Climate and land use change impacts on plant diversity, pollinators and crop yields in Western Europe

MAPPY project

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The MAPPY STUDY

Objectives:

Integrated modelling of crop, pasture and forest plant species, as well as pollinator distribution in the context of climate and land use changes

Raise awareness and inform professionals for adaptation of their practices.

MAPPY

Multisectorial Analysis of climate and land use change impacts on pollinators, plant diversity and crop yields

MAPPY includes 9 partners from 5 countries
is funded by the AXIS programme of JPI-Climate

LIÈGE université · Université de Namur · Naturalis Biodiversity Center · Utrecht University · Universität Kassel · Senckenberg world of biodiversity · PIK · CSIC · BOKU

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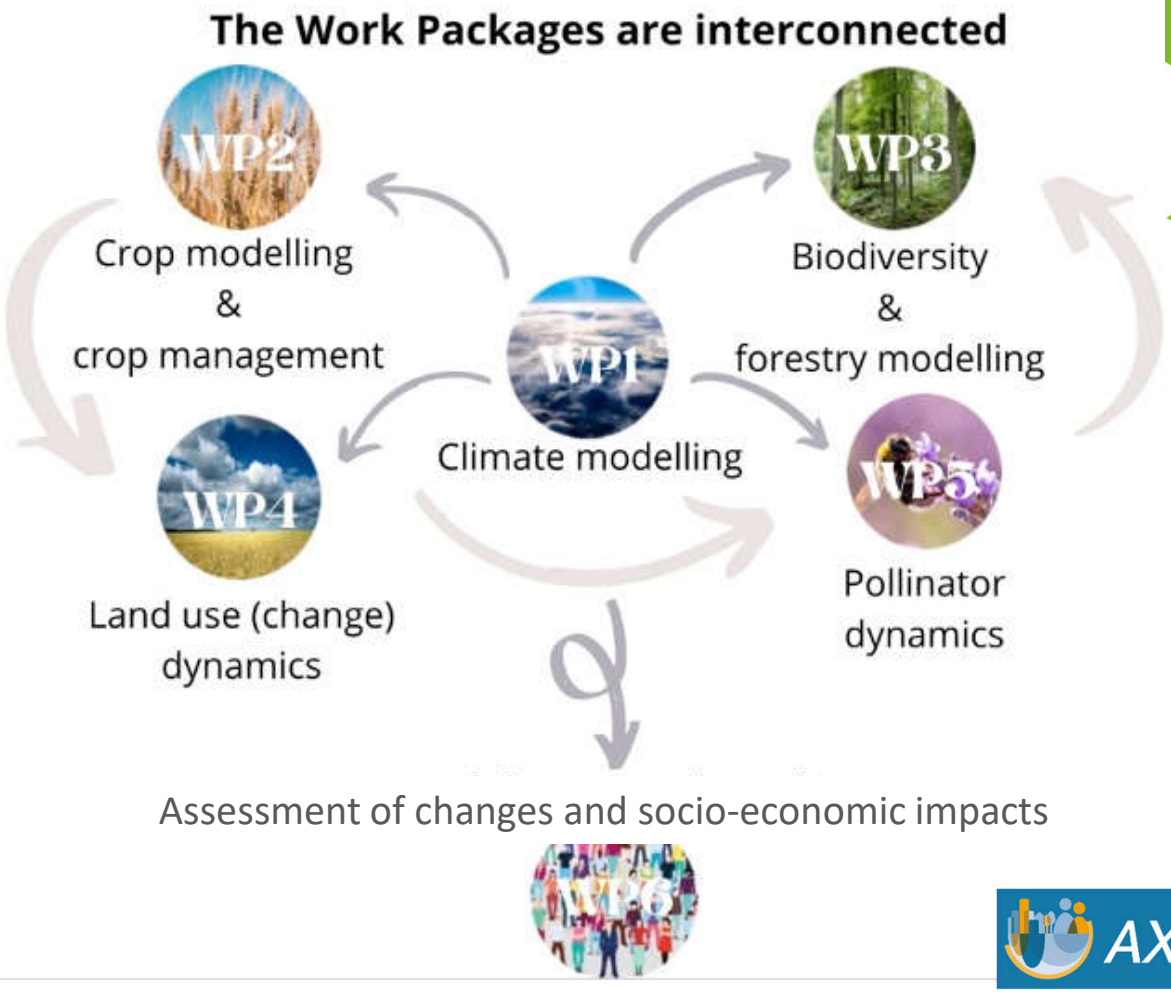
The MAPPY Study

The MAPPY study is one of the first to quantify these processes in an integrated manner, using models that identify their interactions and interrelations.



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Case study sites

Austria: Eisenwurzen Nature Park (5740 km^2)

Belgium: Wallonia (16844 km^2)

Germany: River Rur catchment (2354 km^2),

Rhine-Main area (11000 km^2) and Frankfurt City Forest

Netherlands: South-western area (10000 km^2)

Spain: Cordoba Province in Andalusia (13771 km^2)

WP1 Climate simulations

COSMO-CLM regional climate model

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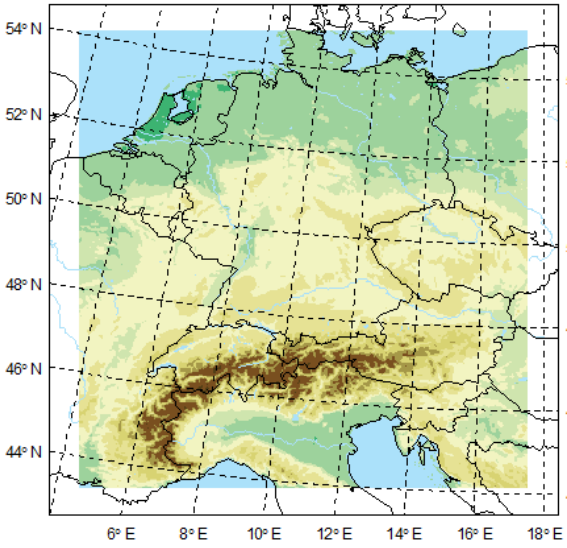
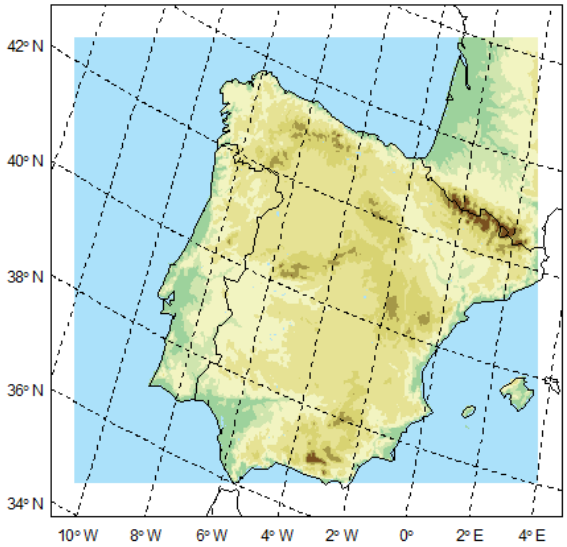
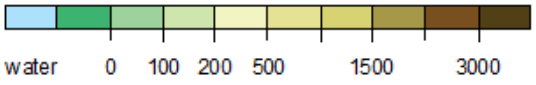
Simulation domains and work steps

Central Europe



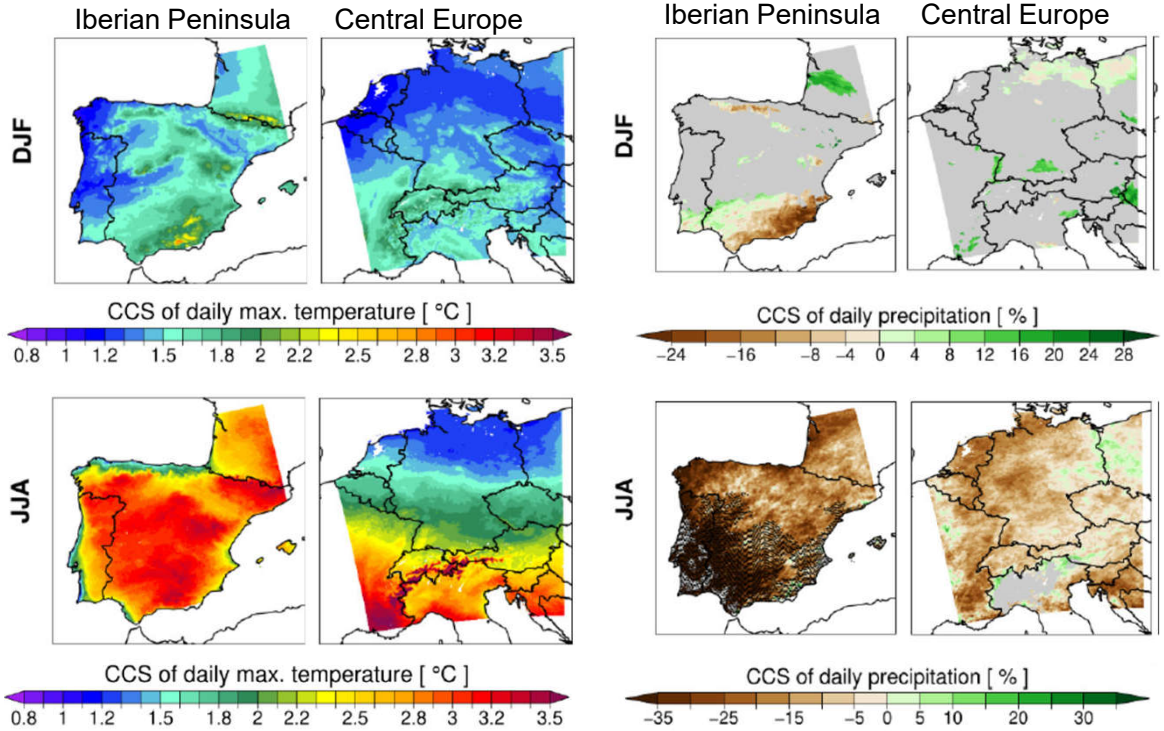
Iberian Peninsula





- Adaption of km-scale at 3 km in the regional climate model COSMO5.0-CLM16
- Evaluation of regional climate model configuration based on ERA5 reanalysis data for 1980 to 2020
- Historical and projection simulations based on RCP8.5 and RCP2.6 for 1980 to 2070
- Bias correction of the scenario simulations
- Dissemination of climate simulations

Climate Change Signal 2041-2070 versus 1981-2010



- RCP8.5 scenario
- T_{max} increases in all seasons with strongest increases in summer months
- Precipitation decreases, especially in summer, in both regions

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WP2 Crop yield simulations

Crop models:

Spanish site: OliveCan, FruitCan, Dssat 4.8

Central European sites: LPJ-ml, CARAIB

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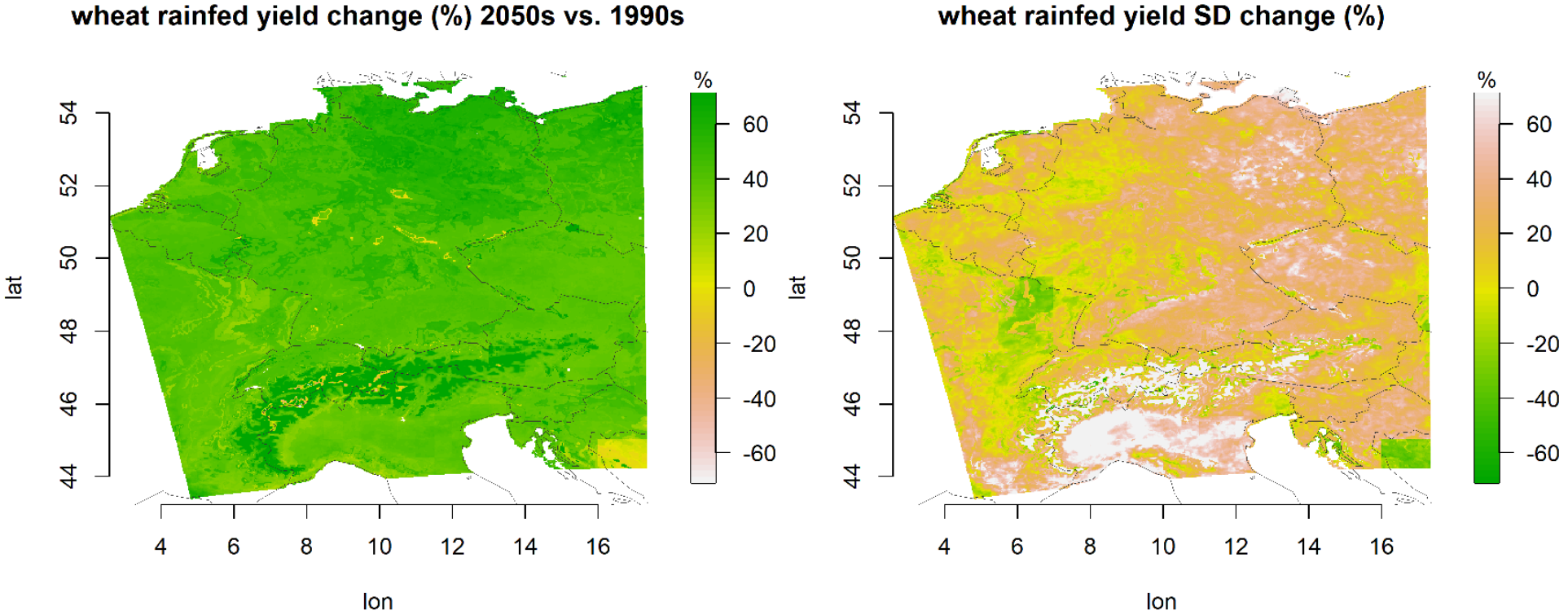
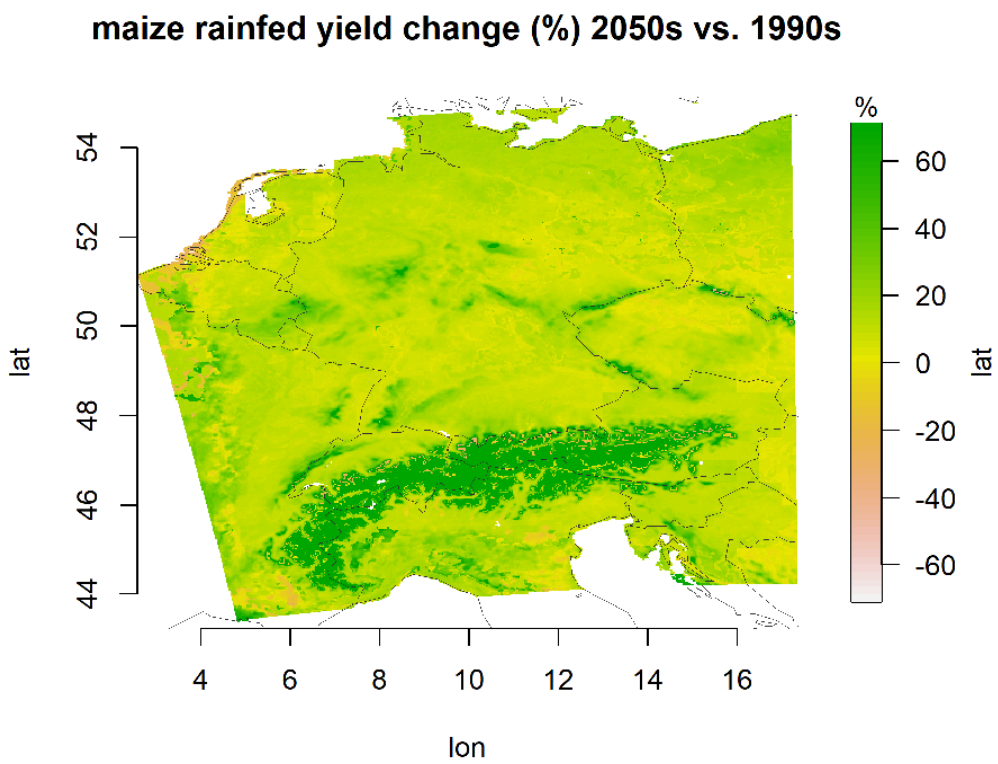
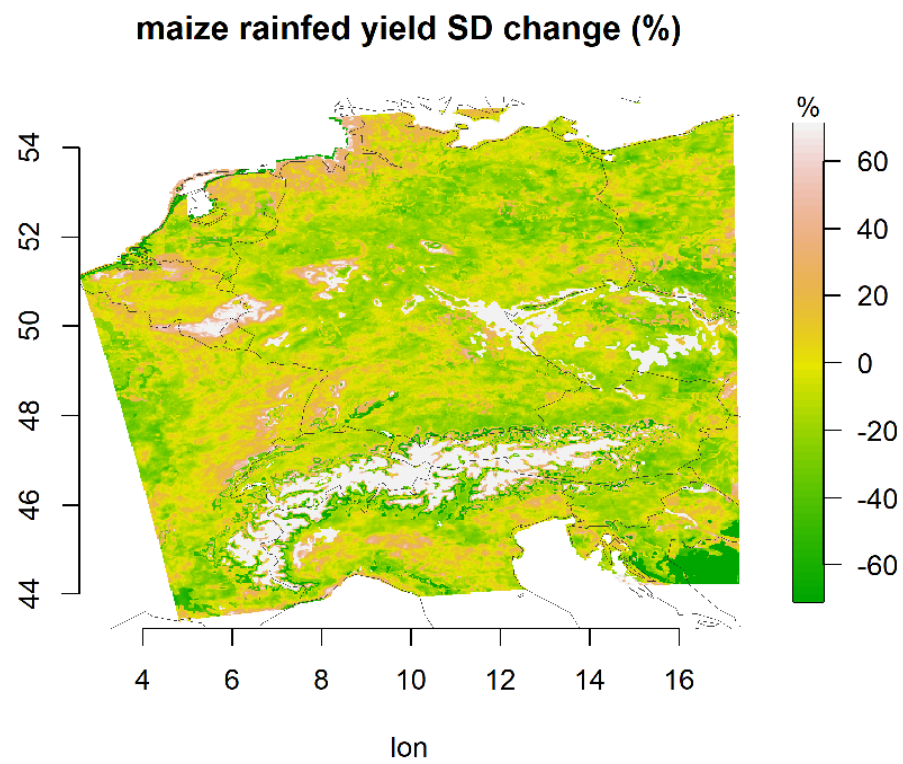
Wheat yields increase, variability does, too



Projected yield changes with LPJmL model, comparing 2040-2069 vs. 1981-2010. Changes >70% are shown as 70%.

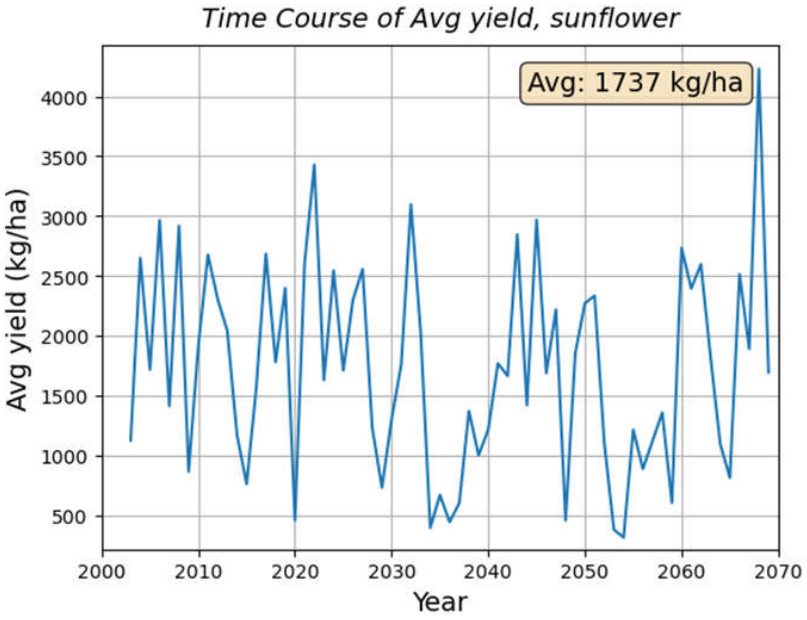
Maize yield changes are small, variability is mixed

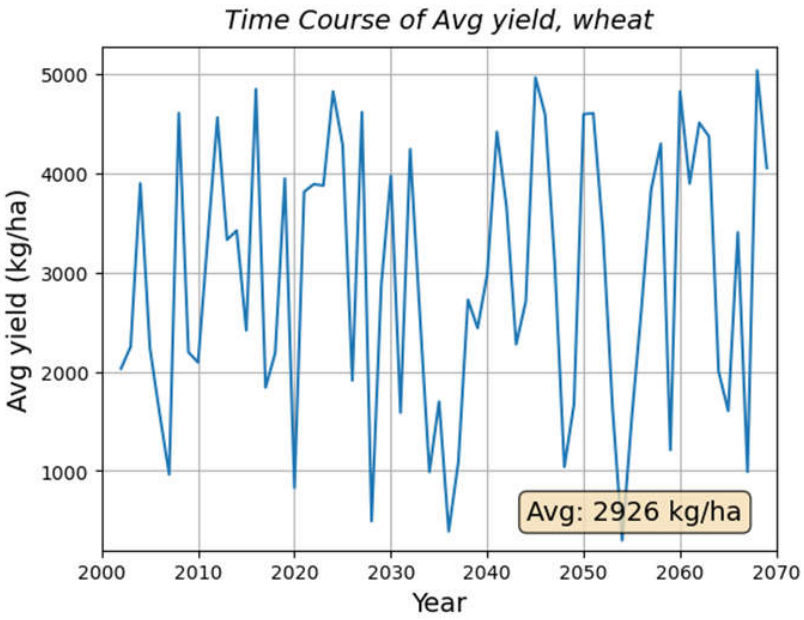




Projected yield changes with LPJmL model, comparing 2040-2069 vs. 1981-2010. Changes >70% are shown as 70%.

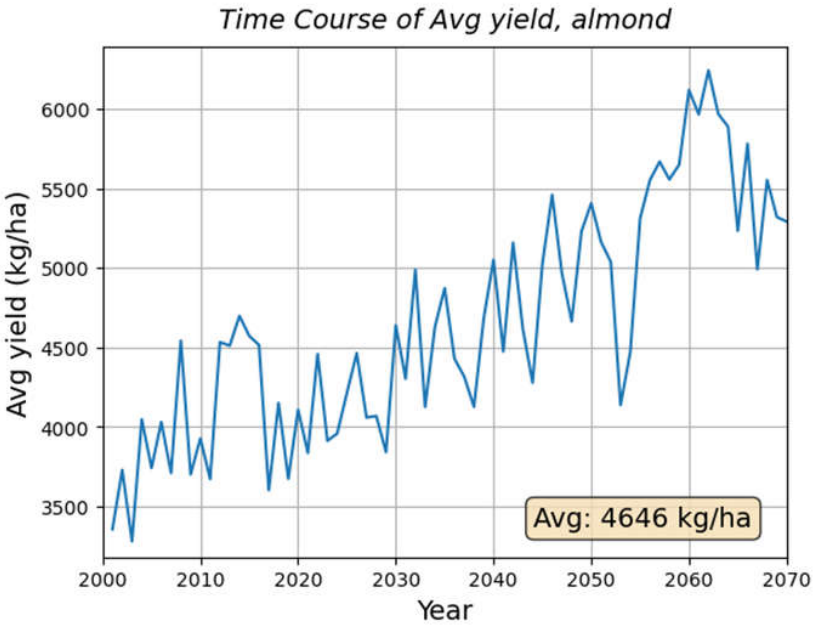
SUNFLOWER / WHEAT YIELDS

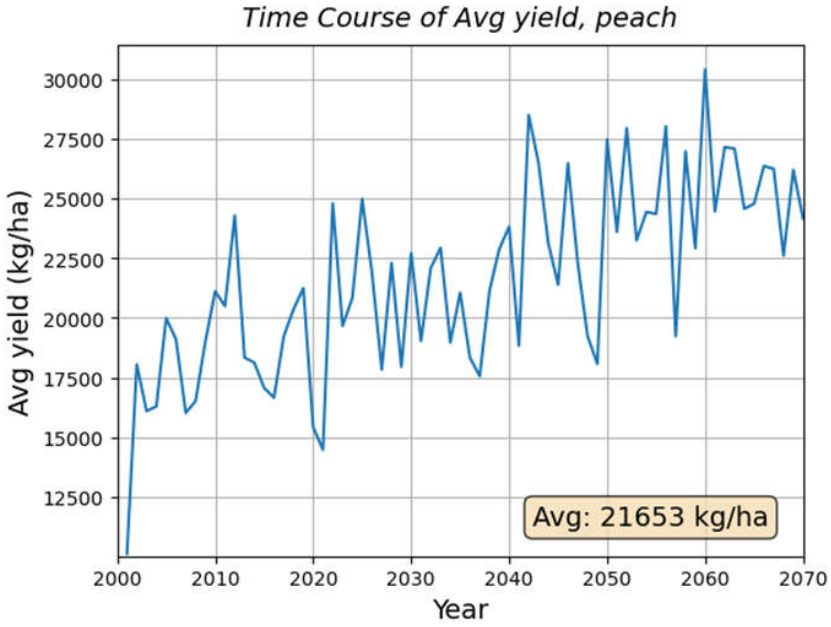




Time course average of the Spanish study site.
Wheat and Sunflower are the main rainfed crops in the province, normally in rotation. They will slightly reduce their productivity, with strong annual variability due to the dependence on the precipitation regime.

ALMOND AND PEACH YIELDS





Time course average of the Spanish study site.

Almond and peach will increase substantially their productivity due to the CO_2 enrichment. As normally well irrigated crops, the impact of the future increased water use is more than compensated

The increase stops in the decade 2060-2070, as [CO_2] will approach the saturation of C3 photosynthesis

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Senckenberg Biodiversity and Climate Research Centre (BiK-F)

WP3 Forests

Dynamic vegetation models:

LPJ-GUESS (forest openess)

CARAIB (forest openness ; understorey plant diversity)

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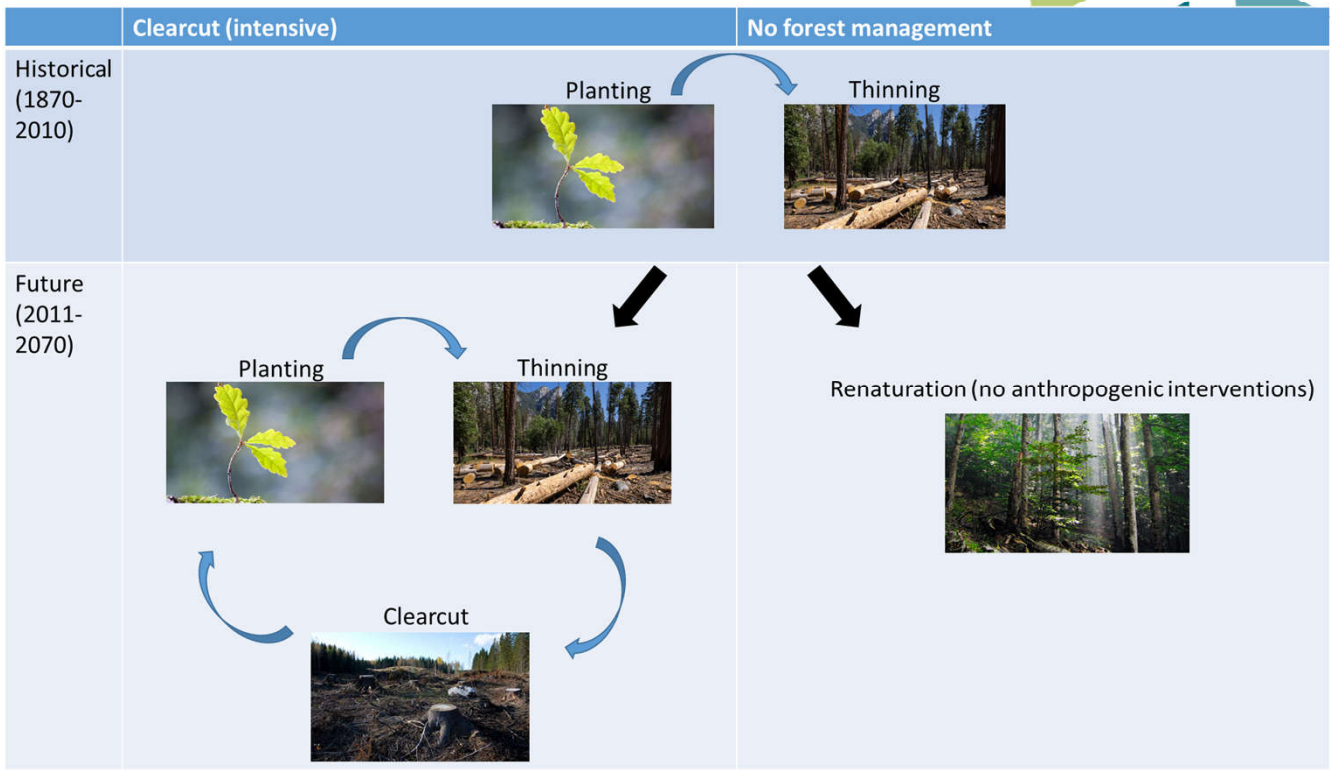
LPJ-GUESS setup

- COSMO-CLM climate data (RCP2.6 & RCP8.5)
- Two future forest management scenarios
  - Instensive forest management scenario (clearcut & thinning)
  - No forest management scenario (renaturation)



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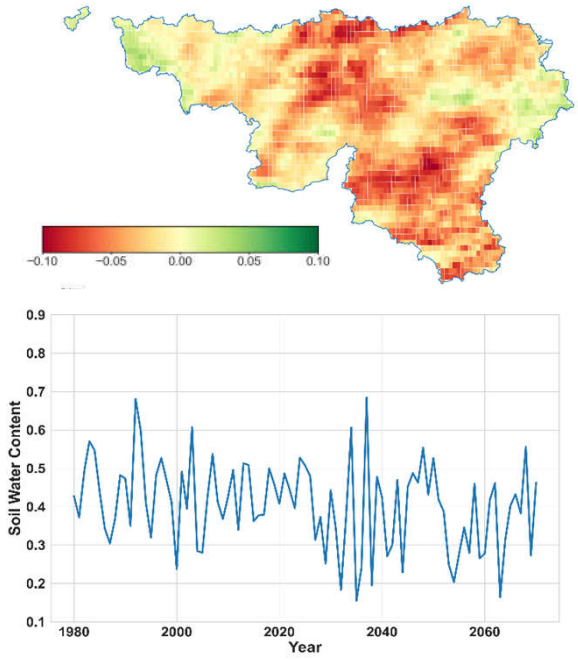
Impact of climate and forest management on forest density

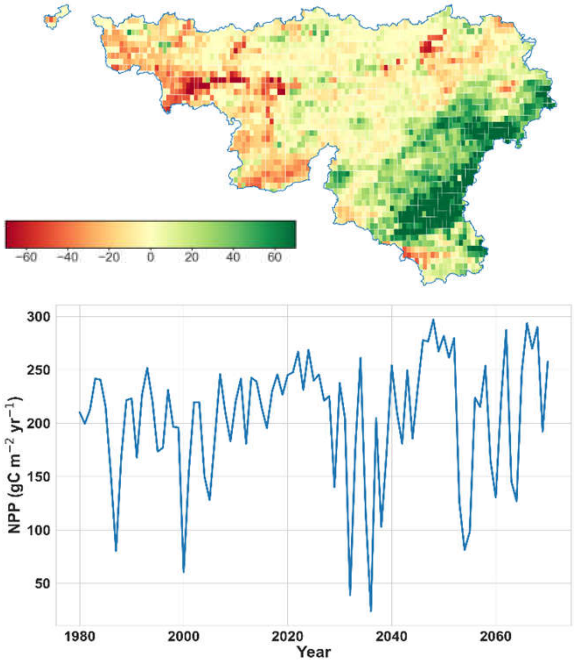
- More open forests with dense understorey vegetation in managed forests
- More productive forests under RCP8.5 due to CO_2-fertilization effect

Climate impact on forest understorey plant species used by pollinators (CARAIB)

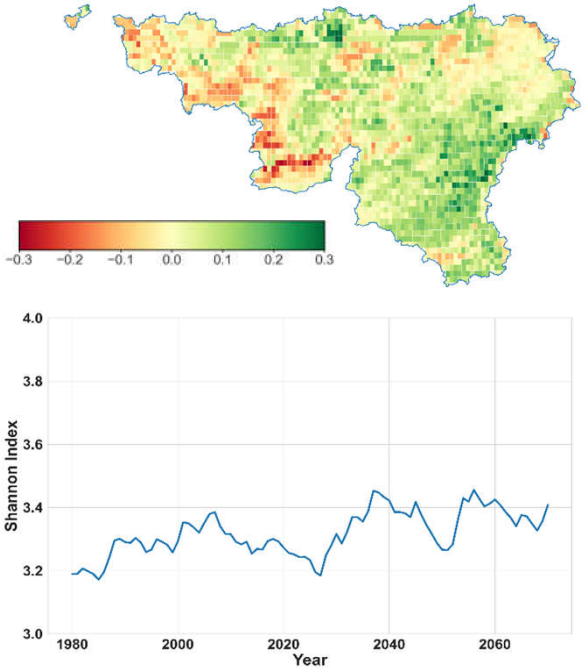
Minimum Monthly Soil Water Content (relative units)
Anomaly between 2060-2070 and 2000-2010
Wallonia



Understorey Net Primary Productivity ($g\ C\ m^{-2}\ yr^{-1}$)
Anomaly between 2060-2070 and 2000-2010
Wallonia



Shannon Index of Understorey Species (index of diversity, dimensionless)
Anomaly between 2060-2070 and 2000-2010
Wallonia



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WP4 Land use dynamics

Land use agent-based model

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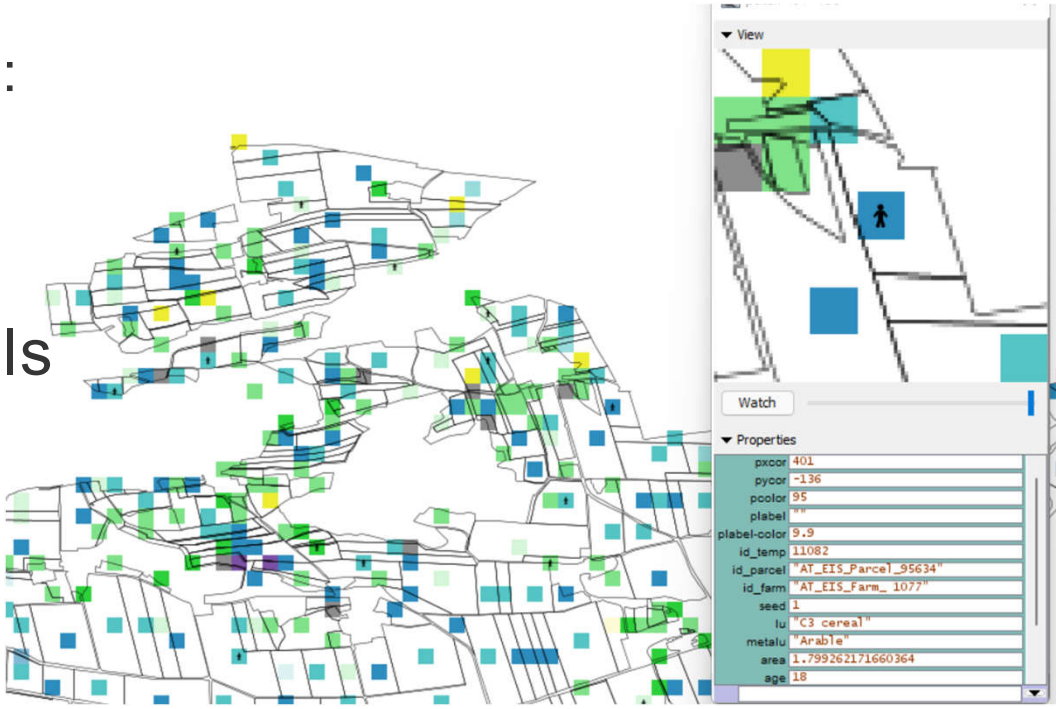
Land-use agent-based model

- **Agents** are farmers
  - Aging with time and interacting with other agents through the redistribution of agricultural parcels
  - Making decision at the farm level:
    - **to be the most profitable**
    - **to align to regulations**
- **World** is the assembly of parcels
- **Stochastic** model



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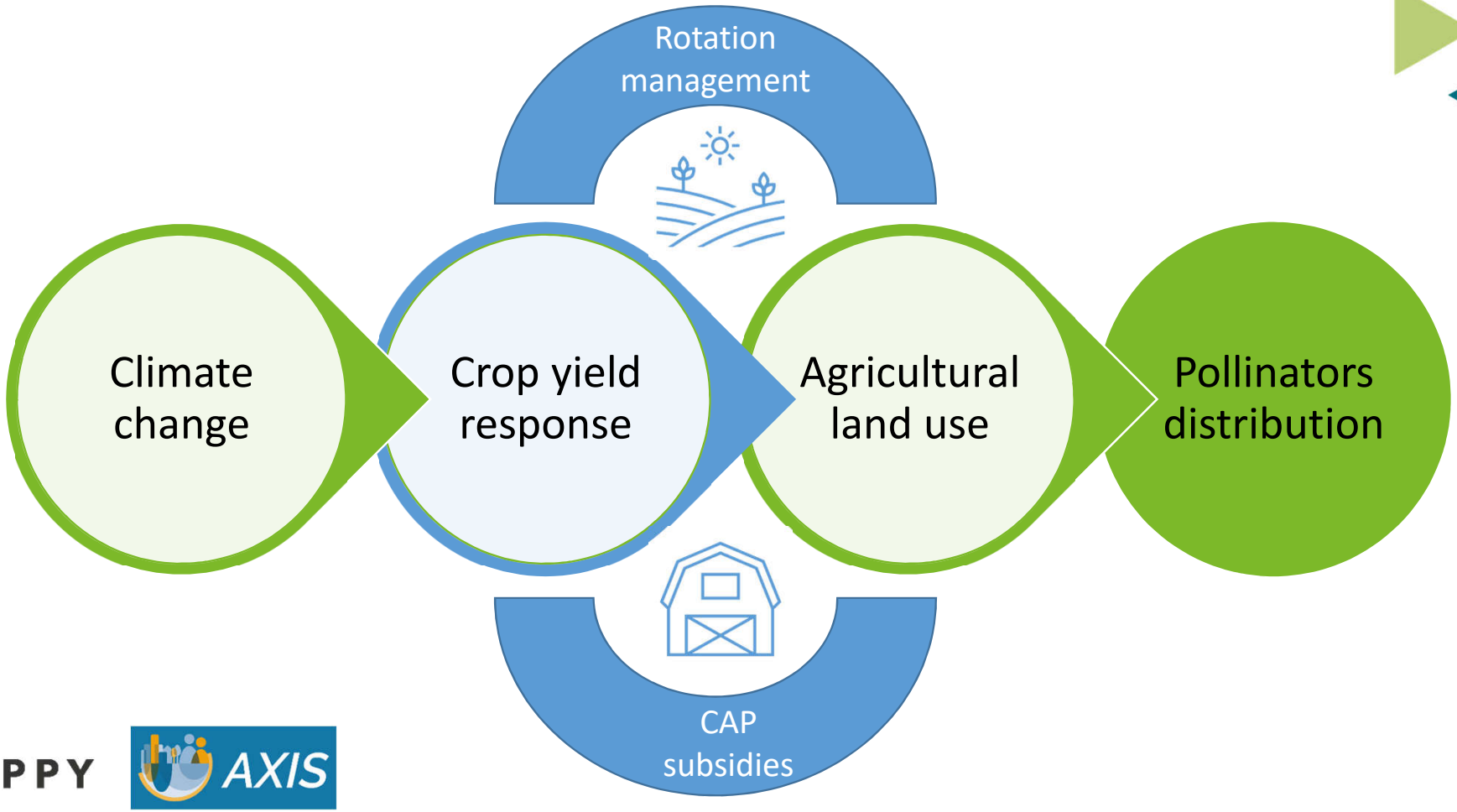
Decisional parameters



Economical scenarios
in addition to climatic scenarios

Regional communities	Global economy
• More small farms • Less abandoned land • Grassland are protected • Crop diversity mandatory • Ecological features mandatory	• Less and bigger farms • More land abandoned • No protection on grassland • No conditionality on crop diversity • No conditionality on ecological features

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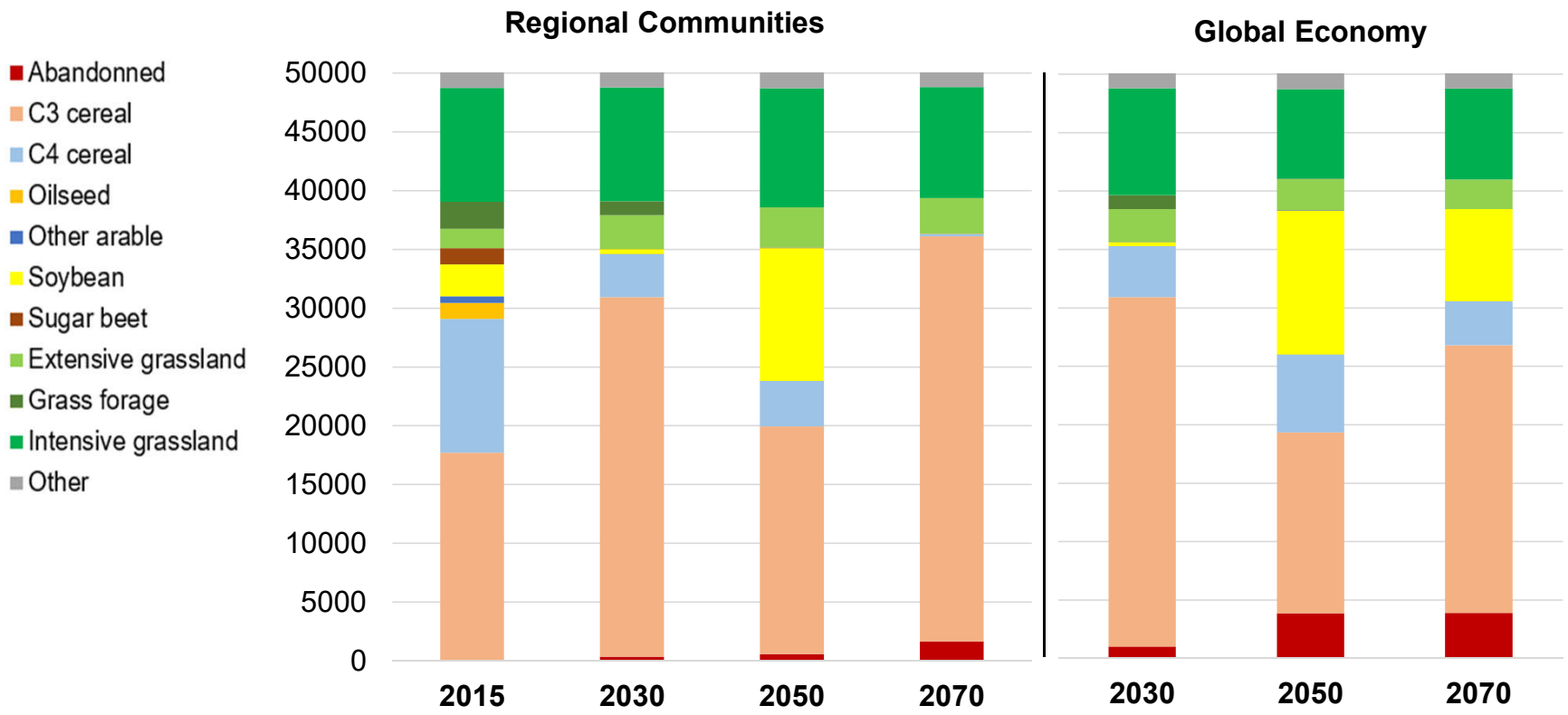
* Alpenvorland region, situated in the North of the study site where most crop from the site is located.

Austrian case study
The cropland* region in RCP2.6



40 runs per scenario
Most probable crops

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WP5 Pollinator dynamics

Species distribution models

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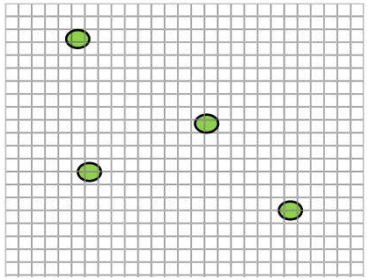
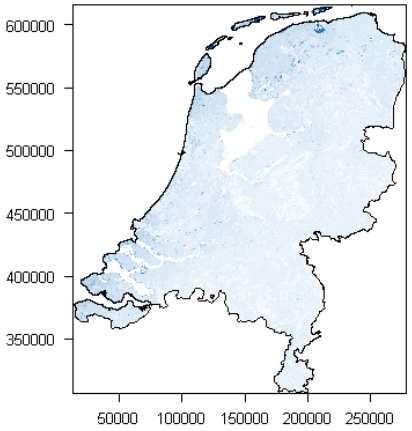
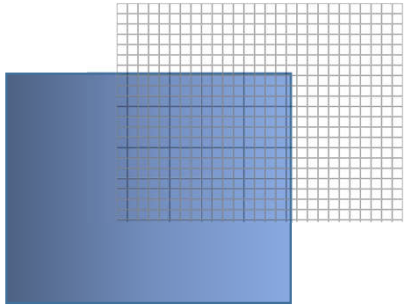
Species distribution modeling

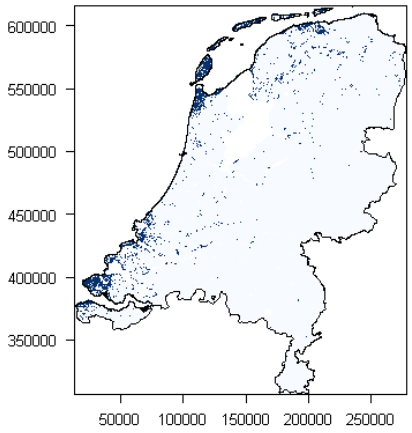
Observations





Environmental variables





Species distribution models are numerical tools that **combine occurrence or abundance data with environmental predictors** [1]. These results can be used for habitat suitability map or environmental correlates.

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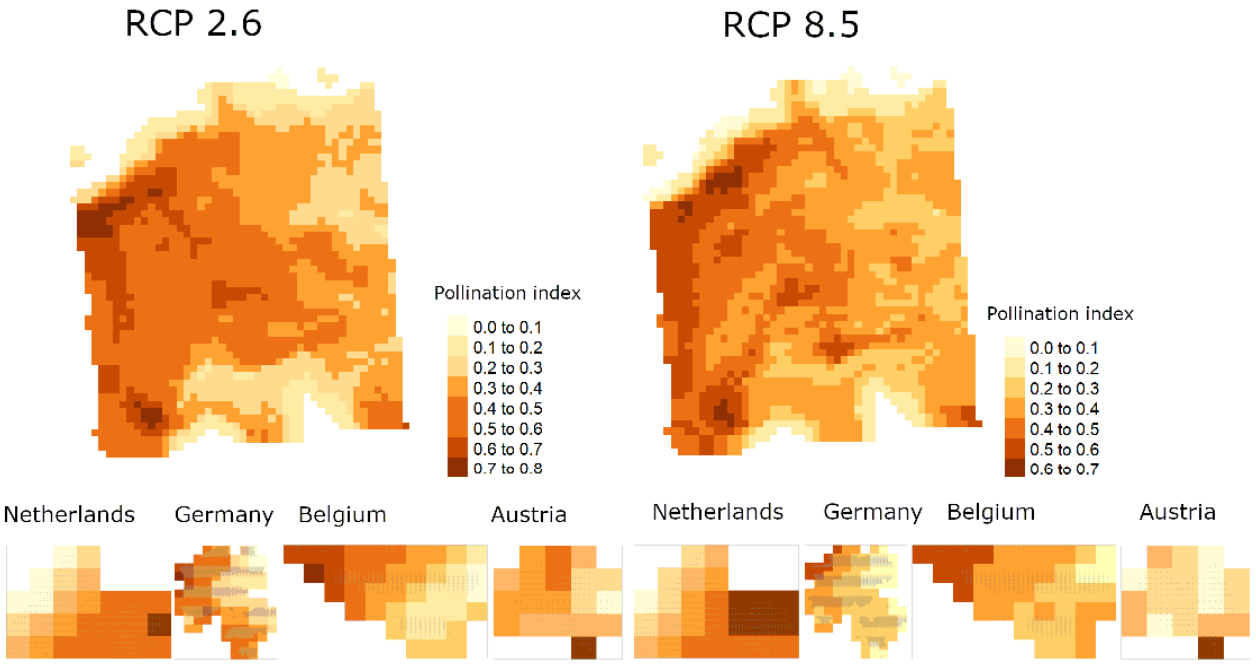
Hierarchical modeling approach

Broad-scale climate models
Resolution 25 km-25km

Small-scale land use models ~3 km

A hierarchical modelling approach [2] involved **large-scale models with climate variables** from WP1 and **small-scale models** with land-use and forest variables from WP3 and WP4 [2].

Results large-scale climate predictions



The large-scale models included a **pollination index** with key crop pollinators in different climate scenarios.

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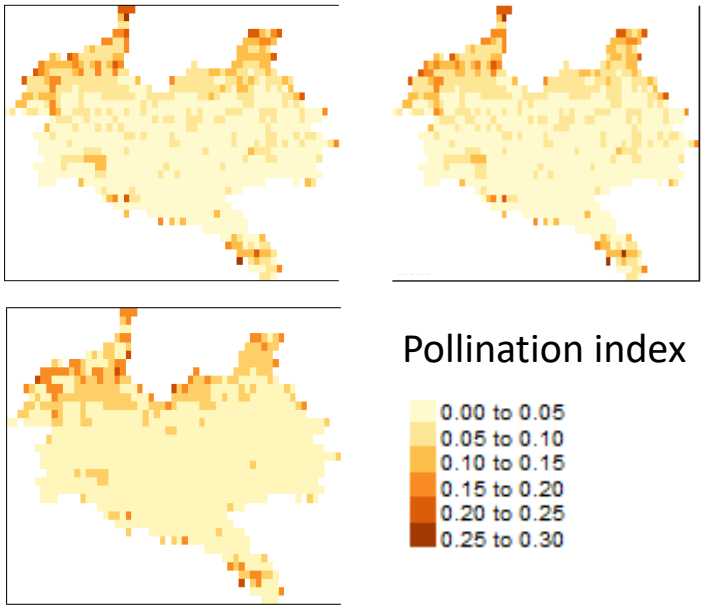
Results small-scale land use predictions

Austrian case study

Brassica napus



Pollination index

\+

72 scenarios

\+

- *Helianthus annuus*
- *Malus domestica*
- *Pyrus communis*
- *Vicia faba*

The small-scale pollination index maps of specific crops were compared between **different scenarios of land use change and forest management** as input. In total we made predictions for 72 scenarios.

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WP6 Socio-economic impacts

Integrating the results from WP1 to WP5

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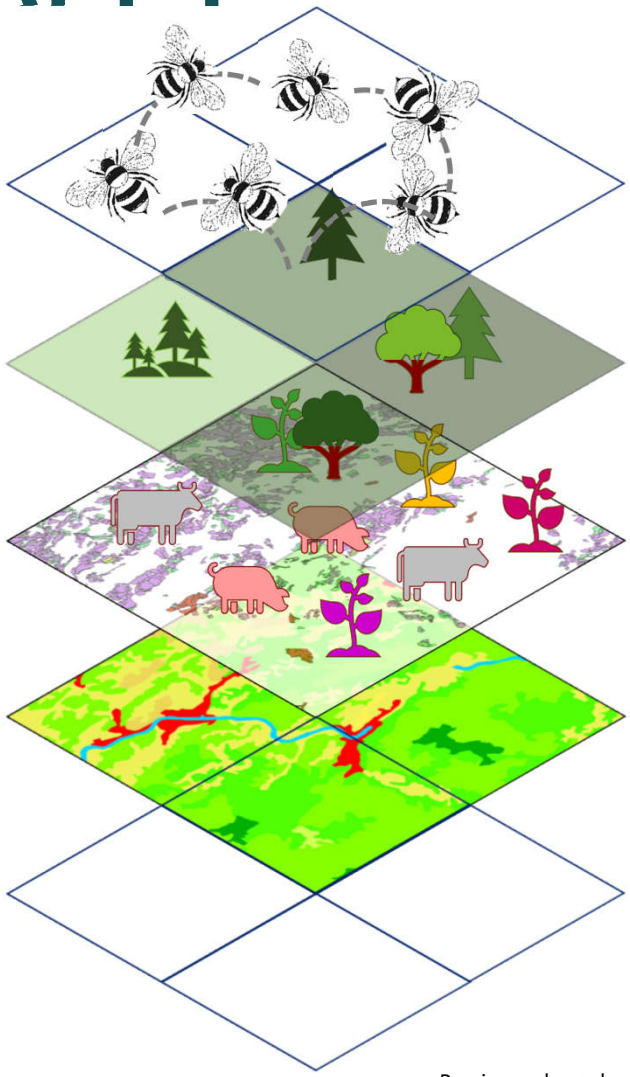
Model chain in MAPPY

- WP6 assessed the socio-economic impacts from the integrated results from WP1-5 based, on an option space approach (Kalt et al. 2021) that integrates 72 change scenarios for the year 2070.

- This evaluation allowed the combination of modelled results with more extreme scenario assumption. Evaluation of
  1. path-dependent results
  2. as well as trend disruptions and extreme (but biophysically feasible) conditions.



WP5: Pollinator-diversity

WP3: Forest management

WP2&WP4: Crop yields & agricultural land use

WP1: Climate

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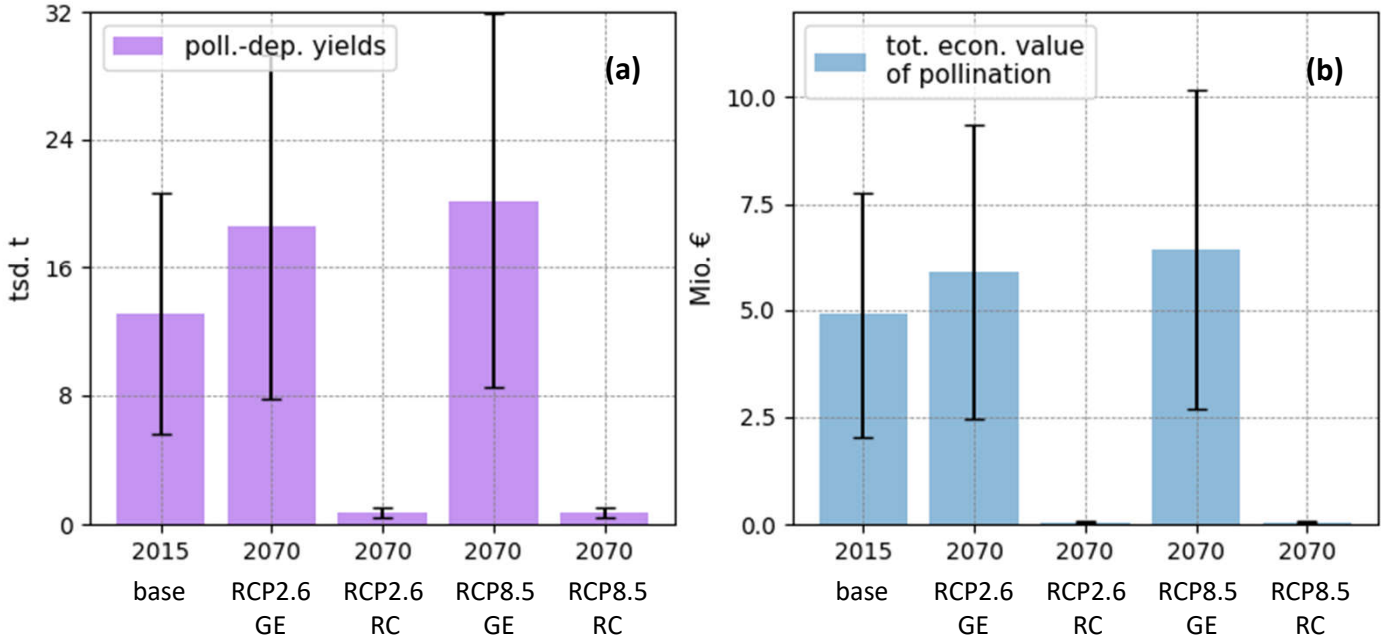
Bee image by Freepik

Economic relevance of pollination

- Until 2070, 6% of total area pollination-dependent (GE scenarios), drastic decline in RC scenarios.
- High economic potential due to modelled positive yield development (rapeseed & soybeans) until 2070.
- Overall increase in pollination-dependent yields (a) and the total economic value of pollination (b)
- High range of uncertainty in results (error bars), due to a wide range of pollination-dependency reported in literature (Zulka & Götzl, 2015; Aizen et al. 2019)

We evaluated the pollination-dependent share of total crop production, and the total economic value of pollination

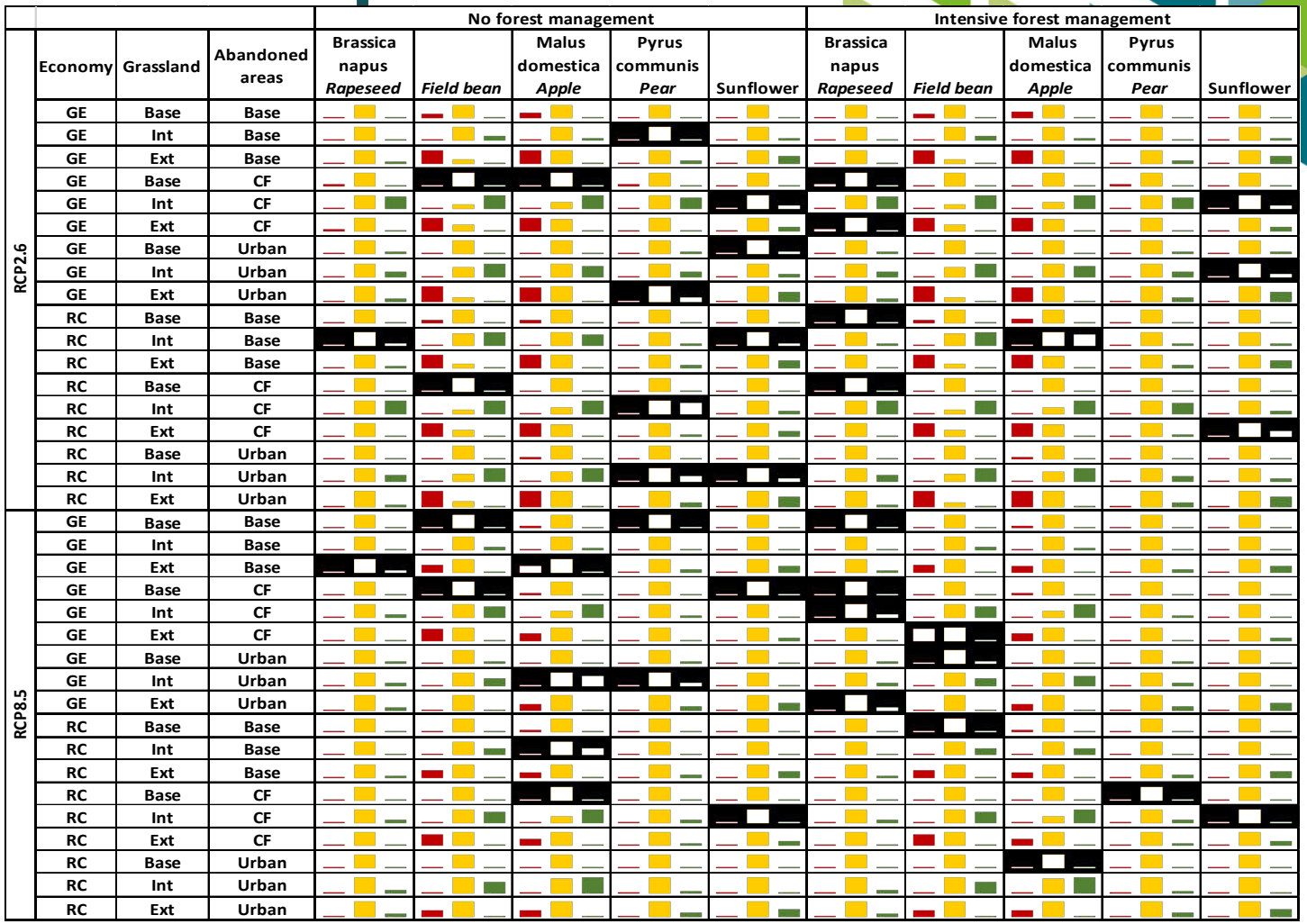
Austrian Case Study



Option Space: Future pollination diversity

- Integrated results for 72 scenarios of cropland, grassland, forest management, and abandoned areas show only mixed impacts for the diversity of pollinators in the Eisenwurzen region in Austria
- Rapeseed, pear and sunflower pollinator seem quite robust to land-use and climatic changes, while field bean and apple pollinators depict stronger negative reactions to land-use changes
- Stronger influence of land-use change in RCP 2.6 than in RCP 8.5

Austrian Case Study



Option space for the diversity of pollinators suitable for the pollination of five different crops for the year 2070 in the Eisenwurzen region in Austria. The bar charts indicate the number of grid cells with negative (red), neutral (yellow), or positive (green) changes in crop-specific pollinator diversity between the base year and 2070. Grid cells with no pollination-relevant crops are excluded from the option space. Average number of grid cells for brassica napus (n = 671), field bean (n = 437), malus domestica (n = 750), pyrus communis (n = 674), sunflower (n = 376). Socio-economic scenarios assessed: GE= Global economy, RC= Regional cooperation; Grassland scenarios assessed: Base = Baseline, Int = strong Intensification, Ext= strong Extensification; Abandoned scenarios assessed: Base = Baseline, CF= Closed Forest, Urban= Urbanization; Forest scenarios assessed: no forest management, intensive forest management; Climate (i.e., representative concentration paths) scenarios assessed: RCP 2.6, RCP85= RCP 8.5

Conclusions

- The MAPPY study has provided future scenarios of **climate and land use changes** at high spatial resolution (3 km) to the 2070 horizon over several case study sites of Western Europe
- Impacts on **crop yields, forest ecosystems and pollinator dynamics** has been studied
- The results will be distributed through various channels to **raise awareness and inform professionals** towards adaptation of their practices

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