Future of Urban Farming series: Fertile-city

Discovering the potential of integrated rooftop greenhouses

Interreg North-West Europe GROOF

Future of Urban Farming series: Next event

30 January 2020

Aquaculture Systems

Interreg North-West Europe GROOF

Future of Urban Farming series: Stay up-to-date!

Social media: WUR Student Challenges

www.urbangreenhousechallenge.nl

Interreg North-West Europe GROOF

www.fertilecity.com

CTM2016-75772-C3-1-R, AI/UE-Feder

2017SGR 1683

Future of Urban Farming series: Fertilecity

An opportunity towards environmental sustainability in cities

November 6th 2019

Prof. Xavier Gabarrell (UAB)

Sostenipra
Vertical Urban Agriculture

FertileCity

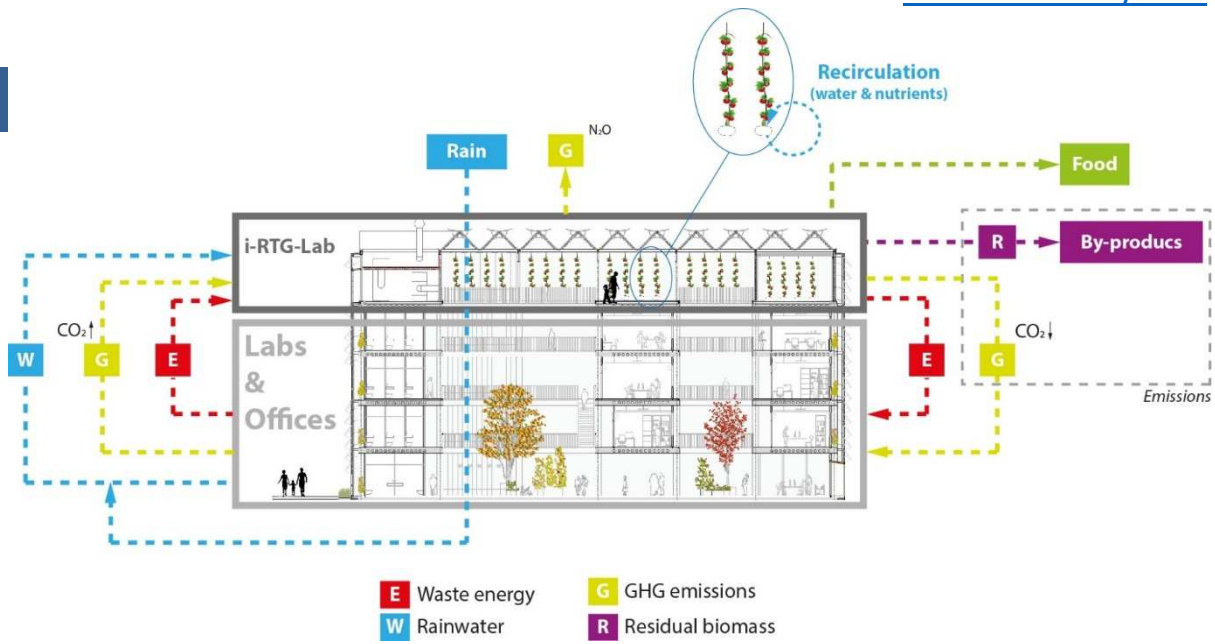



www.fertilecity.com

FertileCity II Project

Integrated rooftop greenhouses: symbiosis of energy, water and CO2 emissions with the building – Towards urban food security in a circular economy

www.fertilecity.com



1. URBAG

ERC Consolidator Grant - Led by Gara Villalba

URBAG Integrated System Analysis of Urban Vegetation and Agriculture

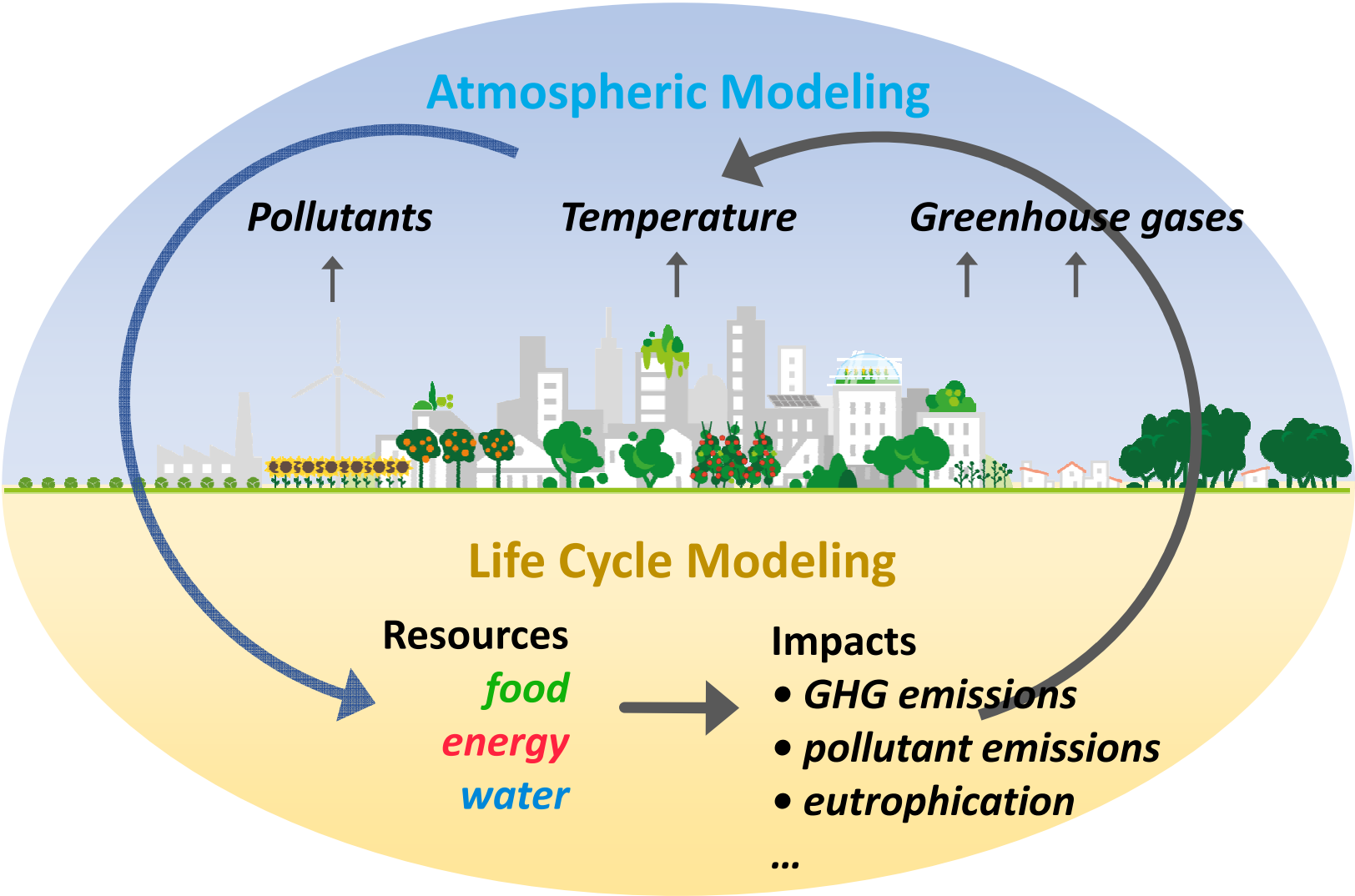
A Horizon 2020 and European Research Council funded project, hosted by ICTA-UAB, to determine to what degreee green infraestructures can be a source of sustainable food, reduce environmental impacts, and promote a more efficient use of resources in urban regions.

gara.villalba@uab.cat

November 2019- November 2024

URBAG

Integrate life cycle modeling with atmospheric modeling



Interreg
EUROPEAN UNION
North-West Europe
GROOF
European Regional Development Fund

GROOF

Greenhouses to Reduce CO_2 on rooFs

GROOF Project

Interreg
North-West Europe
GROOF
European Regional Development Fund

EUROPEAN UNION

11 **Partneers**
France, Belgium, Germany, Spain, Luxembourg

4,9 **Millions euros of budget**

An innovative and multidisciplinary approach to reduce CO2 in the building and agricultural sectors
by combining energy exchange and local food production.

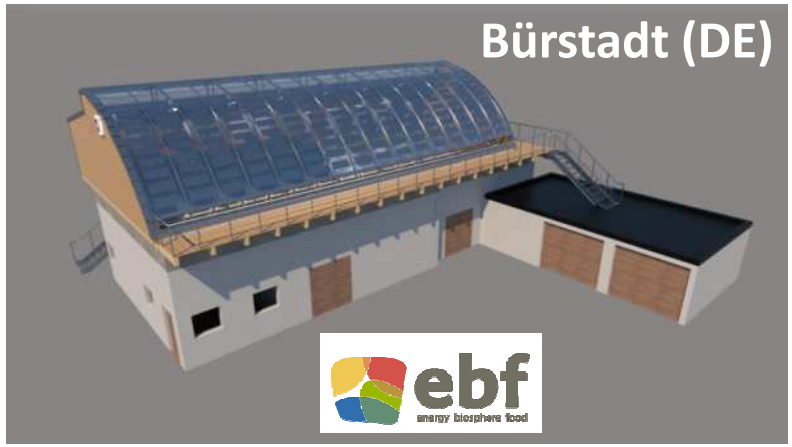
HOW ?

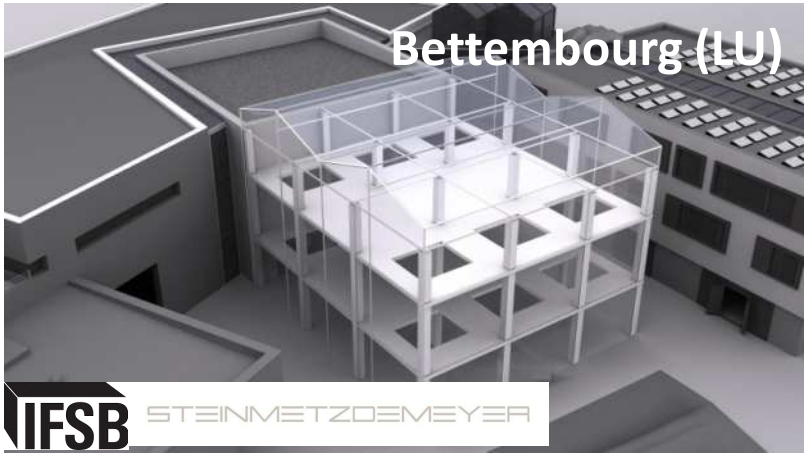
By implement greenhouse on the rooftop of building

Rooftop greenhouses as **useful equipment** for:

- **Reuse resources not consumed by the building** => recovered heat-loss
- **Collect CO_2 produced by people and building activities for the benefit of plants**
- **Increasing food resilience in urban areas**

4 pilots : to experiment and demonstrate the reduction of energy emissions from roof greenhouses





www.fertilecity.com

FertileCity II. Integrated rooftop greenhouses: symbiosis of energy, water and CO_2 emissions with the building – Towards urban food security in a circular economy

CTM2016-75772-C3-1-3-R, (2017-2019)

Partners:

ICTA-UAB

Universitat Autònoma de Barcelona

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Funded by: *MINECO, AEI/FEDER, UE*

Universitat Autònoma de Barcelona

DIVISIÓN DE COORDINACIÓN, EVALUACIÓN Y SEGUIMIENTO CIENTÍFICO Y TÉCNICO
SUBDIVISIÓN DE PROGRAMAS TEMÁTICOS CIENTÍFICO-TÉCNICOS

MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

EXCELENCIA MARÍA DE MAEZTU

June 2019

CTM2016-75772-C3-1-R

ICTA-UAB

Universitat Autònoma de Barcelona

Dr. Xavier Gabarrell
Dra. Maria Rosa Rovira
Dra. Gara Villalba (UAB-ICTA, DIQBA)
Dra Isabel Pont (UAB-ICTA)
Dr Mario Giampietro (ICREA y UAB-ICTA)
MSc. Ana María Manríquez-Altamirano (UAB-ICTA)
MSc. Perla Zambrano (UAB-ICTA)
MSc Susana Toboso (UAB-ICTA)
MSc Alejandra Peña (UAB-ICTA)
MSc Martí Rufí (UAB-ICTA)
MSc Felipe Parada (UAB-ICTA)
MSc Veronica Arcas (UAB-ICTA)

CTM2016-75772-C3-3-R

Universitat Politècnica de Catalunya

Dr. Santiago Gassó (UPC)
Dra. Eva Cuerva (UPC)
Dra. Violeta Vargas (UPC)
Dr. Eusebi Jarauta (UPC)
Dra. Carme Hervada (UPC)
Dr. Adrià Muros (UPC)
Dr. Jose Gibergans (UPC)
Dra. Jelena Nikolic (UPC)
Dr. Torsten Masseck (UPC)
Dr. Oriol Pons (UPC)
Dra. Eva Crespo (UPC)
MSc. Carla Planas (UPC)
MSc Joan Muñoz (UPC)

External co-supervisors

Dr Jorge Sierra (Unizar)
Dr Pere Muñoz (UAB-DIQBA)
Dr Alejandro Josa (UPC)
Dra Anna Petit Boix (Uni-Freiburg)
Dra Cristina Madrid (UAB-ICTA)
Dr Joan Rieradevall

CTM2016-75772-C3-1-R

	Advisore board	
Field	Expert	Entity
Social	Isabelle Anguelowsky	UAB - ICTA
Arquitectura	Arq. Coque Claret	UPC
Energy	Dr Elisa Lopez Capel	University Newcastle
Water	Dr Daniel Barceló	ICRA
Life Cycle Assessment	Dr Francesc Castells	Universitat Rovira i Vigili
Urbanismo	Arq Daniel Calatayud	UPC
Economía	Dr John Slof	UAB
Urban agricultura	Dr Francesco Orsini	Universitat Bolonia
Design	Dr Pere Llorach	Elisava


sostenipra

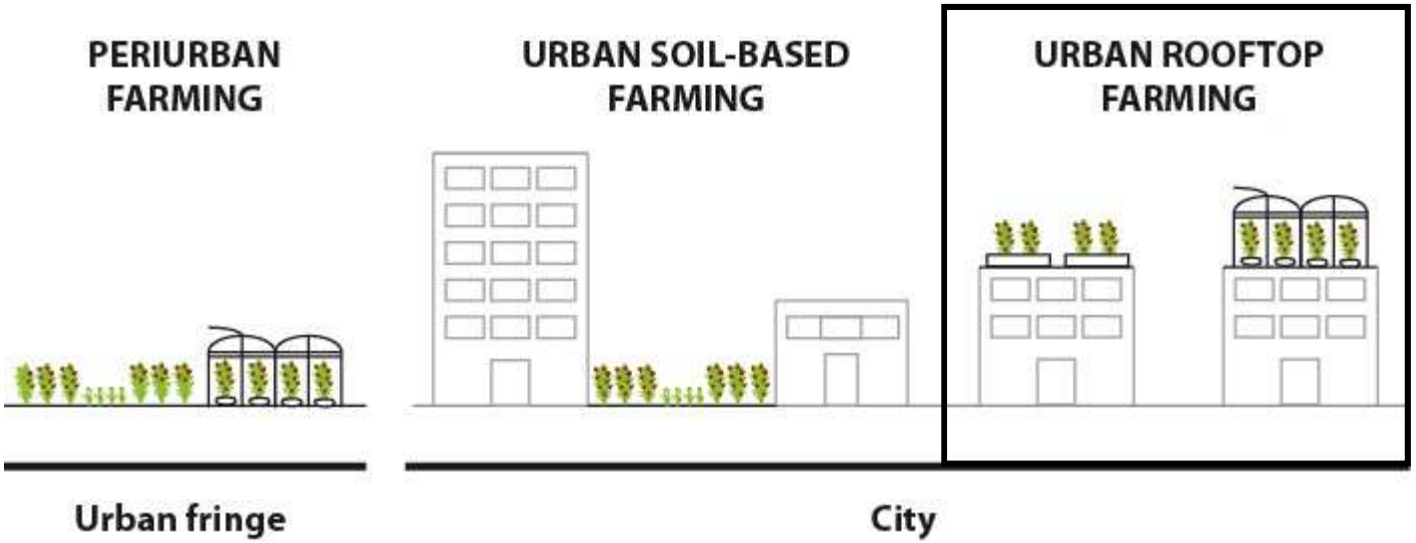

sostenipra

CTM2016-75772-C3-1-R

Agradecimiento a quienes han participado también en 2017 a 2019:

2017	2018	2019
Dr Joan Rieradevall (2017)	Dra Núria Carazo (UPC-IRTA, 2017-2018)	Dr Alejandro Josa (UPC, 2017-2019)
Dr Juan Ignacio Montero (IRTA, 2017)	MSc. Ana Nadal (UAB-ICTA)(2017-2018)	Dra Angela Pedroso Tonon (UAB-ICTA, 2018-2019)
MSc Pere Llorach (2017)	Gaia Stringari (Unibo, 2018)	Greta Casali (Unibo, 2019)
MSc Anna Petit-Boi (2017)	Maria Berlanga (IES, 2018)	Laura Sánchez Robles (IES La Romànica, 2019)
MSc David Sanjuan (2017)	Safir Malonda Costa (Biotec, 2018)	Dr Roberto Quirós, (2017-2019)
MSc Aniol Alabert (UPC, 2017)	Dra Isabel Lavrador Ribeiro (2017- 2018)	Laila Ferrer (2019)
Meritxell Gres Cintas (Biotec, 2017)	Fabiana Corcelli (U. Napoles, 2018)	
Carla Bucio Sistos de la UNAM ENES MORELIA, 2017)	Natalia Alvarado (2018)	
	Anna Boneta (2018)	

Materials & Methods

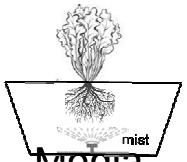


Soilless system

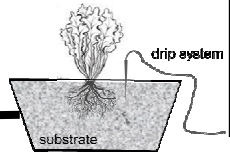
Any method of growing plants without the use of soil as a rooting medium, in which the inorganic nutrients absorbed by the roots are supplied via the irrigation water

- Aquaponic

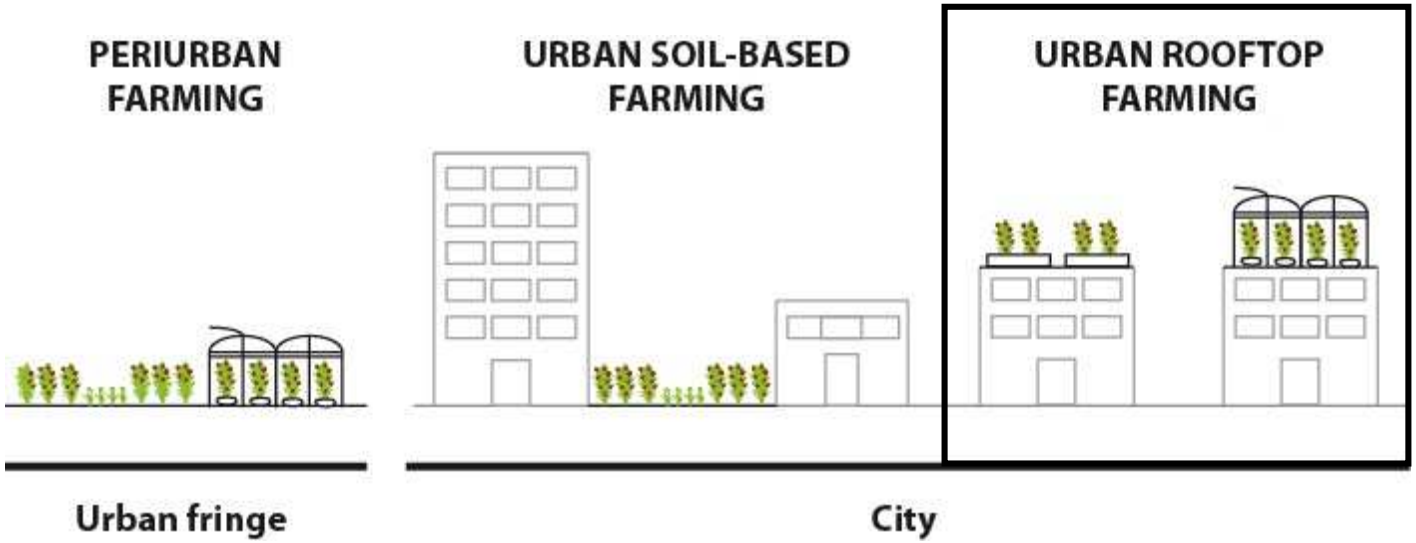
- Aeroponic

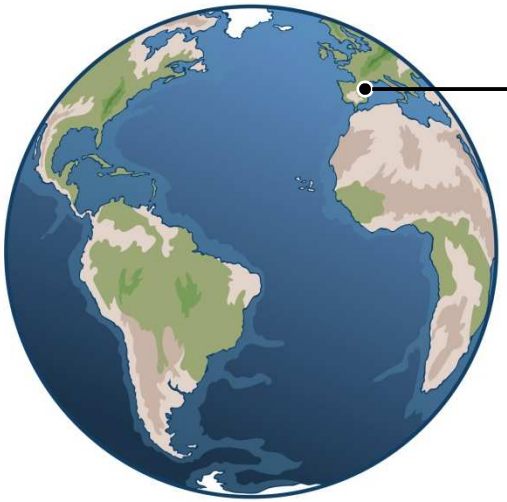


- Media culture



  - Inorganic media
    - Natural media
      - Sand
      - Gravel
      - Volcanic tuff
      - Fiber (rockwool)
      - Expanded clay
      - Perlite
    - Synthetic media
      - Foam mats
      - Plastic foam
  - Organic media
    - Peatmoss
    - Sawdust
    - Pine bark
    - Coco fiber
    - Compost





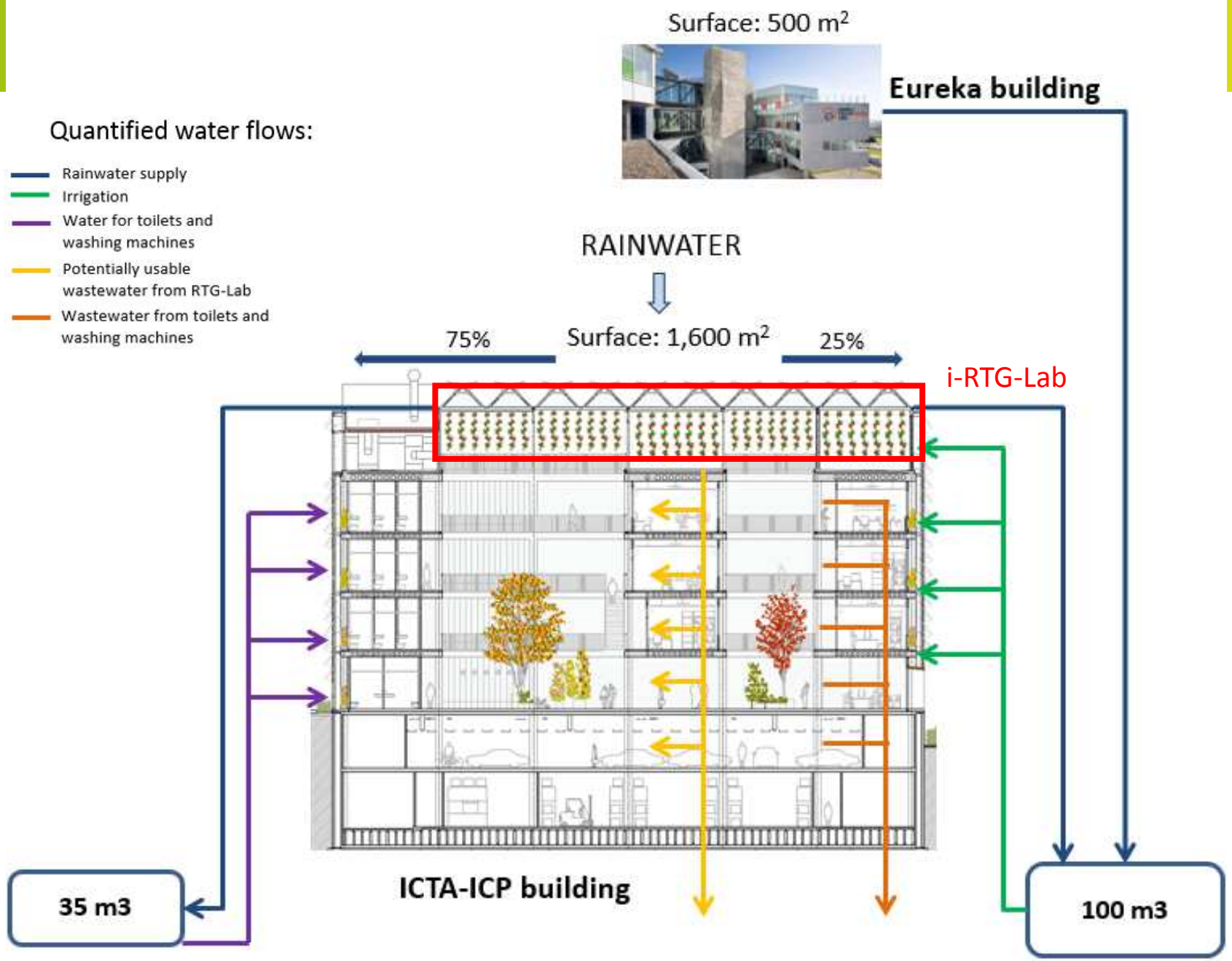
Our case study

The Rooftop Greenhouse Lab

(i-RTG-Lab)

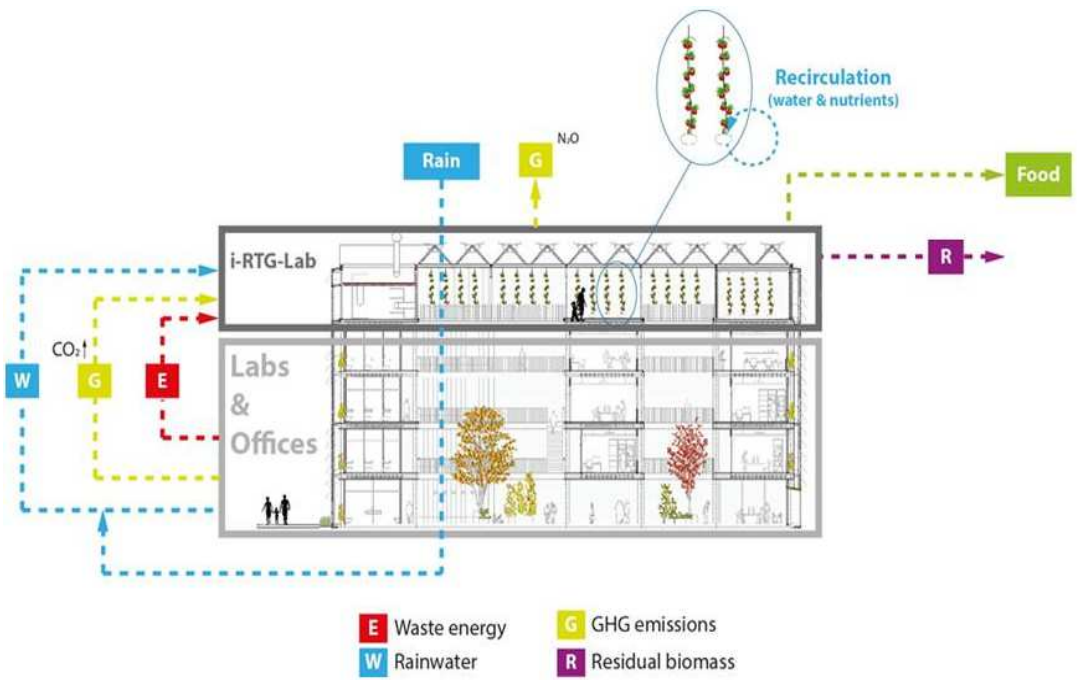
New building ICTA-ICP (UAB)
May 2014 - Bellaterra, Barcelona

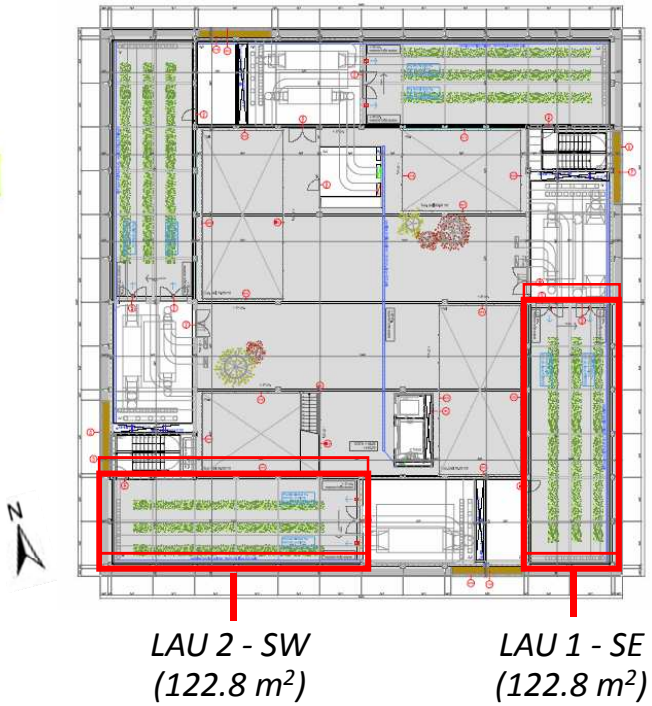
1st integrated RTG in Spain


Surface: 500 m²
Eureka building
Quantified water flows:
Rainwater supply
Irrigation
Water for toilets and washing machines
Potentially usable wastewater from RTG-Lab
Wastewater from toilets and washing machines
RAINWATER
75%
Surface: 1,600 m²
25%
i-RTG-Lab
ICTA-ICP building
35 m3
100 m3

i-RTG-LAB: Development of bean crop

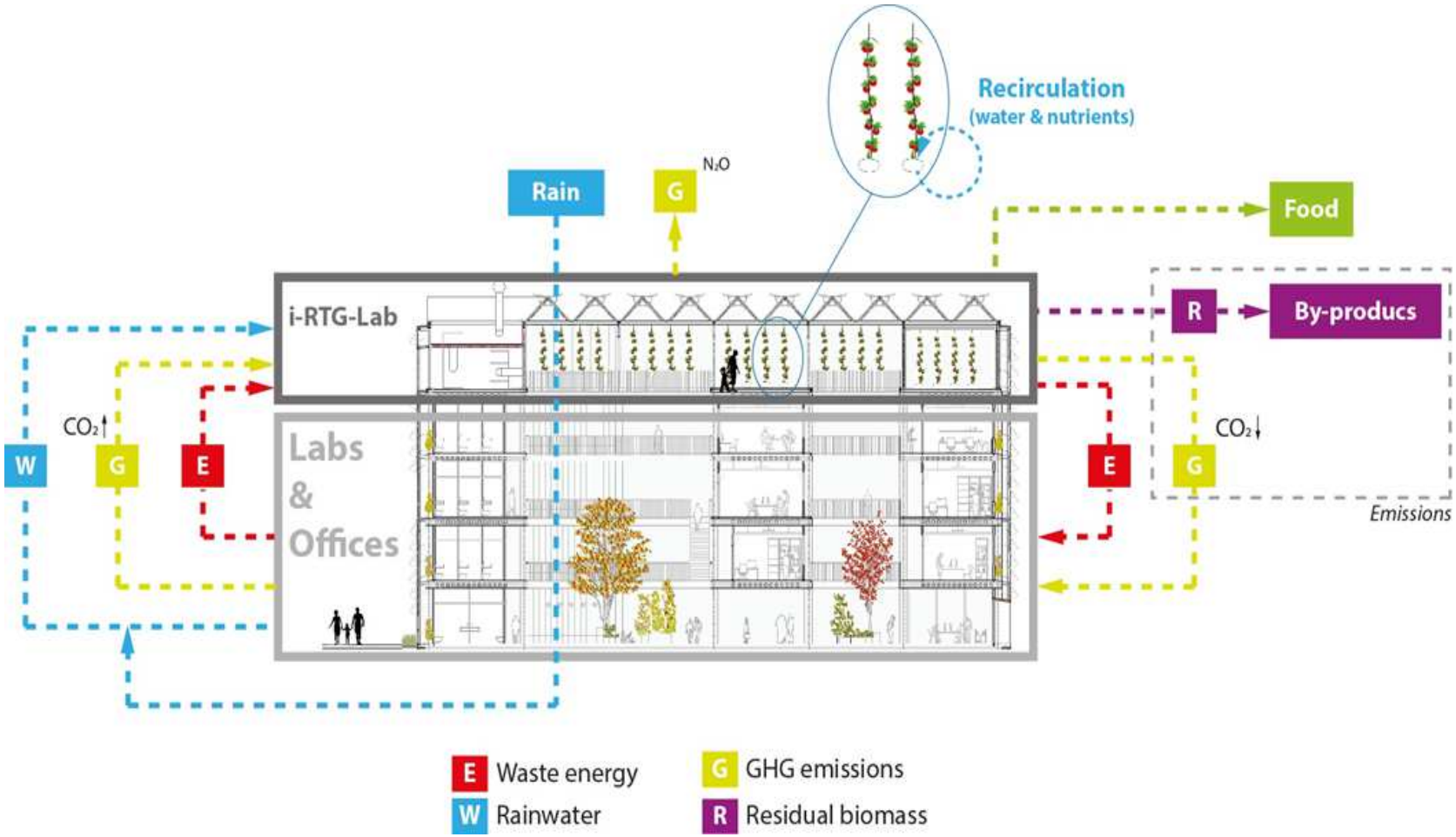
In contrast to conventional RTG projects, the RTG-Lab is an Integrated RTG (i-RTG) that exchanges the residual flows (**energy**, **water** and **gas**) with the ICTA-ICP building. Different crops have been cultivated: tomato, lettuce… and **bean**





2 i-RTGs (122.8m² each, with 84.34m² for the crop)

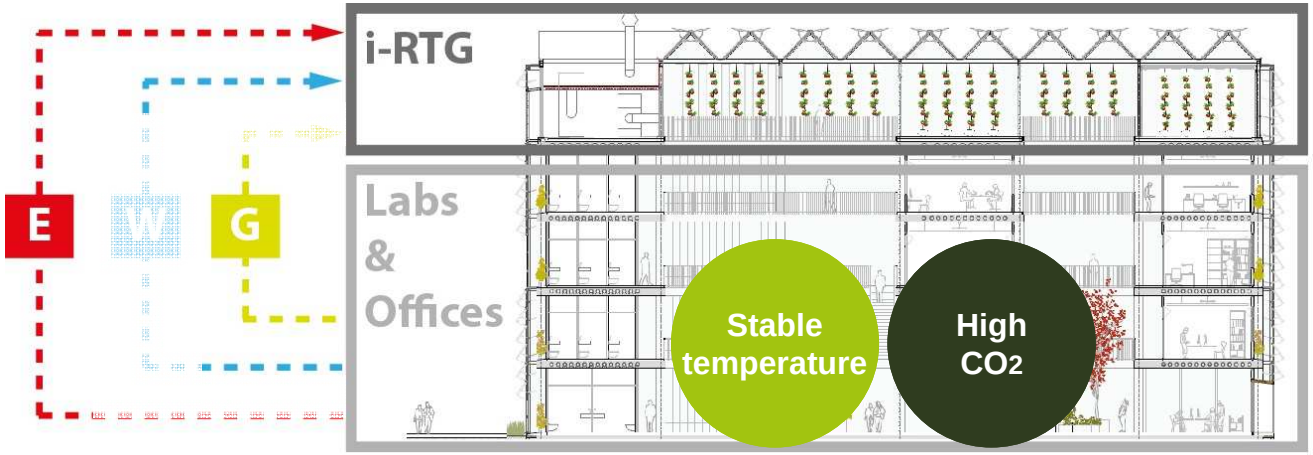
Fertilecity II: Towards a bidirectional connection




FRANPER
FRANPER
ROSETTA
sostenipra
sostenipra


sostenipra
INTERNATIONAL NETWORK IN LIFE CYCLE ANALYSIS AND ECODESIGN FOR ENVIRONMENTAL TECHNOLOGY INNOVATION
Fertilecity

Building-Greenhouse Interconnection



Materials

CO_2 sensor
Air flowmeter
Temperature thermistors

Daytime	Conventional production	i-RTG-Lab
Day	Extreme temperatures for crop production (>35ºC), particularly in summer	Building → **Cold air** → Greenhouse
Night	Extreme temperatures for crop production (<15ºC), particularly in winter	Building → **Waste heat** → Greenhouse
Day	CO_2 is injected to supply crop demand to enhance photosyntesis and crop yield	Building → **CO_2** → Greenhouse

Also... natural ventilation of the greenhouse!

3.1 Objectives

GENERAL

To grow common bean in an i-RTG to assess the suitability of the system for growing this type of crop and to detect any possible problem during the growing period in the autumn season and in a Mediterranean climatic area.

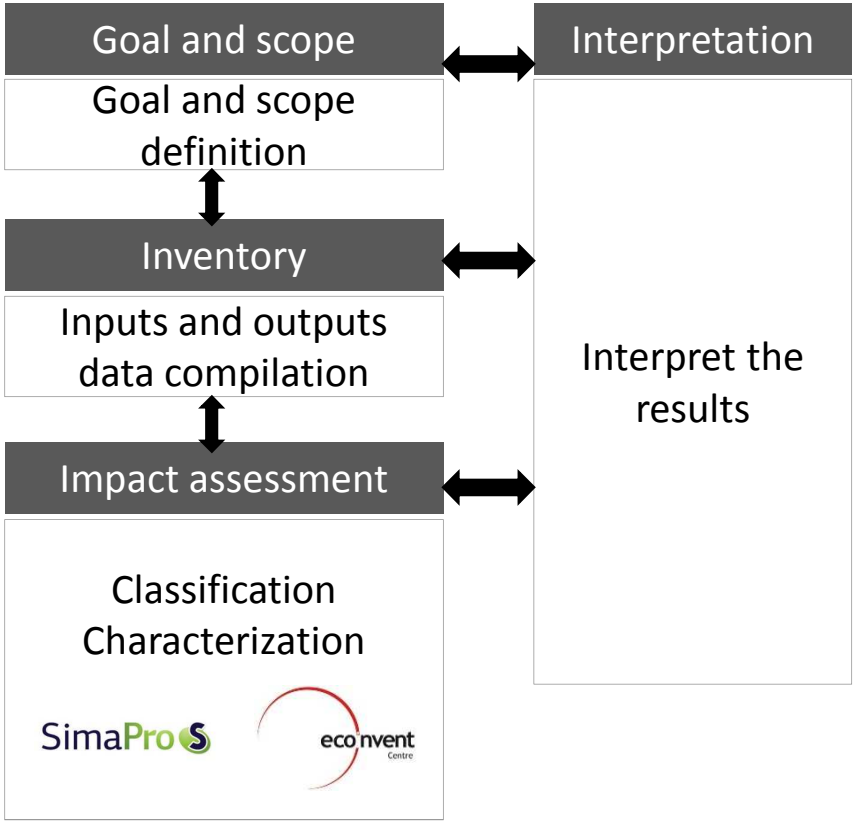
SPECIFIC

- To analyze the impacts of common bean production in hydroponic i-RTGs using the life cycle assessment methodology

- To find the hotspots derived from the production of common beans in hydroponic i-RTGs, and propose potential environmental improvements for future crops

- To assess the suitability of producing locally-grown food by studying the economic framework of the area

Life cycle assessment



ISO 14040-44 *(ISO 2006a, 2006b)*

Functional Unit

1 kg of edible beans produced in the ICTA-ICP i-RTG

CROP ANALYSIS AND CHARACTERIZATION

Periodic methods		
Analysis	Freq.	Materials
pH	diary	pH sensor
Ce	diary	Ce sensors
Fertilizers - leachates	3 per week	Ion Chromatography
Water entrance	diary	Flowmeters

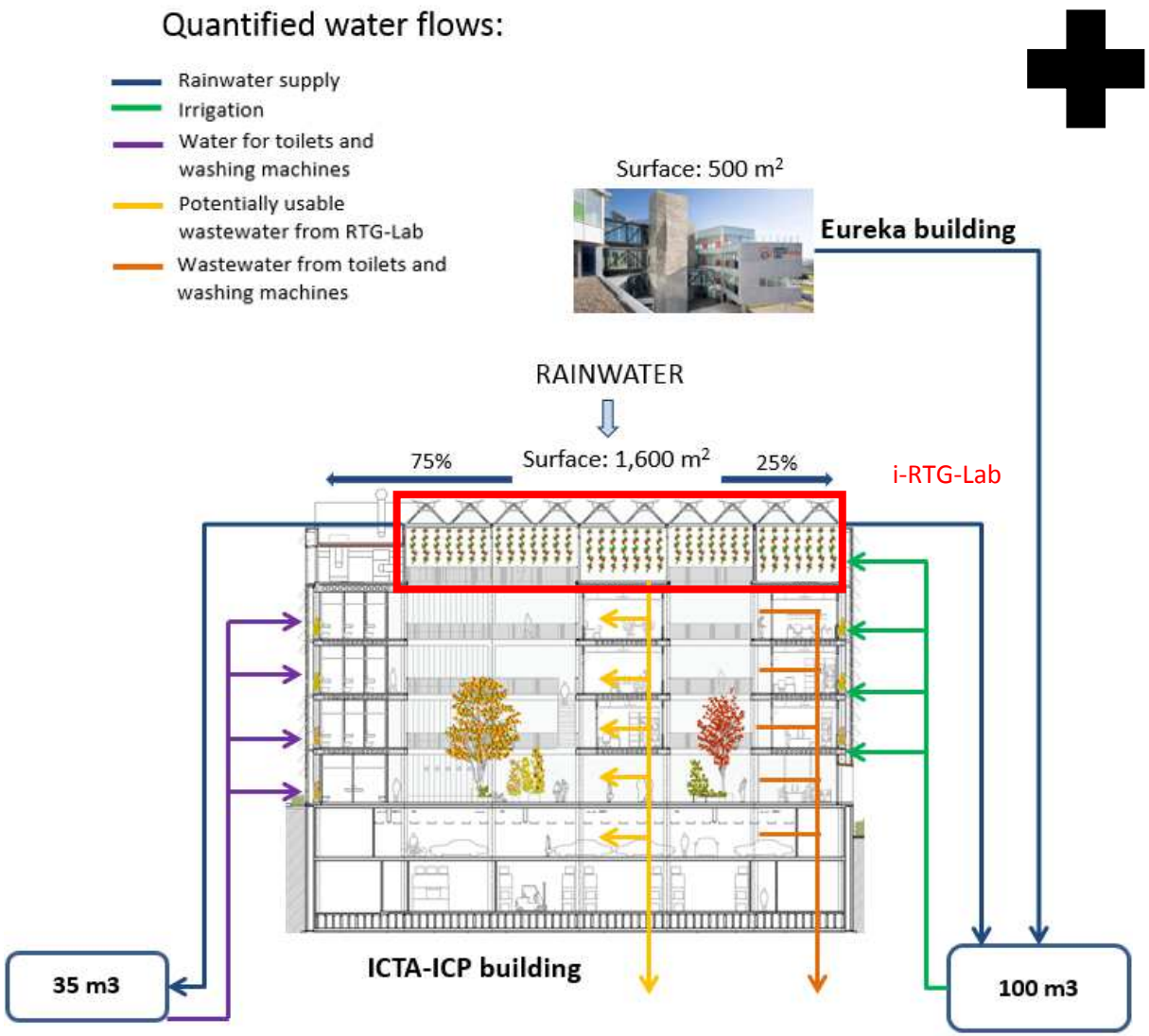
Other analysis

Substrate (Perlite)
Residual biomass (leaves, stem and roots)
Bean (fruit)

Other materials

Atomic Spectroscopy
Temperature and HR sensors

Follow-up by agronomic experts



Economic-commercial framework analysis during the harvesting period

To notice if there is a necessity of beans supply in the local market by gathering the origin of fresh product and analyzing yearly price fluctuations

LCI

System boundaries

i-RTG INFRASTRUCTURE

GREENHOUSE STRUCTURE

RAINWATER HARVESTING SYSTEM
- Water pump
- Water tank

AUXILIARY EQUIPMENT
- Pumps, digital timer, flow meter
- Water tanks
- Pipes, valves, joints, drippers
- Others

LIFE CYCLE STAGES

MATERIALS	PROCESSING	TRANSPORT
CONSTRUCTION	MAINTENANCE	END OF LIFE

OPERATION

INPUTS → OUTPUTS

INPUTS:
- FERTILIZERS
- SUBSTRATE
- WATER
- ENERGY
- OTHERS
- RESIDUAL HEAT (FROM BUILDING)

OUTPUTS:
- LOCAL FOOD PRODUCTION
- WASTE
  - WASTEWATER (LEACHATES)
  - SUBSTRATE
  - BEAN BIOMASS

LIFE CYCLE STAGES

MATERIALS	PRODUCTION	TRANSPORT
USE	END OF LIFE	

IMPACT ASSESSMENT (PER FU)

IMPACTING

Units: % of contribution	Infrastructure			Operation						TOTAL
Category	**Aux. Equipment**	**i-RTG**	**RW-HS**	**Substrate**	**Water**	**Energy**	**Nur. plants**	**Nutrients**	**Pesticides**	
Climate Change	3,37	30,21	54,77	1,63	0,92	2,51	1,32	5,03	0,23	5,67E+00
Terres. Acidification	2,93	29,03	48,75	1,94	1,00	5,74	1,16	8,88	0,58	2,04E-02
Freshwater Eutroph.	1,21	35,06	33,27	0,64	4,07	5,89	1,43	17,81	0,63	9,43E-04
Marine Eutroph.	0,30	4,15	44,06	0,27	0,14	0,36	0,56	49,88	0,28	8,75E-03
Fossil Depletion	5,90	23,34	60,17	2,81	0,72	2,20	1,43	3,17	0,28	2,02E+00
Ecotoxicity	1,53	19,91	49,14	0,54	1,95	2,06	8,69	15,74	0,44	9,39E-02

- **Rainwater Harvesting System**: +IMPACTING in 4/6 categories (Max: 60.2% in FDP)
  - Mainly due to **Glass Fiber Reinforced Plastic** (100 m^3 water tank material)
- **I-RTG infrastructure**: most impacting in Freshwater Eutrophication (35.1%)
- **Fertilizers**: most impacting in Marine Eutrophication (49.9%)
- Less impacting category: **Pesticides**, with <1% of impact in all categories analysed

General results

Bean production. Autumn 2016

Plantation — September 13th

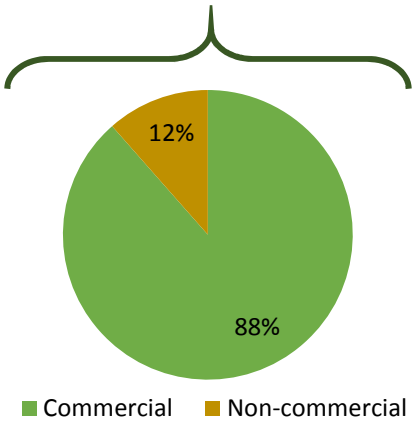
1st harvest — October 20th

Last harvest — November 8th

future crops...

57 days of plantation (20 days of harvest)

PRODUCTION: 43.81 kg (*0.5 kg·m^{-2})



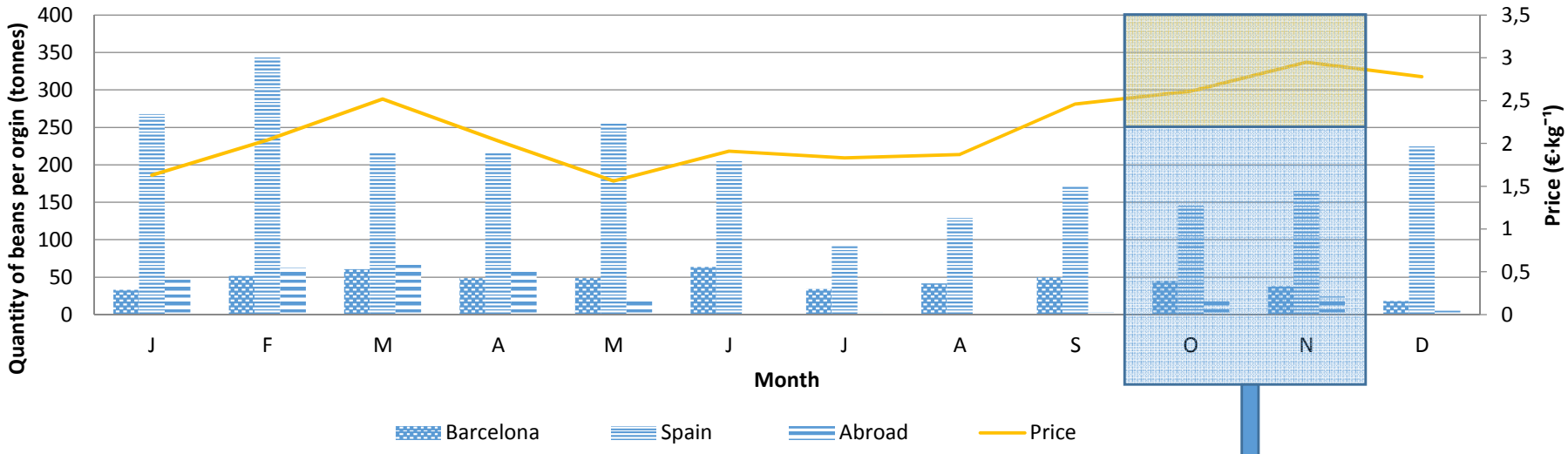
However... all **EDIBLE** production was considered to perform the LCA, due to the crop small area!

Production beneficiaries are the same building inhabitants!

*distance between perlite sacks was adjusted for previous tomato crops, with higher space requirements

Economic-commercial framework

Price and quantity of beans at market level in Mercabarna (2016)



OFF-SEASON PRODUCTION

i-RTGs like ICTA-ICP's could provide fresh, locally-grown vegetables to the market when there is more necessity of these products!

During ICTA-ICP crop harvesting period:

- Highest Price!
- Low quantity of beans available at market level!

Agronomic feasibility of producing bean crop in i-RTG

Temperature
[11.56, 31.68] ºC

Relative Humidity
AVG 66.74%

PRODUCTION
43.81 kg
0.5 kg·m^{-2}

Use of rainwater represented 55% of tap water saving

However...

Rainwater Harvesting System is the most impacting item in the Impact Assessment

i-RTG infrastructure

Fertilizers (Nutrients)

Substrate, Energy

Auxiliary Equipment, Water, Nursery plants, Pesticides

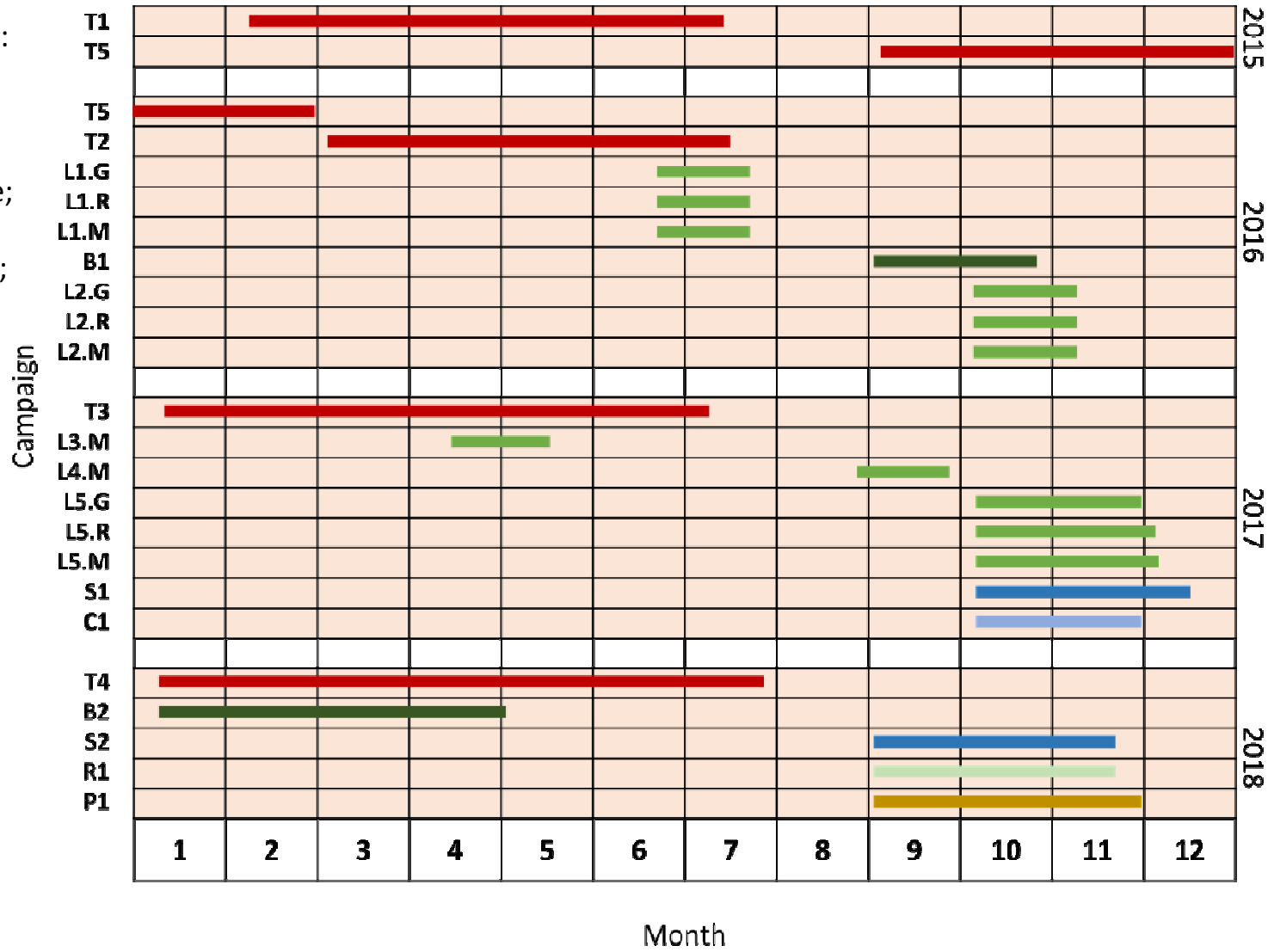
Economic feasibility of producing bean crop in i-RTG

Locally-grown beans when the yearly-price is higher and the supply amount is lower

3.2: Crop Calendar

Figure . Crop calendar:

T – Tomato;
L – Lettuce;
.G – Green oak lettuce;
.R – Red oak lettuce;
.M – Maravilla lettuce;
B – Green bean;
S – Spinach;
C – Chard;
R – Arugula;
P - green pepper.



Goal & Scope

Unidades funcionales y límites del sistema

FU1: 1 kg de producto fresco **FU2: 1 € de valor al mercado al por mayor**

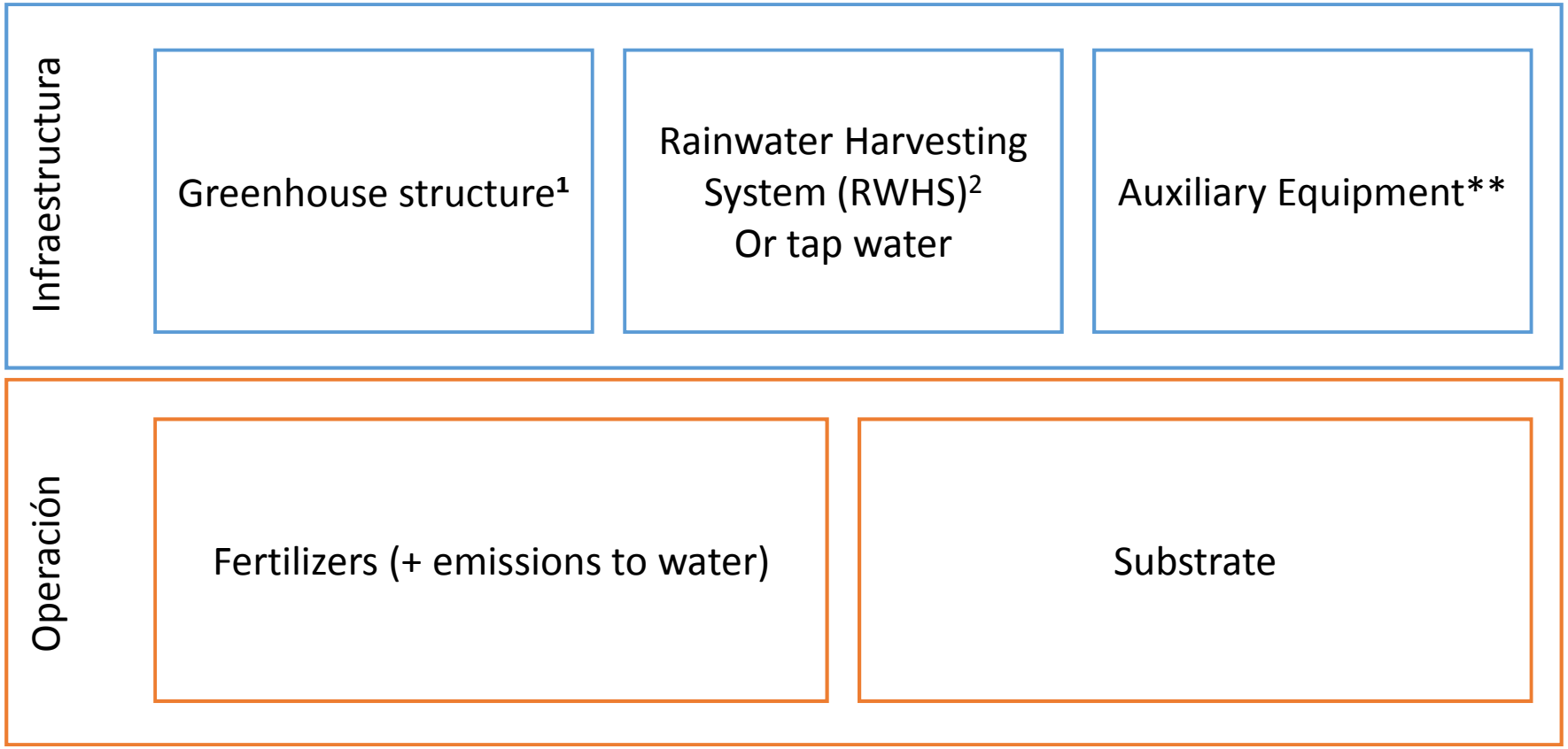


Figure 2. *System boundaries of the System for Intercrop environmental assessment. Simple scheme*

[1]Sanyé Mengual E, Rieradevall J, Montero JI, Oliver i Solà J. Sustainability assessment of urban rooftop farming using an interdisciplinary approach. 2015. https://ddd.uab.cat/record/137919. Accessed April 6, 2017.

[2]*Sanjuan-Delmás D, Llorach-Massana P, Nadal A, et al. Environmental assessment of an integrated rooftop greenhouse for food production in cities. J Clean Prod. 2018;177:326-337.*

Cálculo de impactos

- Software: SimaPro 8.5
- Background data: Ecoinvent v3
- Approach: cut-off

- Method: ReCiPe Midpoint (H)[1]
- Impact categories[2,3]:
  - Climate Change (CC) – kg CO2 eq.
  - Terrestrial Acidification (TA) – kg SO2 eq.
  - Freshwater Eutrophication (FE) – kg P eq.
  - Marine Eutrophication (ME) – kg N eq.
  - Fossil Depletion (FDP) - kg oil eq.
  - Ecotoxicity (ET) = Σ Marine (MET), Terrestrial (TET) and Freshwater (FET) toxicity – kg 1,4-DB eq

[1]*Huijbregts MAJ, Steinmann ZJNN, Elshout PMFMF, et al. ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and enpoint level - Report 1: characterization. Natl Inst Public Heal Environ. 2016. doi:10.1007/s11367-016-1246-y*
[2]*Sanjuan-Delmás D, Llorach-Massana P, Nadal A, et al. Environmental assessment of an integrated rooftop greenhouse for food production in cities. J Clean Prod. 2018;177:326-337. doi:10.1016/j.jclepro.2017.12.147*
[3]*Brentrup F, Küsters J, Kuhlmann H, Lammel J. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. Eur J Agron. 2004;20(3):247-264.*

Results & Discussion: Yield

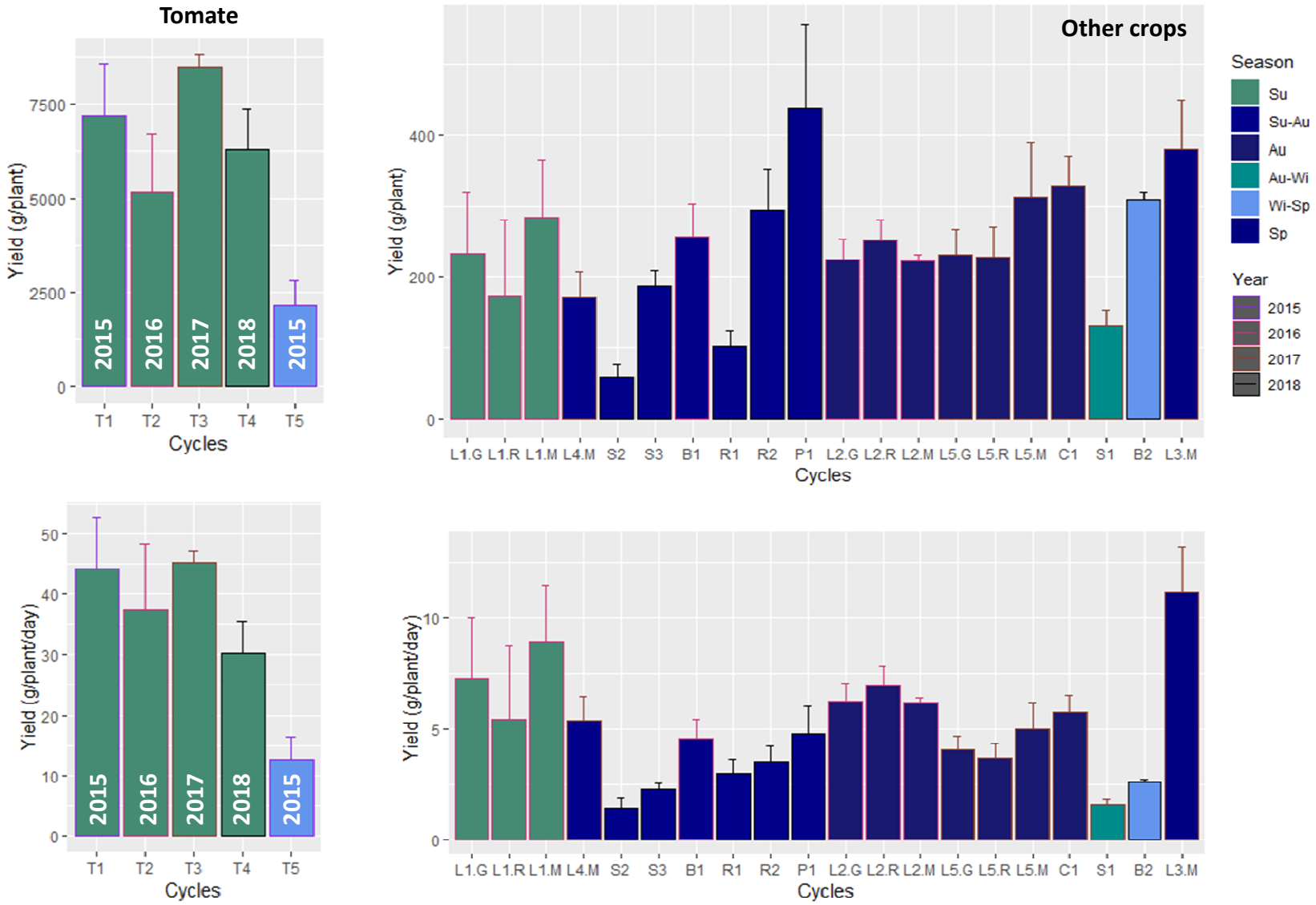
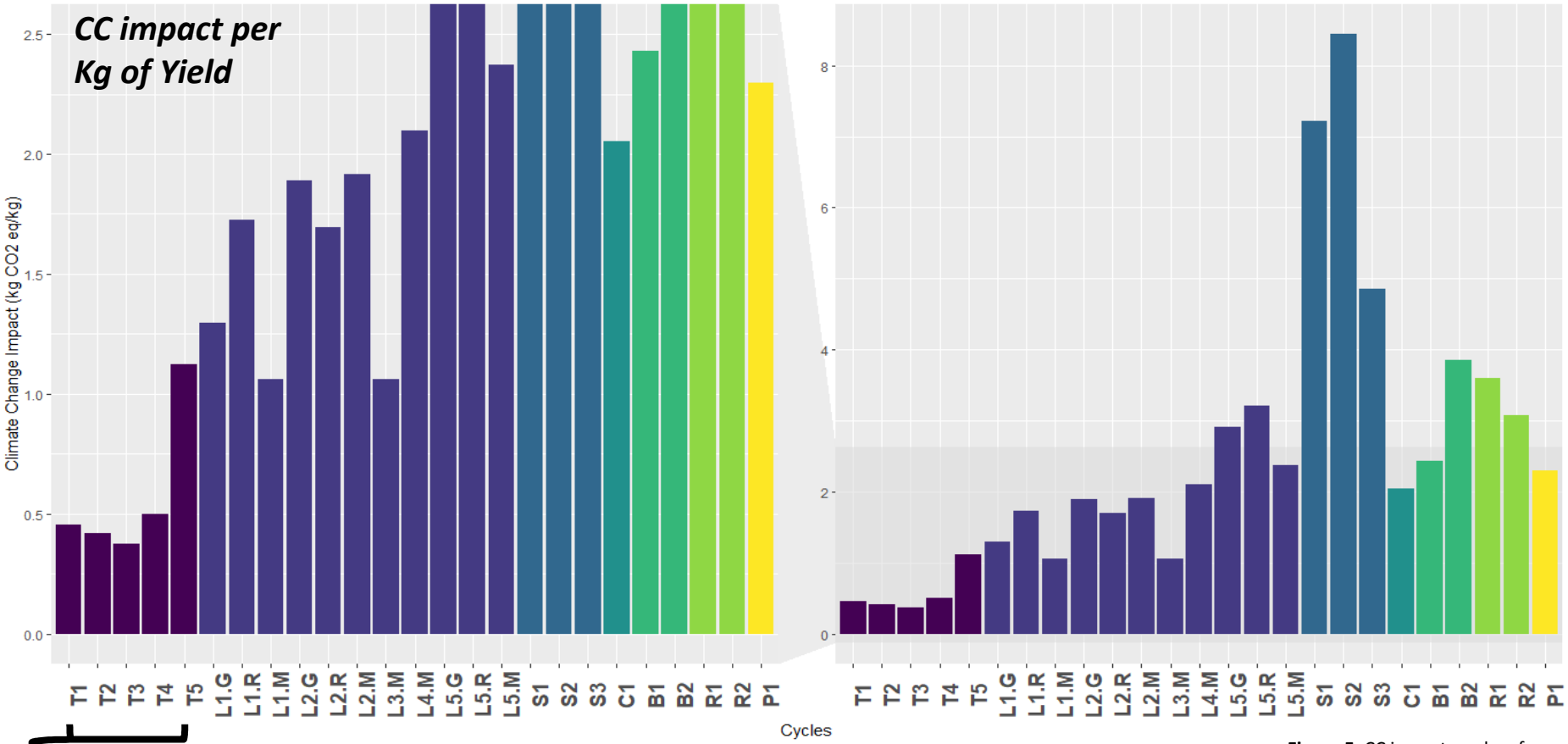


Figure 4. *Yields of the diferent crop cycles. T – Tomato; L – Lettuce; .G – Green oak lettuce; .R – Red oak lettuce; .M – Maravilla lettuce; B – Green bean; S – Spinach; C – Chard; R – Arugula; P - green pepper.*

.

Results & Discussion: LCIA



0.44 ± 0.05 Kg CO2 eq / Kg

0.49 – open air (Kulak et al., 2013)
0.54 – polytunnel Kulak et al., 2013)
3.79 – UK (Audsley et al., 2010)
1.30 – Europe (Audsley et al., 2010)
0.51 – greenhouse (Khoshnevisan et al., 2014)
0.72 – High-Tech indoor (Cellura et al., 2012)
3.45 – Denmark (Möller Nielsen 2007)
1.30 – Sweden (Halberg et al., 2006)

Figure 5. CC impact per kg of yield. *T – Tomato; L – Lettuce; .G – Green oak lettuce; .R – Red oak lettuce; .M – Maravilla lettuce; B – Green bean; S – Spinach; C – Chard; R – Arugula; P - green pepper.*

Results & Discussion: LCIA

Impacto relativo en CC

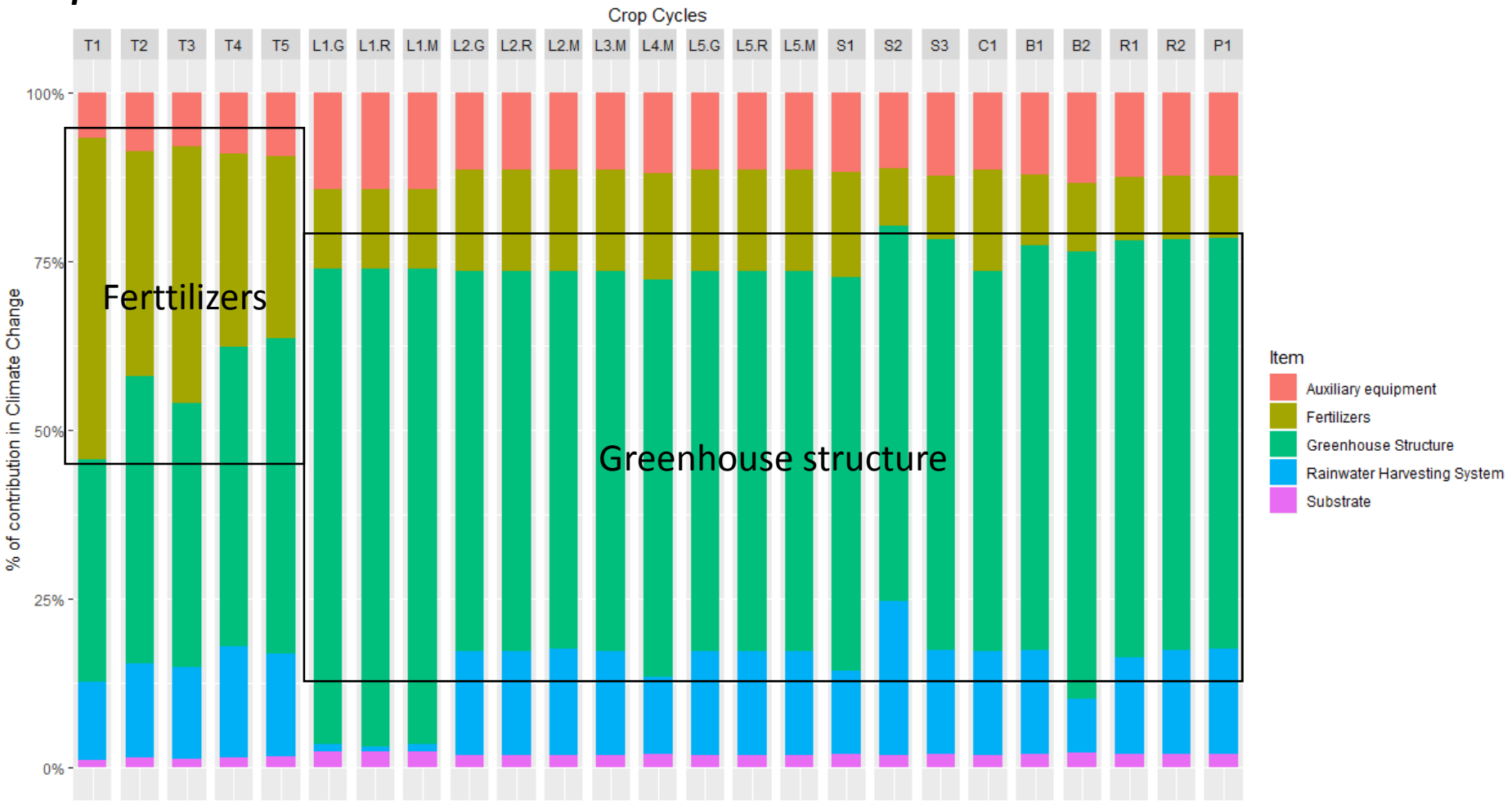


Figure 6. Impactos relativos de cada cultivo en Cambio Climático. *T – Tomate; L – Lechuga; .G – Lechuga hoja de roble verde; .R – Lechuga hoja de roble roja ; .M – Lechuga "Maravilla"; B – Judía verde; S – Espinacas; C – Acelgas; R – Rúcula; P - Pimiento verde.*

Research question

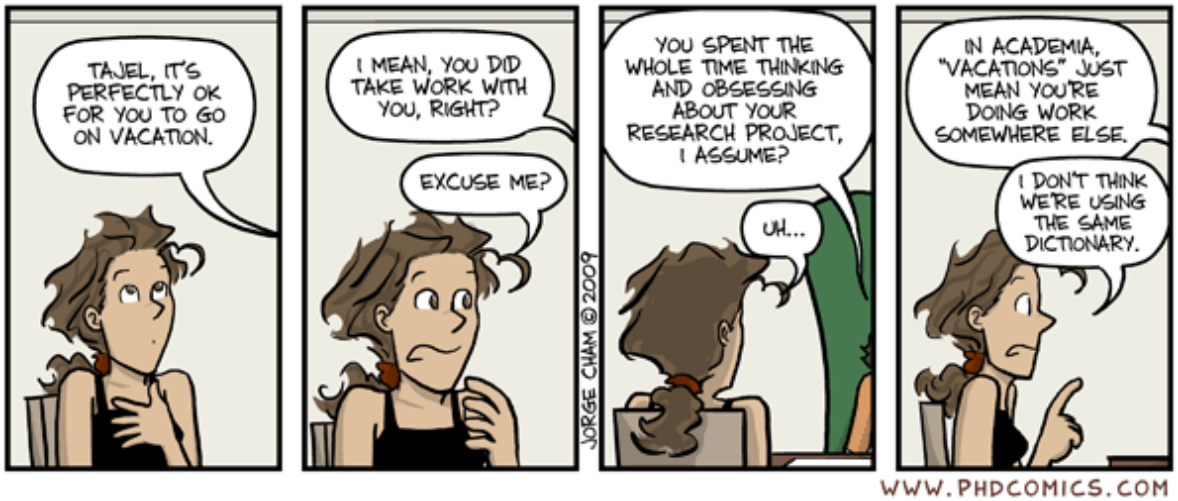
Which is the most efficient year-round combination of crops that have less environmental impact in a Rooftop Greenhouse?

Scenarios

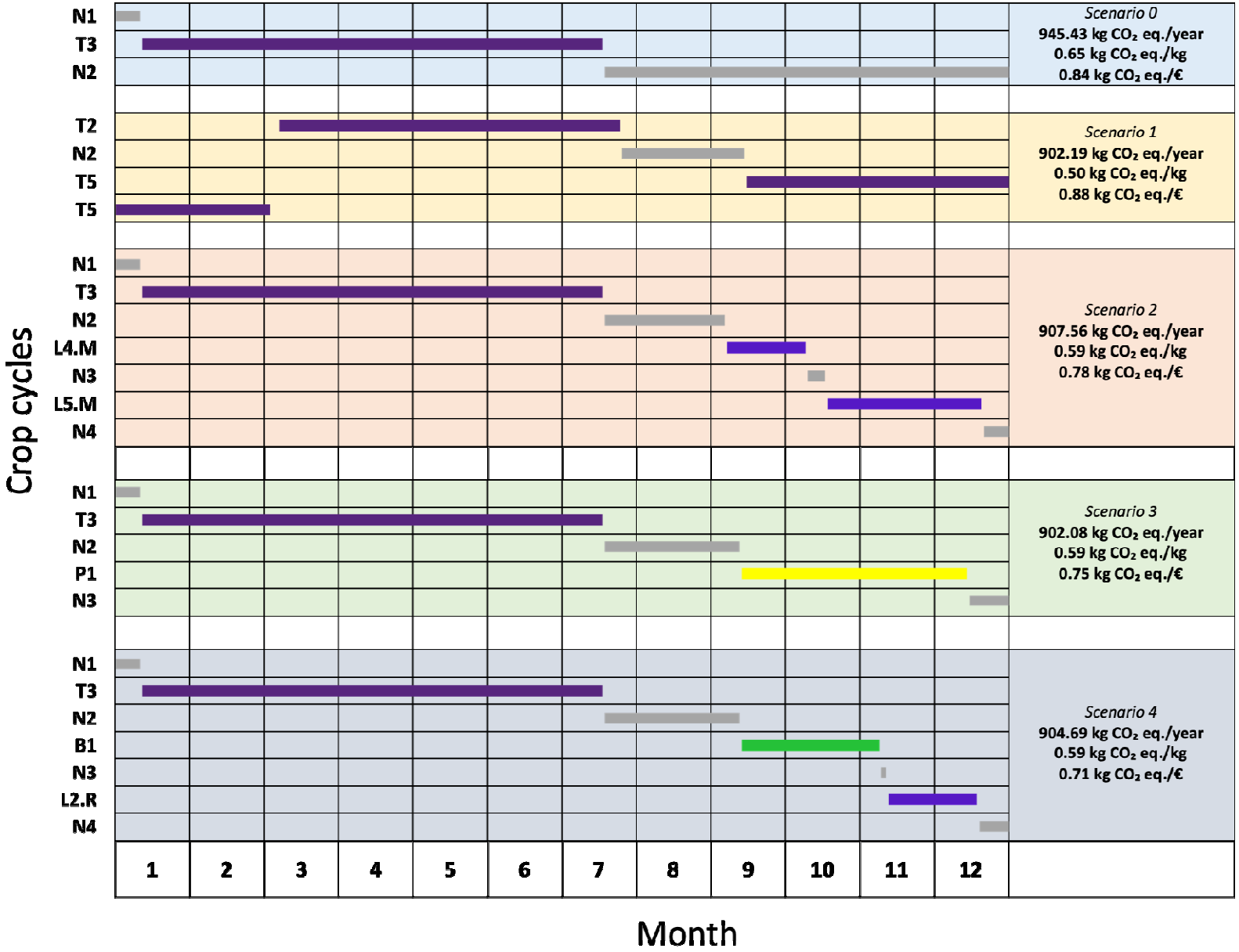
Yearly Scenarios

- Based lowest-impaccting crops
  - Yield functional unit
  - Economic value functional unit

- “Vacation periods”



Results & Discussion: Scenarios



Results & Discussion: what about...?

...and the remaining impact categories?

Studies focus on single crops
(mainly tomato)

Studies focus on single impact categories
(mainly CC/GWP)

High diversity of impact assessment
methods (CML, ReCiPe, etc.)

Low comparability between studies!

Future of Urban Farming series

Thank you!

Interreg North-West Europe GROOF