Anticipating and mapping the future environmental impacts of agrivoltaics around the Mediterranean basin under different climatic and socioeconomic scenarios

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Introduction

Agrivoltaism : a polymorphic system under debate

https://justenergy.com/blog/agrivoltaics/

Allemagne, https://www.lightzoomlumiere.fr/article/agrivoltaisme-velux-et-baywa-r-e-innovent-en-espagne/

Alhendin, Spain, https://www.lightzoomlumiere.fr/article/agrivoltaisme-velux-et-baywa-r-e-innovent-en-espagne/

- Many different configurations
- Different performances
  - For crops
  - For PV production
- Dependent on technology, crop type, climate etc.
- Few LCAs covering few configurations.

Crop	Location	Shading rate	Yield change	References
Lettuce	Santiago, Chile	30%	(−) 8%	[42]
Broccoli	Santiago, Chile	30%	(−) 29%	[42]
Winter Wheat	Heggelbach, Germany	35%	(−) 19% (2017)	[10]
			(+) 3% (heat summer 2018)	
Potato	Heggelbach, Germany	35%	(−) 18%	[10]
			(+) 11%	
Celery	Heggelbach, Germany	35%	(−) 19%	[10]
			(+) 12%	
Clover Grass	Heggelbach, Germany	35%	(−) 5%	[10]
			(−) 8%	
Lettuce (varieties Kiribati and Madelona)	Montpellier, France	Half density, solar tracking, controlled tracking	(−) 5% to (−) 30% with fewer losses on controlled, that is, crop friendly tracking	[46]
Chiltepin pepper	Tucson, Arizona, USA	70%–80%	~ (+) 150%[a]	[40]
Jalapeno	Tucson, Arizona, USA	70%–80%	~ (−) 15%	[40]
Cherry Tomato	Tucson, Arizona, USA	70%–80%	~ (+) 90%	[40]

(Emre et al. 2022)

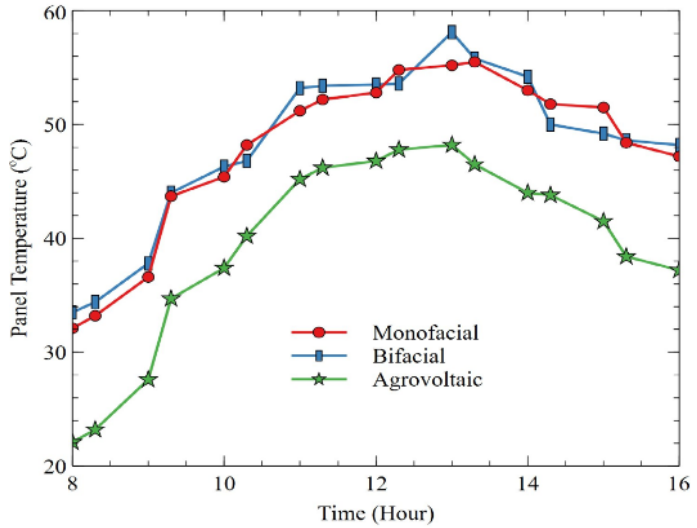


Fig.6. PV panel temperature.

(Anusuya et al. 2024)

A promising system to adapt agriculture to climate change

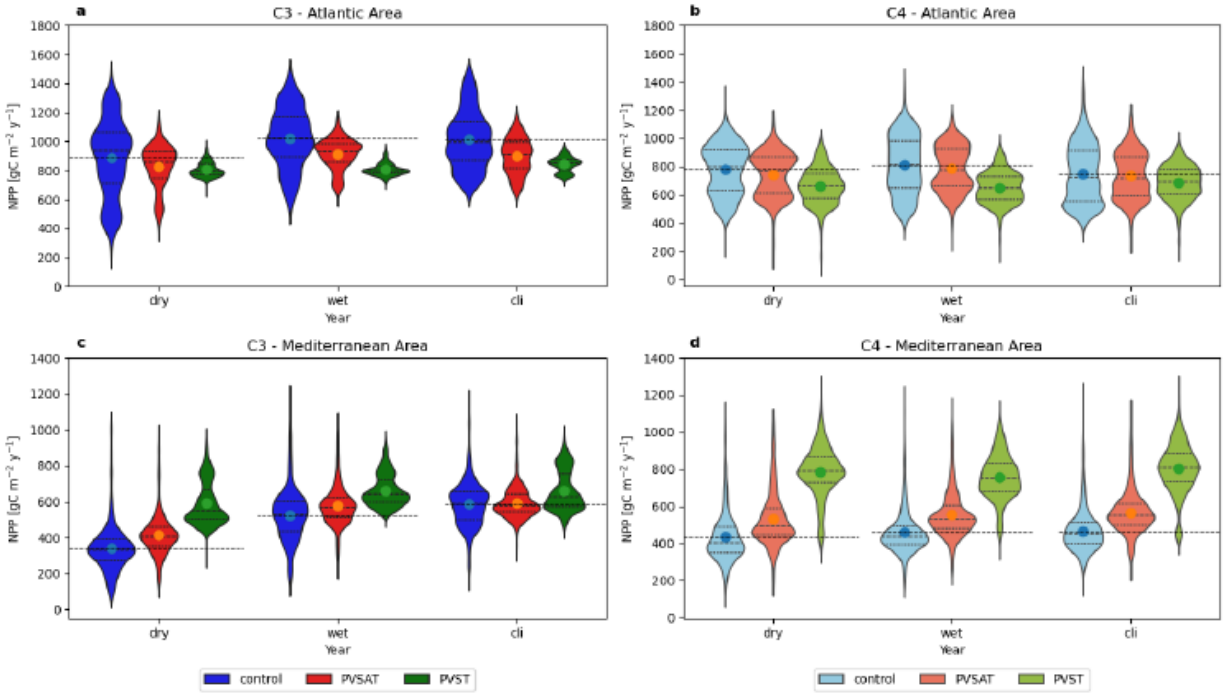
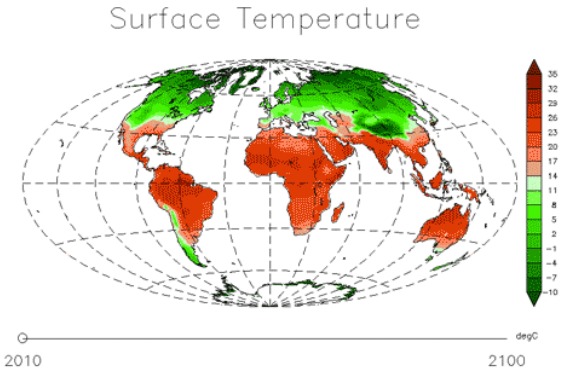


Figure 8. IP. Box plot of the annual NPP [gC $m^{-2}y^{-1}$], grid point values, for each configuration analysed. Panels **a-b** Atlantic area (C3 and C4) panels **c-d** Mediterranean area (C3 and C4). The dots show the mean value for each configuration.

Lia Rapella

+ PV model

ORCHIDEE
LAND SURFACE MODEL



- Higher NPP for AV systems than control conventional cultures in the Mediterranean area.
- Mixed results in other areas, depending on the annual meteorologial conditions.

Research question

Which environmental impacts and benefits for AVS deployment in the Mediterranean basin under different socio-economic pathways and climate trajectories?

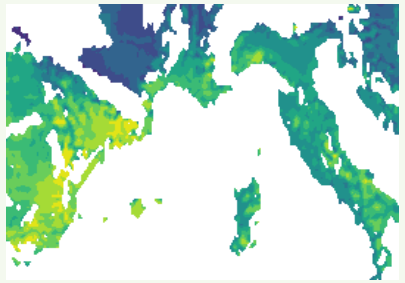
Where and when is it worth supporting AVS deployment ?

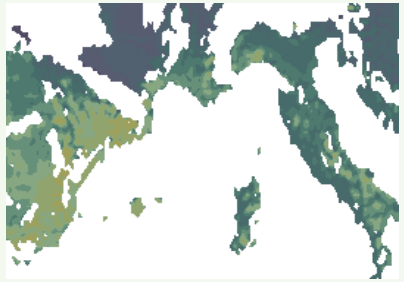
Methods

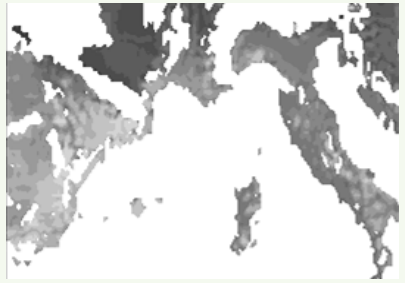
Combining prospective LCA modeling with prospective climatic modeling

Output Orchidee-AV

2030







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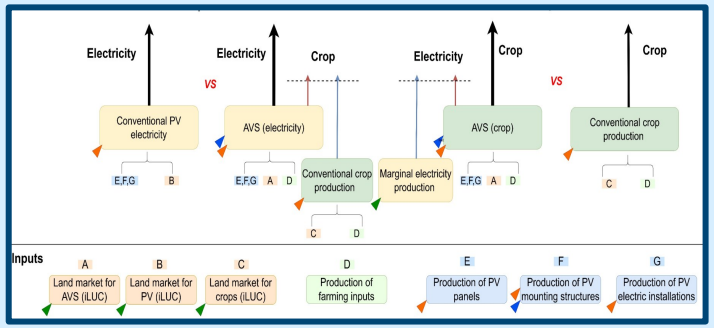
Parameterized LCA model for AV



2030

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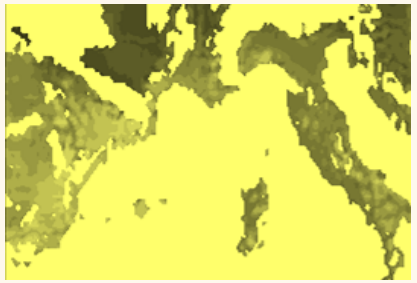
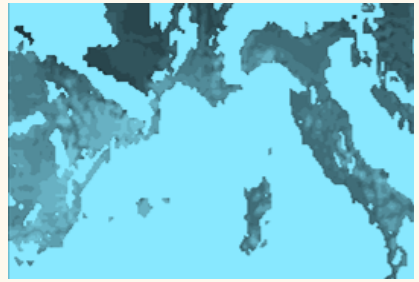
Prospective LCA databases

premise

AV LCA impacts

2030





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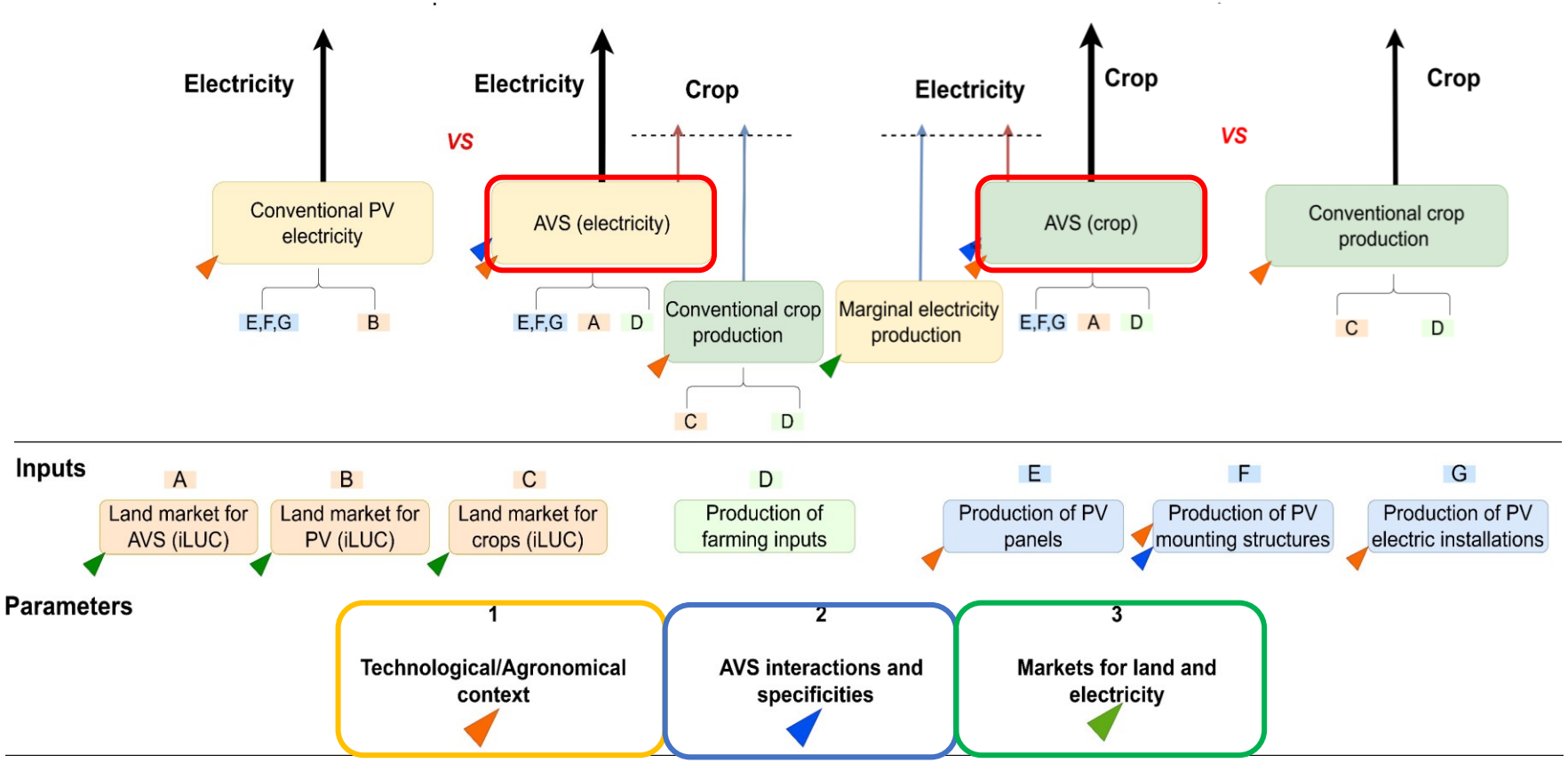
Parameterized Consequential LCA model

- Consequential modeling under two hypotheses regarding the main product of AV.
- Multifunctionality is modeled by substitution.
- Parameterized model
- PV model based on Besseau et al. (2023)
- Crop model based on ecoinvent 3.10 activities
- Includes iLUC modeling from Schimdt et al. (2015)

If demand for electricity drives the deployment of AV
Main product = electricity

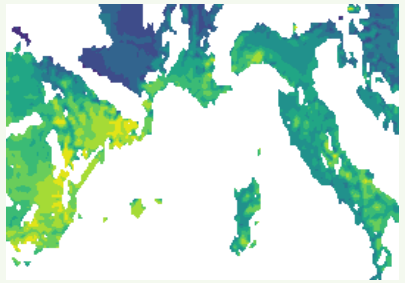
If demand for crops drives the deployment of AV
Main product = crop

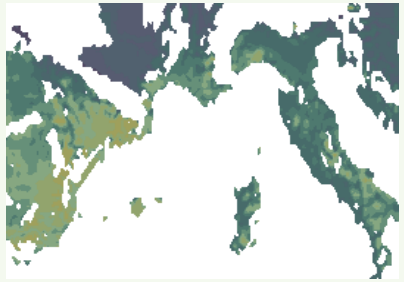


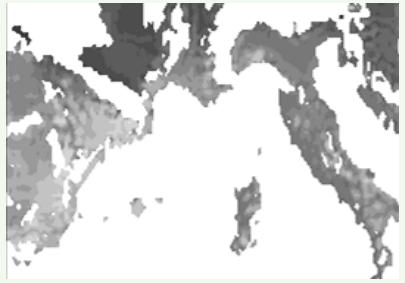
Combining prospective LCA modeling with prospective climatic modeling

Output Orchidee-AV

2030







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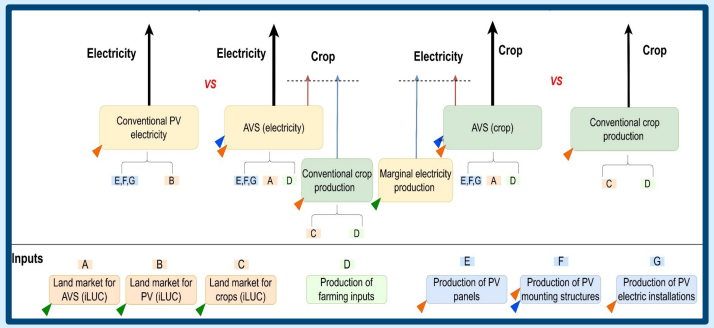

2030

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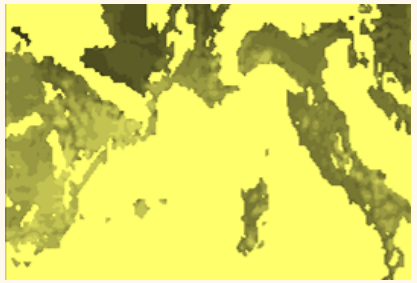
Prospective consequential LCA databases

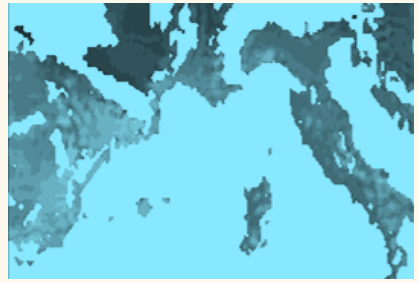
premise

(Maes et al., 2023)

AV LCA impacts

2030





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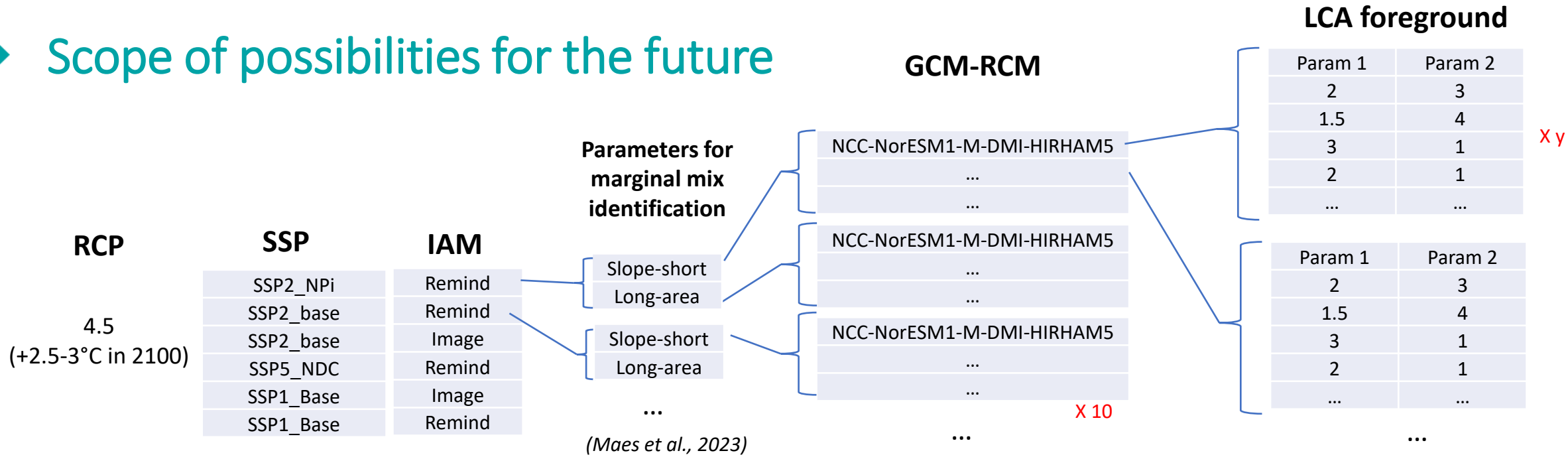
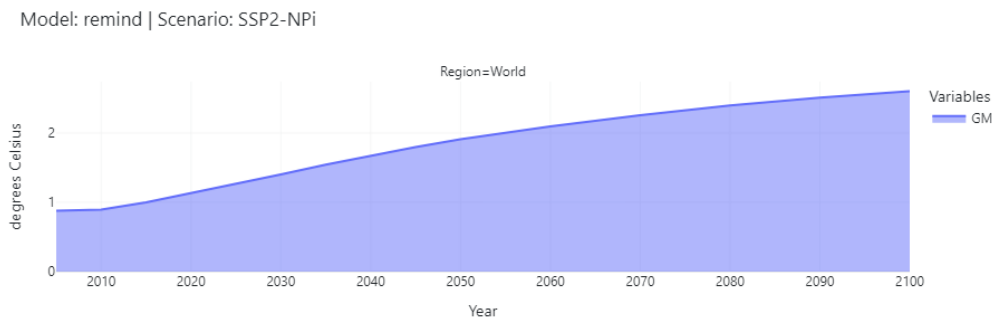
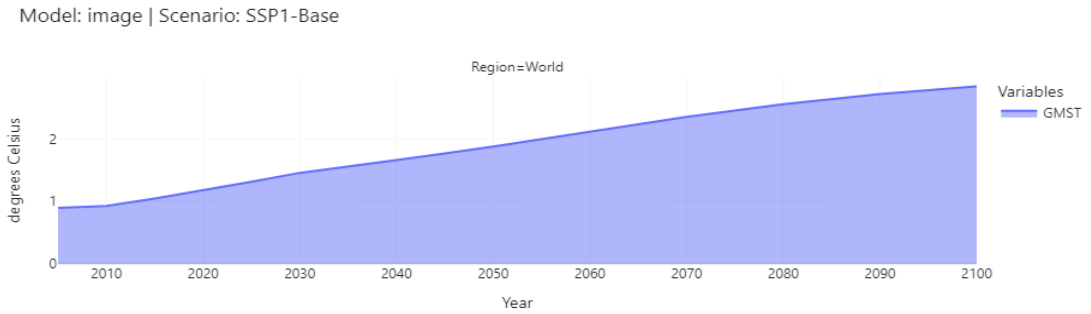
Scope of possibilities for the future



Input parameters to	Orchidee AV	Background LCA db	Background LCA db	Orchidee AV	Foreground LCA





Scope of possibilities for the future

RCP	SSP	IAM
4.5 (+2.5-3°C in 2100)	SSP2_NPi	Remind
	SSP2_base	Remind
	SSP2_base	Image
	SSP5_NDC	Remind
	SSP1_Base	Image
	SSP1_Base	Remind

Parameters for marginal mix identification

- Slope-short
- Long-area
- Slope-short
- Long-area

GCM-RCM

- NCC-NorESM1-M-DMI-HIRHAM5
- …
- …
- NCC-NorESM1-M-DMI-HIRHAM5
- …
- …
- NCC-NorESM1-M-DMI-HIRHAM5
- …
- …

X 10

…

ACV foreground

Param 1	Param 2
2	3
1.5	4
3	1
2	1
…	…

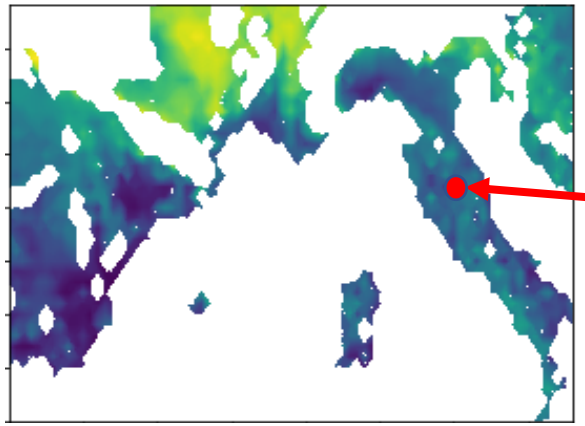
X y

Param 1	Param 2
2	3
1.5	4
3	1
2	1
…	…

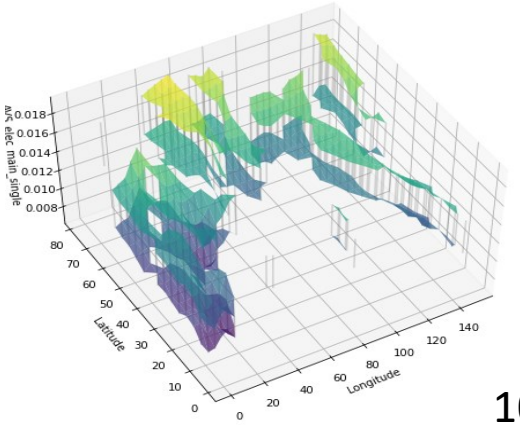
…

(Maes et al., 2023)

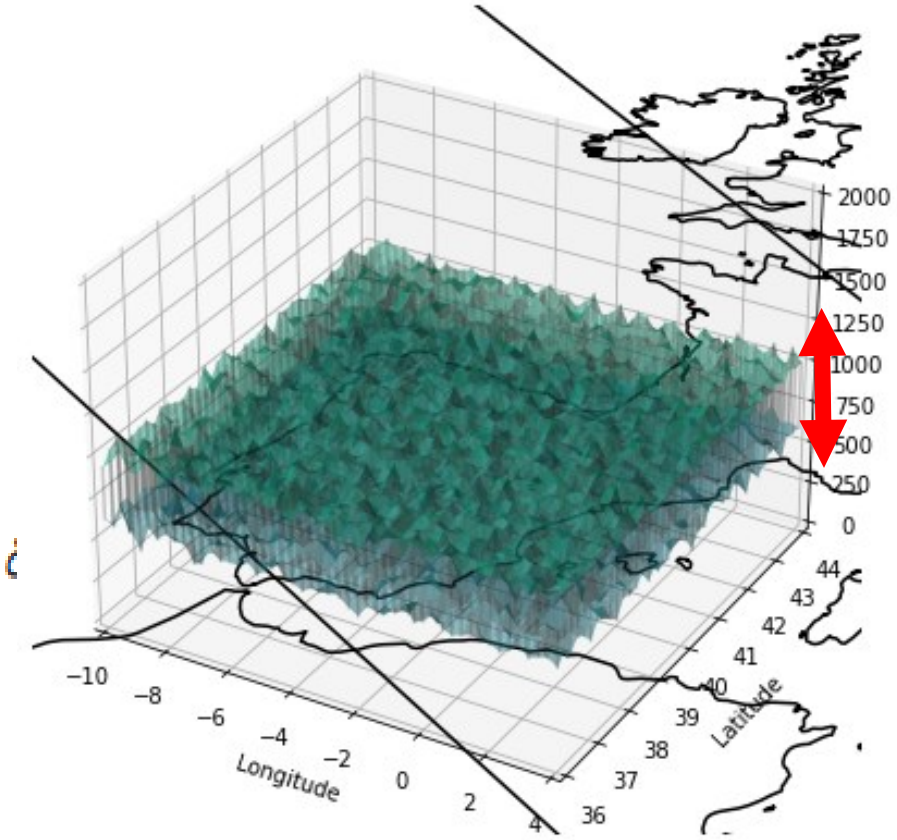
Input parameters to	Orchidee AV	Background LCA db	Background LCA db	Orchidee AV	Foreground LCA



1 point → 6 * 2 *10 * y impact values → Scope of possibilities



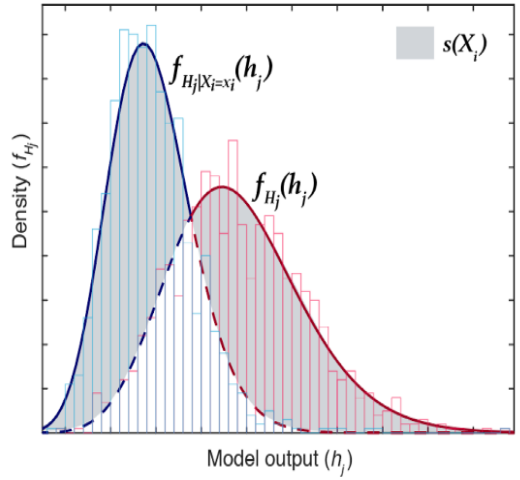
Understanding where the incertitude comes from



Is the output variability mostly due to:

- The background SSP scenarios ?
- The parameters for marginal mix identification ?
- The different climate models ?
- The foreground uncertainty/variability ?

Moment-independent GSA and statistical tests



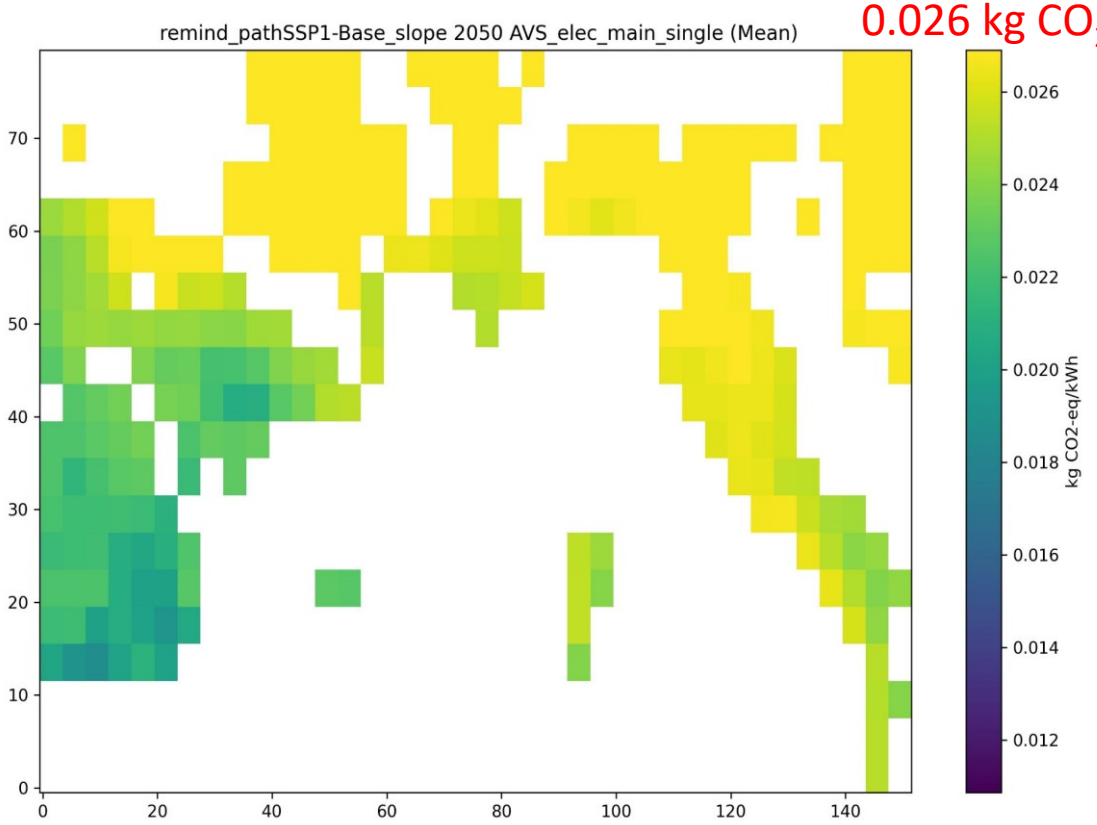
Summary of key differences between AV and conventional PV considered in the model

- Different densities of panels per hectare → Affects iLUC and land-use impact
- Different mounting structures
- AVS imply crop productions with higher or lower yields than conventional ones (substitution)

Preliminary Results

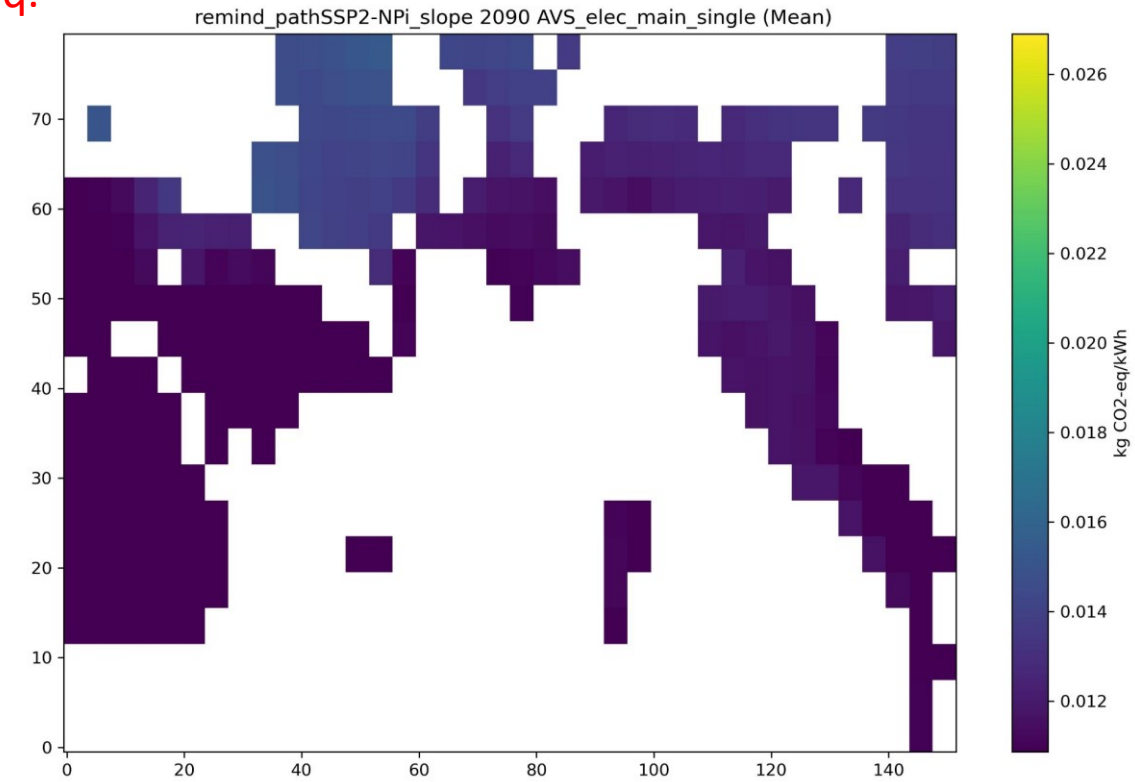
Impact per kWh of AVS (electricity = main product)

0.026 kg CO_2-eq.



SSP1-Base
2050

0.012 kg CO_2-eq.



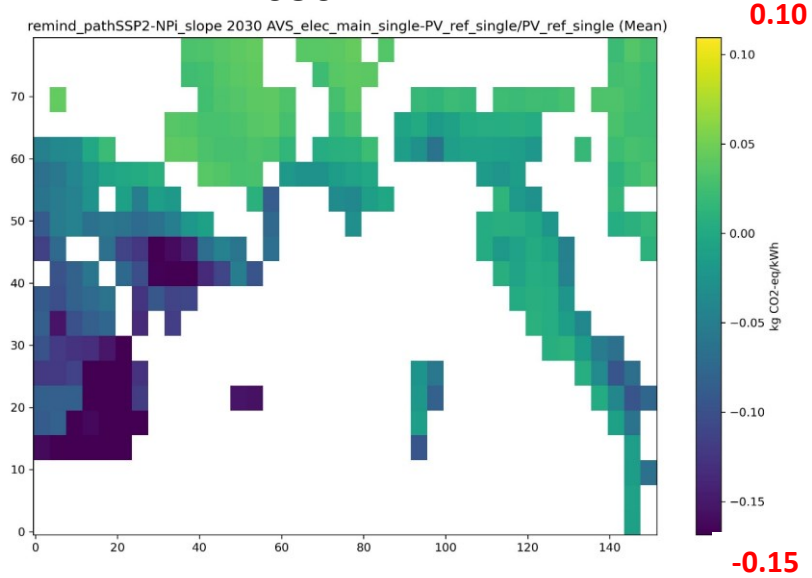
SSP2-NPi
2090

The evolution of AVS benefits over the century is not necessarily monotonous

(Imp(AVS)-Imp(PV_ref))/ Imp(PV_ref))

SSP2-Npi *(Slope)*

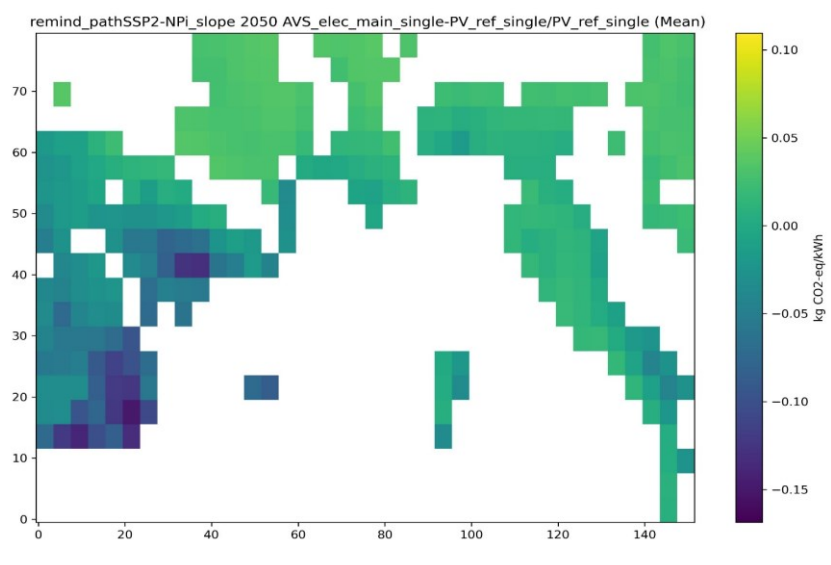
2030



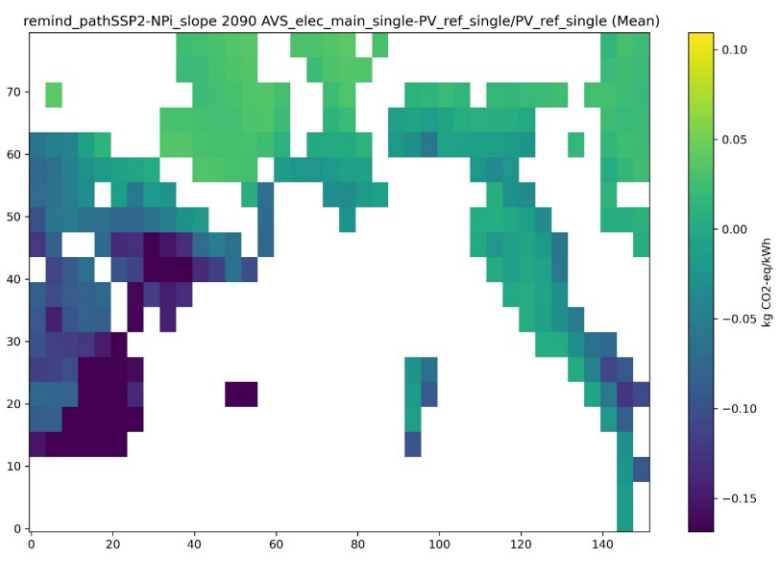
0.10

-0.15

2050



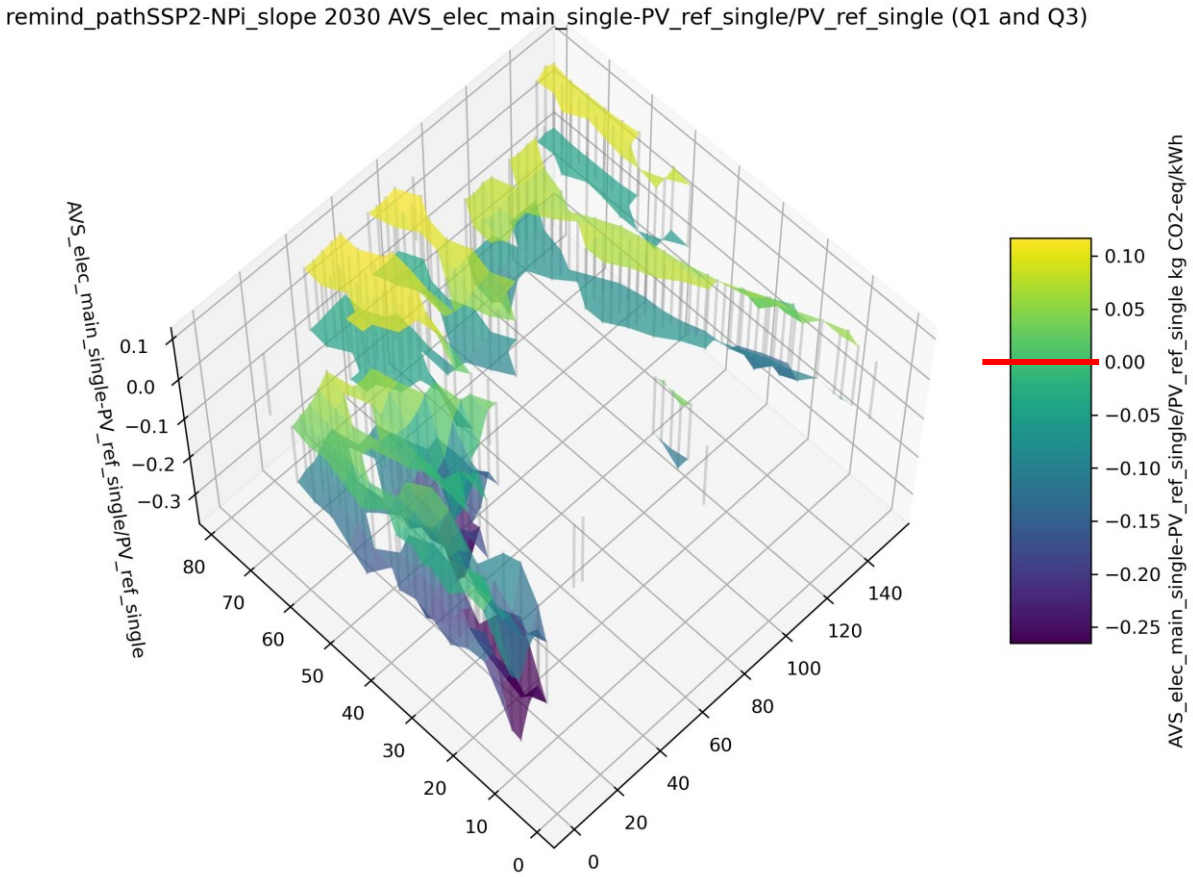
2090

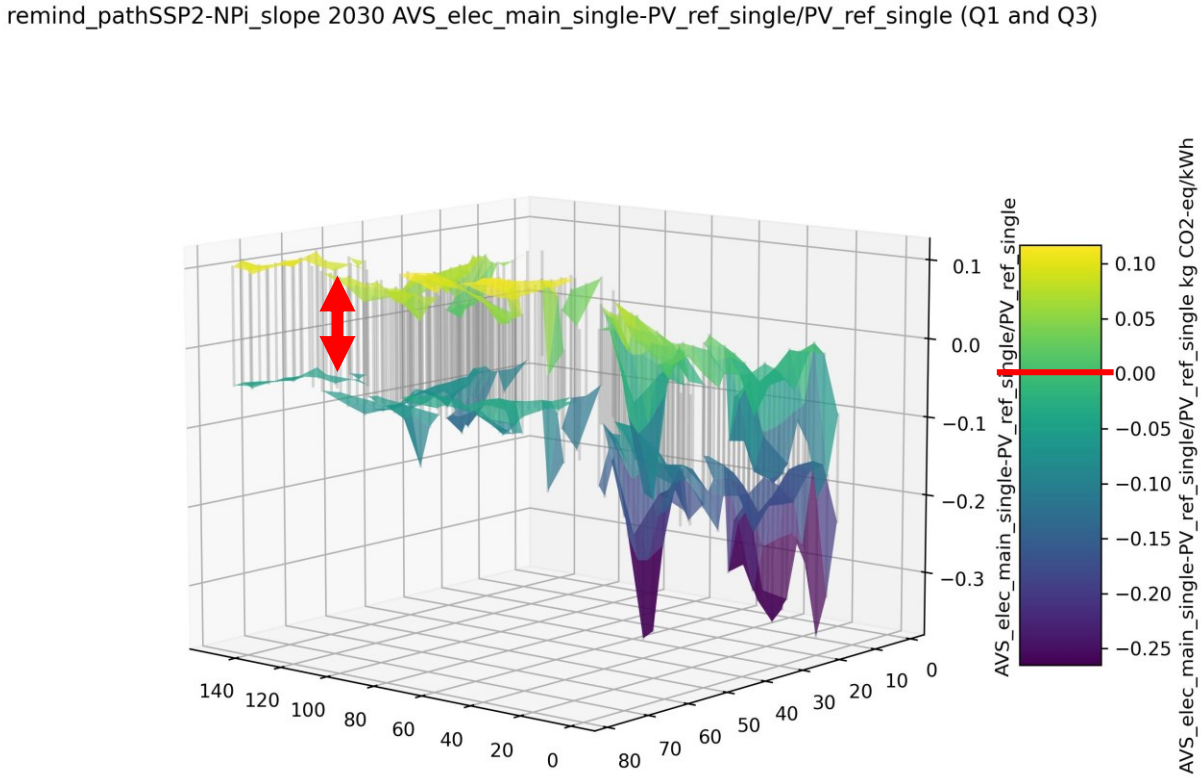


Scope of possibilities

(Imp(AVS)-Imp(PV_ref))/ Imp(PV_ref))

2030

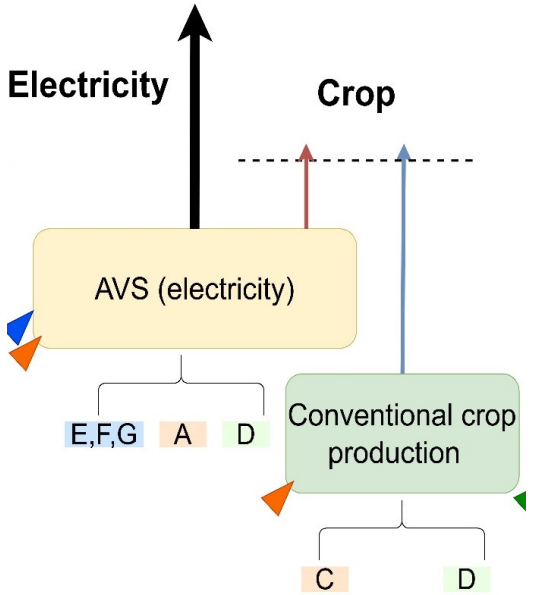




Limits, next tasks and conclusion

Limits

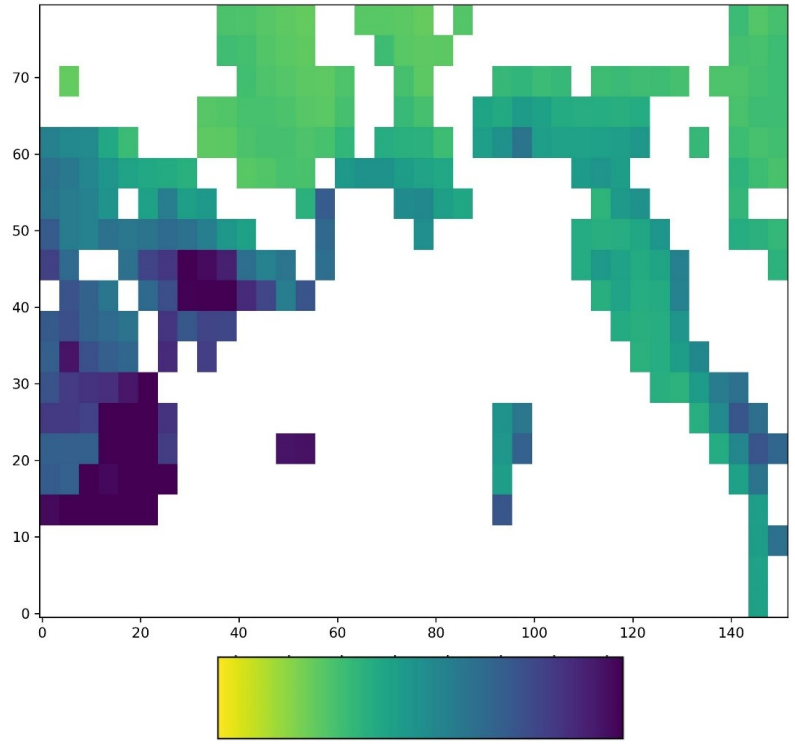
- **Intrinsic to Orchidee AV:**
  - Non-irrigated crops.
  - Generic C3/C4 crop model.
  - No adaptation of the practices/inputs/outputs.
- **Intrinsic to premise databases:**
  - Aggregation of national mixes into bigger regions.
  - Only energy, steel and cement are updated.
- **Intrinsic to consequential modeling of AVS:**
  - Plausibility of the future economic models.
  - **Where is the marginal supply for the co-produced crop?**



Marginal crop = Conventional crop = Nearby crop

Further work

- Sensitivity analysis of the LCA model and of the Orchidee AV model.
- « Nested Discernibility » analysis accross SSP scenarios and across uncertain values per SSP scenarios.
- Calibration of the conversion of NPP to actual yields.
- Refining of uncertainty ranges for the LCA foreground parameters (PV mounting structures etc.)
- Assessing yield stabilities and water efficiencies.
- Carbon accumulation in the soil for AVS.



Nested discernability

% of SSP-scenarios for which median(Imp(AVS))<median(Imp(Pvref))

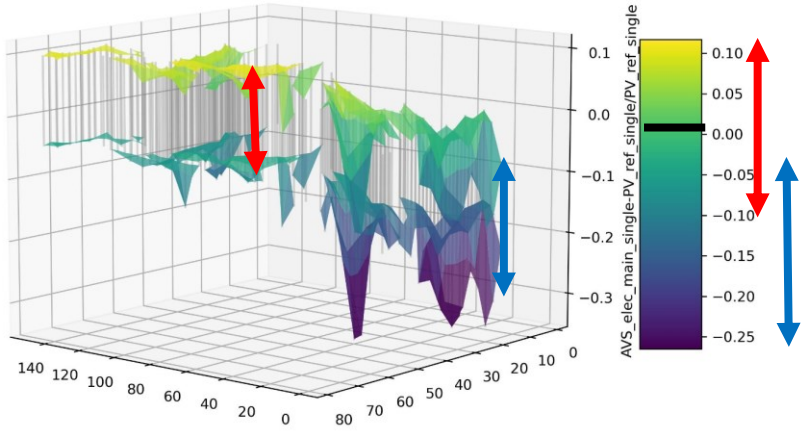
within a SSP- scenario: % of climate models for which median(Imp(AVS))<median(Imp(Pvref))

Etc.

Conclusion

- Prospective LCA coupling prospective background (future economies) and foreground (future agro-climatic conditions).
- Extended assessment of the scope of possibilities and the associated incertitude for better decision-making.
- Preliminary results for the deployment of AVS across the European mediterranean basin show interesting potential for AVS with uncertain conclusions in the northern parts.

remind_pathSSP1-Base_slope 2030 AVS_elec_main_single-PV_ref_single/PV_ref_single (Q1 and Q3)



Thank you for your attention

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