA impacts of VFs vs CA

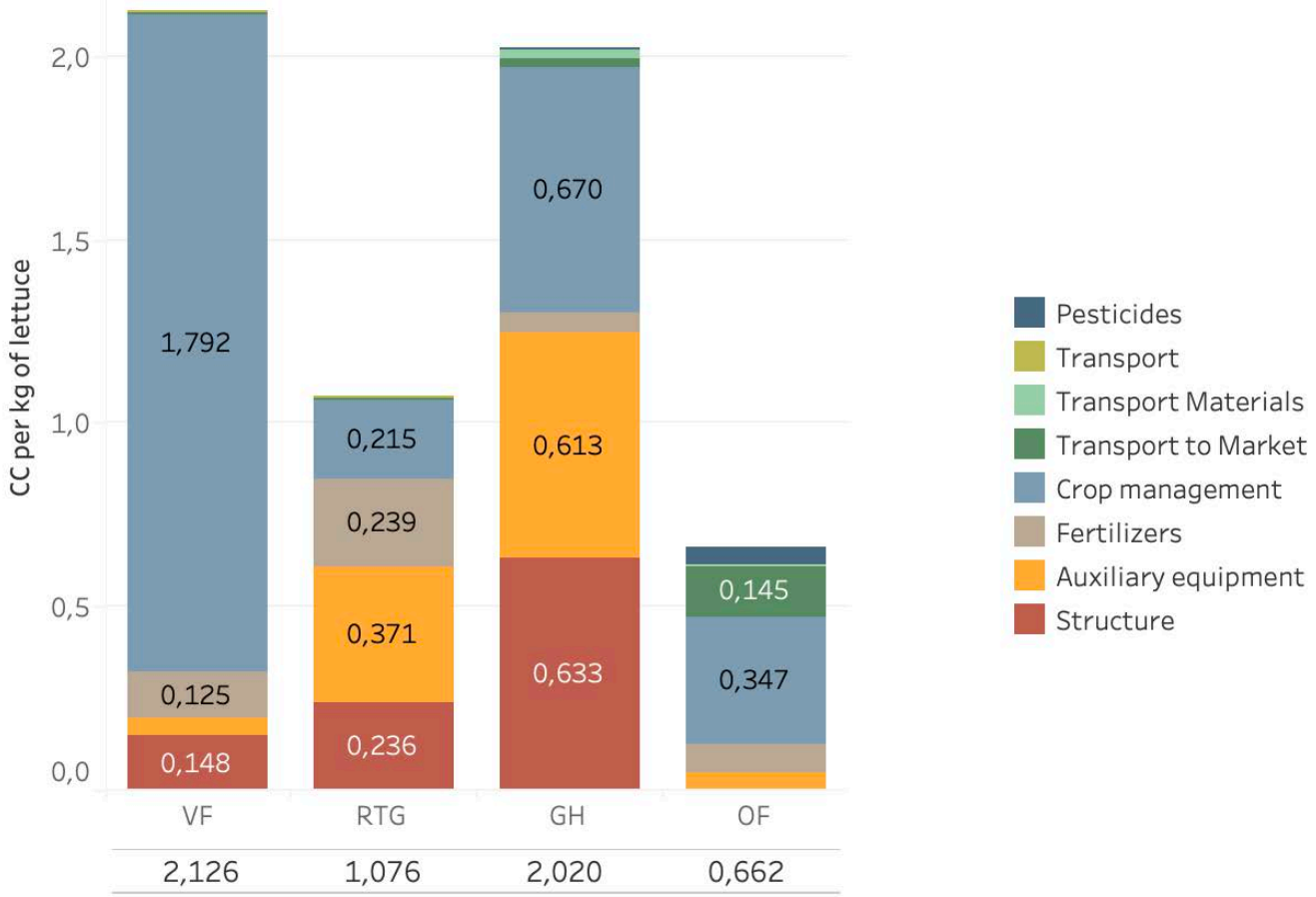
global warming impacts
1kg of lettuce

VF

GH

RTG

OF



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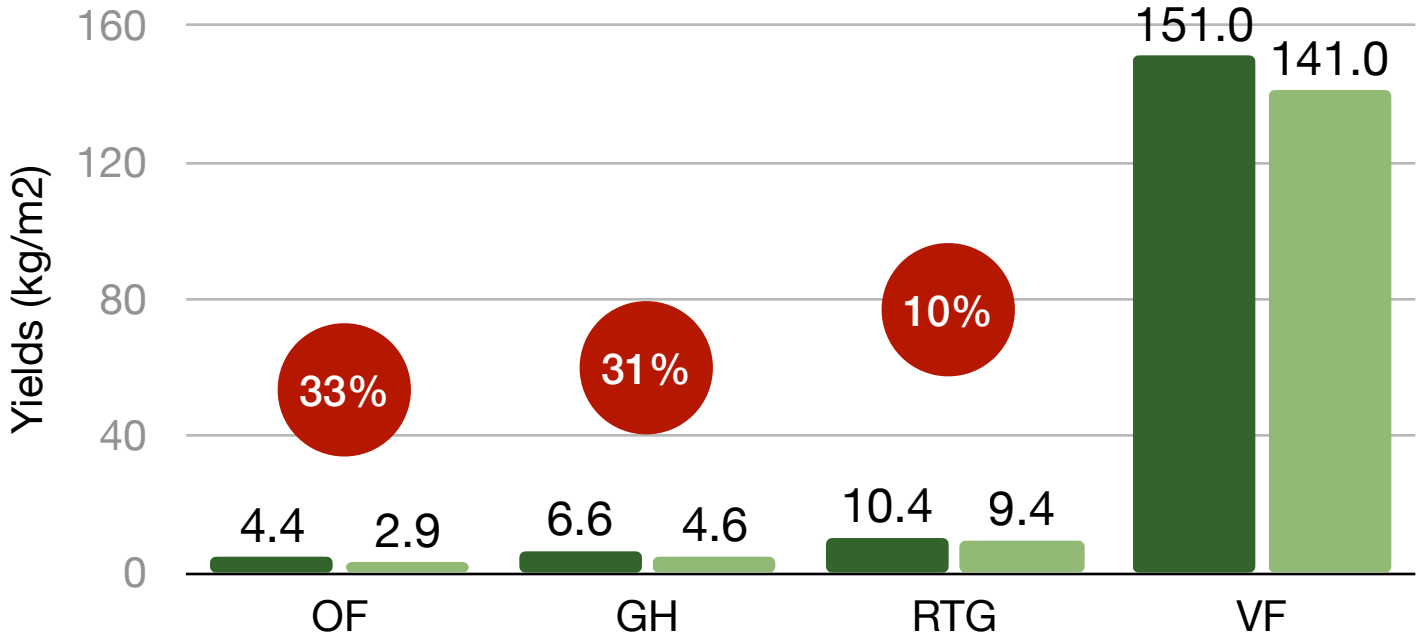
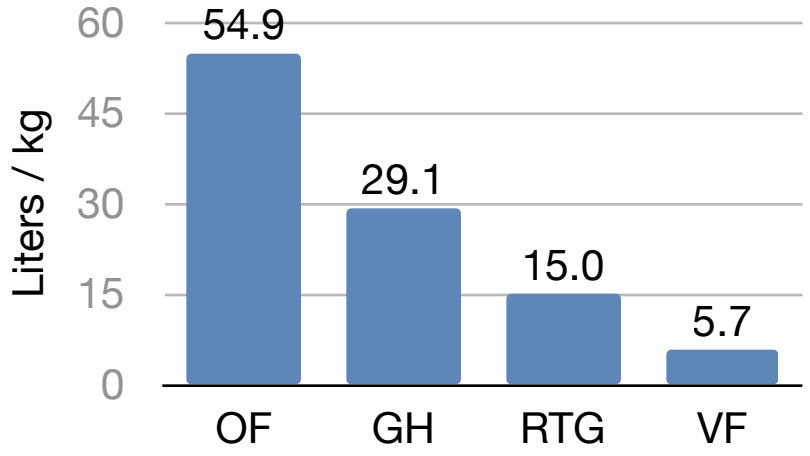
1 LCA impacts of VFs vs CA

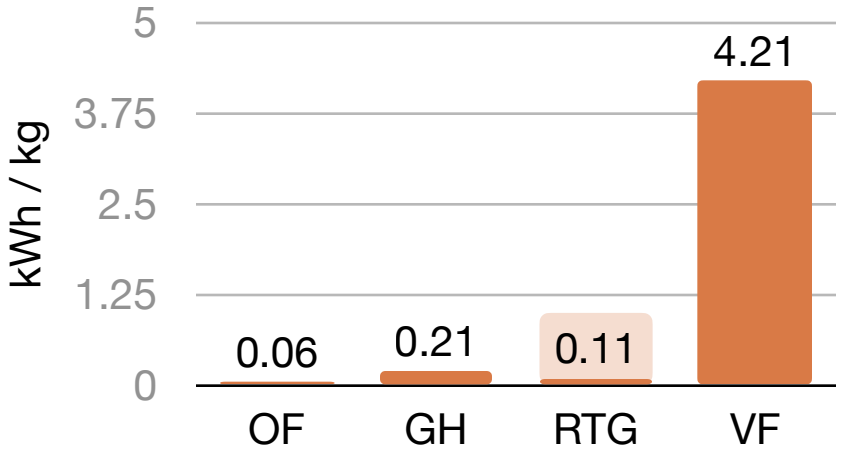
crop yield productivities + food losses



water consumption



energy consumption



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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

1 LCA impacts of VFs vs CA: challenges

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#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

LCA contribution analysis of 4 vertical farming systems

(ReCiPe method, Ecoinvent 3.9.1)

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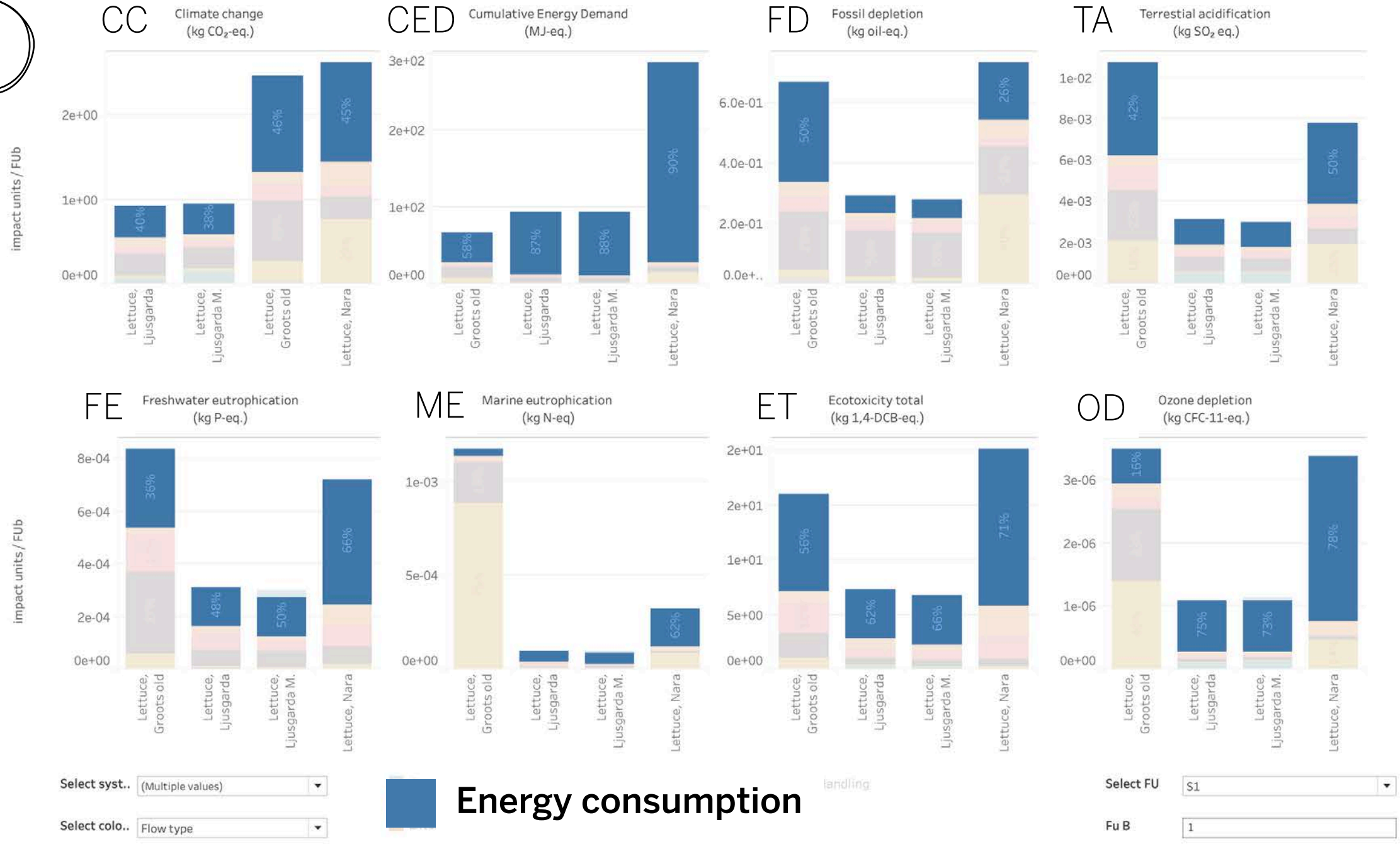
CC
Climate change
(kg CO_2-eq.)
CED
Cumulative Energy Demand
(MJ-eq.)
FD
Fossil depletion
(kg oil-eq.)
TA
Terrestial acidification
(kg SO_2 eq.)
FE
Freshwater eutrophication
(kg P-eq.)
ME
Marine eutrophication
(kg N-eq)
ET
Ecotoxicity total
(kg 1,4-DCB-eq.)
OD
Ozone depletion
(kg CFC-11-eq.)
impact units / FUb
Lettuce, Ljusgarda
Lettuce, Ljusgarda M.
Lettuce, Groots old
Lettuce, Nara
Select syst..
(Multiple values)
Select colo..
Flow type
Chemicals
Energy
External benefit
Fertilizer
Infrastructure
Other
Packaging
Seeds and Subs..
Transport
Waste Handling
Water
Select FU
S1
Fu B
1

1


CC
Climate change
(kg CO_2-eq.)
CED
Cumulative Energy Demand
(MJ-eq.)
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Ecotoxicity total
(kg 1,4-DCB-eq.)
OD
Ozone depletion
(kg CFC-11-eq.)
impact units / FUb
Lettuce, Ljusgarda
Lettuce, Ljusgarda M.
Lettuce, Groots old
Lettuce, Nara
Select syst..
(Multiple values)
Select colo..
Flow type
Energy consumption
Select FU
S1
Fu B
1

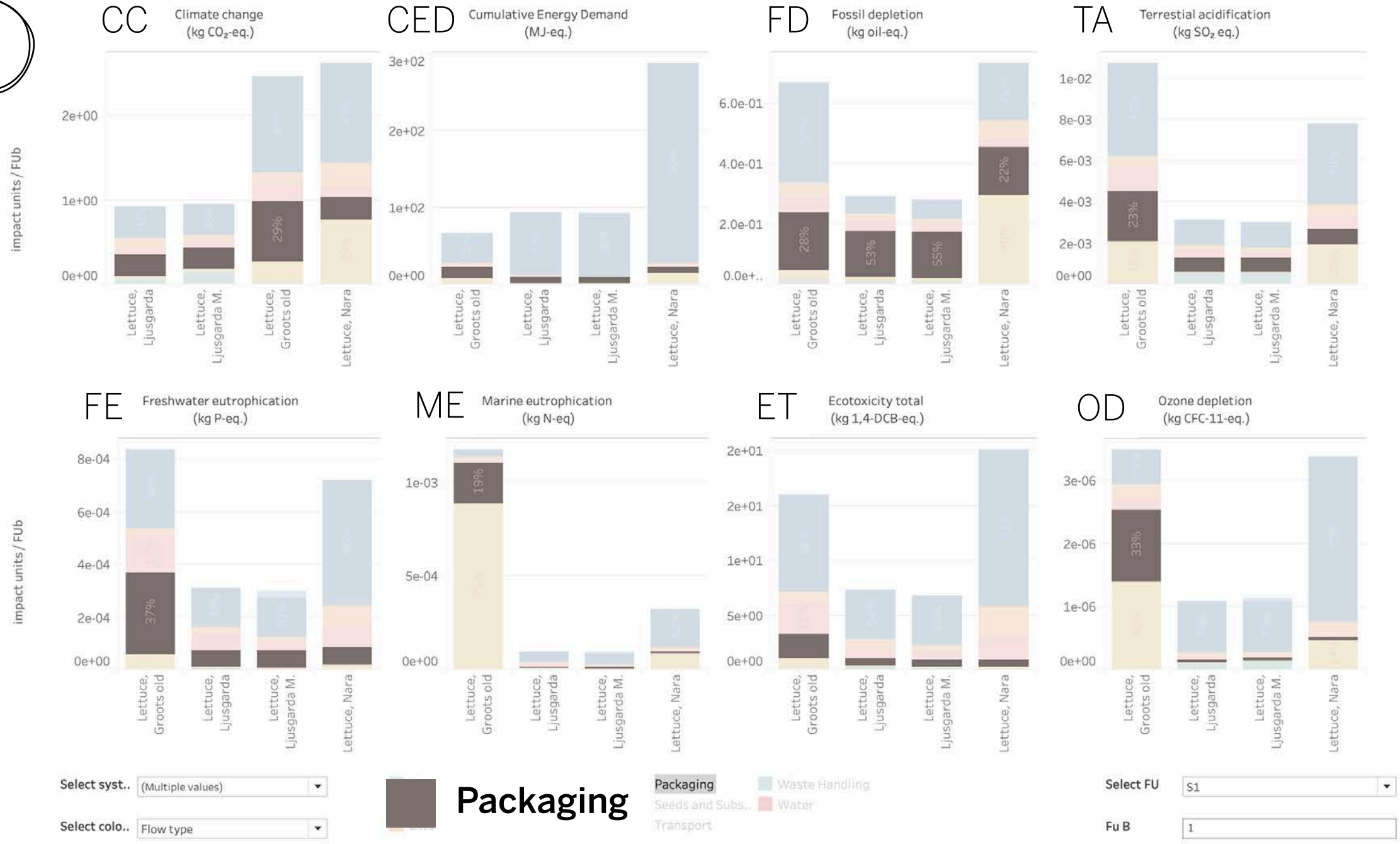
2


CC
Climate change
(kg CO_2-eq.)
CED
Cumulative Energy Demand
(MJ-eq.)
FD
Fossil depletion
(kg oil-eq.)
TA
Terrestial acidification
(kg SO_2 eq.)
FE
Freshwater eutrophication
(kg P-eq.)
ME
Marine eutrophication
(kg N-eq)
ET
Ecotoxicity total
(kg 1,4-DCB-eq.)
OD
Ozone depletion
(kg CFC-11-eq.)
impact units / FUb
Lettuce, Ljusgarda
Lettuce, Ljusgarda M.
Lettuce, Groots old
Lettuce, Nara
17%
18%
Select syst..
(Multiple values)
Select colo..
Flow type
Infrastructure
Waste Handling
Water
Select FU
S1
Fu B
1

3


CC
Climate change
(kg CO_2-eq.)
CED
Cumulative Energy Demand
(MJ-eq.)
FD
Fossil depletion
(kg oil-eq.)
TA
Terrestial acidification
(kg SO_2 eq.)
FE
Freshwater eutrophication
(kg P-eq.)
ME
Marine eutrophication
(kg N-eq)
ET
Ecotoxicity total
(kg 1,4-DCB-eq.)
OD
Ozone depletion
(kg CFC-11-eq.)
impact units / FUb
Lettuce, Ljusgarda
Lettuce, Ljusgarda M.
Lettuce, Groots old
Lettuce, Nara
Select syst..
(Multiple values)
Select colo..
Flow type
Fertilizers
Packaging
Seeds and Subs..
Transport
Waste Handling
Water
Select FU
S1
Fu B
1

4


CC
Climate change
(kg CO_2-eq.)
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Lettuce, Ljusgarda
Lettuce, Ljusgarda M.
Lettuce, Grroots old
Lettuce, Nara
Select syst..
(Multiple values)
Select colo..
Flow type
Packaging
Waste Handling
Seeds and Subs..
Water
Transport
Select FU
S1
Fu B
1

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2 Assessing LCA impacts of 2 VFs applying different improvements

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**

Challenge

: how to compare herbs & other leafy crops?

: how to compare different technology maturity levels?

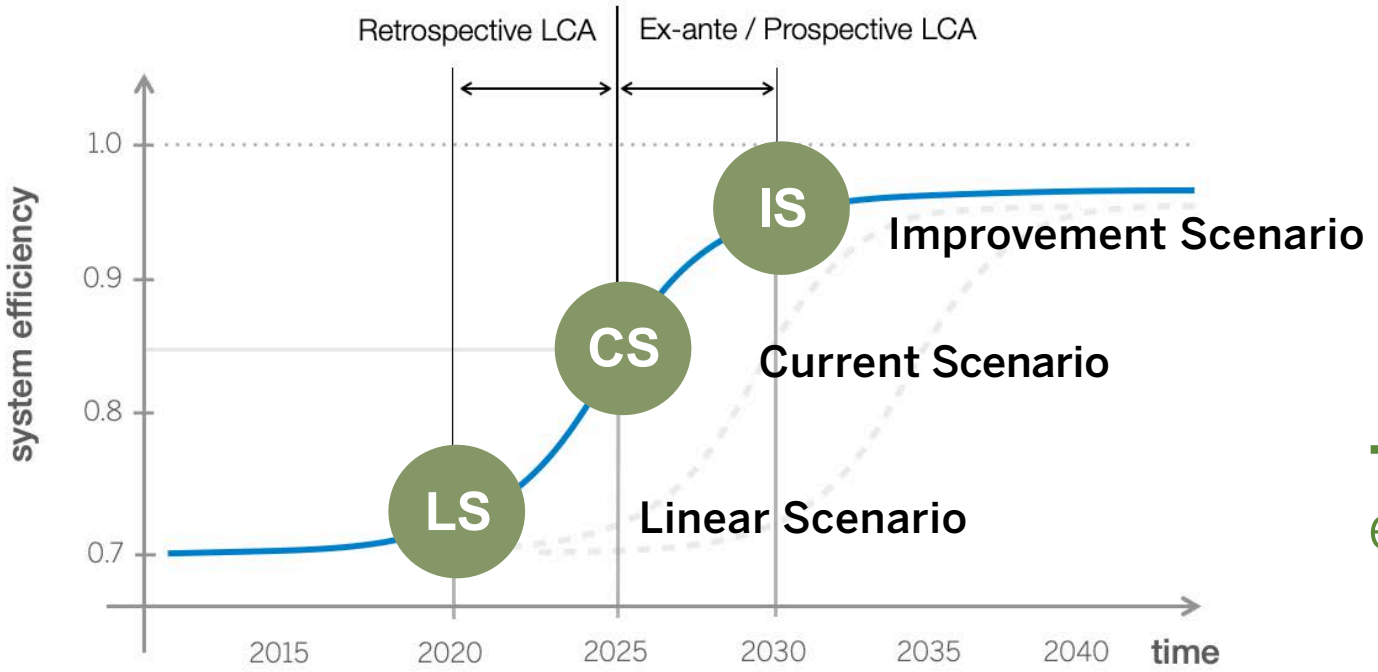
: how to compare different farming setups / dimensions?

2 Assessing LCA impacts of 2 VFs applying different improvements

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**

foreground systems



➔ compare system environmental efficiency

Scenarios considered

CS Current Scenario

VF1 → Strategies 3, 4, 7, 8

VF2 → Strategies 3, 4, 7

LS Linear Scenario

No circular strategies.

IS Improvement Scenario

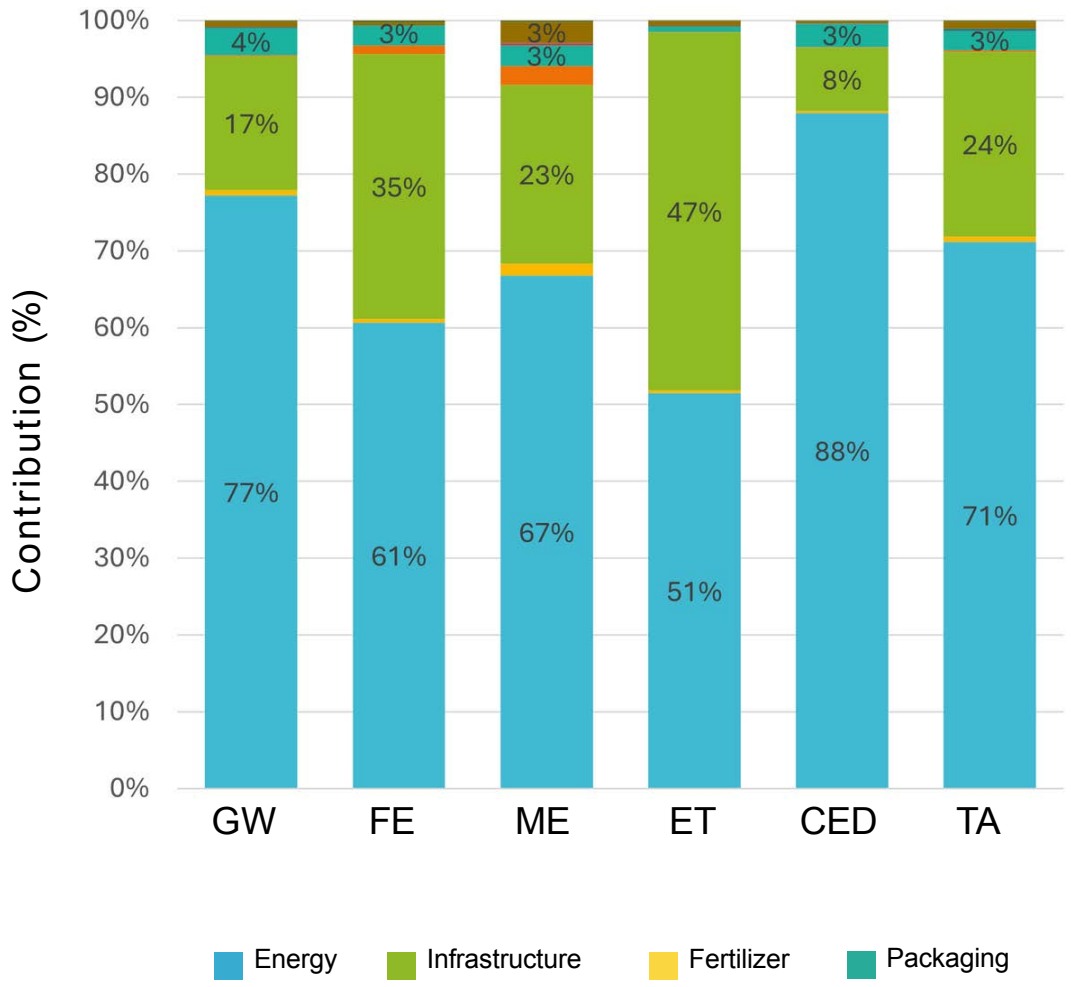
All circular strategies.

→

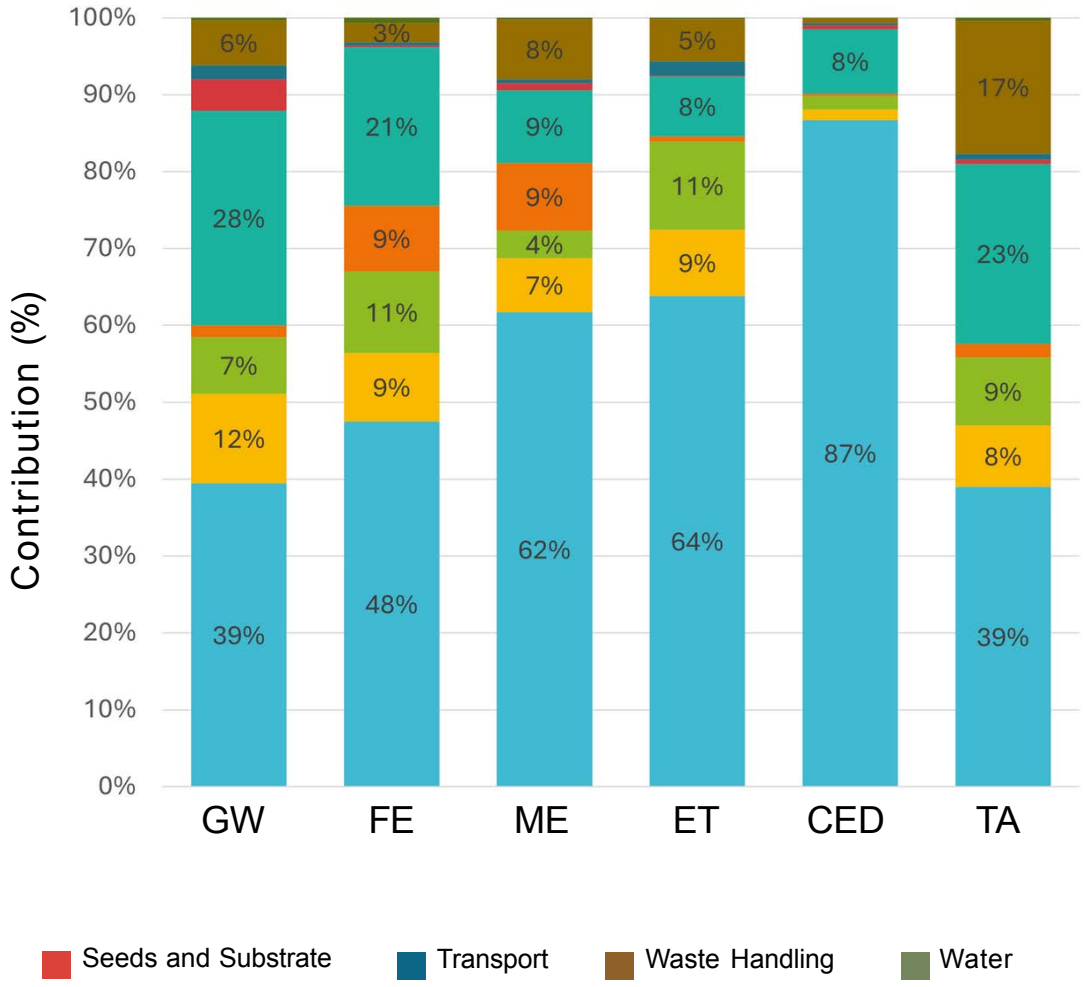
- **S1** Compost
- **S2** Rainwater harvesting system
- **S3** Closed-loop irrigation system
- **S4** Condensed water recovery
- **S5** Struvite
- **S6** Reuse waste heat
- **S7** Recycling of materials
- **S8** PV panels

Contribution analysis

VF1 Current Scenario



VF2 Current Scenario



Energy | Infrastructure | Fertilizer | Packaging | Other | Seeds and Substrate | Transport | Waste Handling | Water

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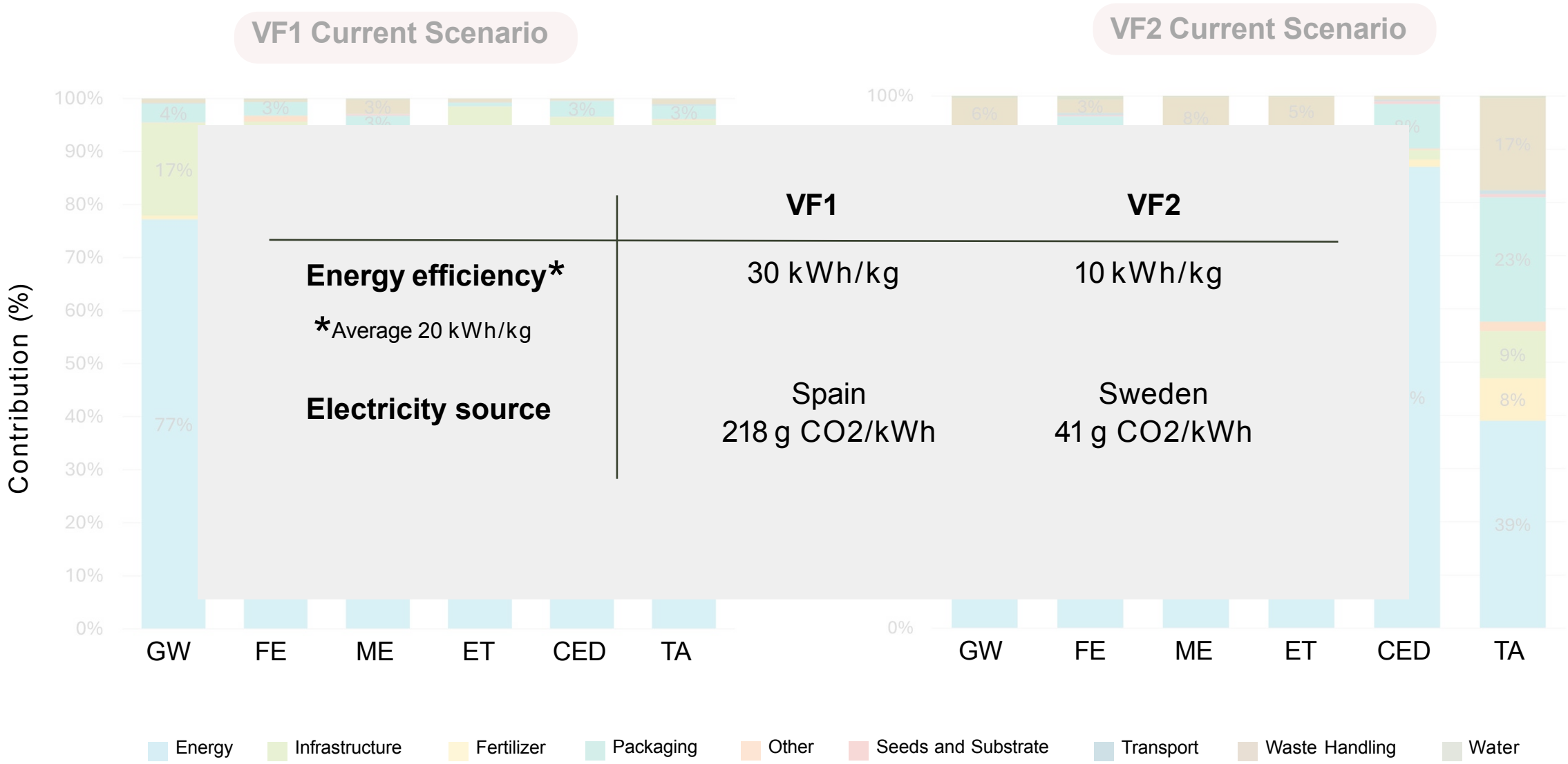
Pennisi et al. (2019); Ember (2024)

Contribution analysis



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S1 Compost

S2 Rainwater

S3 Closed-loop irrigation

S4 Condensed water

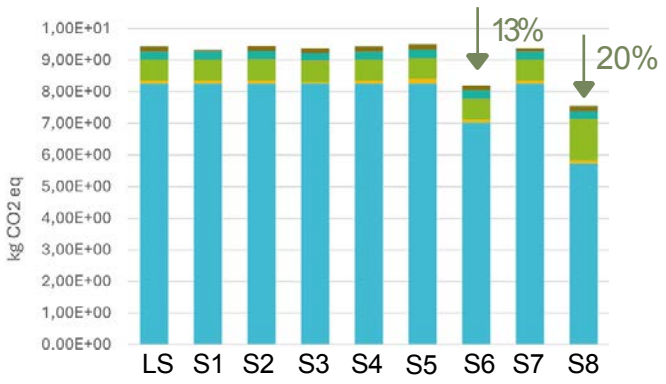
S5 Struvite

S6 Waste heat

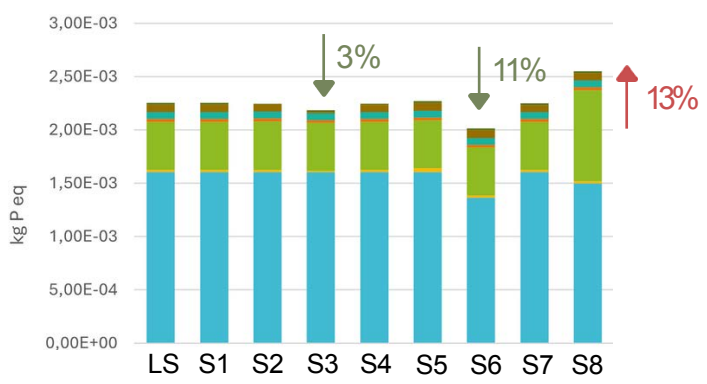
S7 Recycling

S8 PV panels

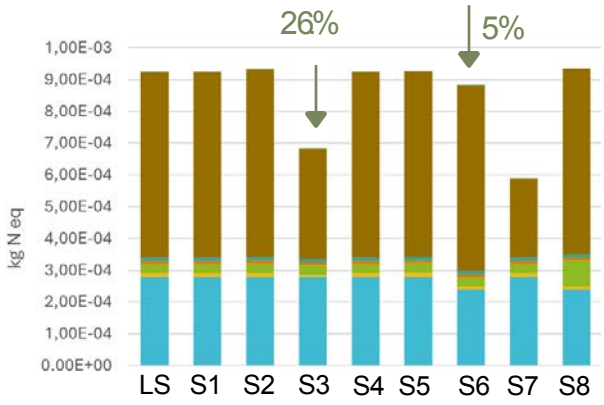
GW



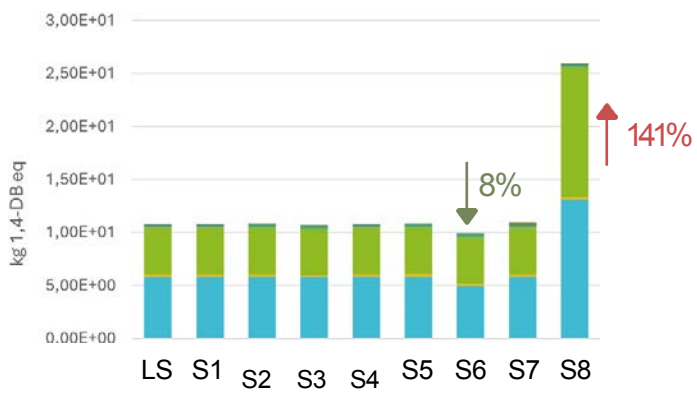
FE



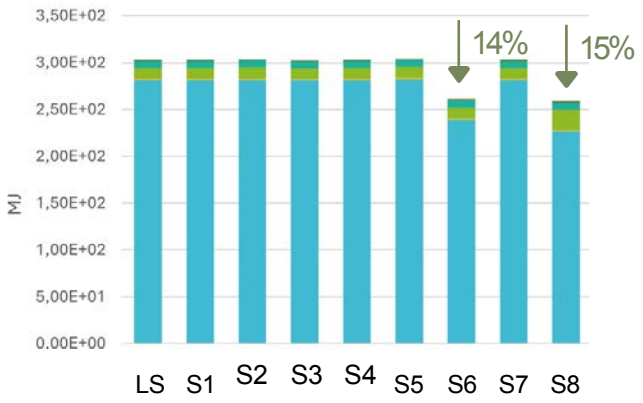
ME



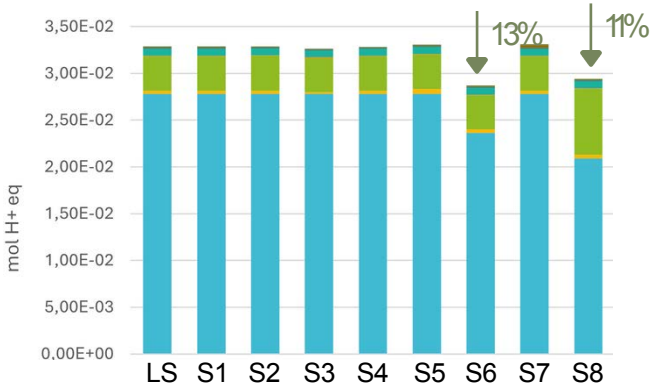
ET



CED



TA



Energy Infrastructure Fertilizer Packaging Other Seeds and Substrate Transport Waste Handling Water

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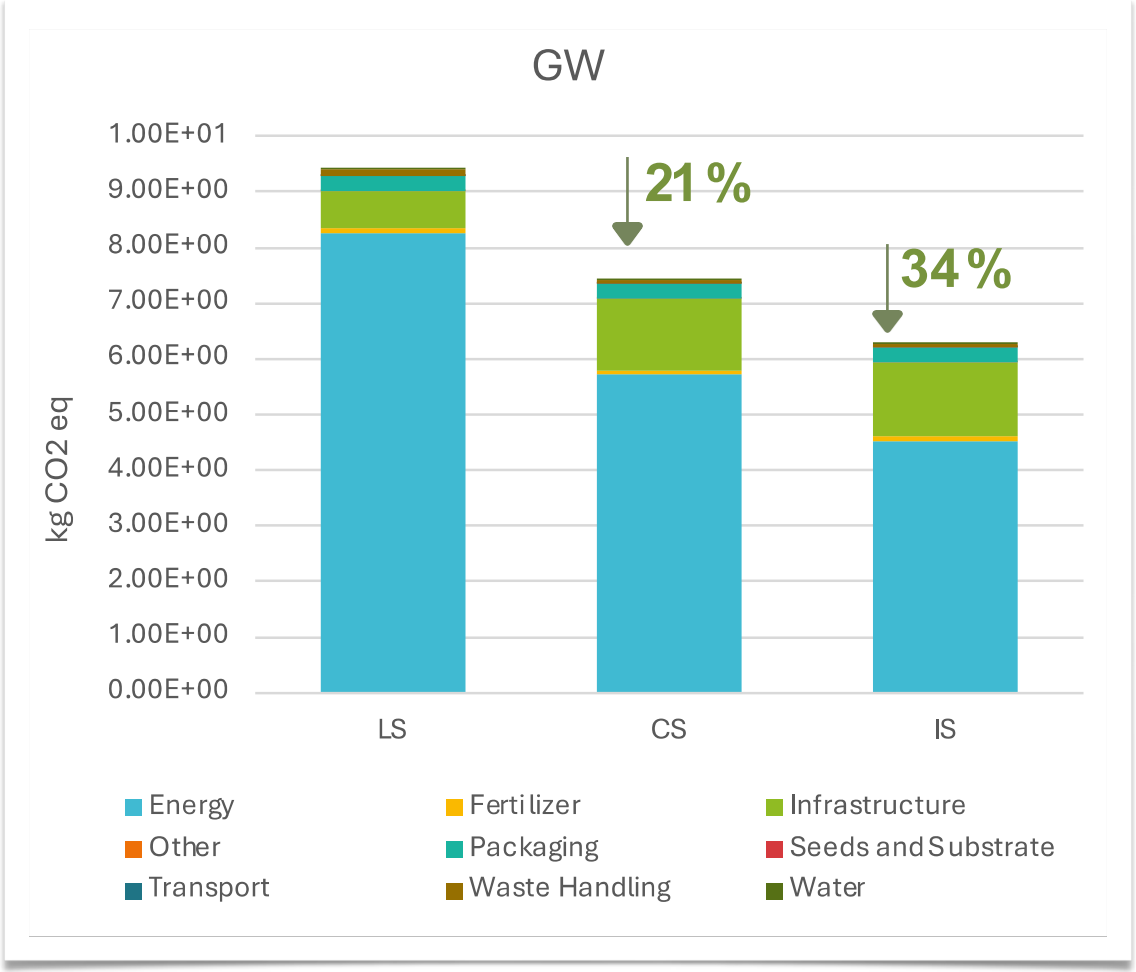
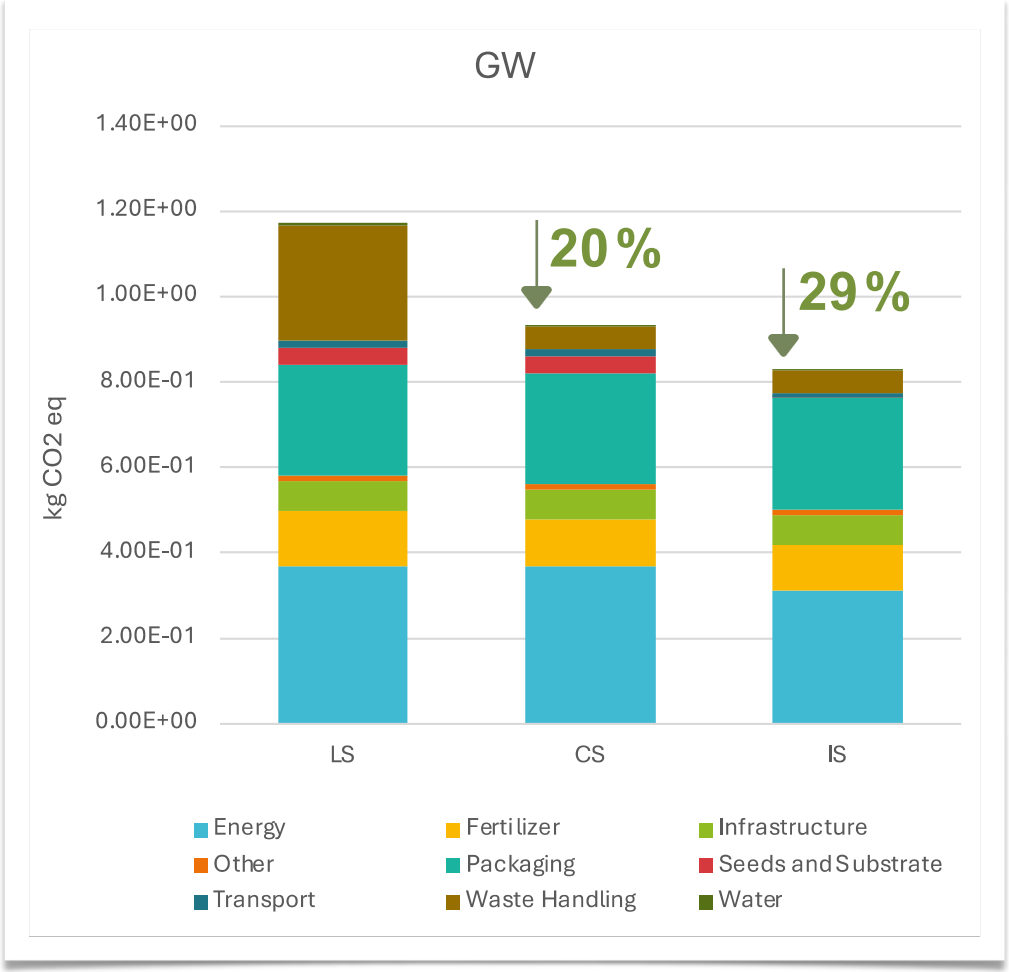
Comparative analysis of 2 VFs



VF1 Barcelona



VF2 Stockholm

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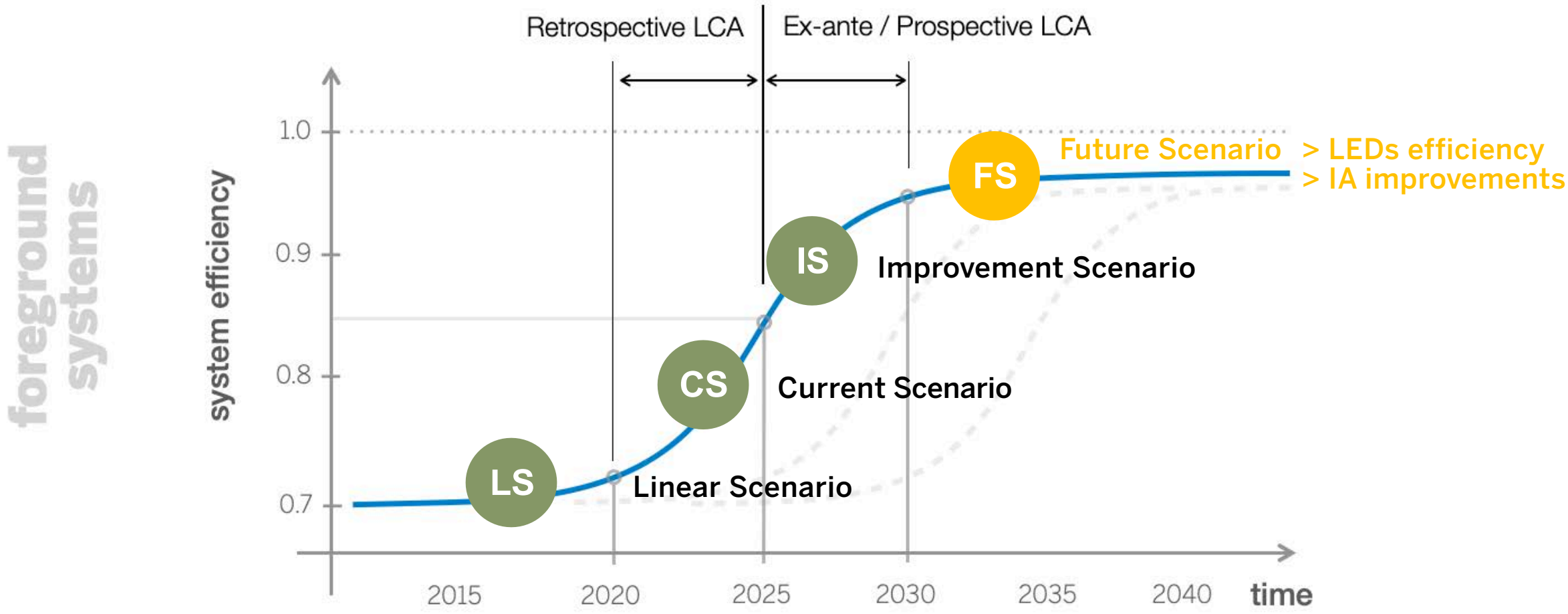
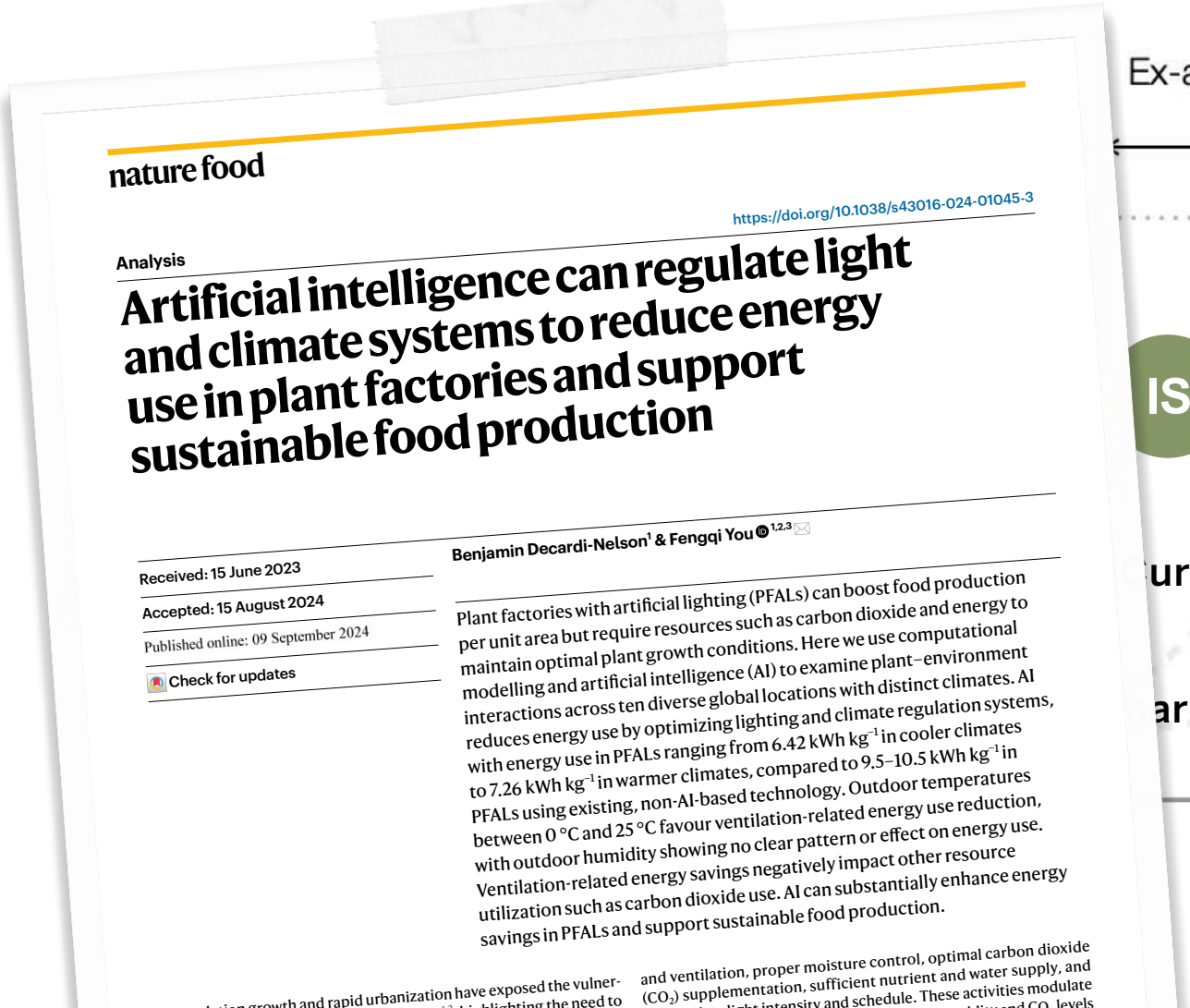
3 Assessing LCA impacts of VFs in the future



Assessing the environmental impacts of different circular strategies in 2 VFs



nature food

Analysis

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

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

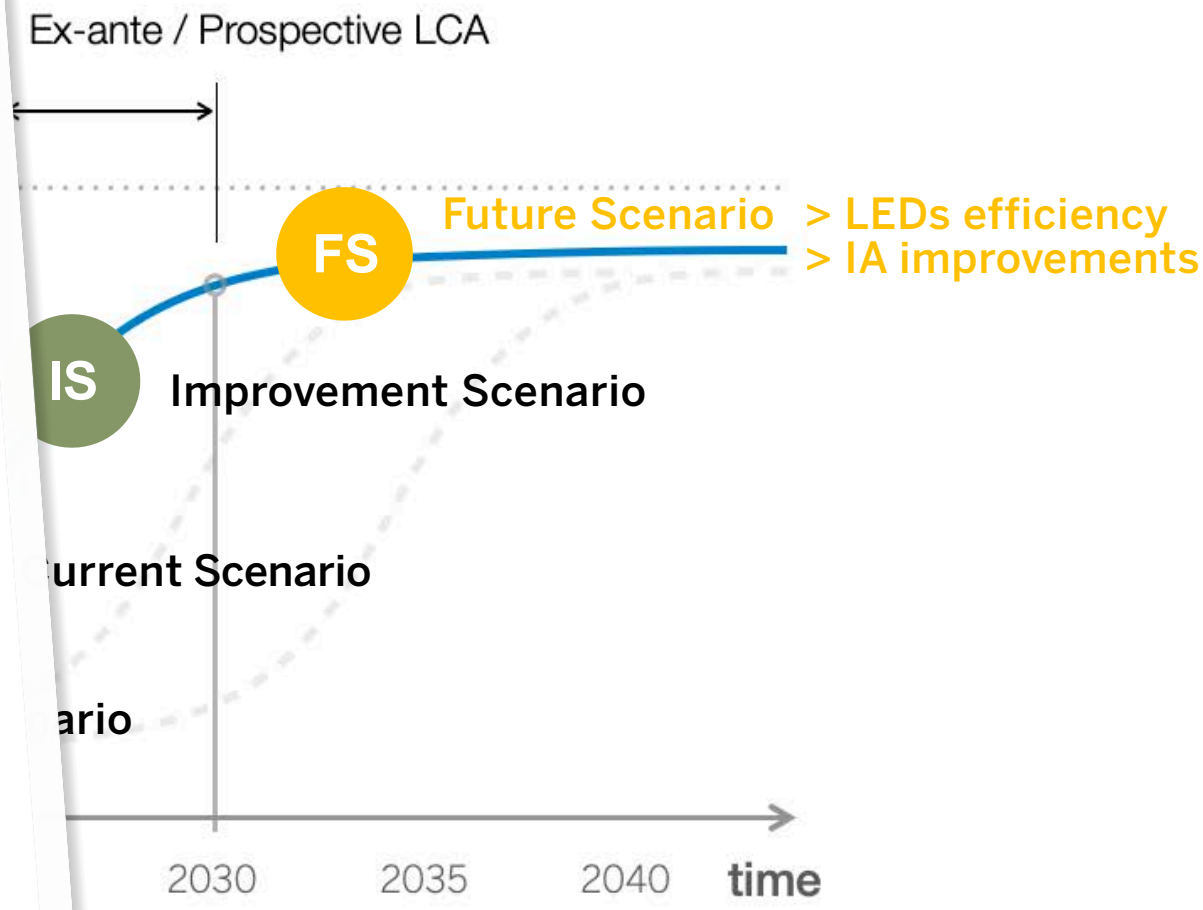
Published online: 09 September 2024

Check for updates

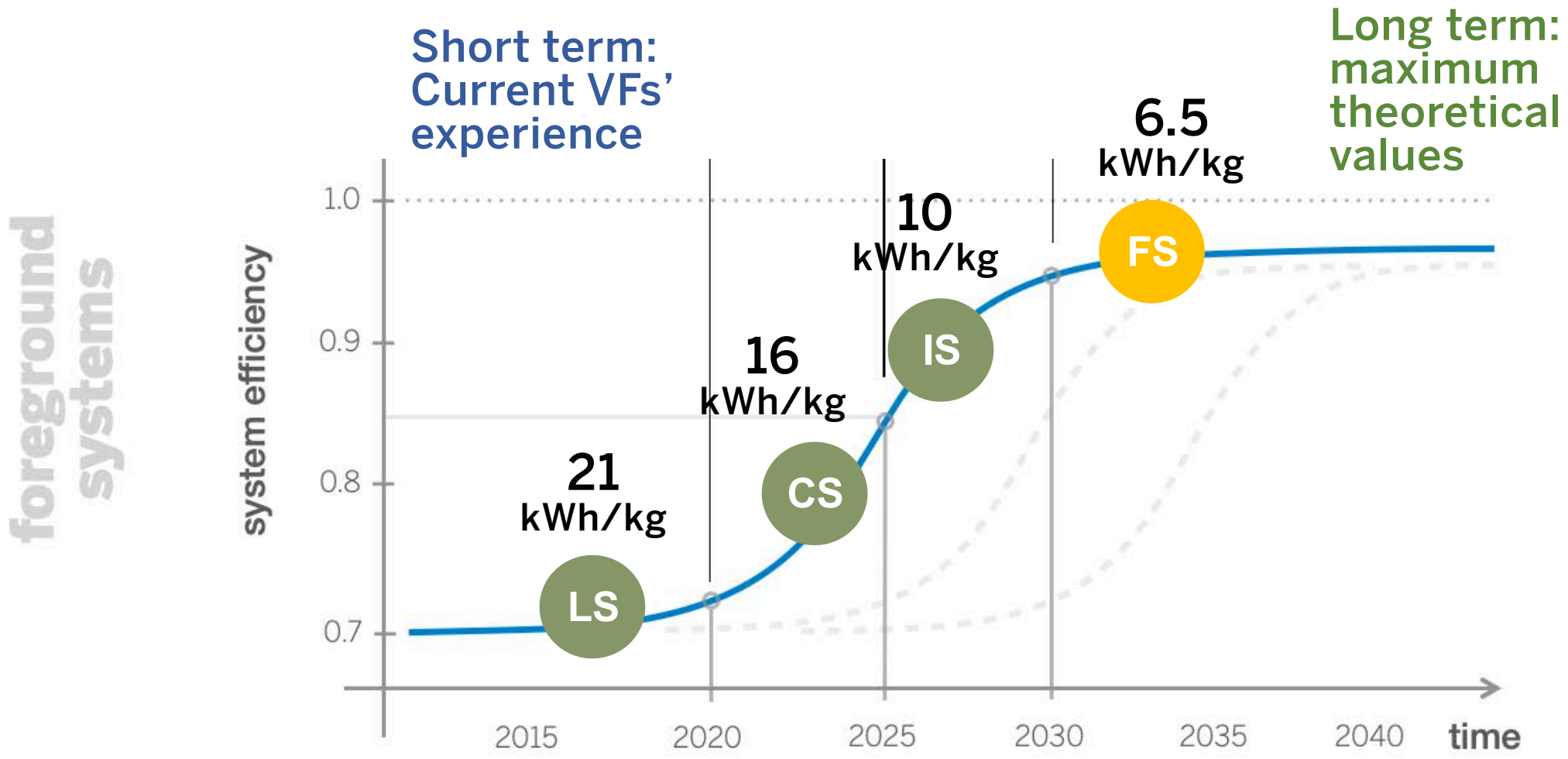
Benjamin Decardi-Nelson[1] & Fengqi You[1,2,3]

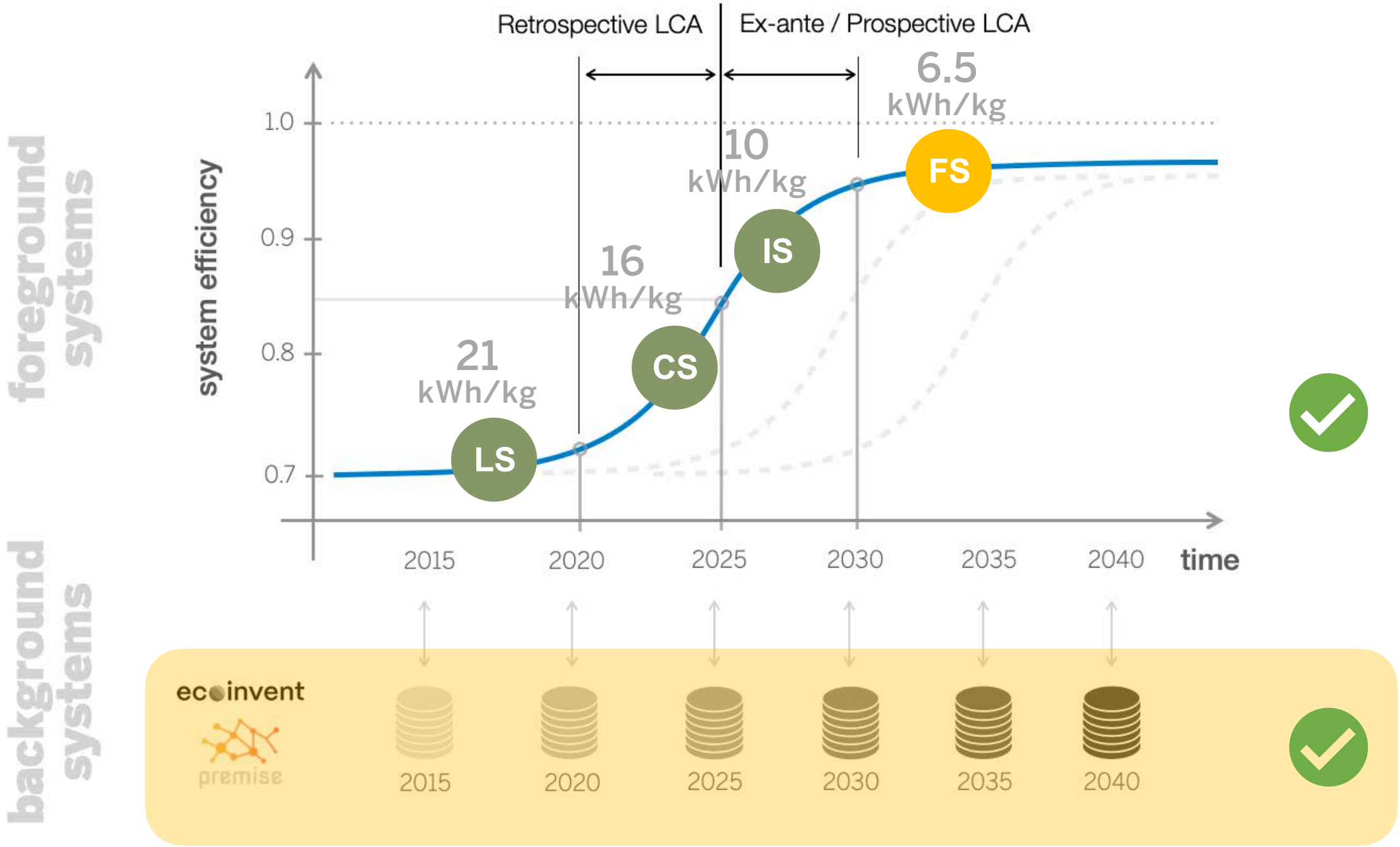
Plant factories with artificial lighting (PFALs) can boost food production per unit area but require resources such as carbon dioxide and energy to maintain optimal plant growth conditions. Here we use computational modelling and artificial intelligence (AI) to examine plant–environment interactions 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.

and ventilation, proper moisture control, optimal carbon dioxide (CO_2) supplementation, sufficient nutrient and water supply, and



Assessing the environmental impacts of different circular strategies in 2 VFs




Retrospective LCA
Ex-ante / Prospective LCA
foreground systems
system efficiency
1.0
0.9
0.8
0.7
21 kWh/kg
16 kWh/kg
10 kWh/kg
6.5 kWh/kg
LS
CS
IS
FS
2015
2020
2025
2030
2035
2040
time
background systems
ecoinvent
premise
2015
2020
2025
2030
2035
2040

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 **circular strategies,** VFs' environmental impacts could be further decreased by up to **29-34%.**

3

- Vertical farming systems should be assessed from a prospective LCA perspective since they have the potential to **improve resource-use efficiency of plant growth in the future** compared to open farming.

Thank you!

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