Urban Green Infrastructure opportunities for circularity and resource resilience

GORDON conference of Industrial Ecology
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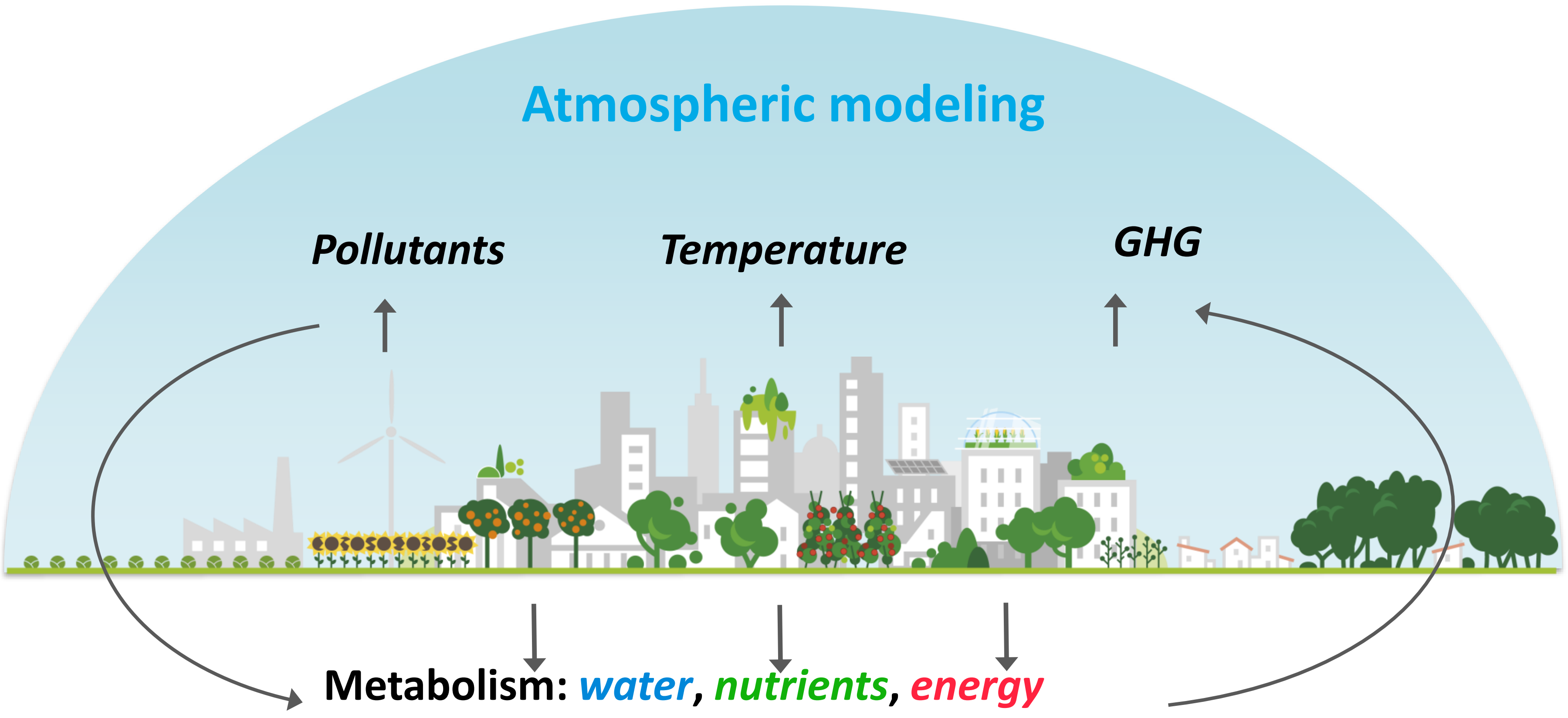
URBAG Integrated System Analysis of Urban Vegetation and Agriculture

Horizon 2020
European Research
Council- Cosolidator
2019-2024

Urbag.eu

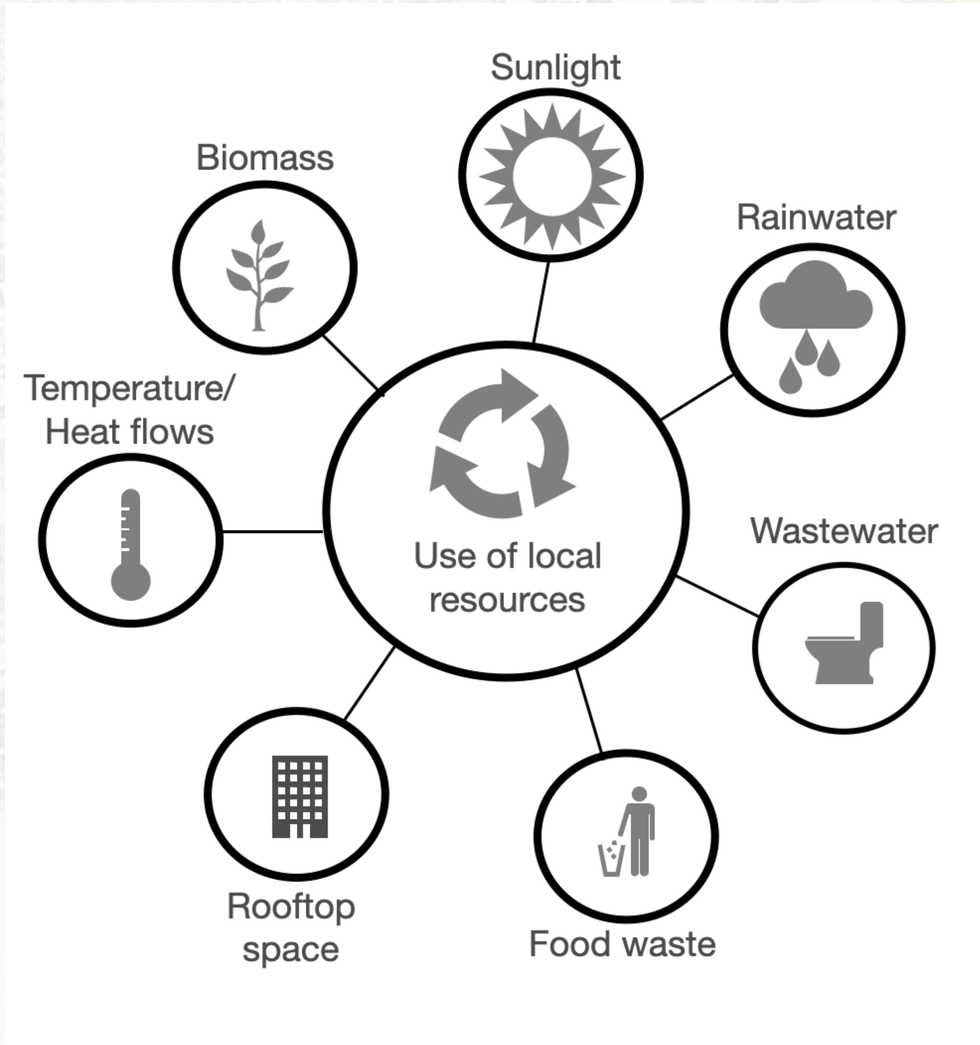
General Vision of URBAG



Regionalized life cycle modeling

Urban and peri-urban agriculture

Urban and peri-urban agriculture



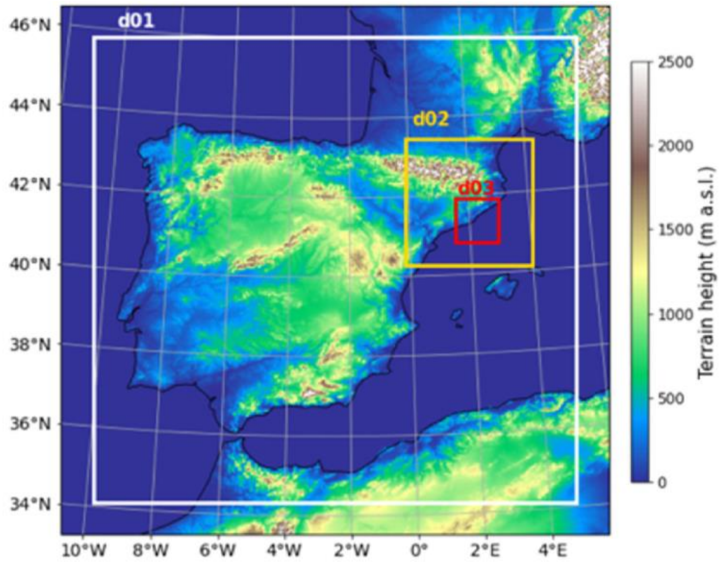
Urban and peri-urban agriculture

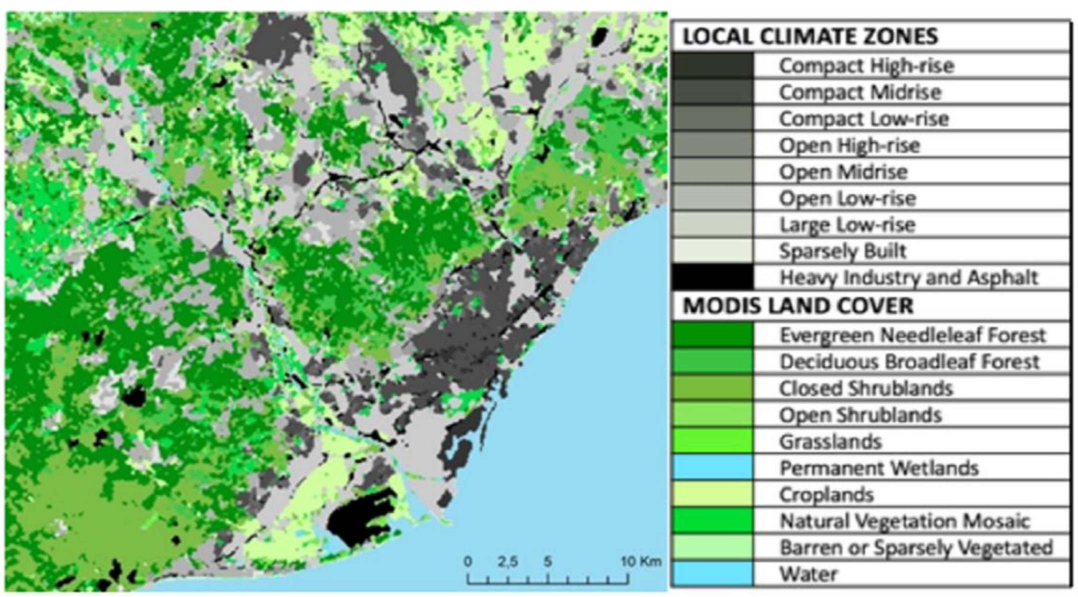
Water:
How much water is needed and how does it affect our river basin ecological status? What will be future needs as we increment urban agriculture in light of future reductions in precipitation and river flows?

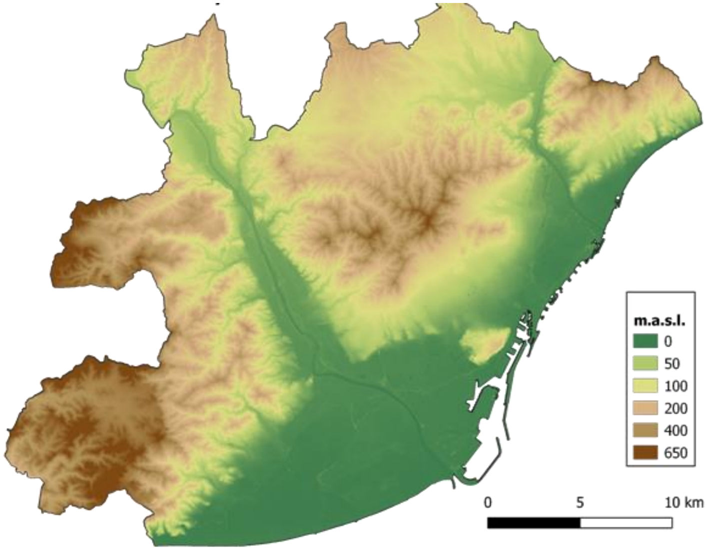
Energy:
Does peri-urban agriculture result in a cooling belt around the more urban area?

Nutrients:
What are the impacts associated to urban agriculture in terms of fertilizer use? How can circularity of nutrients in urban areas reduce impacts, both direct and indirect?

Case Study: The Metropolitan Area of Barcelona (AMB)

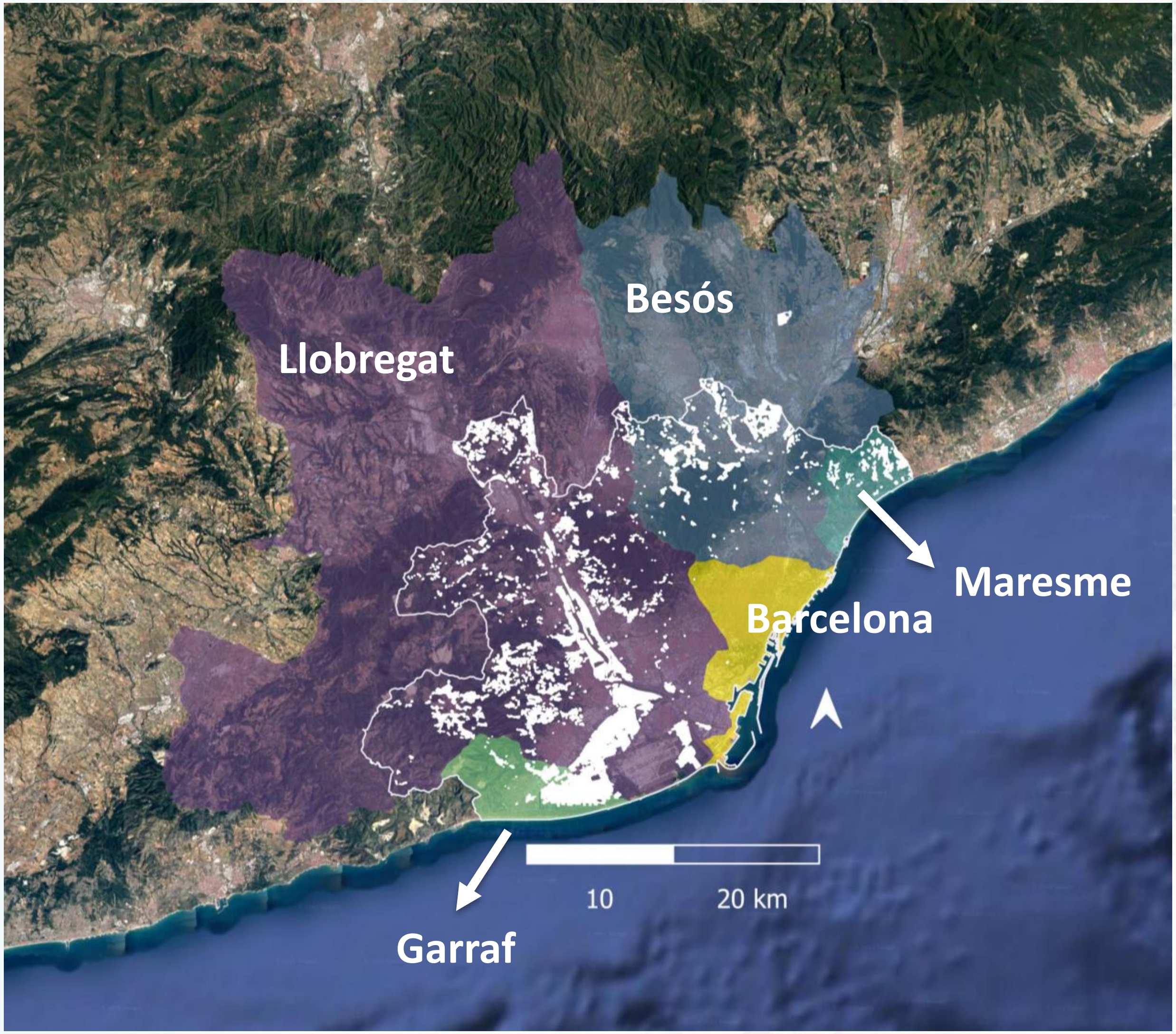






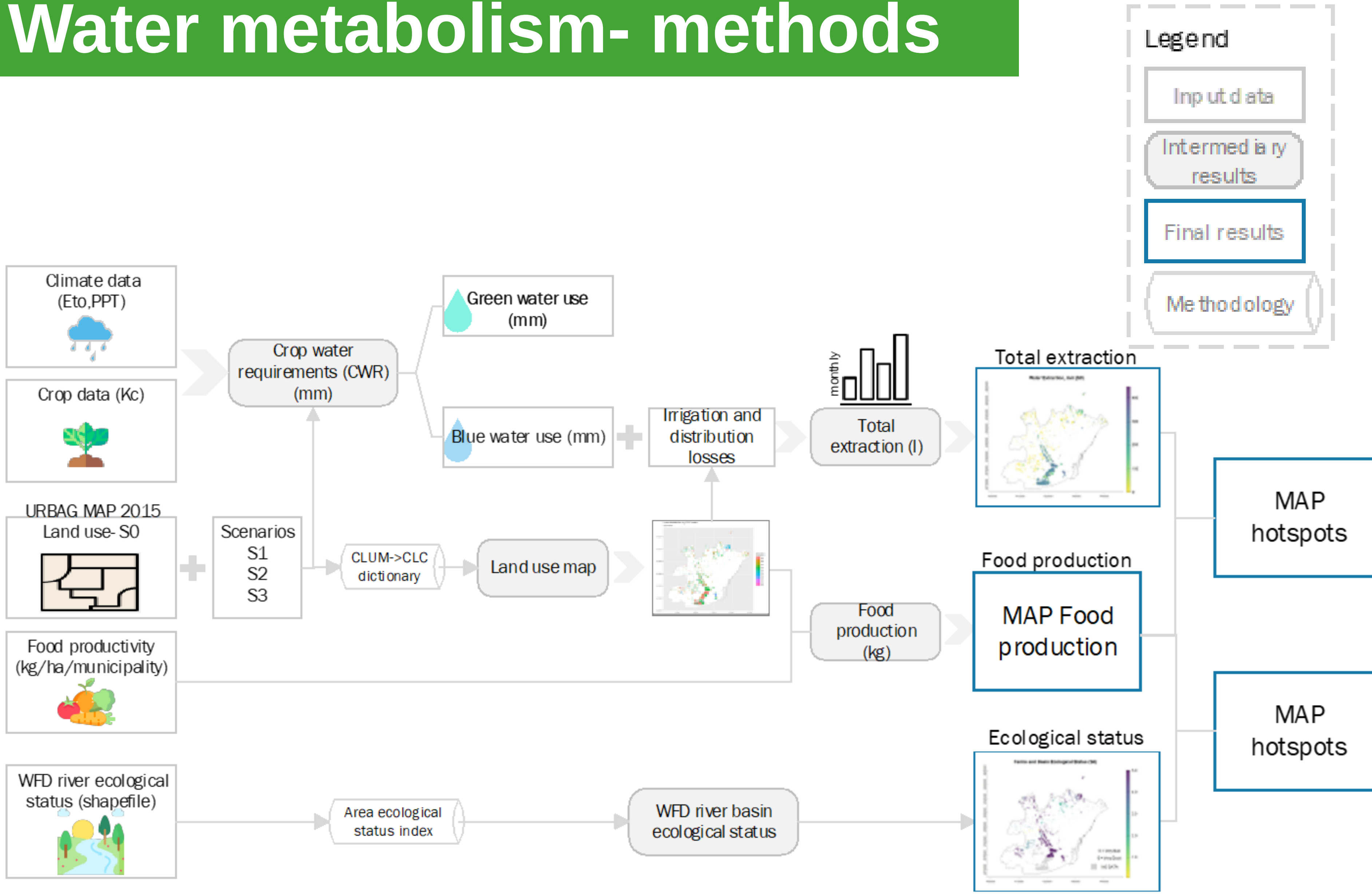
- Total area of AMB: 636 $km^{2:}$
  - 40% urban fraction
  - 8% peri-urban agriculture
- 3.3 million people
- 16,000 people/km^2
- AMB is limited by two rivers running Llobregat and Besòs

Water for peri-urban agriculture

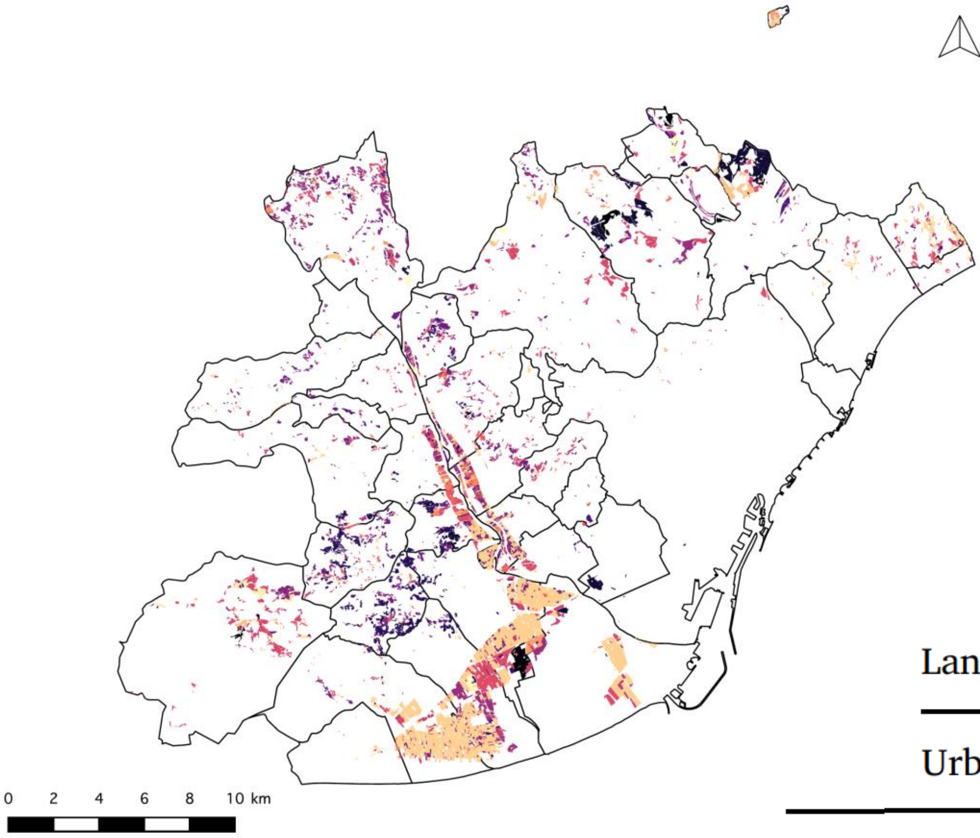


There are five major river basins in the AMB (background image from Google satellite).

Water metabolism- methods



Water- peri-urban agriculture scenarios



Land-cover

	Urban*	Forest**	Agriculture	Pastures	Other***
S0.	45%	42%	8%	3%	2%
S1.	52%	38%	6%	2%	2%
S2.	46%	38%	12%	2%	2%
S3.	45%	32%	20%	2%	2%

Padró et al., 2020

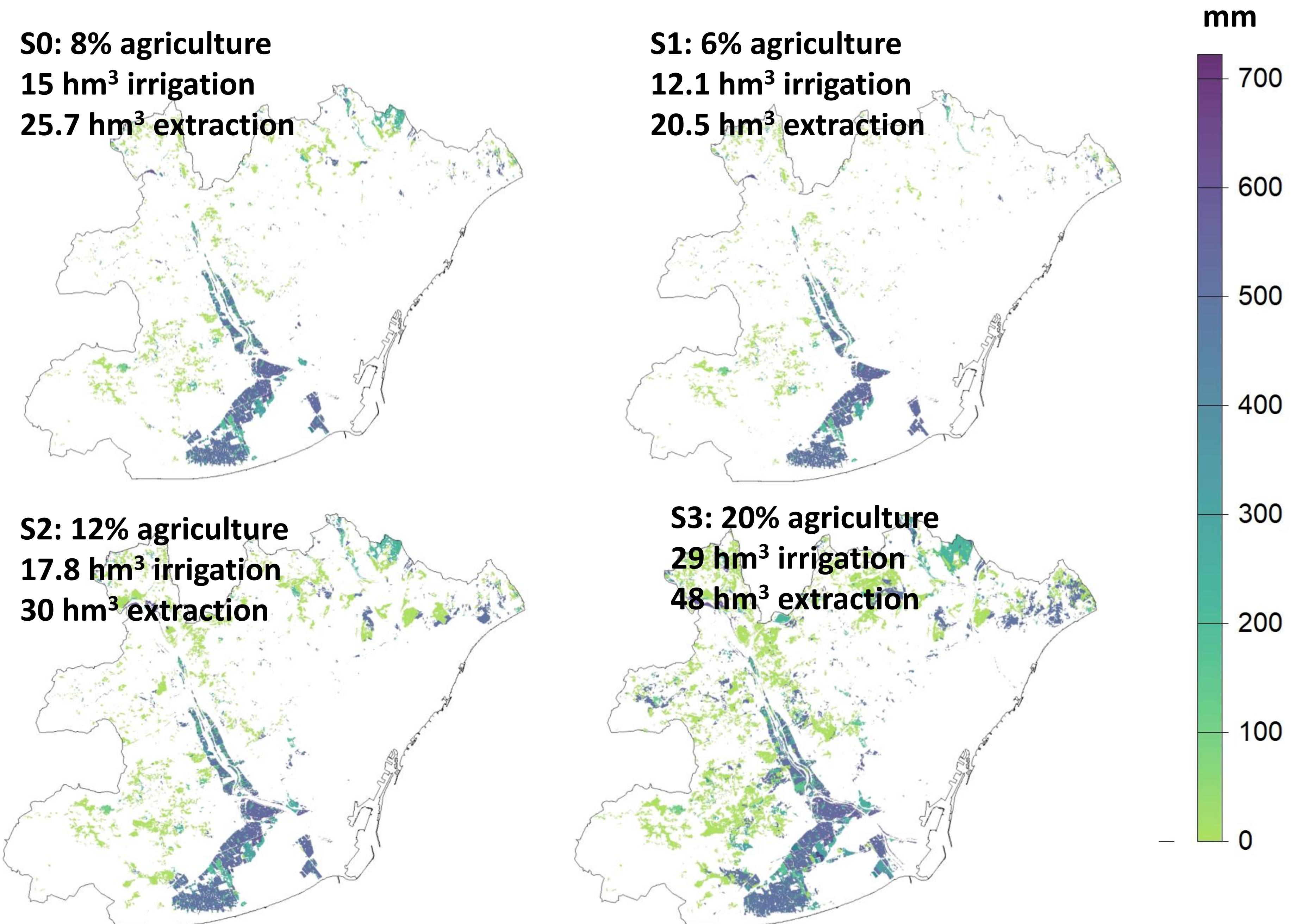
Water: irrigation

S0: 8% agriculture
15 hm³ irrigation
25.7 hm³ extraction

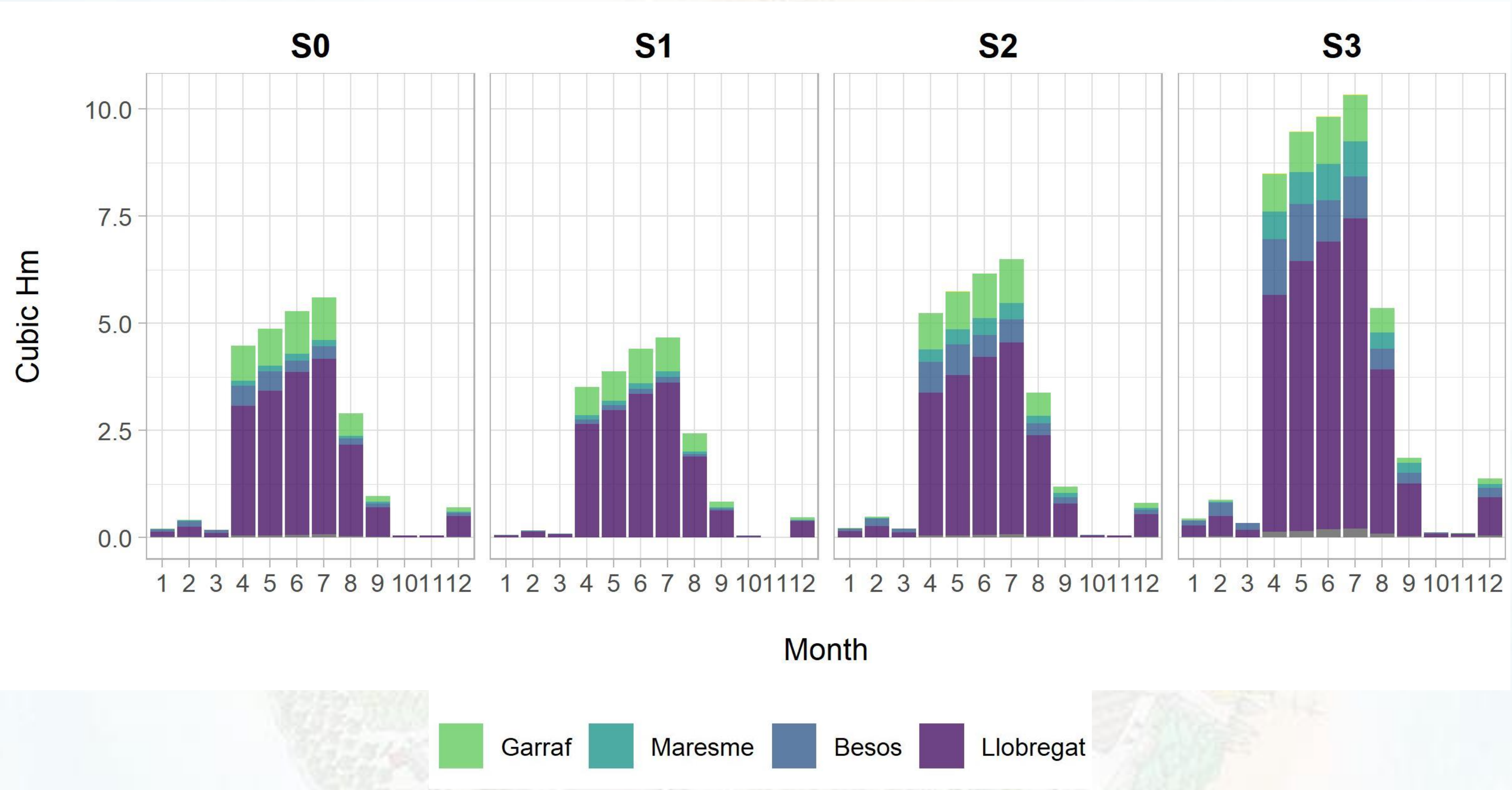
S1: 6% agriculture
12.1 hm³ irrigation
20.5 hm³ extraction

S2: 12% agriculture
17.8 hm³ irrigation
30 hm³ extraction

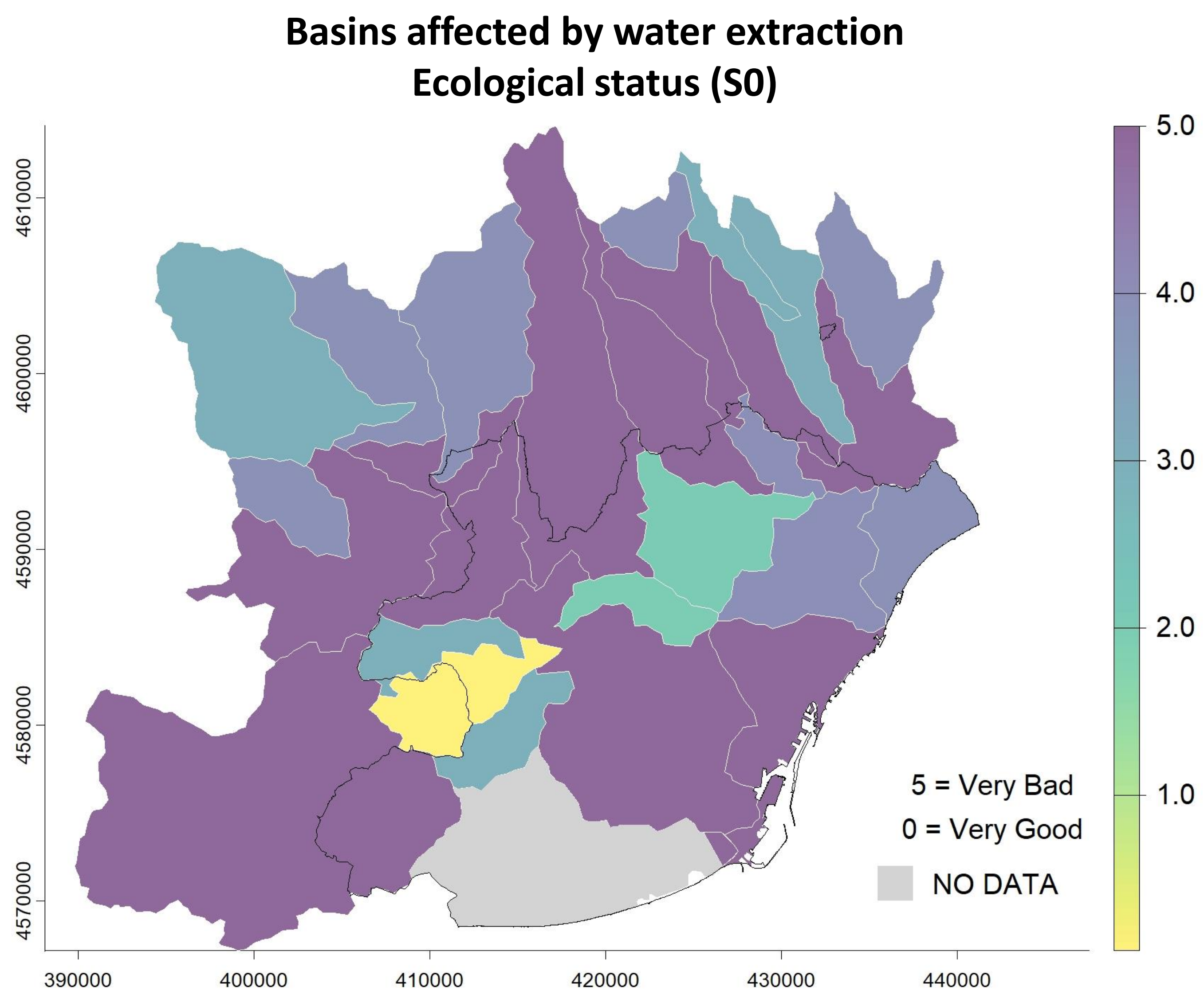
S3: 20% agriculture
29 hm³ irrigation
48 hm³ extraction



Water: extraction per month



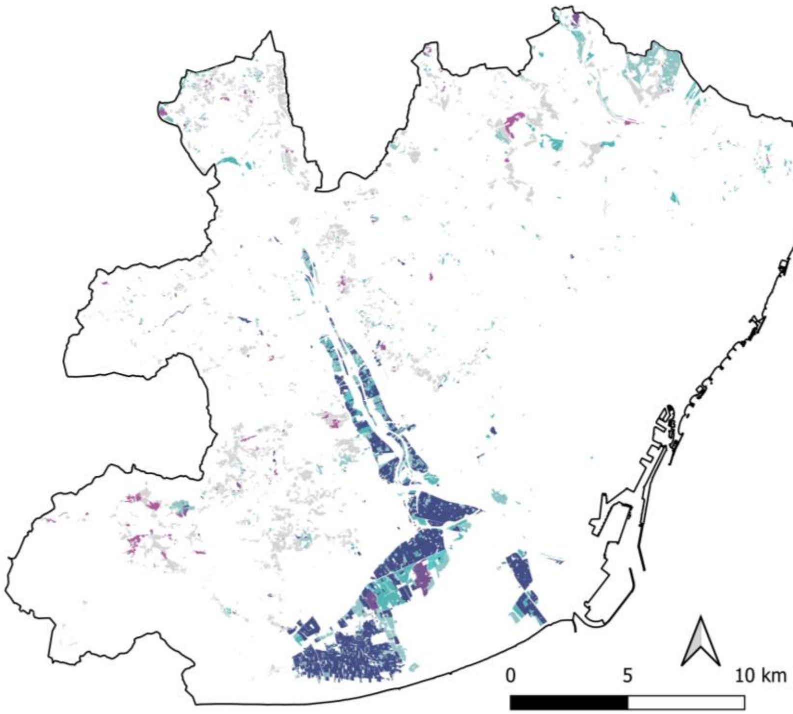
How does water extraction affect ecological status?



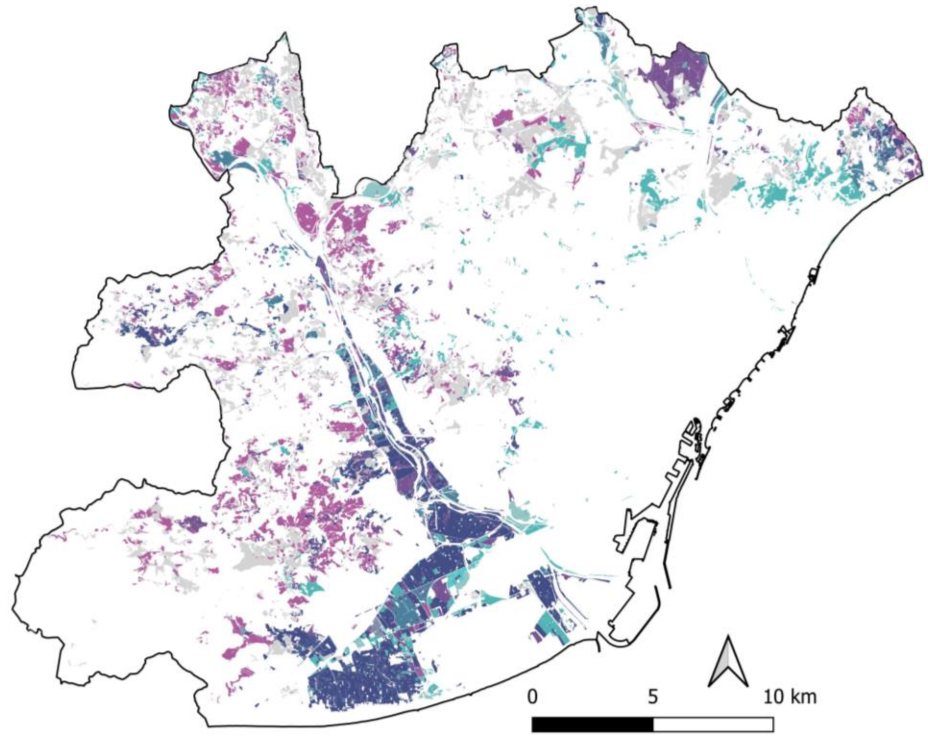
Ecological Status: Pollution, water extraction, physiological alterations, habitat impact, saline intrusion, temperature.

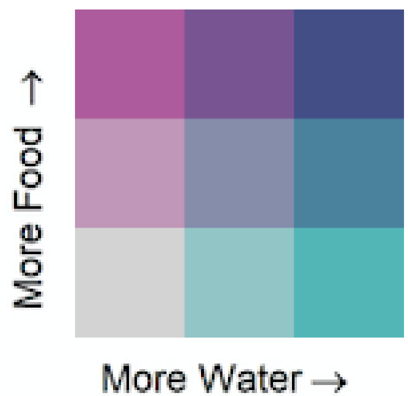
Water-food nexus

S0: 8% agriculture



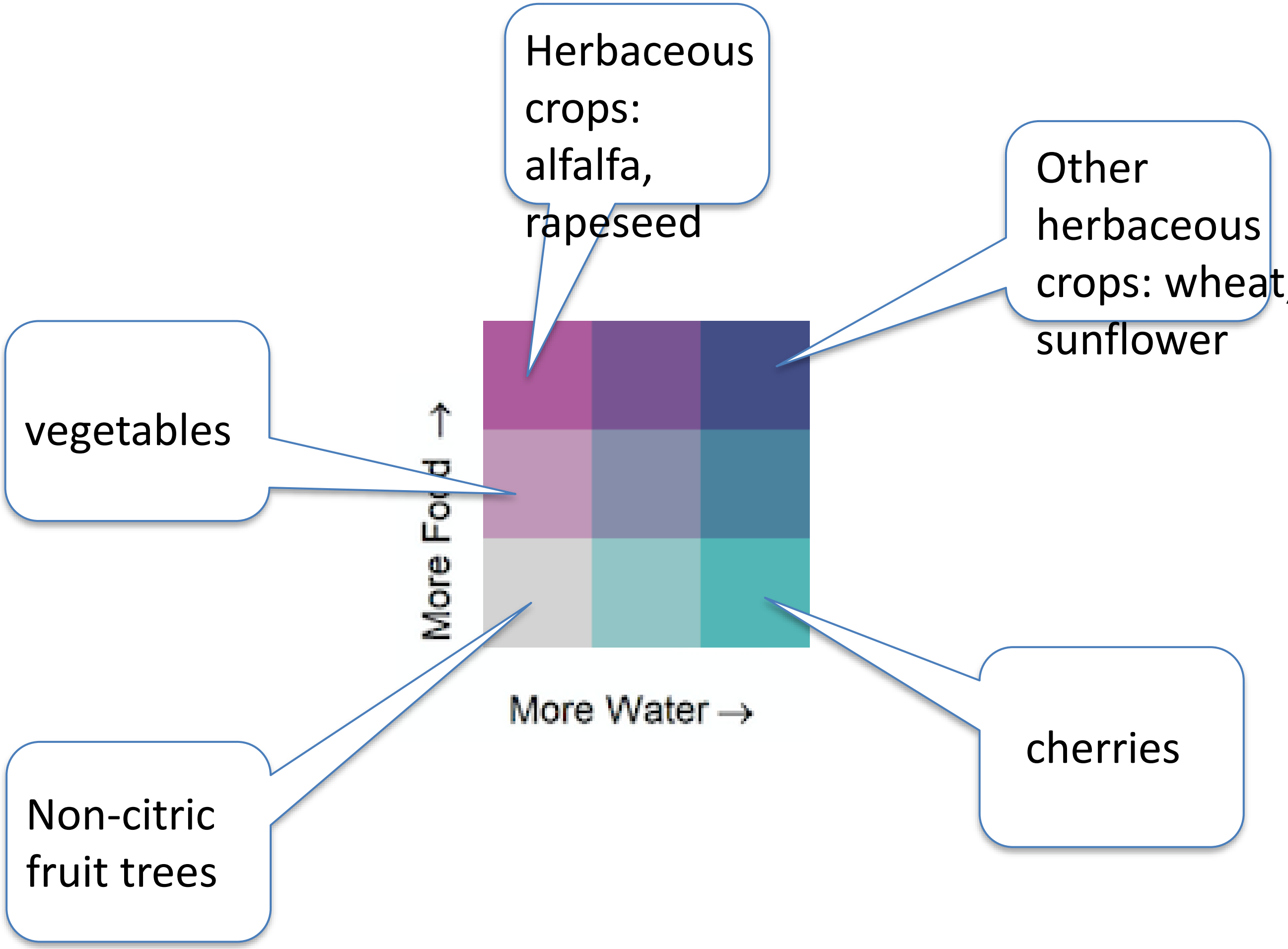
S3: 20% agriculture





Manuscript: "A georeferenced sustainability water metabolism assessment for managing trade-offs at the nexus between water, peri-urban agriculture, and the environment" in progress.

Water-food nexus



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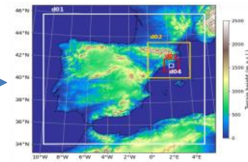
Crop irrigation: cooling belt?

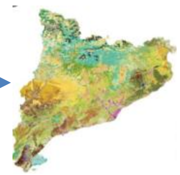
Weather Research Forecasting Model with Urban Canopy Model Building Effect Parameterization and Building Energy Model

Meteo



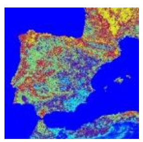
Input meteo: ERA5 DATA

Land-use



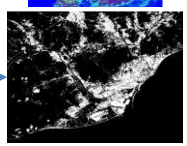
CREAF 2015 (MCSC v4)
Reference map
PDU Scenarios

Green fraction



Green fraction:
FAPAR (Copernicus Global land Service)

Urban fraction

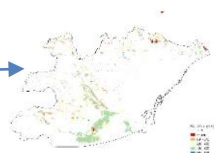


Urban fraction:
NDVI (Alamus et al., 2018)
Nonurban >0.2
Urban <0.2

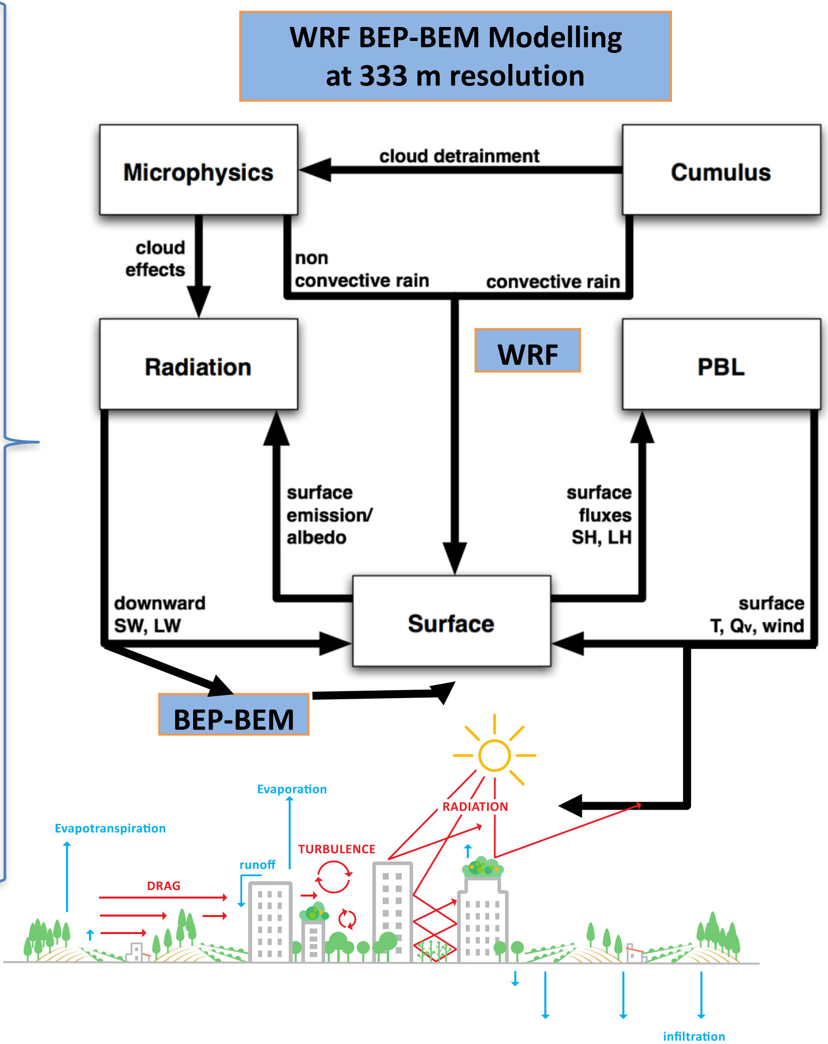
Urban morphology

Building heights:
MDS – MDT
1:5000

Irrigation



Irrigation:
Crop water requirement - Precipitation



2m Temperature

Wind fields

Humidity

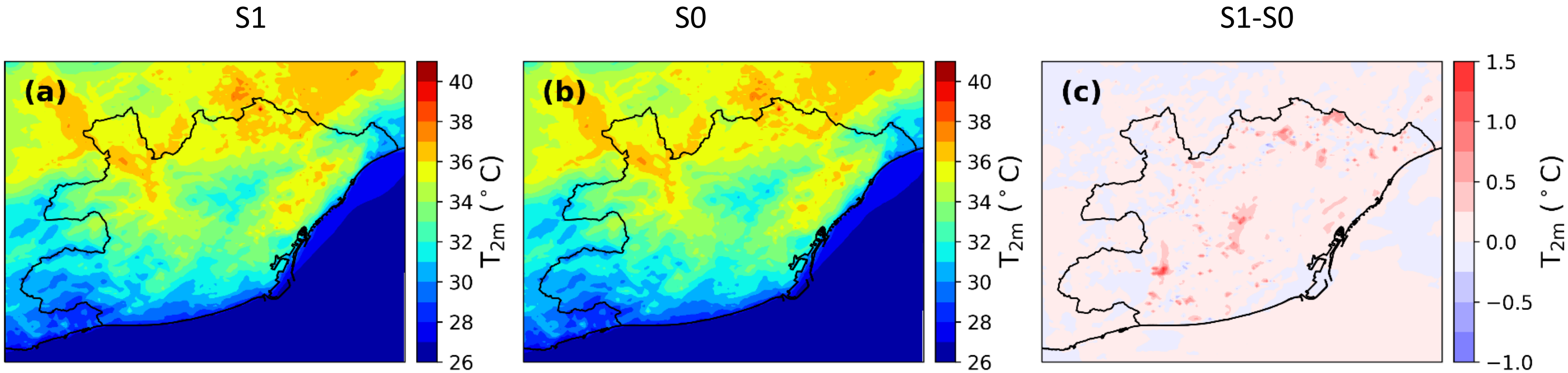
Building energy consumption

PBL height

Vertical profiles

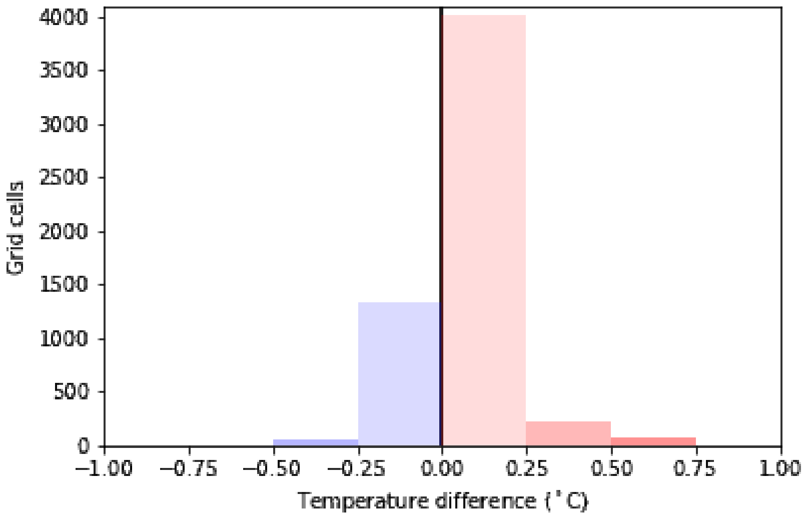
Crop irrigation: cooling belt? Scenario 1

Hourly average 2m temperature between 1 and 4pm during Heat Wave 2015



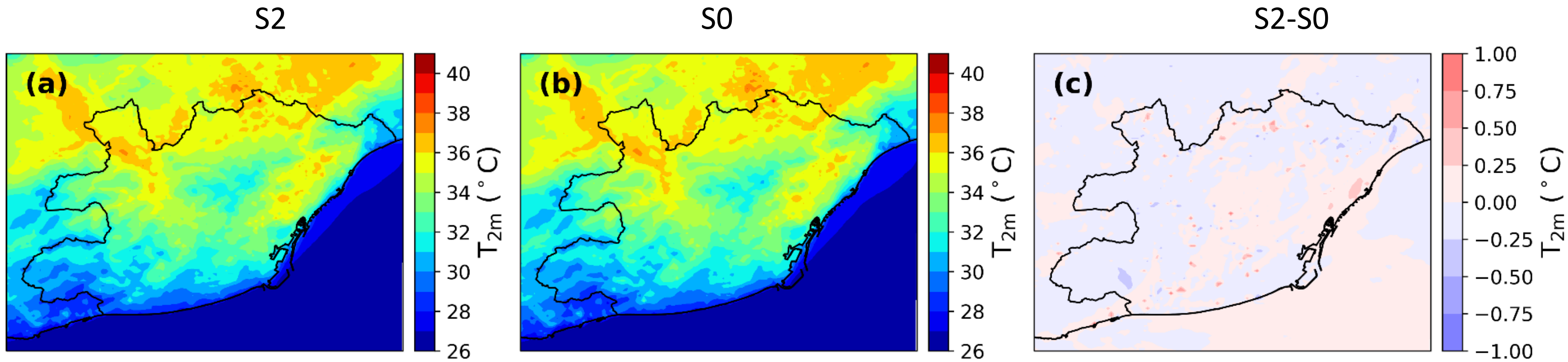
Maximum local reduction of 0.86 ºC.

Maximum local increase of 1.37 ºC.



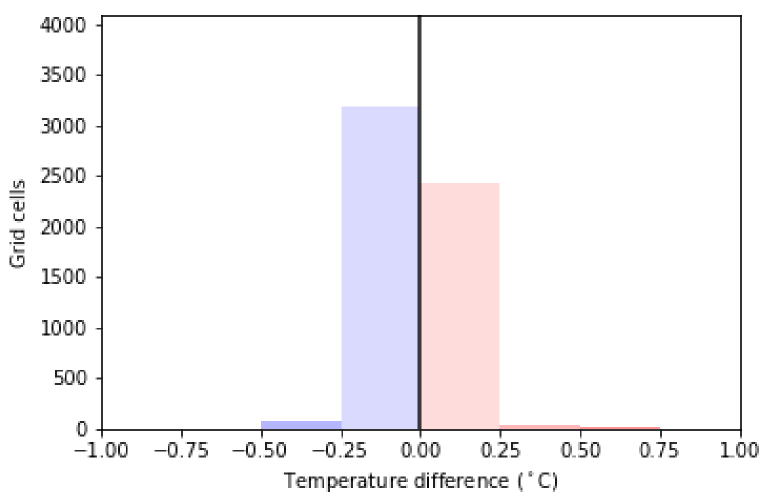
Crop irrigation : cooling belt? Scenario 2

Hourly average 2m temperature between 1 and 4pm during Heat Wave 2015



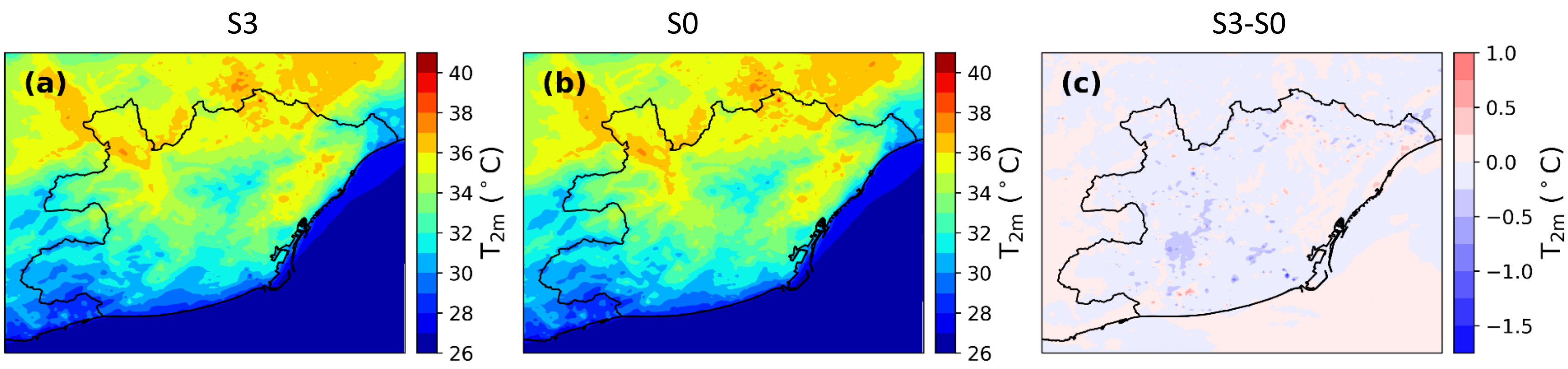
Maximum local reduction of 0.95 ^{o}C.

Maximum local increase of 0.96 ^{o}C.



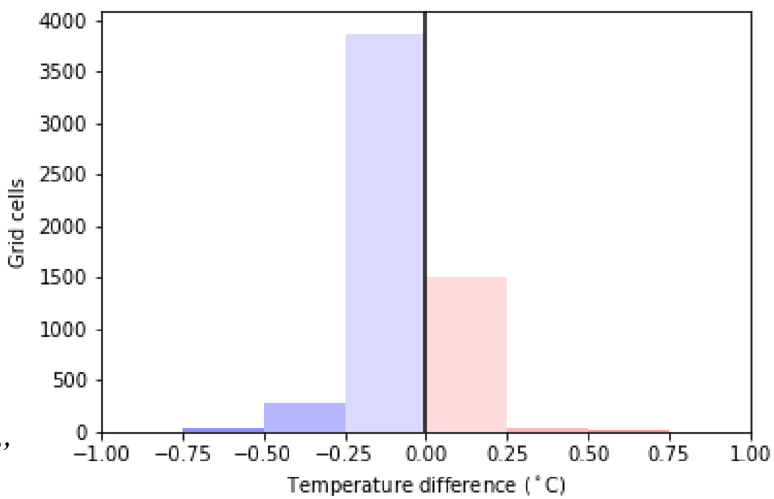
Crop irrigation: cooling belt? Scenario 3

Hourly average 2m temperature between 1 and 4pm during Heat Wave 2015



Maximum local reduction of 1.73 ºC.

Maximum local increase of 0.79 ºC.



Manuscript: "The cooling effect of peri-urban agriculture in cities."

Urban and peri-urban agriculture

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How much water is needed and how does it affect our river basin ecological status? What will be future needs as we increment urban agriculture in light of future reductions in precipitation and river flows?

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Does peri-urban agriculture result in a cooling belt around the more urban area?

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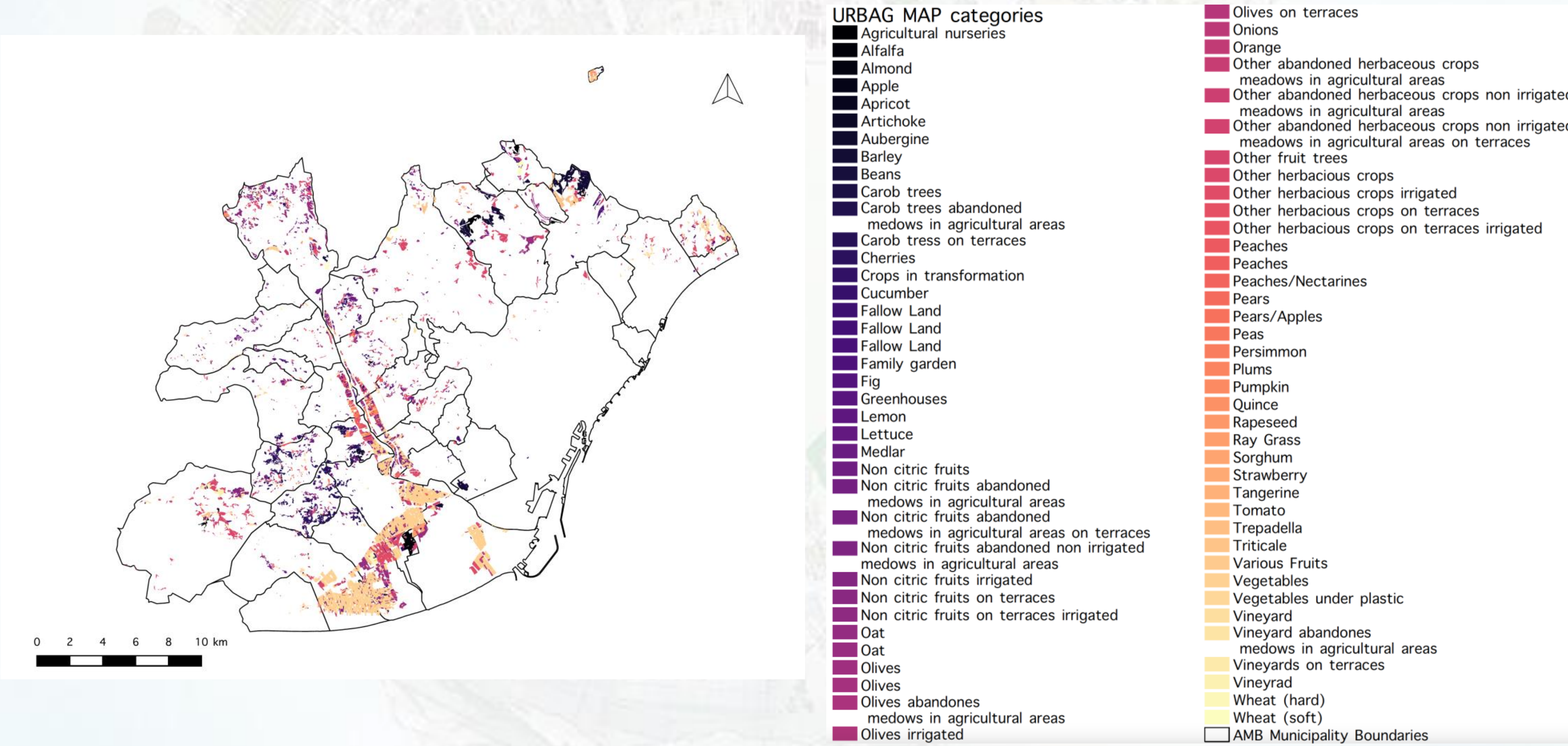
Nutrients: peri-urban agriculture

5,584 ha **105,868 tones of crops per year**

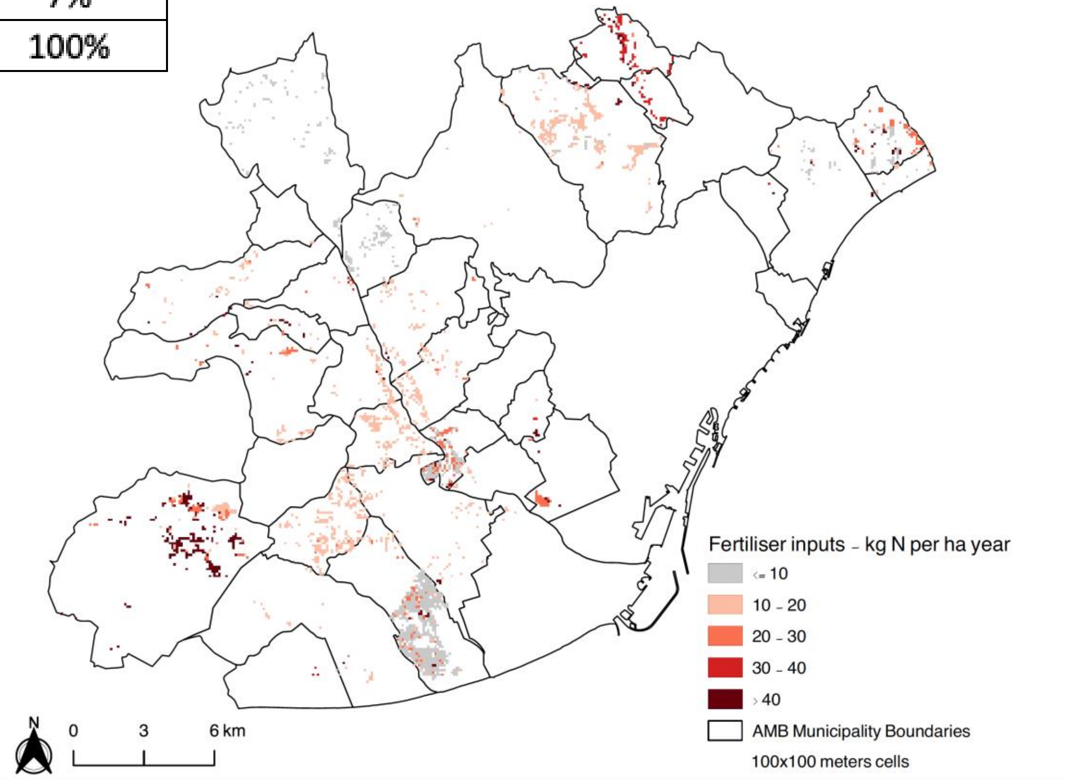


Location of peri-urban agriculture in the Metropolitan Area of Barcelona (AMB) and different land uses according to the URBAG map. Taken from: Mendoza Beltran et al., (2022)

Nutrients: peri-urban agriculture

Nutrient requirements: 53.24 tonnes N /year of mineral fertilizer (2015)

N input	Amount (tonnes N/yr)	Percentage
Mineral fertilizers	53.24	31%
Manure	97.9	56%
Agricultural residues	9.96	6%
Symbiotic N fixation	13	7%
Total	174.1	100%

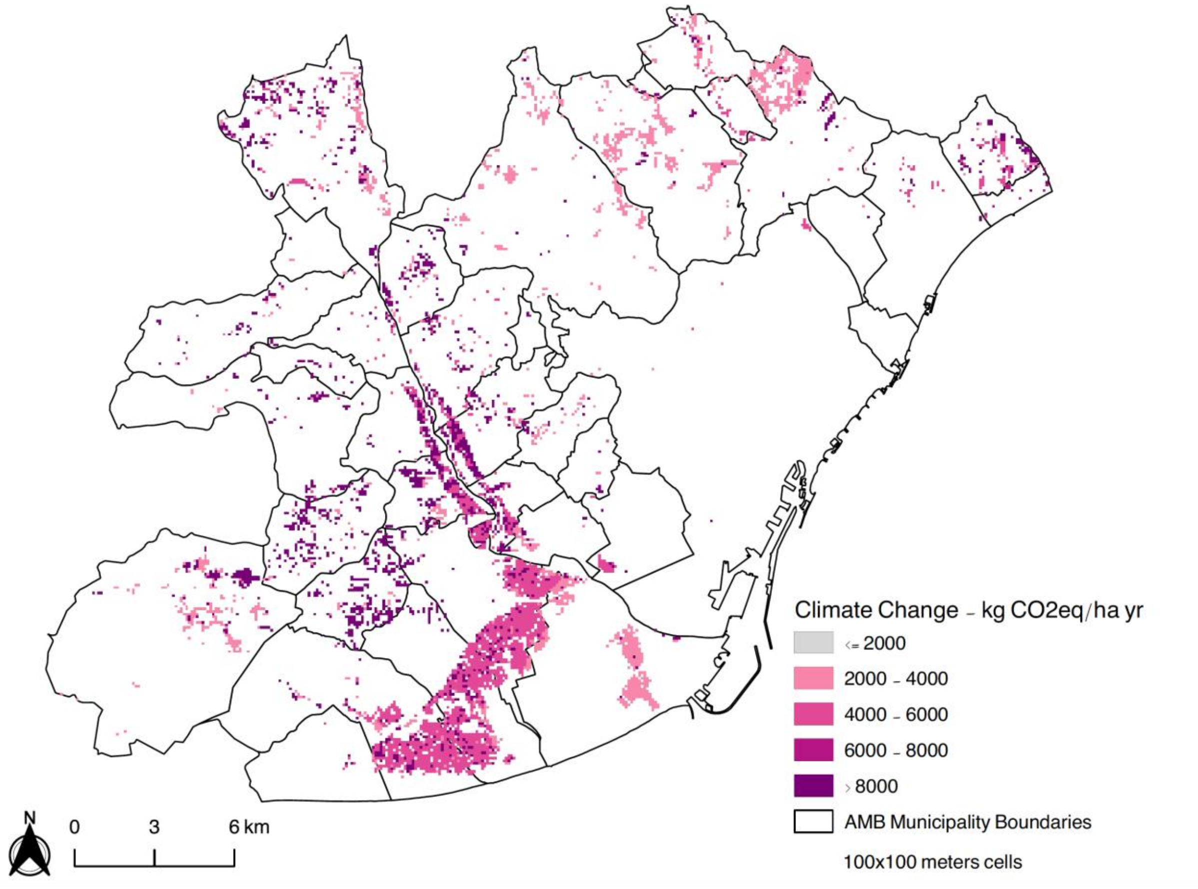


Manuscript: "Displaying geographic variability of peri-urban agriculture environmental impacts in the Metropolitan Area of Barcelona: a regionalized life cycle assessment" recently submitted to Science of the Total Environment

Nutrients: peri-urban agriculture

Carbon footprint 699,126 tonnes CO2e (2015)

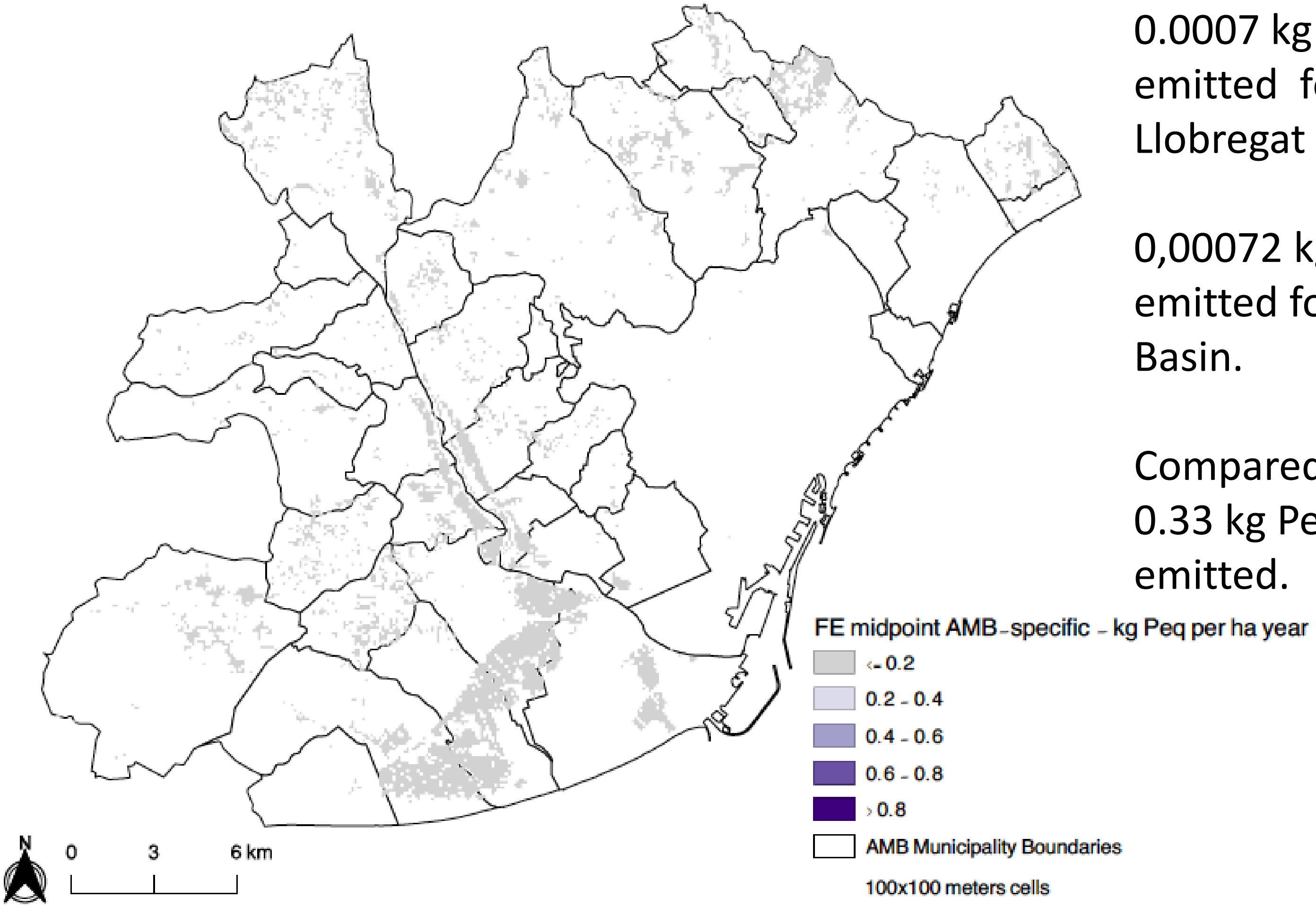
For the functional unit of total crop production of AMB , which is 105,868 tonnes.



Nutrients: peri-urban agriculture

Freshwater Eutrophication 0.0335 tonnes P eq (only direct emissions)

For the functional unit of total crop production of AMB , which is 105,868 tonnes.



0.0007 kg Peq/kg P emitted for the Llobregat Basin.

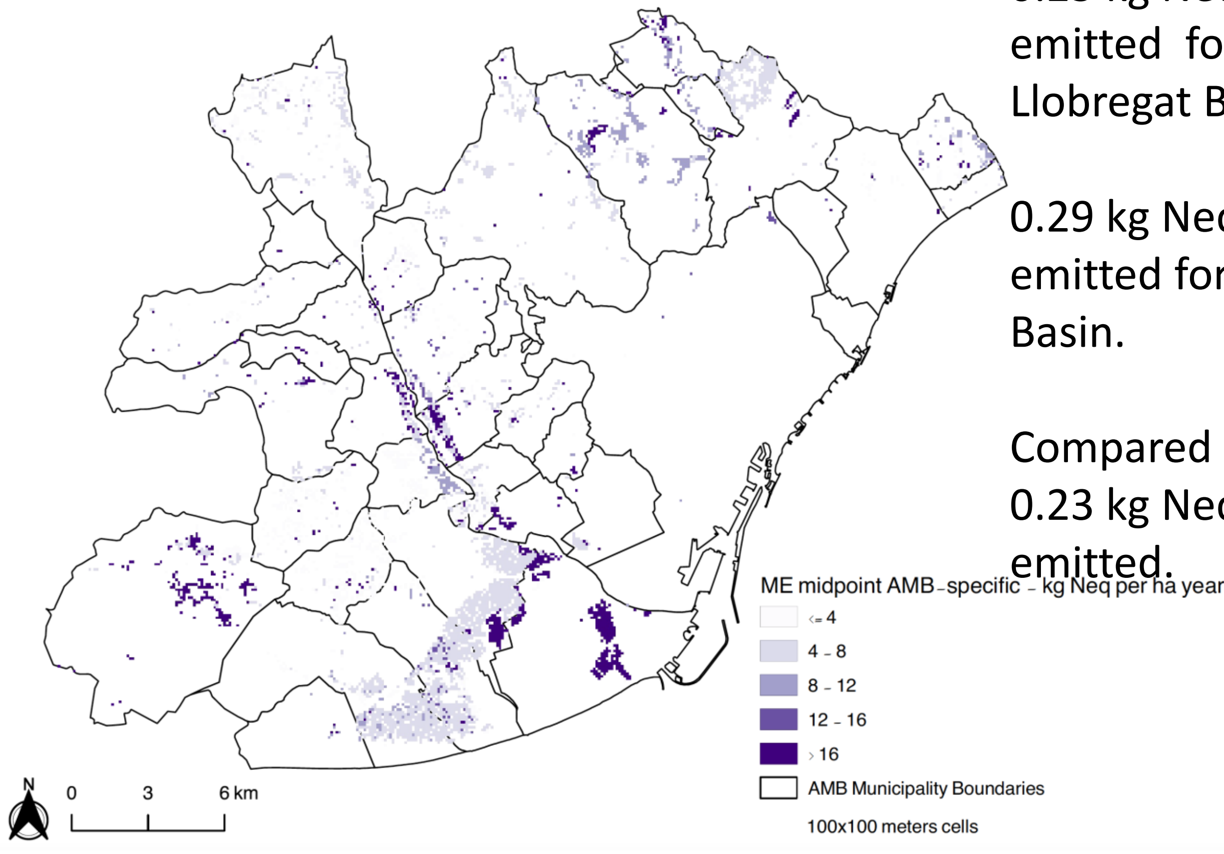
0,00072 kg Peq/kg P emitted for Besós Basin.

Compared to ReCiPe: 0.33 kg Peq/kg P emitted.

Nutrients: peri-urban agriculture

Marine Eutrophication 48.9 tones N eq (only direct emissions)

For the functional unit of total crop production of AMB , which is 105,868 tonnes.

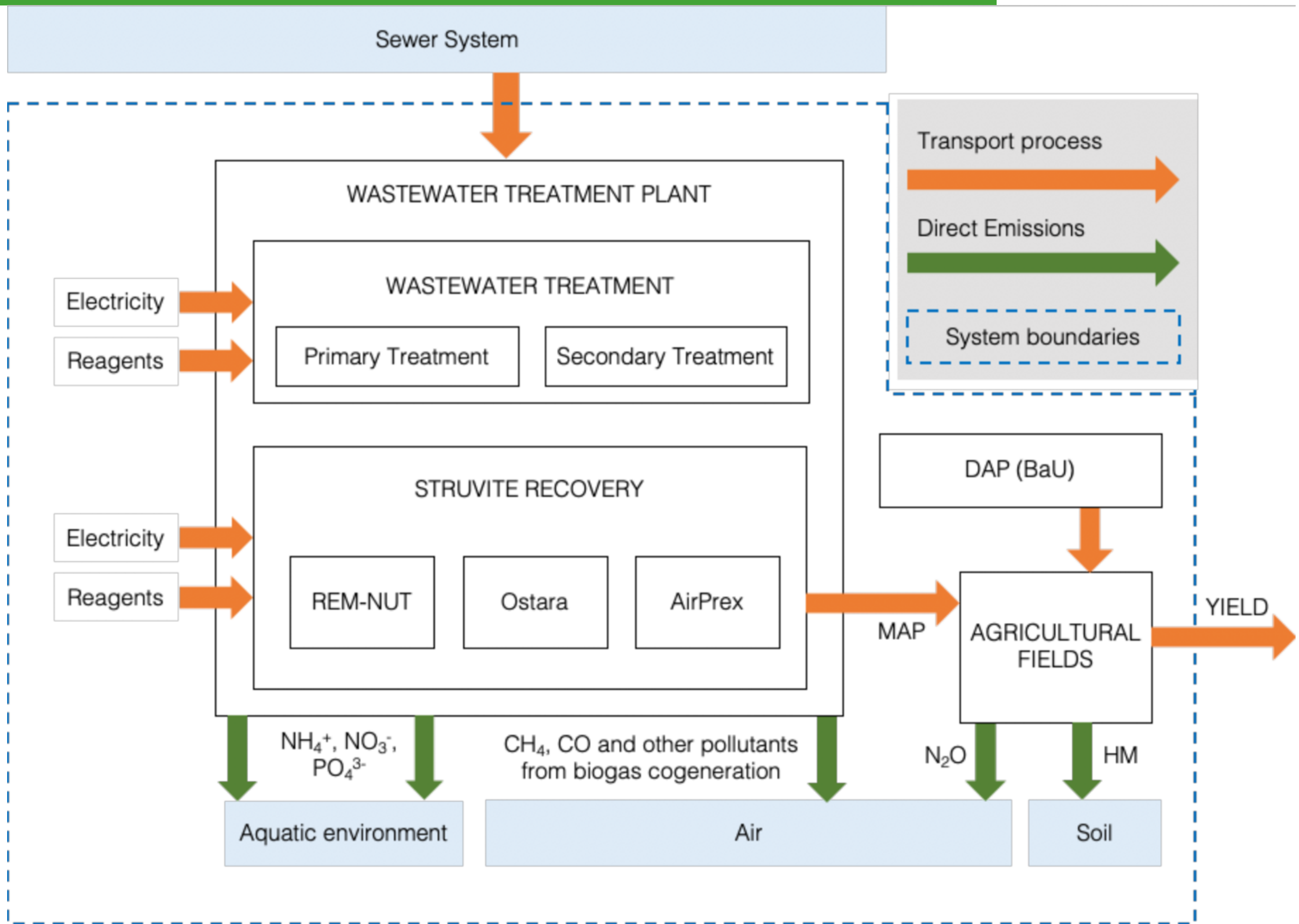


0.25 kg Neq/kg nitrate emitted for the Llobregat Basin.

0.29 kg Neq/kg nitrate emitted for Besós Basin.

Compared to ReCiPe: 0.23 kg Neq/kg nitrate emitted.

Nutrients: recovery through struvite



- all technologies are able to recover between 5 and 30 times the amount of phosphates required to fertilize the entire agricultural area of the AMB annually

Rufí et al., 2020

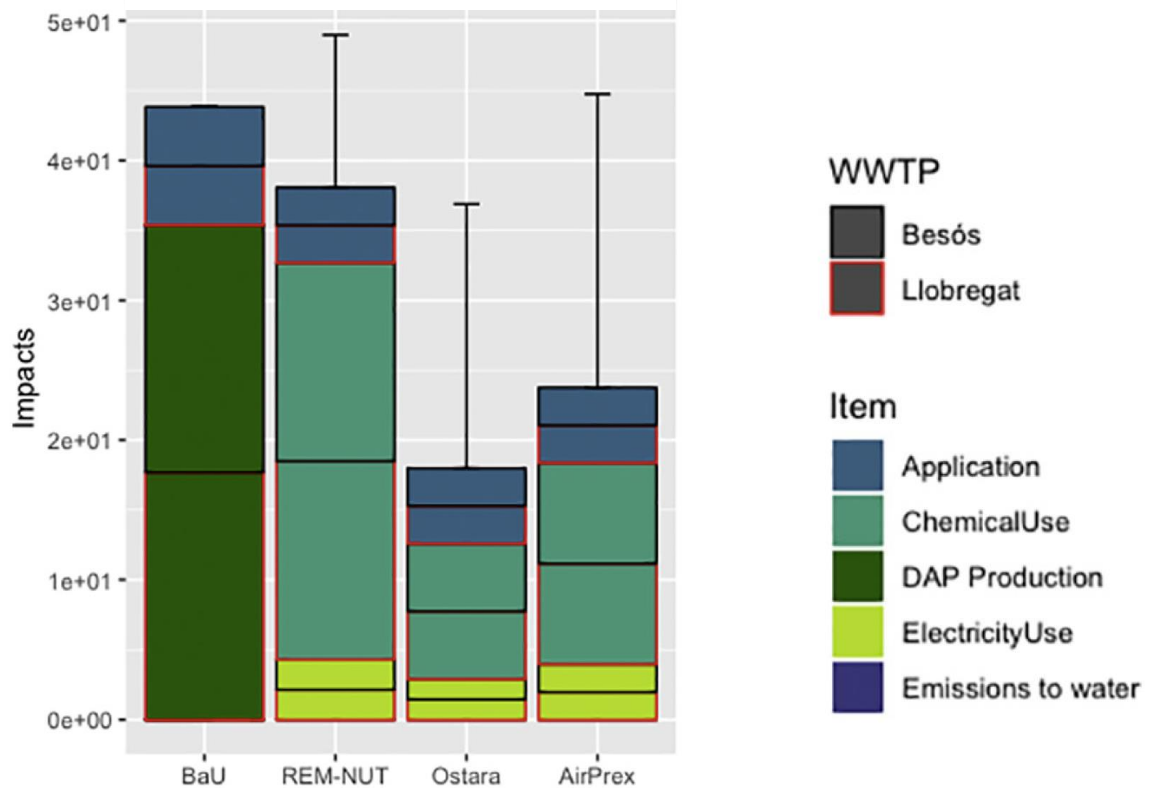
Nutrients: recovery through struvite

Functional Unit: kg of P recovered and applied.

Error bar upper value represents maximum possible impact based on the range of P-recovery for every specific technology.

So after seeing this, our question here is how would the use of struvite help us reduce the impacts of fertilization in peri-urban agriculture?

Global Warming Potential
kg CO2 eq

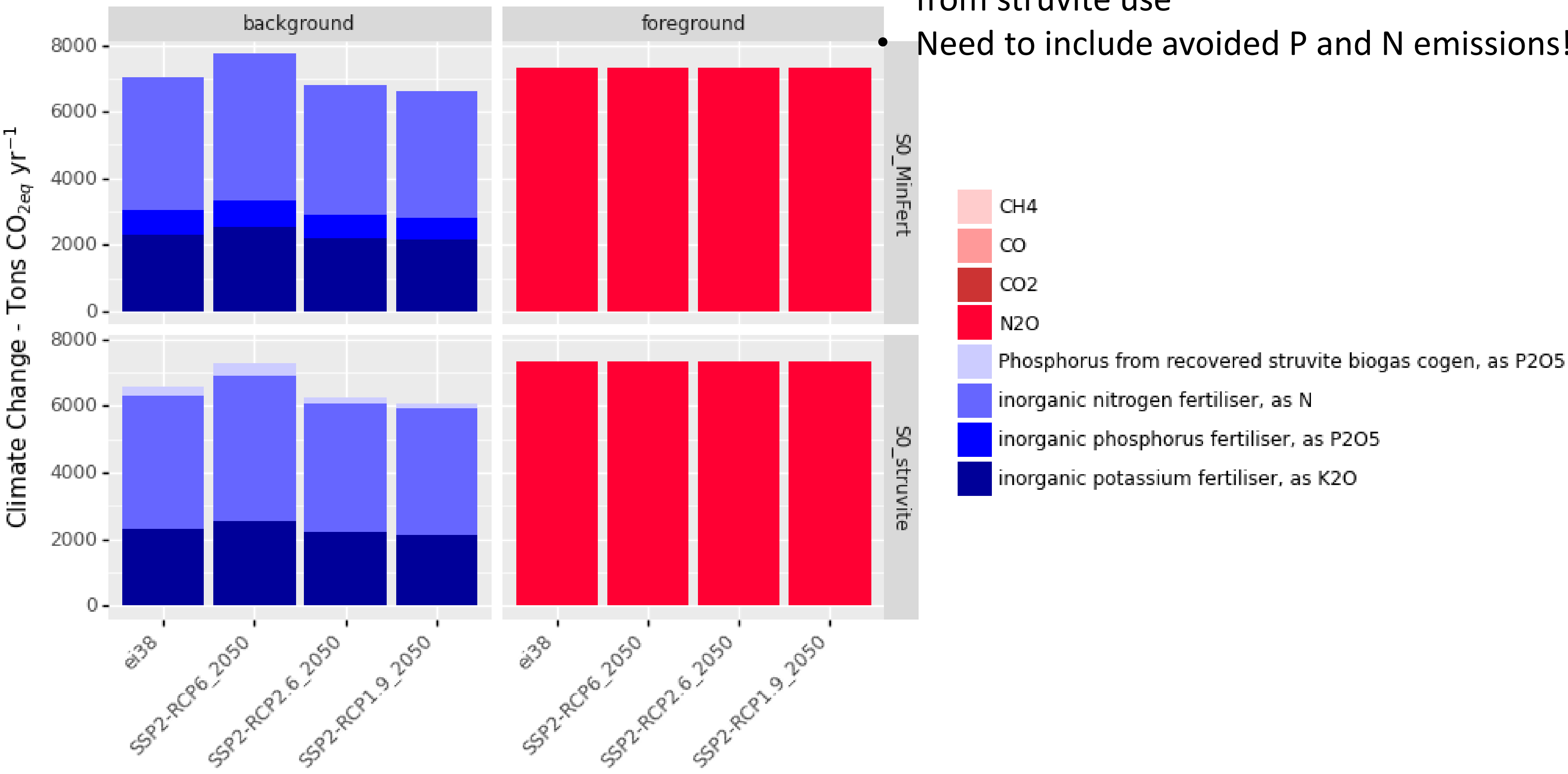


technologies

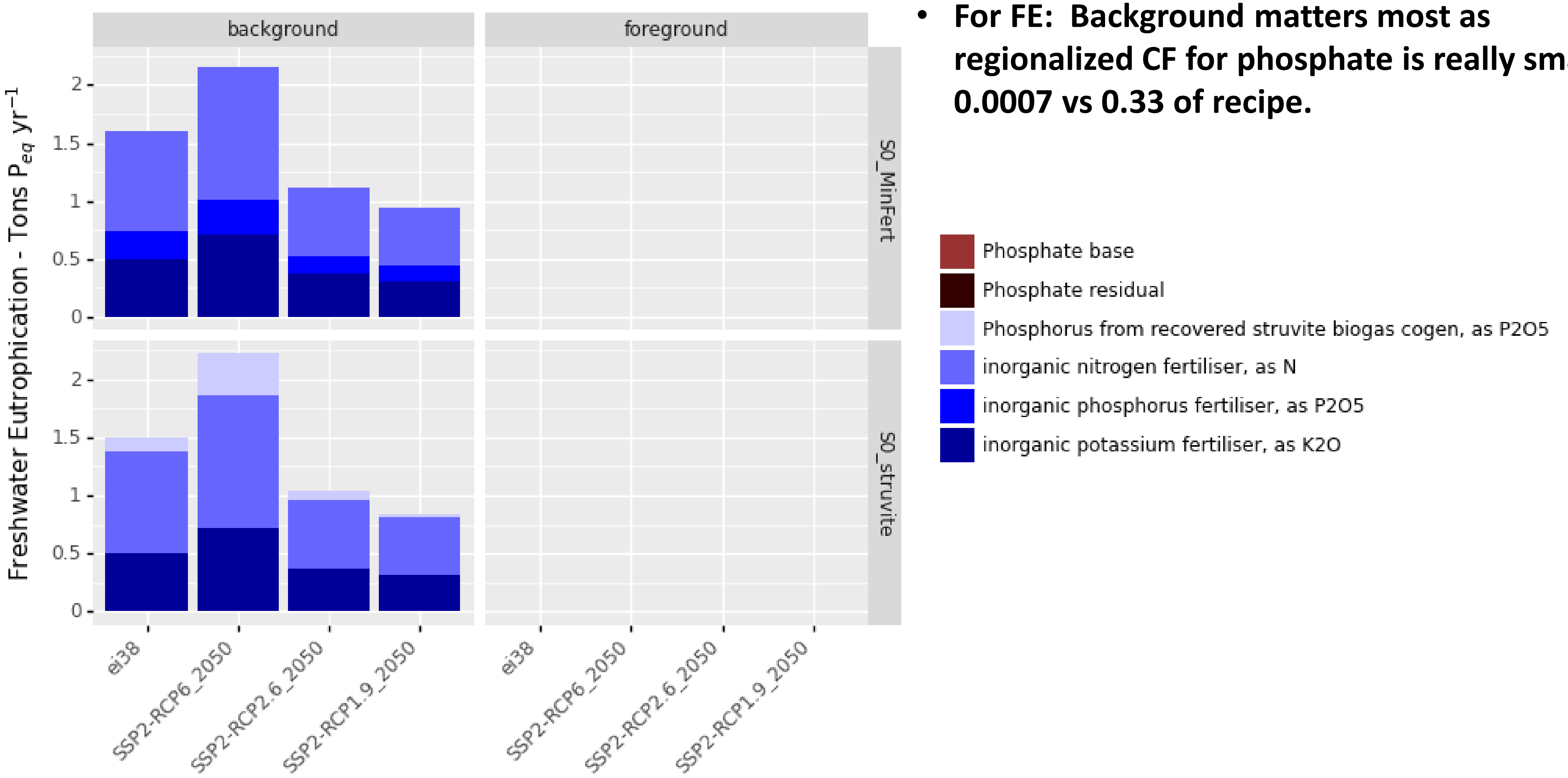
Nutrients: recovery through struvite, future scenarios

We learn some interesting things… and key research gaps are identified:

- More or less equal foreground and background
- Nitrogen and potassium much more relevant on the background
- Thus few changes in struvite scenario background
- Need to research more on N_2O emissions from struvite use
- Need to include avoided P and N emissions!!

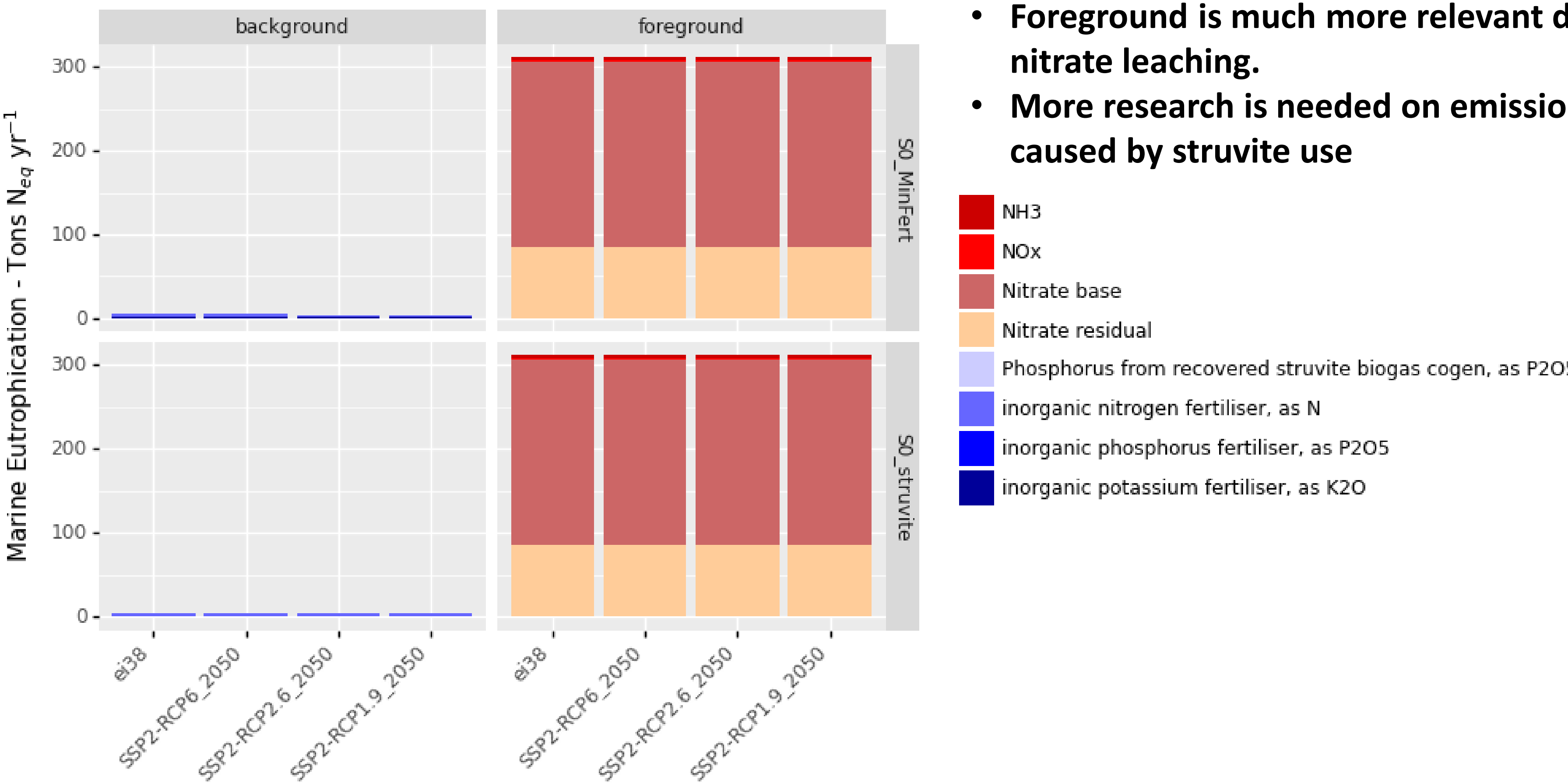


Nutrients: recovery through struvite, future scenarios



- **For FE: Background matters most as regionalized CF for phosphate is really small 0.0007 vs 0.33 of recipe.**

Nutrients: recovery through struvite, future scenarios



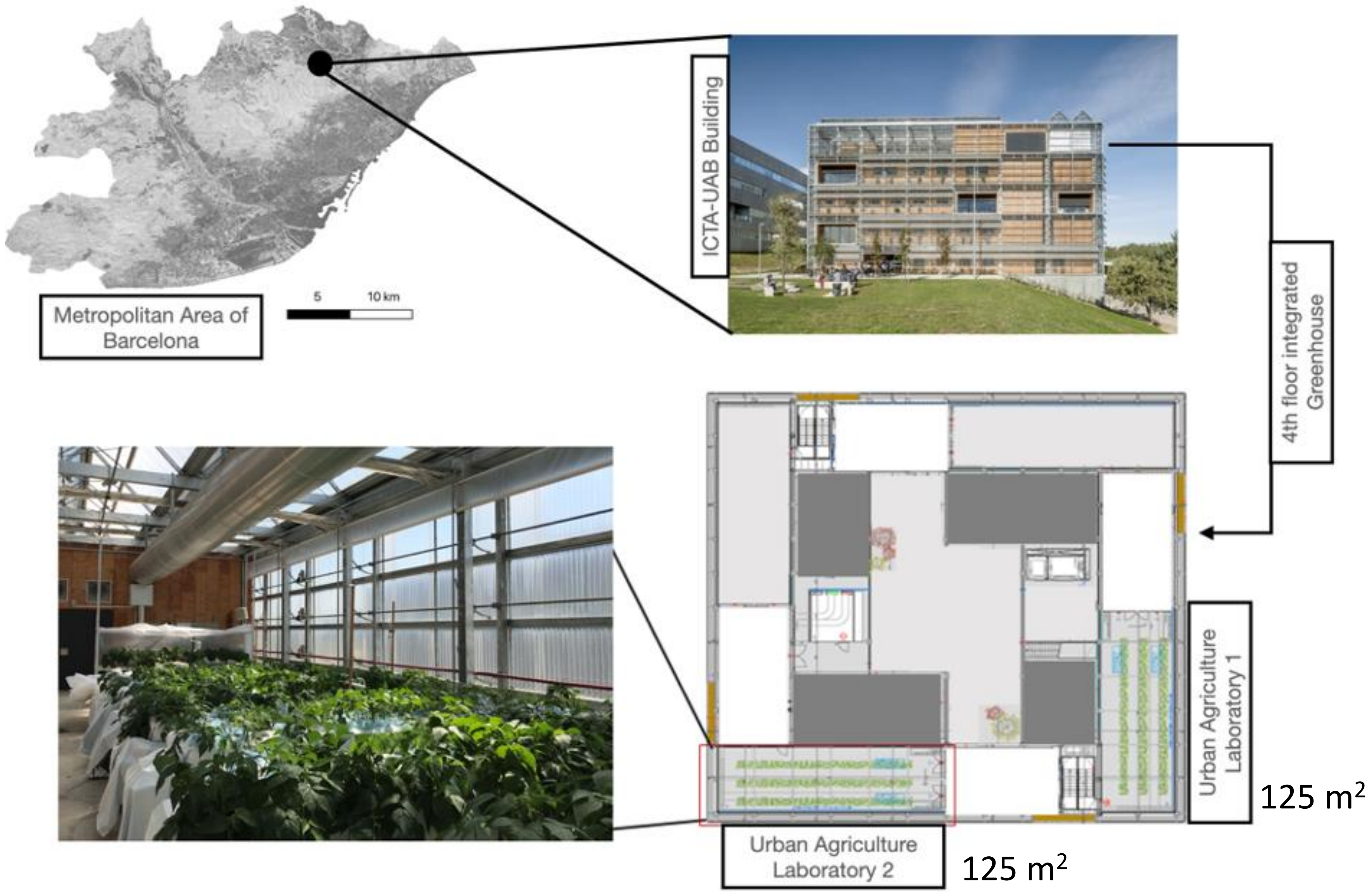
- **For ME:**
  - **Foreground is much more relevant due to nitrate leaching.**
  - **More research is needed on emissions caused by struvite use**

Implications of this:

- **N circularity is much more important than P in terms of GWP and eutrophication, but P recovery is EXTREMELY IMPORTANT from a resource depletion perspective.**

- **P and N recovery need to go hand in hand for circularity to make sense.**

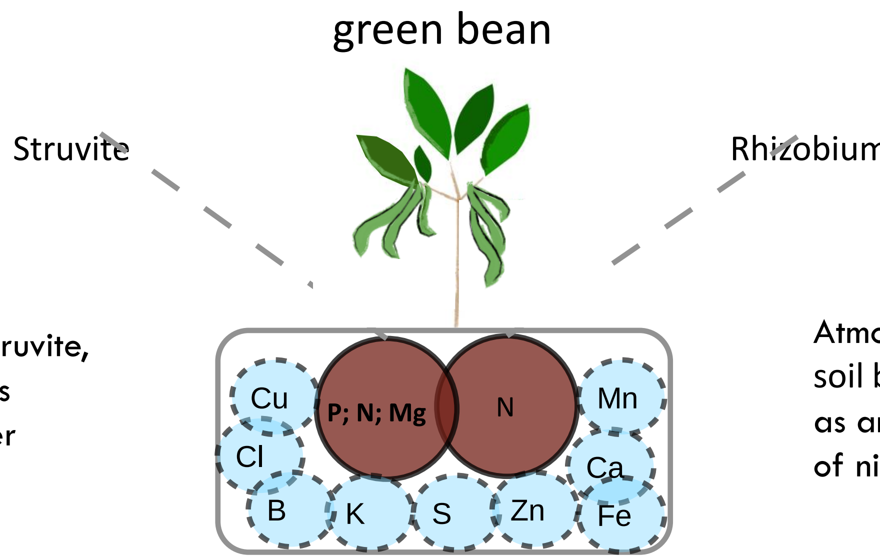
From theory to practice



From theory to practice

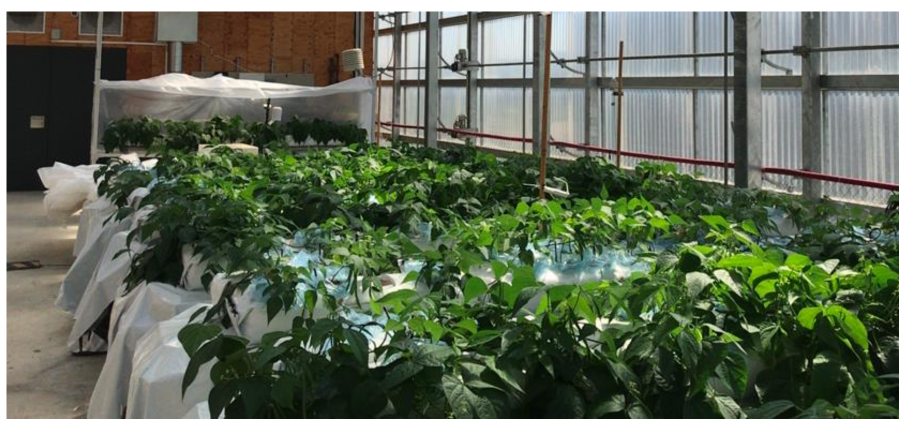
Reduction of mineral fertilizer by using struvite and Rhizobium inoculation

Slow releasing fertilizer struvite, generated by spontaneous precipitation in wastewater treatment plants (WWTP)



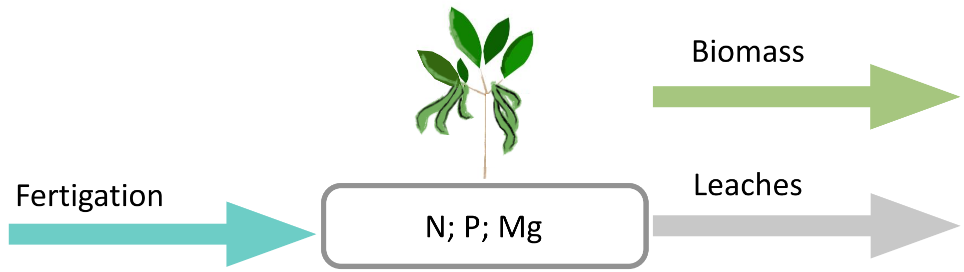
Atmospheric N_2 fixing soil bacteria rhizobium as an additional source of nitrogen

SR2, SR5, SR10 and SR20



From theory to practice

Methodology and sampling



- The P, N and Mg content was determined for incoming and outgoing water-flows.

<u>Life Cycle Analysis</u>

- The functional unit (FU) was defined as 1kg of fresh beans.

<u>The experiment infrastructure</u>

- greenhouse structure,
- rainwater harvesting system,
- auxiliary equipment

<u>The experiment operation system</u>

- energy,
- pesticides,
- fertilizers,
- substrates

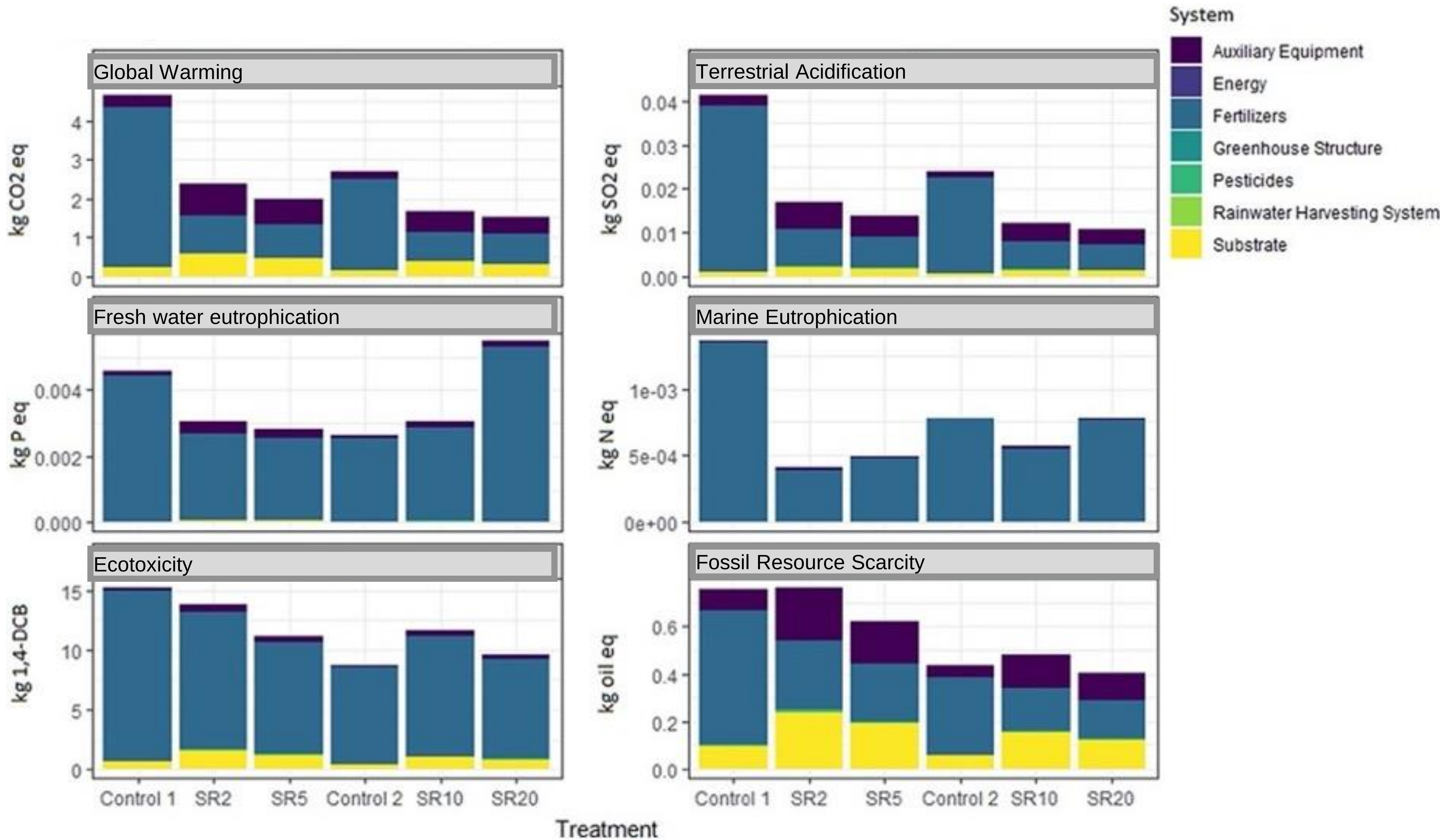
From theory to practice: results

Yield

Production	2019			2020		
Treatment	SR2	SR5	Control 1	SR10	SR20	Control2
Total	1899.2 g	2375.6 g	4726.7 g	3542.2 g	4821.5 g	8198.4 g
Average per plant	59.3 g	74.2 g	147.7 g	110.7 g	150.6 g	256.2 g
Dif to control*	40.2%	50.3%	100%	43.2%	58.8%	100%

From theory to practice: results

Environmental impact of operational phase per kg of fresh beans.

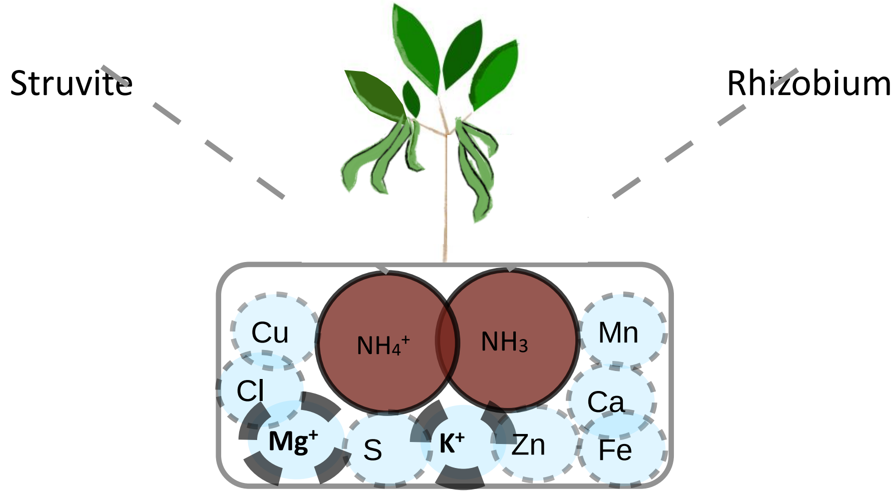


From theory to practice: results

Future research:

Struvite quantity insufficient due to Rhizobium inoculation

Electrochemical imbalance in the rhizosphere due to the missing anion in form of NO_3^-



SR2, SR5, SR10 and SR20

URBAG Integrated System Analysis of Urban Vegetation and Agriculture

References

Mendoza, K. Jepsen, M. Rufí-Salís, S. Ventura, C. Madrid-López, G. Villalba* (2022) ***Mapping direct N_2O emissions from peri-urban agriculture: The case of the Metropolitan Area of Barcelona.*** Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2022.153514

Verónica Arcas-Pilz, Martí Rufí-Salís, Felipe Parada, Xavier Gabarrell, Gara Villalba* (2021) ***Assessing the environmental behavior of alternative fertigation methods in soilless systems: The case of Phaseolus vulgaris with struvite and rhizobia inoculation.*** Science of The Total Environment; https://doi.org/10.1016/j.scitotenv.2020.144744

Martí Rufí-Salís, Nadin Brunnhofer, Anna Petit-Boix, Xavier Gabarrell, Albert Guisasola, Gara Villalba* (2020) ***Can wastewater feed cities? Determining the feasibility and environmental burdens of struvite recovery and reuse for urban regions.*** Science of The Total Environment; https://doi.org/10.1016/j.scitotenv.2020.139783

Roc Padró, et al., (2020) ***Assessing the sustainability of contrasting land use scenarios through the Socioecological Integrated Analysis (SIA) of the metropolitan green infrastructure in Barcelona.*** Landscape and Urban Planning. https://doi.org/10.1016/j.landurbplan.2020.103905

URBAG Integrated System Analysis of Urban Vegetation and Agriculture

Thank you!

Please check out our entire team and invidual profiles at urbag.eu

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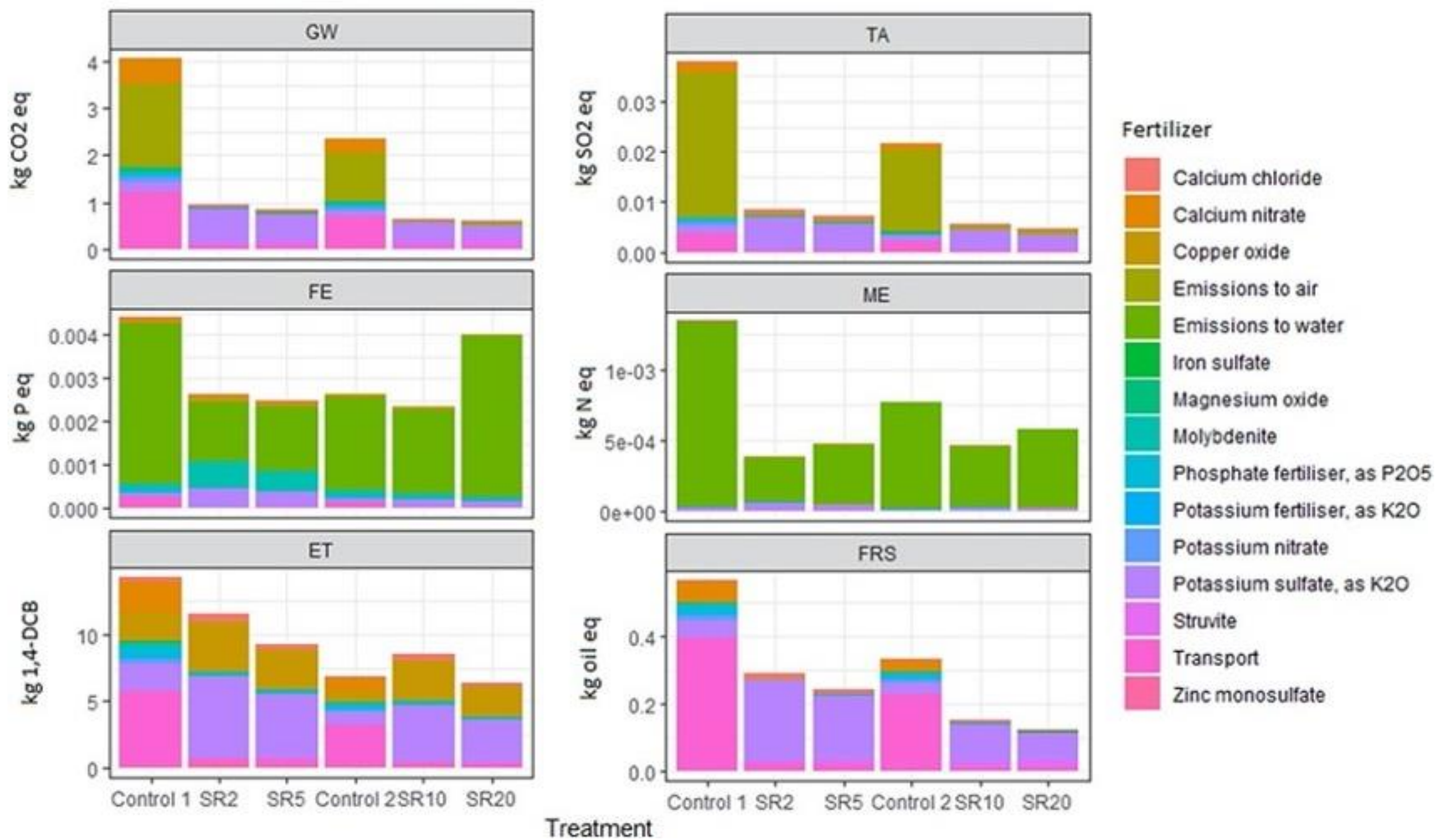
https://urbag.eu/

From theory to practice: results

Environmental impact of use of fertilizer/alternative per kg of fresh beans.



URBAG

Policy and planning opportunities and constraints

Urban planners
Policy makers
Public administration…

Life Cycle/Atmospheric Assessment

Agencies of climate change, biodiversity, waste management…

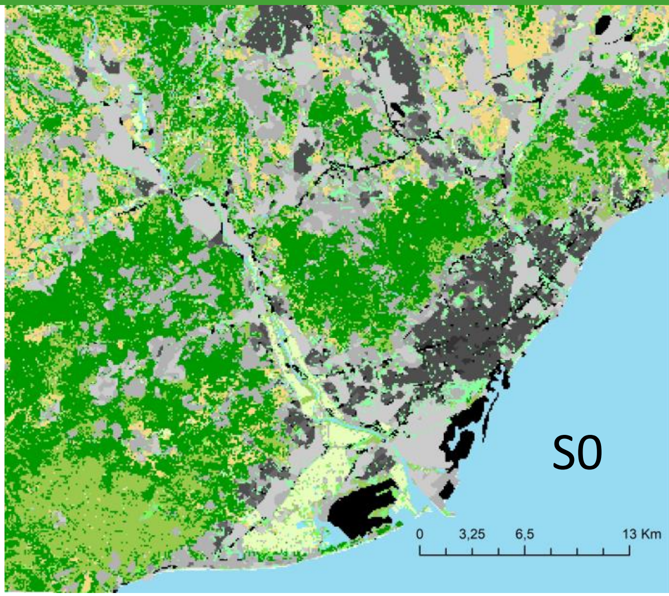
Communication and research transfer strategy

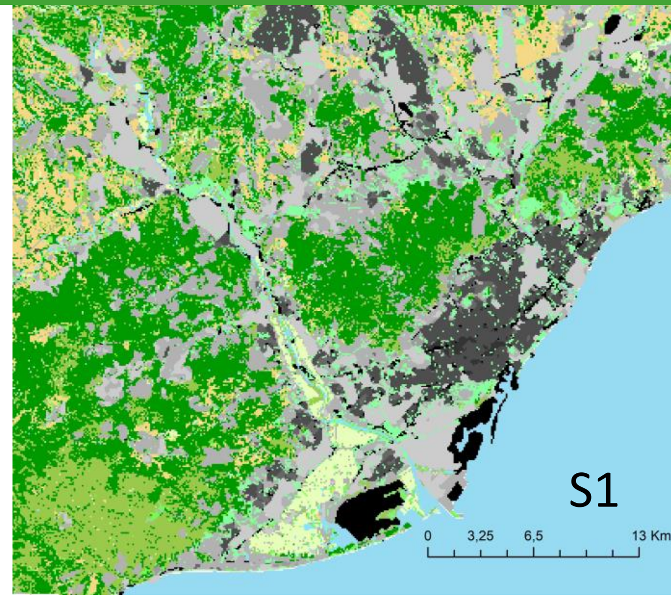
Stakeholder workshops

Social benefits for surrounding communities

End-users, SMEs, Associations
Agency of Urban Services…

AMB Urban Master Plan





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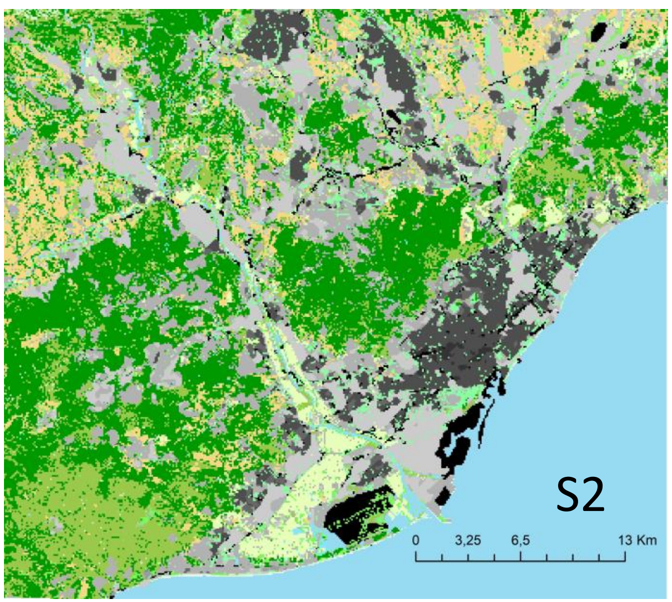
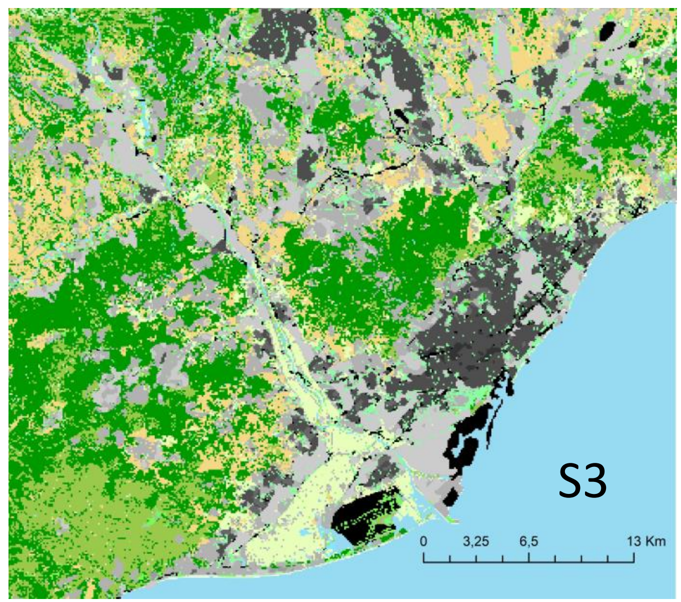
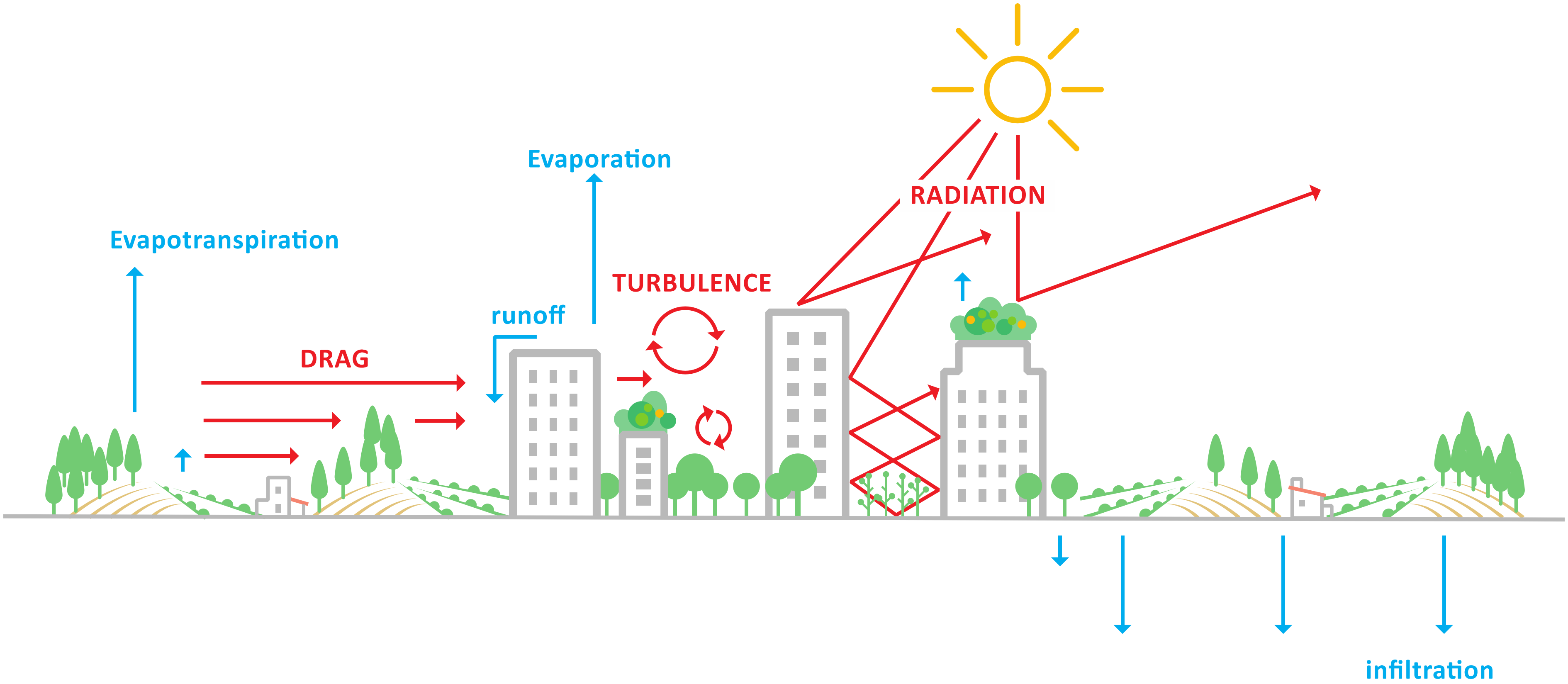
S2.	46%	38%	12%	2%	2%
S3.	45%	32%	20%	2%	2%



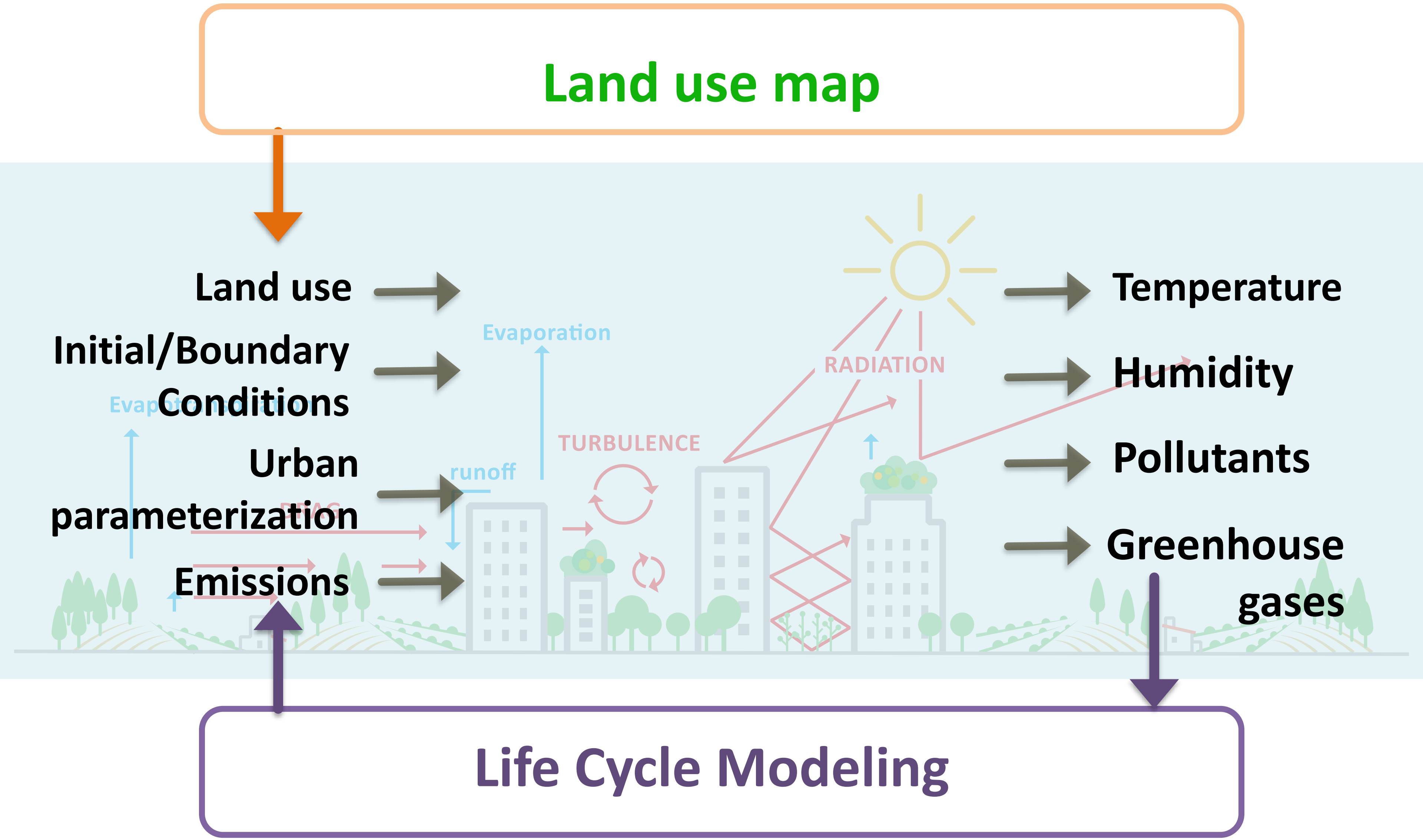


Develop a spatially-temporally resolved framework for quantitative analysis and simulation of green infrastructures

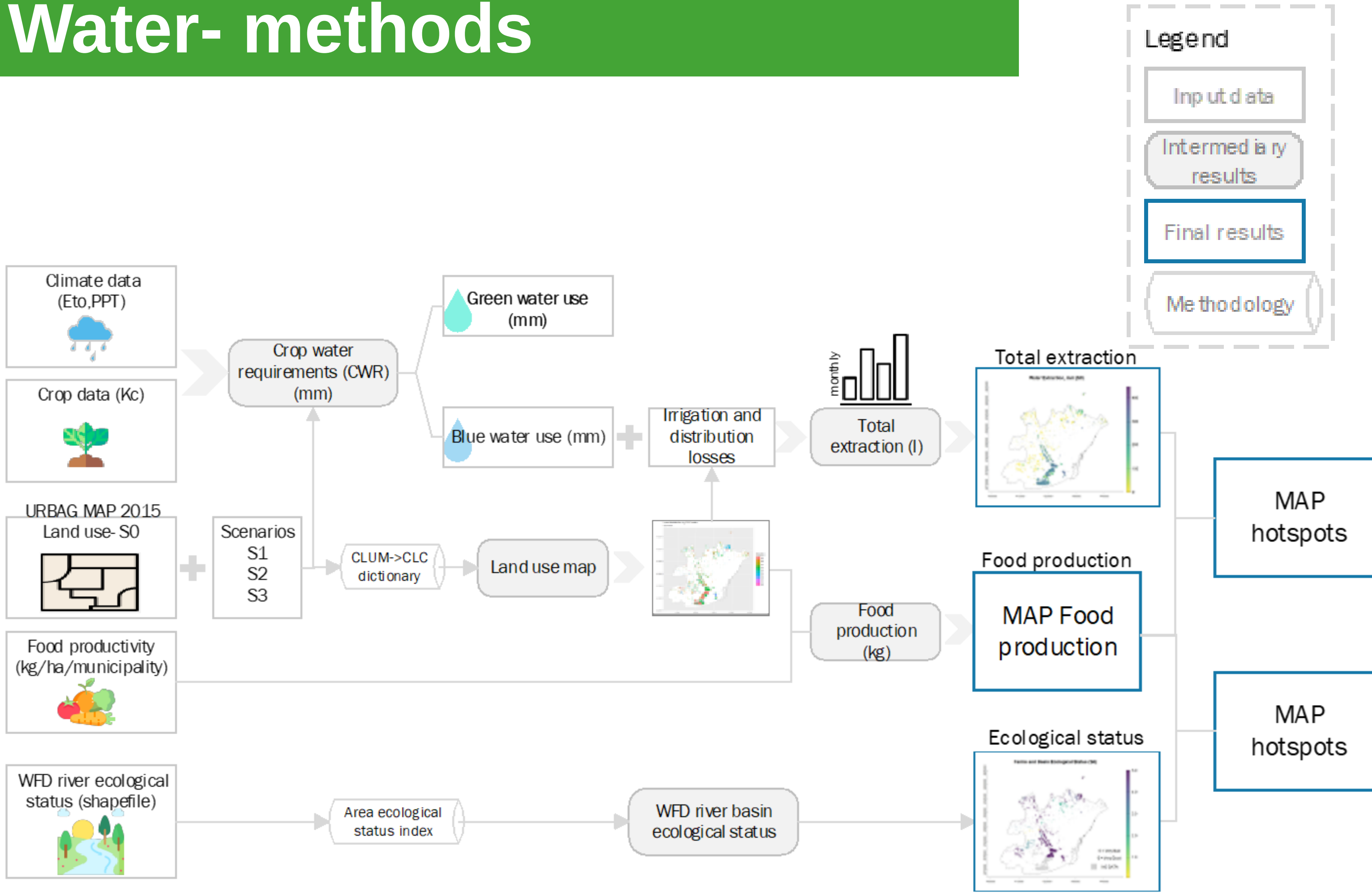
Weather Research Forecasting Model with Chemical Transport and Urban Canopy Model

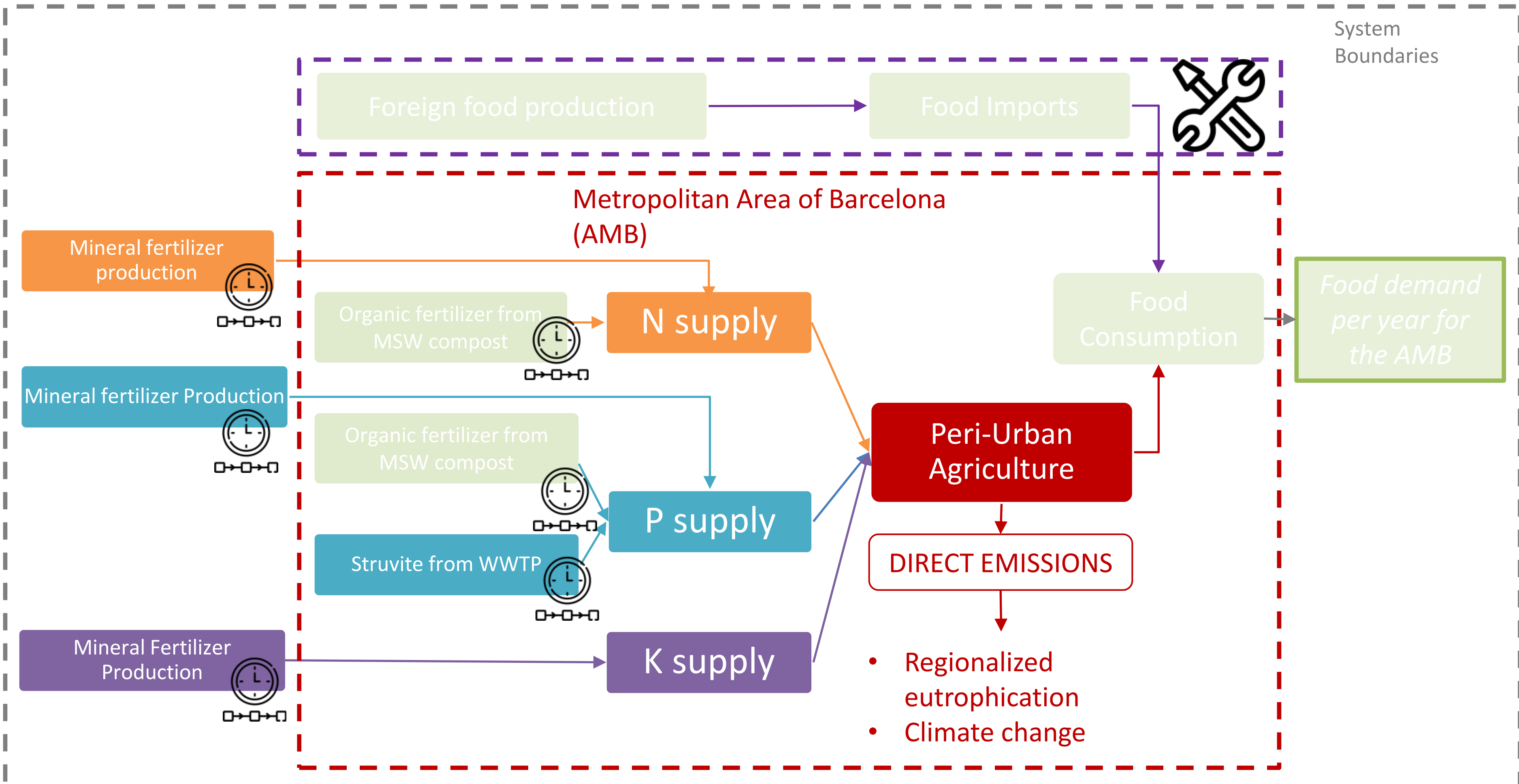


Develop a spatially-temporally resolved framework for quantitative analysis and simulation of green infrastructures.



Water- methods




System Boundaries
Foreign food production
Food Imports
Metropolitan Area of Barcelona (AMB)
Mineral fertilizer production
Organic fertilizer from MSW compost
N supply
Food Consumption
Food demand per year for the AMB
Mineral fertilizer Production
Organic fertilizer from MSW compost
P supply
Peri-Urban Agriculture
Struvite from WWTP
DIRECT EMISSIONS
Mineral Fertilizer Production
K supply
Regionalized eutrophication
Climate change

Scenario Name	Abbreviation	Land cover map	Nutrient supply	Ecoinvent	Prospective scenarios for background	Years	Direct Emissions	Description	Reference
Current peri-UA 100% supply of nutrients from mineral fertilizer	S0_MinFert	S0	NPK from mineral fertilizer only	v3.8 Prospective v3.8	 SSP2_RCP6 SSP2_RCP2.6 SSP2_RCP1.9	2015 2050	NH3_fert_air NH3_struv_air NOx_fert_air NOx_struv_air NO3_groundwater NO3_groundwater_struv N2O_direct_air N2O_direct_air_struv N2O_direct_air_total N2O_indirect_Volat_air N2O_indirect_LeachRunoff_air N2O_indirect_air N2O_total_air PO43_runoff_water PO43_runoff_struv PO43_runoff_water_total	Current peri-UA áreas with 100% supply of nutrients from imported mineral fertilizer. Background impacts calculated for current and prospective ecoinvent.	Land use scenario: Padrò et.al (2020) Background LCI databases: Sacchi et.al (2022)
Current peri-UA P supply from recovered struvite N and K from mineral fertilizers	S0_struvite	S0	P from struvite from WWTP. N and K from mineral fertilizer	v3.8 Prospective v3.8	 SSP2_RCP6 SSP2_RCP2.6 SSP2_RCP1.9	2015 2050	NH3_fert_air NH3_struv_air > zero NOx_fert_air NOx_struv_air > zero NO3_groundwater NO3_groundwater_struv> zero N2O_direct_air N2O_direct_air_struv> zero N2O_direct_air_total N2O_indirect_Volat_air N2O_indirect_LeachRunoff_air N2O_indirect_air N2O_total_air PO43_runoff_water PO43_runoff_struv > zero PO43_runoff_water_total	Current peri-UA areas with 100% supply of P from locally recovered struvite from WWTP. N and K are supplied from mineral fertilizer. Background impacts of current and prospective ecoinvent.	Land use scenario: Padrò et.al (2020) Struvite recovery inventories based on but updated to ecoinvent v3.8: Rufií-Saliís et.al (2020) Background LCI databases: Sacchi et.al (2022)

From theory to practice

Results

Environmental impact resulting in all impact categories considering infrastructure and operation