Research note on MAPPY work package 4, Land use change dynamics. High resolution land use change projections on MAPPY case study areas and their analysis.

Smet, Sarah; Dendoncker, Nicolas

Publication date:
2023

MAPPY Work Package 4, Land use change dynamics

Deliverable 4.3

Introduction

The WP4 of the MAPPY project aims to project the agricultural land use dynamics of the case studies between the early 2000's (initiation year varying between case studies) and 2070. The developed agent-based model is described in the deliverable 4.2 and depends, in the MAPPY chain, on the simulated future crop yields which came from LPJmL (von Bloh *et al.*, 2018; Lutz *et al.*, 2019; Herzfeld *et al.*, 2021) for arable crops excepting potatoes, and CARAIB model (Jacquemin et al., 2020) for grasses and potato. In order to blur differences emerging from the functioning modes of the two models, we calculated and used relative differences from years to years rather than absolute yields values. The yields were simulated from 2020 based on two climate forcing scenarios, RCP8.5 and RCP2.6.

This document presents the Austrian case study which focuses on the *Eisenwurzen* region, and the Belgian case study which focuses on the *Wallonia* region.

A. Eisenwurzen (AT) case study

1. Materials and Methods

1.1 Model Description and setup

The MAPPY land use change model is derived from the open-source agent-based ADAM model that has been developed at the Geography Department of the University of Namur (Beckers et al., 2020). The model is described in the deliverable D4.2.

Data input consisted in on one hand, one-time data used for the model setup, and on the other hand yearly crop yield data provided by WP2 at a resolution of 3 x 3 km according the two climatic scenarios (RCP 2.6 and RCP 8.5). In addition, we considered two additional scenarios specific to the land use model: the Regional Communities (RC) and the Global Economy (GE) which parameters and rules are presented in D4.2. Shortly, the GE should favor bigger farms with less crop diversity while it would be the opposite for the RC scenario.

1.2. Data acquisition for the setup

Data for the Eisenwurzen case study were extracted from several sources and the setup year was set to 2015 as it was the earliest year where all data were available. The model setup and initiation between 2015 to 2020 were identical between the four scenarios.

- Administrative borders: https://earthworks.stanford.edu/catalog/stanford-xt654bx3470, obtained in February 2020
- Agricultural regions: https://data.statistik.gv.at/web/meta.jsp?dataset=OGDEXT_LWPG_1, obtained in February 2020
- Less favored area: http://afoludata.jrc.ec.europa.eu/dataset/less-favoured-areas-hsmus, obtained in July 2021
- Natura 2000 regions: obtained in Septembre 2022
    - Styria (Steiermark): https://www.data.gv.at/katalog/dataset/b943d920-12c2-11e2-a565-f23c91aec05e
    - Lower Austria (Niederösterreich): https://www.data.gv.at/katalog/dataset/03c89e7a-c2df-4c41-a43d-ab7b05892ff9

    - Upper Austria (Oberösterreich): https://www.data.gv.at/katalog/dataset/07b4e90b-0518-4e26-8f25-91c6a5505b1c
- Agricultural parcels: https://www.data.gv.at/?s=invekos+2015#, obtained in May 2021
- Structure of agricultural holdings by NUTS 3 regions - main indicators: https://ec.europa.eu/eurostat/databrowser/view/EF_R_NUTS__custom_899517/default/table?lang=en, obtained in May 2021 by:
    - holding sizes,
    - age of the holder,
    - gender of the holder,
    - farm type
- National mortality rate: https://ec.europa.eu/eurostat/web/population-demography/demography-population-stock-balance/database, obtained in September 2021

Additional local information were provided by Andreas Mayer and Claudine Egger from University of Natural Resources and Life Sciences (BOKU, Vienna, Austria) :

- Standard gross margin for crops and animal-derived products
- CAP subsidies by ha
- Land tenure and rent extracted from Eurostat in May 2022
- Land abandonment rate extracted from a BOKU's study in May 2022
- Farm succession statistics extracted from a BOKU's study in May 2022
- Legal retirement age based on local knowledge
- INVEKO's identification code of the Mountainous grasslands (SNAR CODE 990)
- Amount of subsidies allocated to ecological elements by regions (ÖPUL), obtained in July 2022

The world of the model was therefore composed of 110176 agricultural parcels owned by 7612 farmers. One run of the model, from 2015 to 2070, took approximately 4 hours and the model was ran 40 times for each scenario which lead to 160 runs in total.

2. Results

2.1. Farms distribution

The initiation year for the Eisenwurzen region was set to 2015 and no more recent farm number data were available for a model calibration. The model was run 40 times between 2015 to 2070 and the average farm numbers, and associated standard deviations if high, are presented.

2.1.1. Eisenwurzen region

The graphs presents the average numbers of farms by class size for 40 model runs, the spreading is not presented as the standard deviations for all classes, year and scenarios were small (between 10 to 20).

As per the model construction, the economic scenarios influence the farm size distribution though a great number of lost farms as decades are passing. As the farmers are getting older, from 2050, there is a clear shift between RC and GE scenarios where farms between 5 to 50 ha are disappearing. The number of farms greater than 50 ha remains stable due to the transfer of the agricultural areas of lost farms to neighboring farms. Farms that are kept by the farmers above retirement present decreasing sizes which explain the increasing number of farms with size below 5 ha.

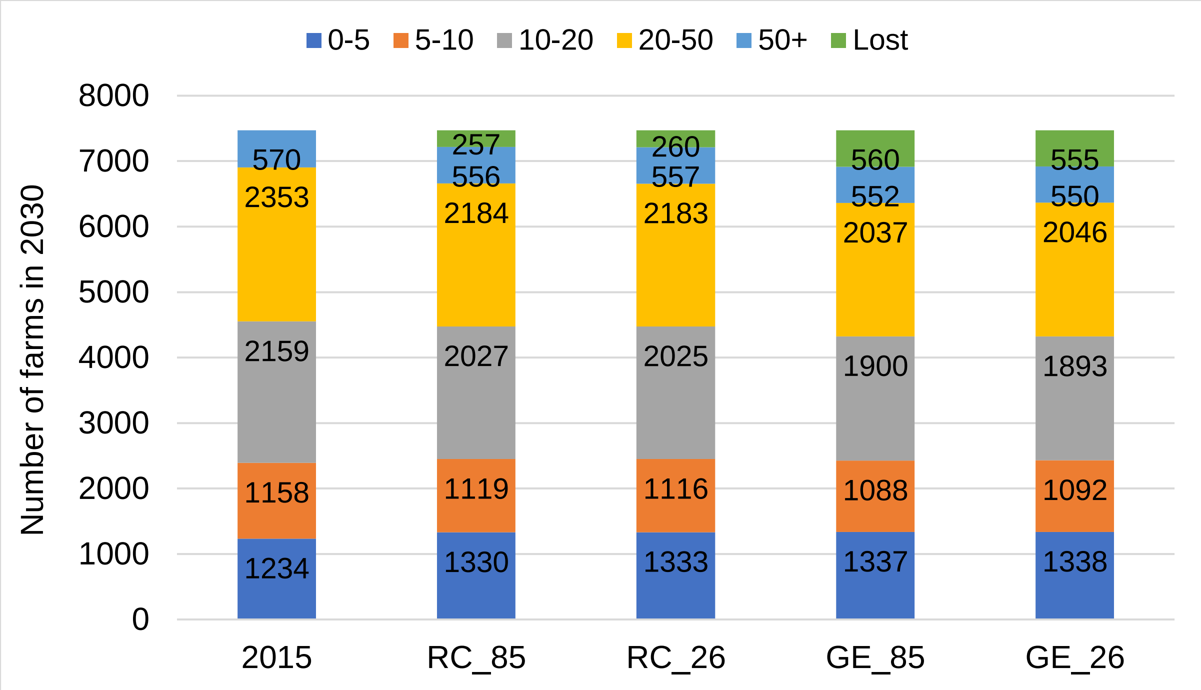


Figure 1. Projected number of farms in the Eisenwurzen regions by scenarios in 2030. The numbers are the average over 40 model runs.

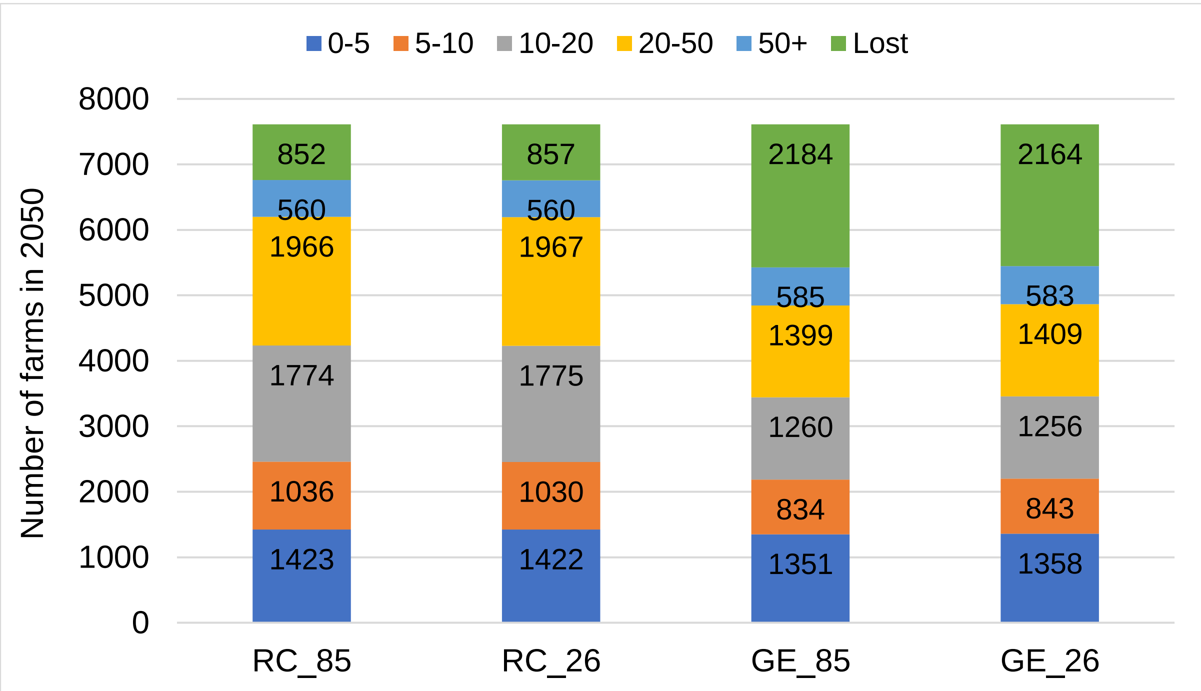


Figure 2. Projected number of farms in the Eisenwurzen regions by scenarios in 2050. The numbers are the average over 40 model runs.

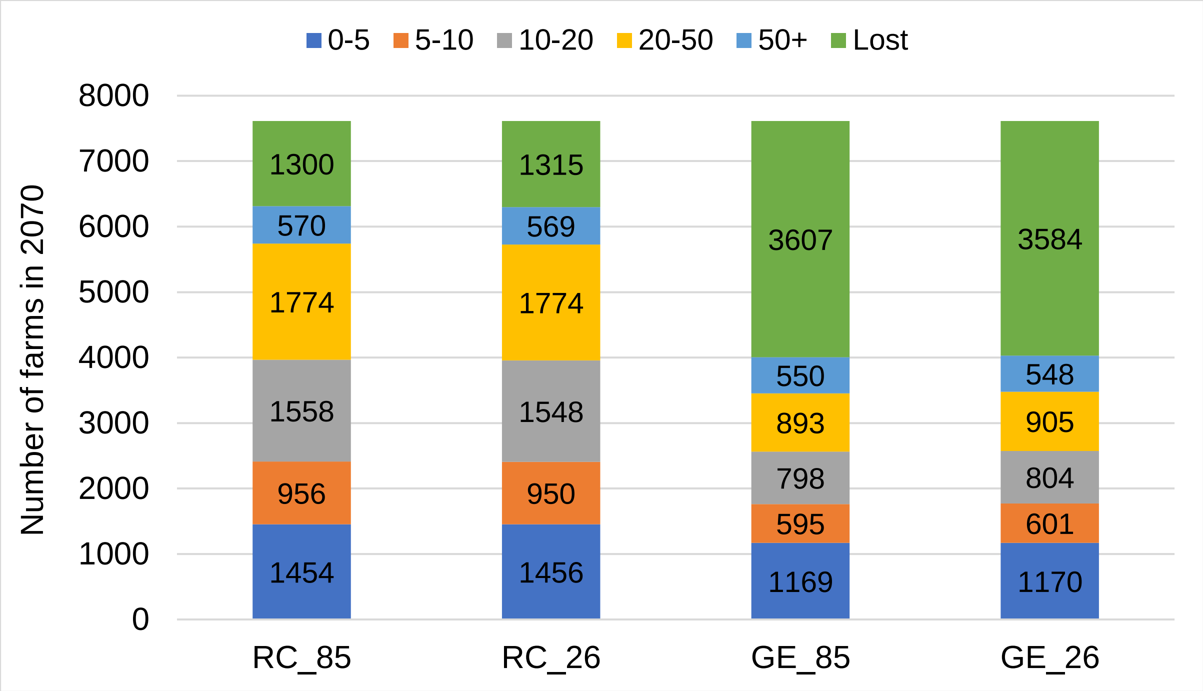


Figure 3. Projected number of farms in the Eisenwurzen regions by scenarios in 2070. The numbers are the average over 40 model runs.

2.1.2. By Agricultural regions

Globally, the number of farms with sizes between 5 and 50 ha decrease for any scenarios from 2015 to 2070. The same pattern is observed in the Alpenvorland and Voralpen agricultural regions, both presenting the largest numbers of farms and therefore leading the global trend, but however presenting varying agricultural landscape. The Alpenvorland is a crop-dominated region while the Voralpen is a grass-dominated region. Both regions presents however similar averaged farm size with low standard deviations, with an average farm size of 18.5 ha (stdev=18 ha) for the Alpenvorland and 16.8 ha (stdev = 19 ha) for the Voralpen. The Alpenostrand and Hochalpen regions both presents largest decrease in the number of farms. Those two regions are smaller in comparison to the Alpenvorland and Voralpen, which are dominated by grasslands and presents larger averaged farm size (26.4 ha and 31.7 ha respectively) with larger standard deviations (77.7 ha and 121.8 ha respectively). The disappearance of farms is based on the national successorship statistics that is reevaluated regionally from the economic profitability of the farm in comparison to the average economic profitability of the region, and it explains the greatest decrease in farm number in those two regions.

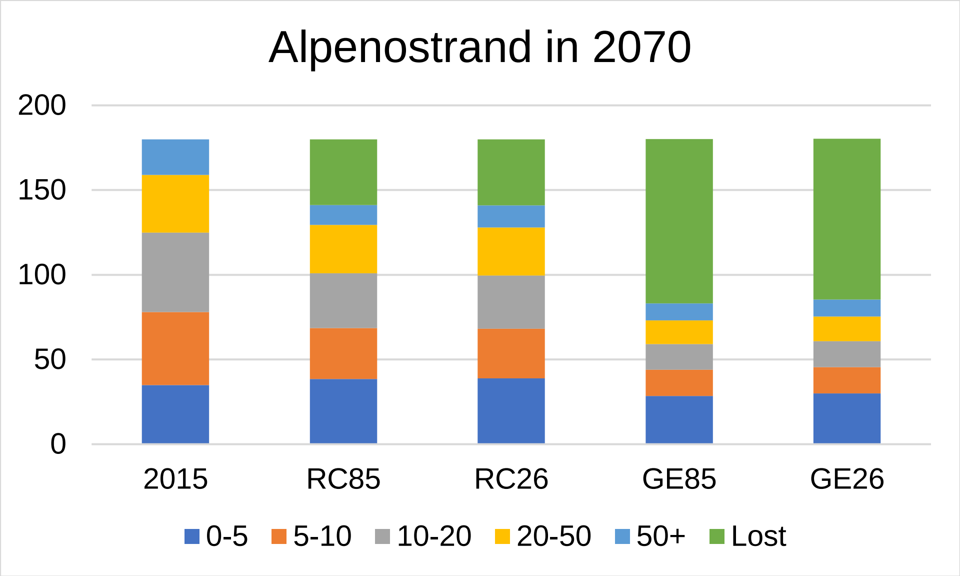


Figure 4. Projected number of farms in the Alpenostrand region by scenarios in 2070. The numbers are the average over 40 model runs.

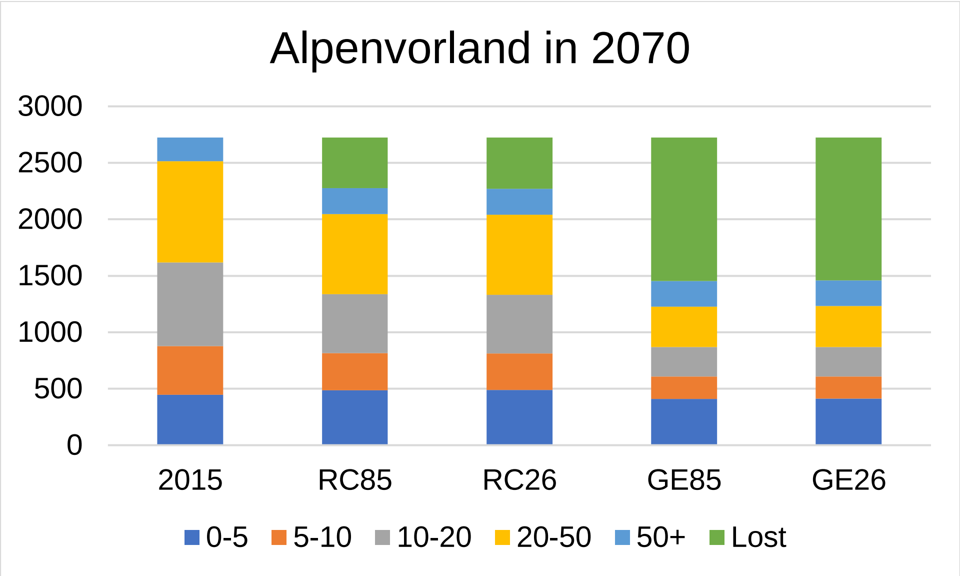


Figure 5. Projected number of farms in the Alpenvorland region by scenarios in 2070. The numbers are the average over 40 model runs.

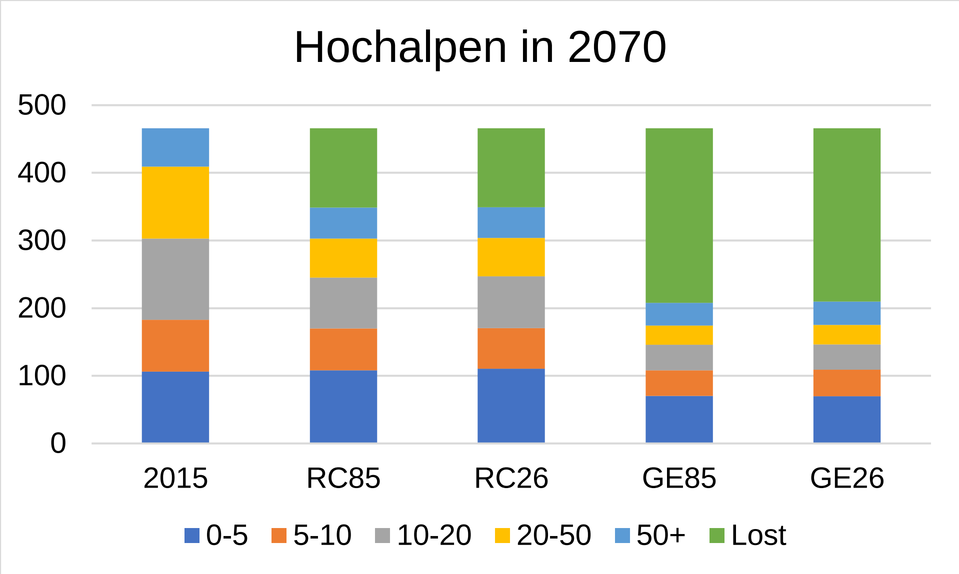


Figure 6. Projected number of farms in the Hochalpen region by scenarios in 2070. The numbers are the average over 40 model runs.

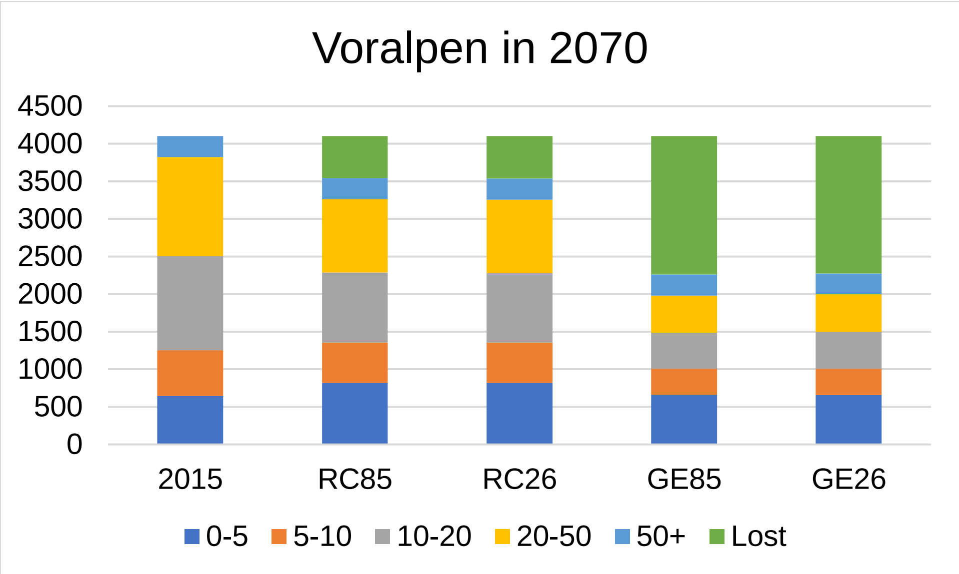


Figure 7. Projected number of farms in the Voralpen region by scenarios in 2070. The numbers are the average over 40 model runs.

Table 1. Relative variations (%) in the number of farms by farm size classes, regions and scenarios.

Eisenwurzen	**RC_85**	**RC_26**	**GE_85**	**GE_26**
0-5	18%	18%	-5%	-5%
5-10	-17%	-18%	-49%	-48%
10-20	-28%	-28%	-63%	-63%
20-50	-25%	-25%	-62%	-62%
50+	0%	0%	-3%	-4%
Alpenostrand	**RC_85**	**RC_26**	**GE_85**	**GE_26**
0-5	10%	11%	-18%	-15%
5-10	-30%	-32%	-64%	-64%

10-20	-31%	-33%	-68%	-67%
20-50	-16%	-17%	-59%	-57%
50+	-44%	-39%	-53%	-53%
Alpenvorland	**RC_85**	**RC_26**	**GE_85**	**GE_26**
0-5	9%	9%	-8%	-8%
5-10	-24%	-25%	-54%	-54%
10-20	-29%	-30%	-65%	-65%
20-50	-21%	-21%	-60%	-59%
50+	10%	10%	9%	9%
Hochalpen	**RC_85**	**RC_26**	**GE_85**	**GE_26**
0-5	2%	4%	-33%	-34%
5-10	-20%	-22%	-51%	-49%
10-20	-37%	-36%	-69%	-69%
20-50	-46%	-46%	-73%	-73%
50+	-20%	-21%	-41%	-40%
Voralpen	**RC_85**	**RC_26**	**GE_85**	**GE_26**
0-5	27%	27%	2%	2%
5-10	-12%	-12%	-43%	-43%
10-20	-26%	-26%	-61%	-61%
20-50	-26%	-26%	-63%	-62%
50+	0%	0%	-1%	-2%

2.2. Land use distribution

The model was run 40 times and the future land use projection were analyzed along two ways. First, we applied the standard approach, when dealing with stochastic model, of computing the average outputs. This approach do not however provide spatial information that could be used in the next work package (WP5). Within the frame of the MAPPY project, the most recurrent land use and its frequency along the 40 times was therefore associated to each parcels.

The Eisenwurzen regions is composed of four agricultural regions, three of them are dominated by grasslands while the Alpenvorland presents most of the croplands of the Eisenwurzen.

2.2.1. Average land use

2.2.1.1. 2020 results

We firstly compared 2020 results to the actual agricultural crop land use distribution (Figure 8). We focused on the croplands as grasslands are not supposed to change between 2015 and 2020. Municipalities which are not shown did not present any parcels with crops in 2020 projections, the largest NRMSE are produced by municipalities presenting only few hectares of crops that mostly disappeared between 2015 and 2020. Because the Alpenvorland present the largest crop diversity, we focused on the adequacy between projections and observations for both RC and GE scenarios (no climatic projections scenarios between 2015 and 2020, Figure 9). RC scenario provides lower NRMSE as the rules of the land use model for the RC scenario before 2020 follow the current CAP rules, and NRMSE are satisfactory for most municipalities.

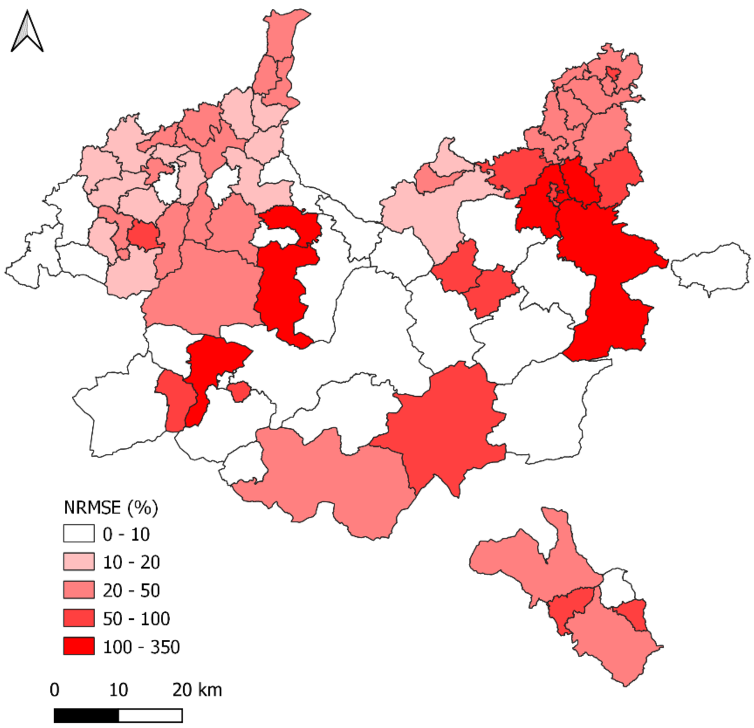


Figure 8. NRMSE (%) of crop land use calculated by municipalities for the Eisenwurzen region.

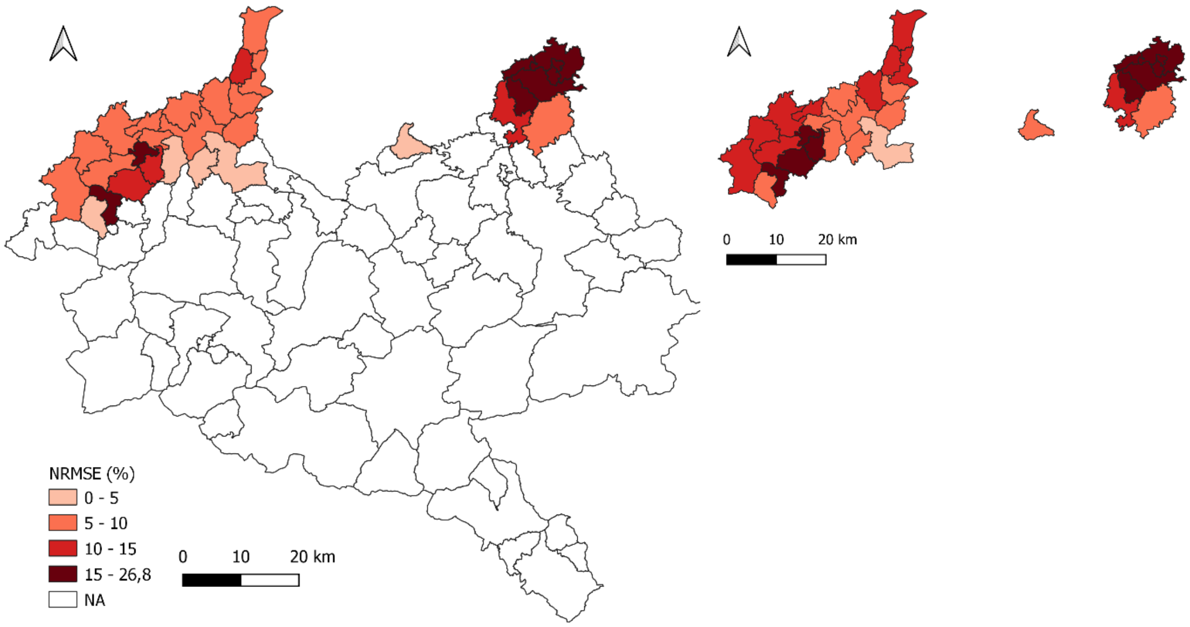


Figure 9. NRMSE (%) of crop land use calculated by municipalities for the Alpenvorland region. Left side is the Regional Communities scenario. Right side is the Global Economy scenario.

2.2.1.2. Alpenvorland

Not all crop categories are shown as some are kept constant throughout the years: "Fruit or nut tree", "Other horticultural" and "Mountainous grassland". The category "Other arable", with 573 ha in 2015, is disappearing for all scenarios in 2030, 2050 and 2070 and therefore not shown.

A scenario-by-scenario comparison first shows that differences between runs are mostly more pronounced in RCP2.6 than in RCP 8.5, although the yields changes do not show drastic differences between RCP2.6 and RCP8.5 scenarios (Table 2). In addition, both economic scenarios present similar trend by climatic scenarios. The decision process is indeed dependent on the projected crop yields and those are different by climatic scenarios. It suggests that the crop economic profitability is more prevalent in the emerging global land use than the rotation pattern or the subsidies conditionality about crop diversity. This also leads to the domination of C3 cereal in RCP2.6 scenarios and soybean by 2070 in RCP8.5 scenario which present the highest yield variation respectively (Table 2), vice-versa C4 cereal which presents the lightest yield increase in RCP2.6 scenario is less dominant in 2070 in RCP2.6 than in RCP8.5 scenario.

Table 2. Projected changes in Eisenwurzen crop yields in percent for the period 2041-2070 relative to the period 1991-2020 under the RCP 2.6 and RCP8.5 climate forcing trajectories. Table adapted from MAPPY D2.4.

Crop	Yield change (%) RCP 2.6	Yield change (%) RCP 8.5
C3	34	36
C4	9.3	25
Oilseed	21	24
Sugar beet	23	23
Soybean	31	52

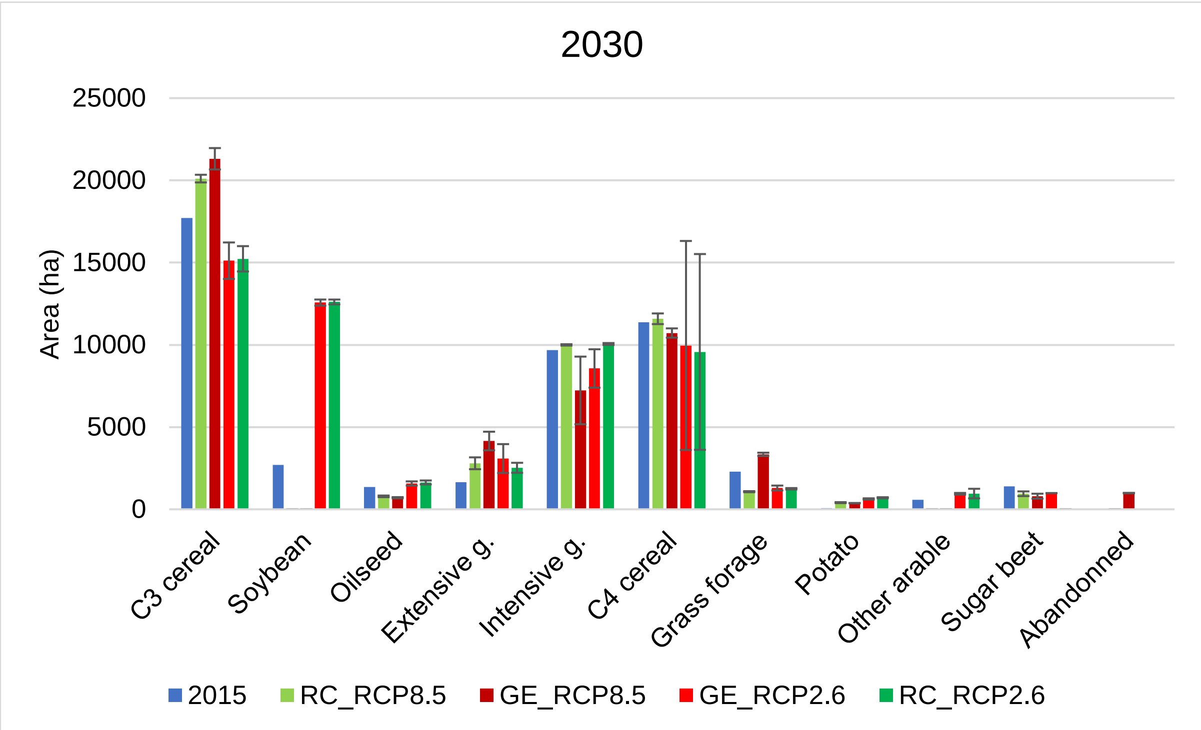


Figure 10. 2030 projection of future land use in Alpenvorland region (average and standard deviation)

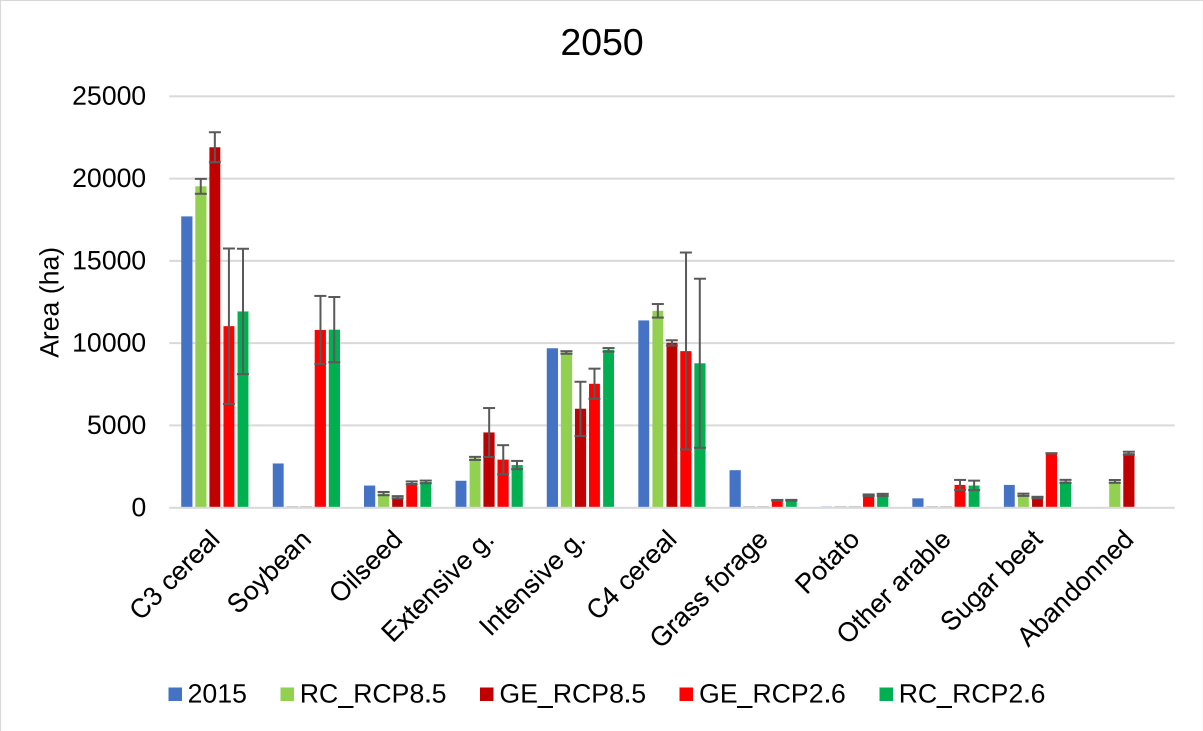


Figure 11. 2050 projection of future land use in Alpenvorland region (average and standard deviation)

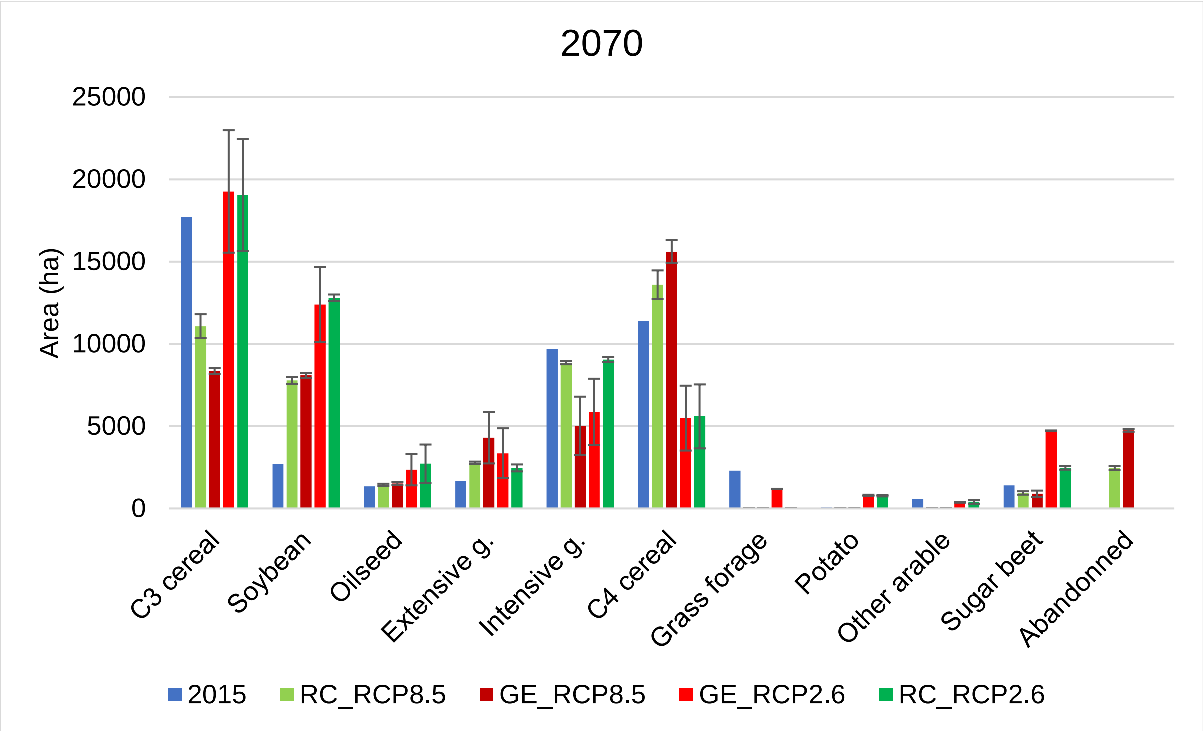


Figure 12. 2070 projection of future land use in Alpenvorland region (average and standard deviation)

2.2.1.3. Grasslands

The mountainous grasslands were kept constant throughout the years and are not shown. The areas of the ecological features spread on the parcels are not taken into consideration.

The effects of the climate scenarios on the projected grasslands distribution is negligible, and not shown, while the economical scenarios involve greater shifts between projected land uses (Figure 13 and 14).

The Alpenostrand agricultural region is the less represented in the Eisenwurzen region and is mostly composed of “Mountainous grasslands” with larger averaged parcels areas (1.8 ha +/- 7.18 ha), involving less abandoned parcels for both RC and GE scenarios, as the process is constrained by a parcel area threshold. This threshold is higher within the GE scenario, leading to a larger abandoned area coming from former “intensive grassland”. Beside the larger decrease in “Intensive grassland” leading to a larger abandoned area for all regions in GE scenario, an interesting trend is that this decrease is also transferred to a greater “Extensive grassland” area with the same pattern between 2030, 2050 and 2070. In the RC scenario, the trends are more straightforward and linear as no actions are eligible on grasslands due to in-place policies.

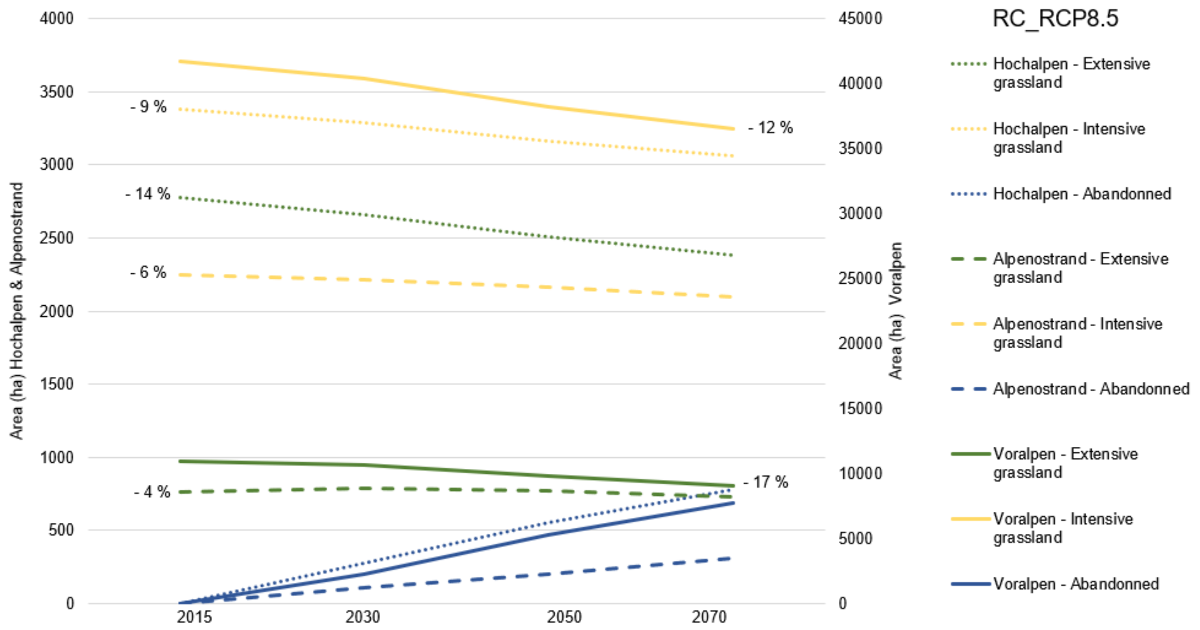


Figure 13. Evolution of the averaged surface area of grasslands for three regions for the regional communities (RC) scenario combined to RCP8.5 climatic scenario. The Voralpen relative (%) and absolute variations are displayed on the right of the graph.

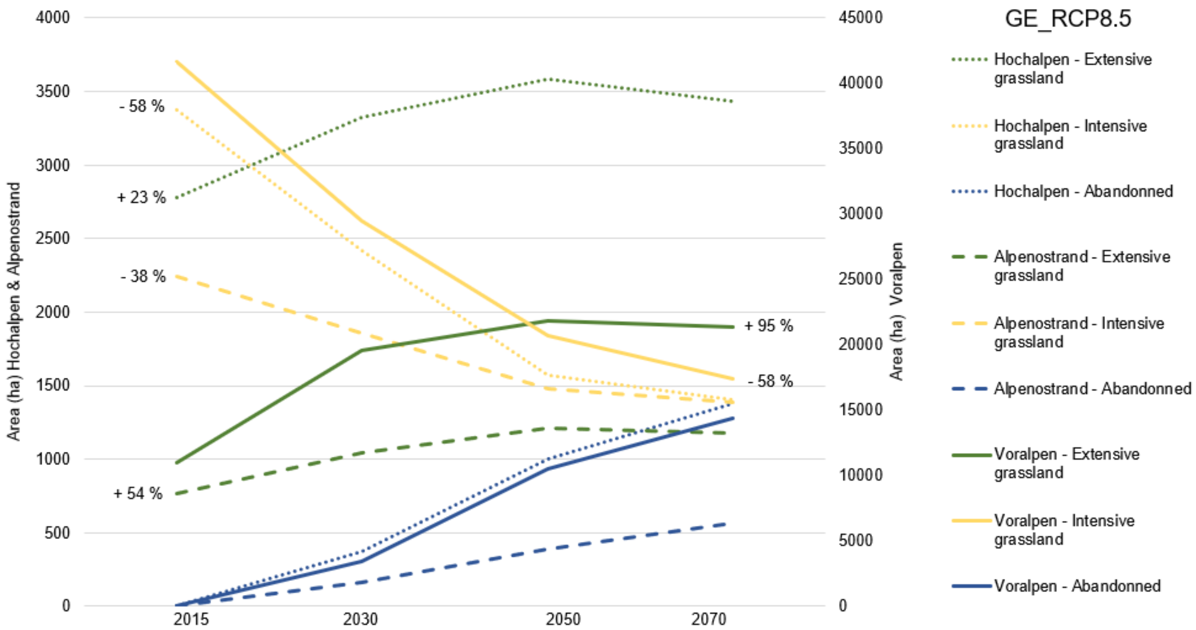


Figure 14. Evolution of the averaged surface area of grasslands for three regions for the global economy (GE) scenario combined to RCP8.5 climatic scenario. The Voralpen relative (%) and absolute variations are displayed on the right of the graph.

Those results are afterwards used in a spatial species distribution model, it is therefore interesting to evaluate the spreading of abandoned areas across the agricultural regions (Figure 15) and their fate, which is part of scenarios developed by WP6.

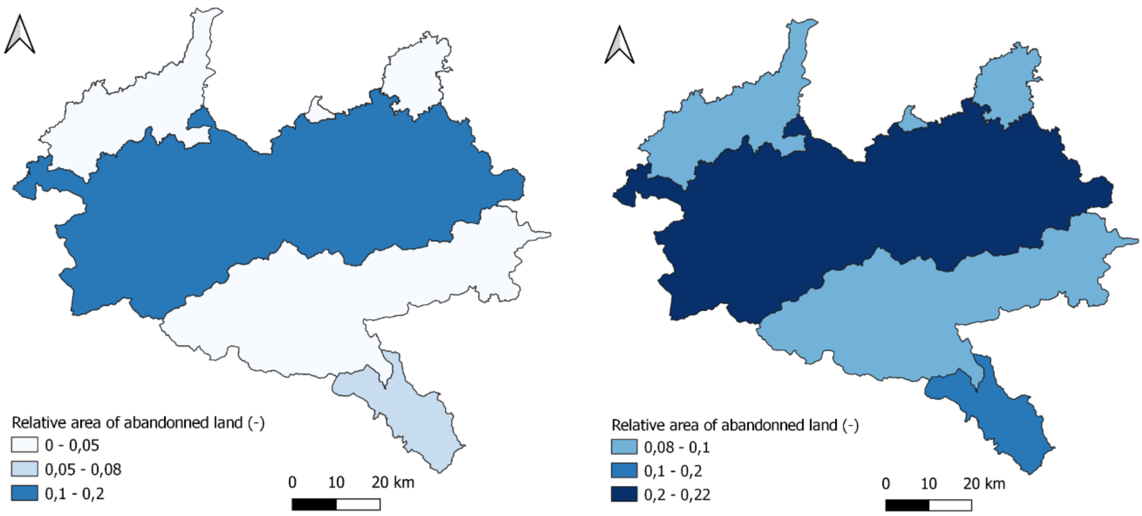


Figure 15. Relative area of abandoned land (-) in 2070, under the RCP8.5 climate forcing scenario, by agricultural regions within the Eisenwurzen. Left side is the Regional Communities scenario. Right side is the Global Economy scenario.

2.2.2. Most recurrent land use

Computing the most recurrent land use, it is possible to extract precise spatial land use information that will be use in WP5. We present a small portion of the Alpenvorland region with the distribution of land use and their respective frequencies for the GE_RCP8.5 scenario (Figure 16). Frequencies range from 0.15 to 0.975 with a median of 0.725. We delivered to WP5 future projected land use, with their frequencies, of 110176 parcels, in the form of csv file and shapefile. The latter was combined with Corine database 2012 in order to have a continuous layer, and the data were rasterized to fit the standard 3x3 km² MAPPY grid. Results from WP3 (mass of carbon and LAI of forest) were also added to each cell. The Austrian partner of the project computed the data for the Eisenwurzen region and we generated a standard code for all regions.

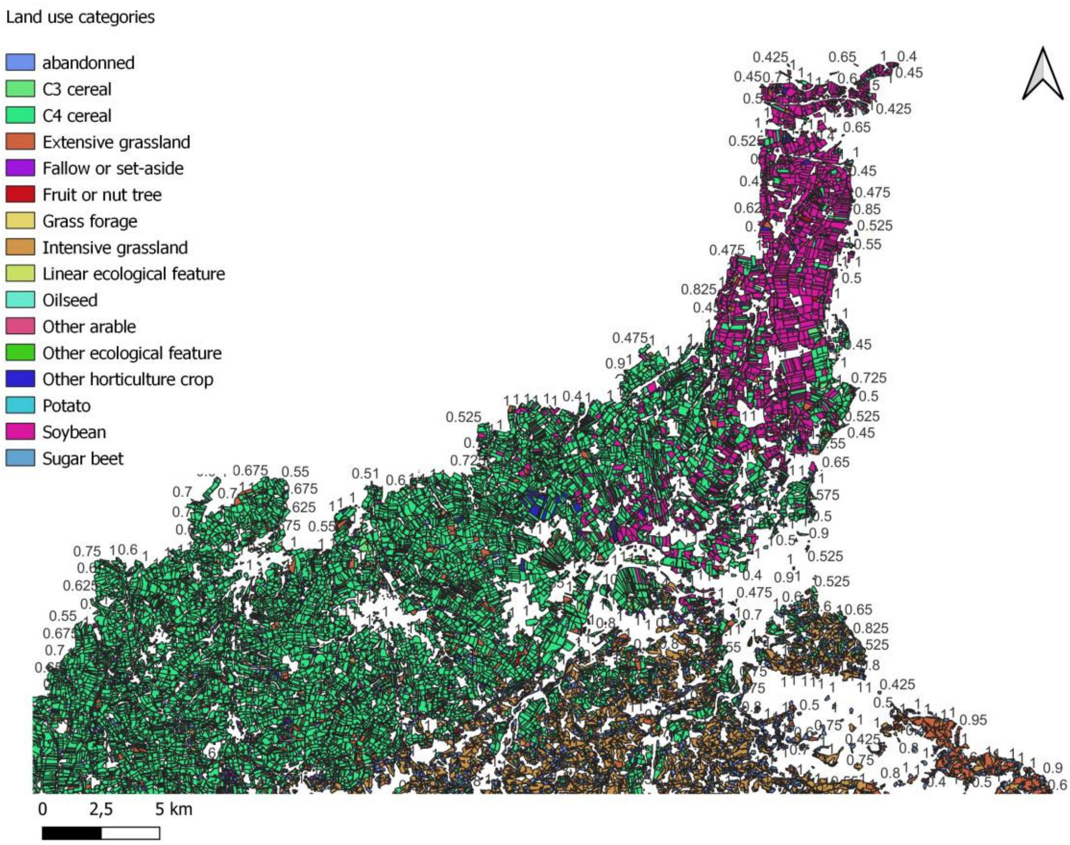


Figure 16. Most recurrent crop for a small portion of the Alpenvorland region in 2070 for the GE_RCP8.5 scenario.

2.3. Landscape diversity

2.3.1. Ecological features distribution

An important land use characteristic to the distribution of pollinators is the spreading of ecological features across the region. The average area of ecological feature for each parcels was also provided to WP5. The average ecological areas by municipalities are similar between climate forcing scenario (Figure 17), differences emerging from the random allocation of ecological features within a farm. The greatest difference arise between the RC and GE scenarios, as per the model rules. The grassland areas present the largest ecological areas within the GE scenarios while the croplands do in the RC scenarios.

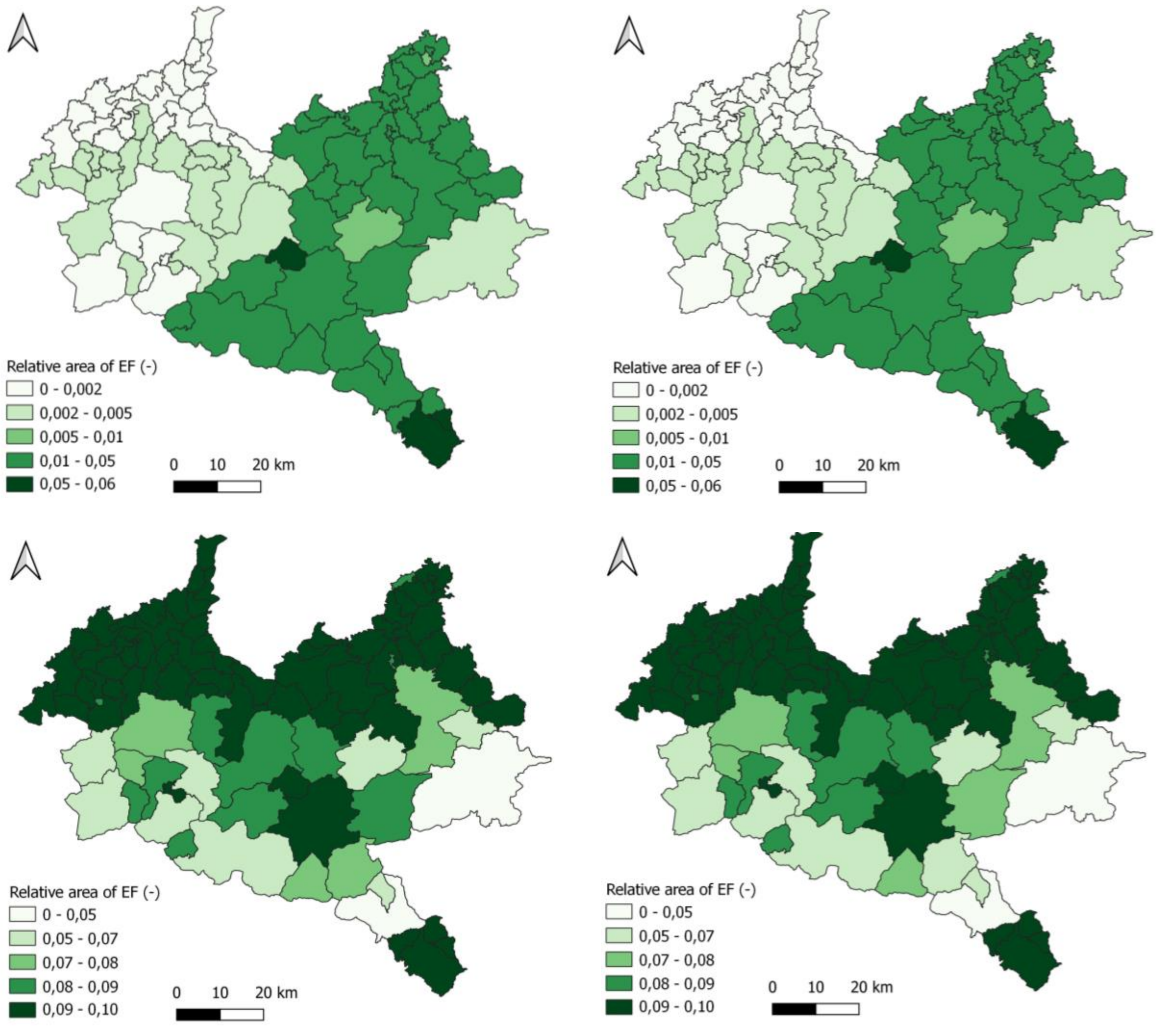


Figure 17. Relative area of ecological feature (-) by municipalities in 2070 across the Eisenwurzen region, by scenario. Upper left : GE_RCP85. Upper right: GE_RCP26. Lower left: RC_RCP85. Lower right: RC_RCP26.

2.3.2. Diversity indexes and farm sizes

The structure of the landscape can be assessed through the computation of the Shannon and Simpson indexes (Table 3), quantifying, respectively, the richness and the evenness of diversity (Nagendra, 2002). It is suggested that the climate projection, by influencing the crop choice, influence more the regional landscape structure than the economic scenario (Table 3), with a greater increase under the RCP8.5 climate forcing scenario. This has also prevail when unsuccessfully attempting to link the influence of the farm size to the landscape diversity.

Table 3.diversity indexes (Shannon and Simpson indexes) for the Eisenwurzen region in 2070 by scenarios.

	2015	RC_RCP85	GE_RCP85	RC_RCP26	GE_RCP26
Mean Shannon index	2,7974	3,1130	3,0978	3,0790	3,0753
St. dev. Shannon index		0,0026	0,0184	0,0239	0,0391
Mean Simpson index	0,7681	0,8441	0,8393	0,8410	0,8373
St. dev. Simpson index		0,0005	0,0104	0,0018	0,0106

The Alpenvorland region presents the highest landscape diversity with the highest Shannon and Simpson indexes, which both show the same trends between years and scenarios (Figure 18 and 19). The projections under the RCP8.5 climate forcing scenario, presents the highest diversity in 2070, while the RCP2.6 scenario present a clear increasing trend between 2015 and 2050 before dropping.

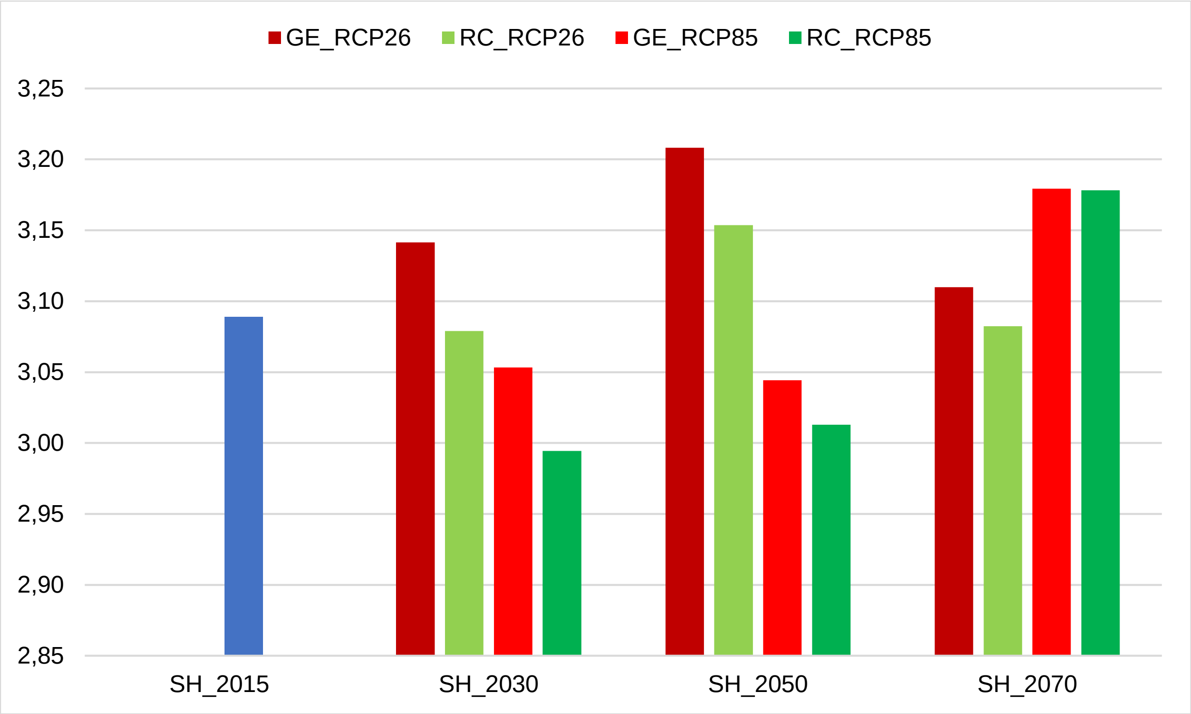


Figure 18. Evolution of Shannon Index from 2015 to 2070 by scenarios for the Alpenvorland region.

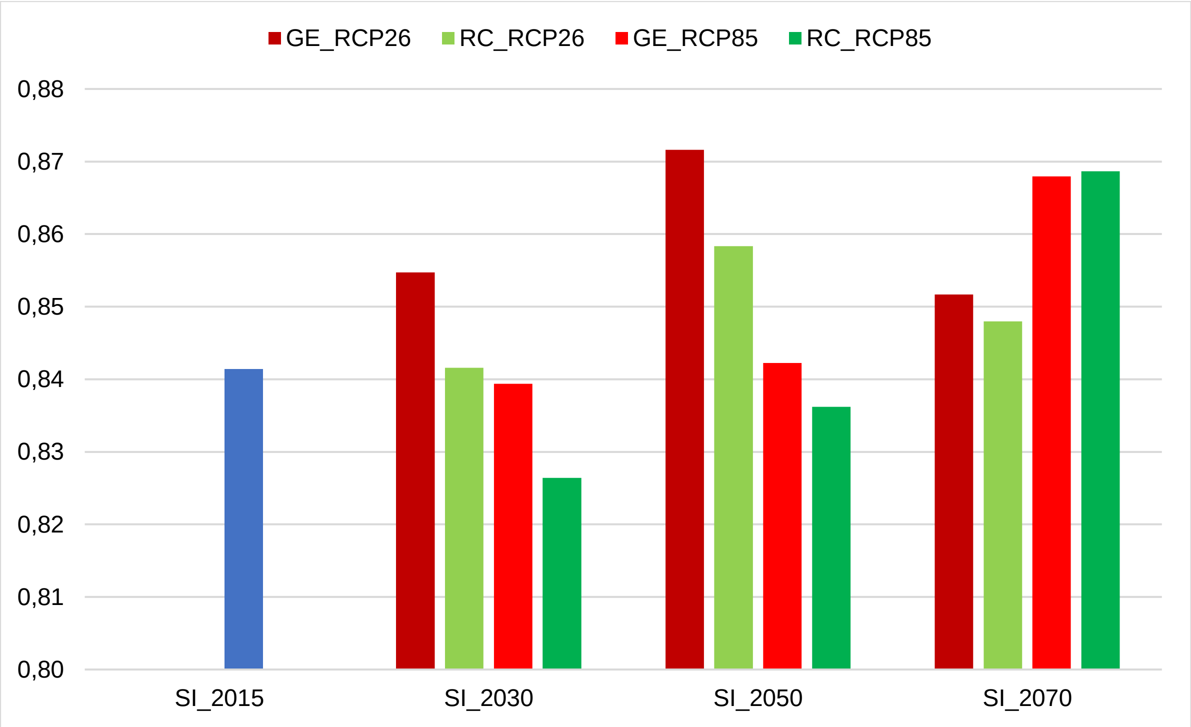


Figure 19. Evolution of Simpson index from 2015 to 2070 by scenarios for the Alpenvorland region.

B. Wallonia (BE) case study

1. Materials and Methods

1.1 Model Description and setup

The MAPPY land use change model is derived from the open-source agent-based ADAM model that has been developed at the Geography Department of the University of Namur (Beckers et al., 2020). The model is described in the deliverable D4.2.

Data input consisted on one hand in one-time data used for the model setup, and on the other hand on yearly crop yield data provided by WP2 at a resolution of 3 x 3 km according the two climatic scenarios (RCP 2.6 and RCP 8.5). In addition, we considered two additional scenarios specific to the land use model: the Regional Communities (RC) and the Global Economy (GE) which parameters and rules are presented in D4.2 but, shortly, the GE should favor bigger farms with less crop diversity while it would be the opposite for the RC scenario.

1.2. Data acquisition for the setup

Data for the Wallon case study were extracted from several sources and the setup year was set to 2006 as it was the earliest year where all data were available. The model setup and initiation between 2006 to 2020 were identical between the four scenarios.

- Administrative borders: https://www.geo.be/#!/catalog/details/fb1e2993-2020-428c-9188-eb5f75e284b9?l=en, obtained in February 2020
- Agricultural regions: https://geoportail.wallonie.be/catalogue-donnees-et-services, obtained in February 2020
- Less favored area: http://afoludata.jrc.ec.europa.eu/dataset/less-favoured-areas-hsmus, obtained in July 2021
- Natura 2000 regions: https://geoportail.wallonie.be/catalogue-donnees-et-services, obtained in September 2022
- Agricultural parcels: https://geoportail.wallonie.be/catalogue-donnees-et-services, obtained in May 2021
- Structure of agricultural holdings by NUTS 3 regions - main indicators: https://ec.europa.eu/eurostat/databrowser/view/EF_R_NUTS__custom_899517/default/table?lang=en, obtained in May 2021 by:
    - holding sizes,
    - age of the holder,
    - gender of the holder,
    - farm type
- National mortality rate: https://ec.europa.eu/eurostat/web/population-demography/demography-population-stock-balance/database, obtained in September 2021
- Standard gross margin for crops and animal-derived products, CAP subsidies by ha: https://etat-agriculture.wallonie.be/contents/indicatorsheets/EAW-A_I_b_2.html#, obtained in August 2022.
- Ecological subsidies by units (“MAEC”): https://etat-agriculture.wallonie.be/contents/indicatorsheets/EAW-A_I_b_3.html#, obtained in August 2022
- Participation to the ecological program (“MAEC”): https://etat-agriculture.wallonie.be/contents/indicatorsheets/EAW-A_I_b_3.html, obtained in August 2022.

- Land abandonment rate estimated from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Agri-environmental_indicator_-_risk_of_land_abandonment&oldid=327077, in June 2022.
- Land tenure and rent extracted from Eurostat in May 2022 by our partners from BOKU (Vienna)
- Farm succession statistics: https://statbel.fgov.be/en/themes/agriculture-fishery/farm-and-horticultural-holdings#figures, obtained in June 2022.
- Legal retirement age based on local knowledge.

The world of the model was therefore composed of 270,227 agricultural parcels owned by 15720 farmers. One run of the model, from 2006 to 2070, took approximately 200 hours and the model was ran 20 times for each scenario which lead to 80 runs in total.

1.3. Calibration

Farm's distribution data from 2020 were used to calibrate the successorship parameter. This parameter is used to evaluate whether a farm, with a retired or dead agent, will be taken over or not (see D4.2). The numbers acquired from the National surveys are presented with 4 possibles answers to the question : "do you have identified a successor?":

- Yes: 16%
- No: 29.5 %
- Don't know: 41.7%
- No answer: 12.8 %

The majority of replies from the survey (combination of "don't know" and "no answer" leading to 54.5%) did not provide a specific answer regarding the successorship of the farm. We therefore firstly conducted a sensitivity analysis to evaluate the influence of the successorship probability with "yes" values between 40 to 85%.

The results were compared to the evolution of official data of farms numbers, by farm size, between 2006 and 2020 for the Walloon region. From discussions with local experts, we however warn that the official data might not be representative of the field realities. First, the National Statistics Direction (Statbel) aligned to the CAP procedure for collecting farms data in 2011. Second, since the implementation of the redistributive payment in 2017, the first 20 ha of a farm are the most valuable. Many farms have therefore split on papers while remaining a single agricultural holding in the field. The local experts advised that a global decrease of 2 to 3% was observed before 2017. Following this rule, the actual decrease of farms should be between 25 to 35% between 2006 and 2020, while noting that larger small farms disappear faster than big farms (Table 4).

Table 4. Extrapolated variations in number of farms between 2006 and 2020

Farm size (ha)	2006-2020 variation	Variation relative to the total
0-5	-69%	36%
5-10	-37%	14%
10-20	-22%	11%
20-50	-26%	32%
>50	-2%	3%
All farms	-27%	na

This lead us to perform a second type of sensitivity analysis where we applied different successorship probabilities to small and big farms. Firstly, the farm were considered as "big" with a total area of more than 50 ha and were applied a high successor rate (70.5%) while the rest of the farms would present a successor rate of 16%, both rate extracted from official agricultural survey. Finally, we also tested three rates applied to three farm categories: farm above 50 ha with a successor rate of 95%, farms between 20 to 50ha with a rate of 70.5%, and farms below 20ha with a rate of 16%.

2. Results

2.1. Calibration

2.1.1. Farm distribution

Evaluating the effects of the successorship rate on the evolution of the number of farms, we observe that the relative variations in numbers of farms are comparable between each farm size categories, with although a smaller slope for the larger farms and a larger one for the medium size farms, 10-20ha (Figure 20). This is explained by the rule of the model: a farmer that should be retired but yet is without a successor sees its farm's size decreasing in favor to the surrounding farms, and this impacts the number of farms in the other categories. No values of successorship could reproduce the general trend observe in Wallonia (Table 4) which is a global decrease of 27% in the total number of farms between 2006 and 2020. In addition, no successorship rate achieves to decrease the numbers of small farms more largely than the number of bigger farm relatively to the total decrease in number of farms (Figure 21 and Table 4).

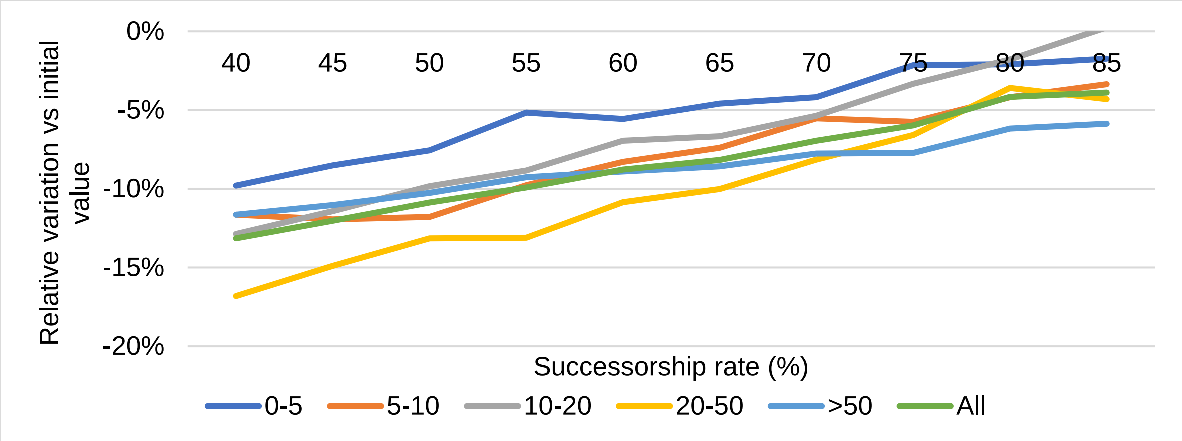


Figure 20. Relative variations of number of farms versus the initial numbers of farms by farm size categories and by successorship rate, between 2006 and 2020.

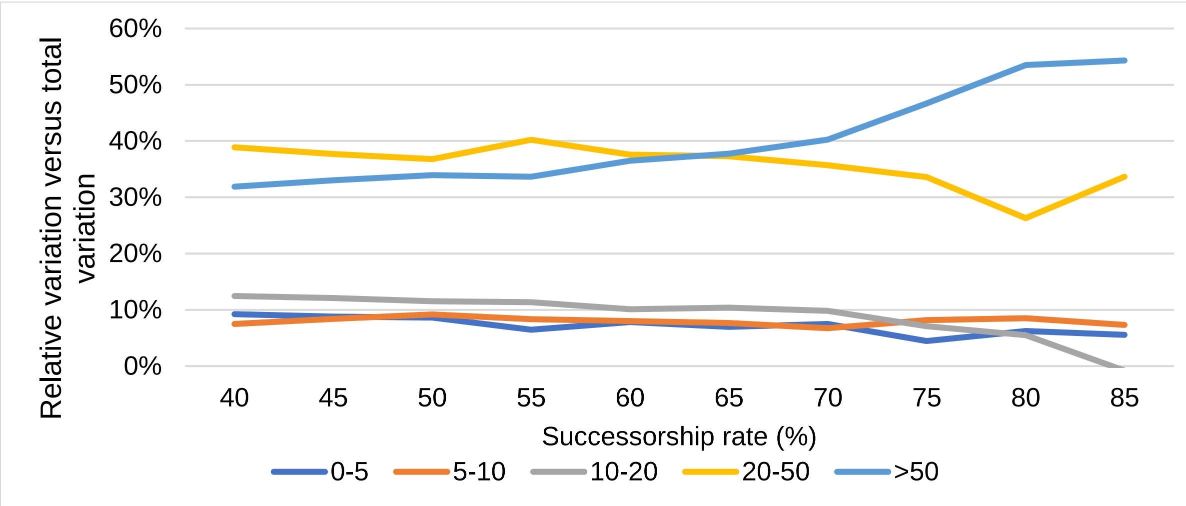


Figure 21. Relative variations of number of farms versus the total variations of farms by farm size categories and by successorship rate, between 2006 and 2020.

The aim of the second calibration test was to differentiate the successor chance by the farm size (Table 5). Farms > 50ha would have a high successor chance (70.5%) while the smallest would present a lower successor chance (16%). Comparing to the precedent test (Figure 21), the variation in the number of large farms (>50ha) is more appropriately projected, although the number of farms with a size between 20 and 50 ha are projected to be responsible of 48%

of the total decrease in the number of farms. The objective of the following test (successorship rates are 95% for farms > 50ha, 70.5% for farms < 50ha and > 20 ha, and 16% for farms < 20ha) was to minimize the influence of the middle size farms on the decreasing number of total farms but did not have the expected impact (Table 6).

Table 5. Average of ten runs of the models until 2020 evaluating the variation in the number of farms by farm size categories. The variations are relative to the initial numbers of farms in 2006. The successorship rates are 70.5% for farms > 50ha, and 16% for farms < 50ha.

Farm size (ha)	Obs. absolute variations	Mod. absolute variations	Obs. relative variations	Mod. relative variations
0-5	-69%	-17%	36%	14%
5-10	-37%	-21%	14%	11%
10-20	-22%	-18%	11%	15%
20-50	-26%	-24%	32%	48%
>50	-2%	-5%	3%	11%
Sum	-27%	-15%		

Table 6. Average of ten runs of the models evaluating the variation in the number of farms by farm size categories (between 2006 and 2020). The variations are relative to the initial numbers of farms in 2006. The successorship rates are 95% for farms > 50ha, 70.5% for farms > 20 ha but < 50 ha, and 16% for farms < 20ha.

Farm size (ha)	Obs. absolute variations	Mod. absolute variations	Obs. relative variations	Mod. relative variations
0-5	-69%	2%	36%	-5%
5-10	-37%	-2%	14%	4%
10-20	-22%	4%	11%	-13%
20-50	-26%	-11%	32%	79%
>50	-2%	-4%	3%	34%
SUM	-27%	-4%		

With the lowest normalized RMSE (NRMSE), we eventually selected the following successorship rate: farms > 50ha would have a high successor chance (70.5%) while the smallest would present a lower successor chance (16%) for the RC scenarios, and a lower successor chance (16%) for all farm size categories for the GE scenarios The NRMSE was normalized with the range values of the observations and was calculated as the average of 80 runs of the model which consisted in the four scenarios ran 20 times each (Figure 22).

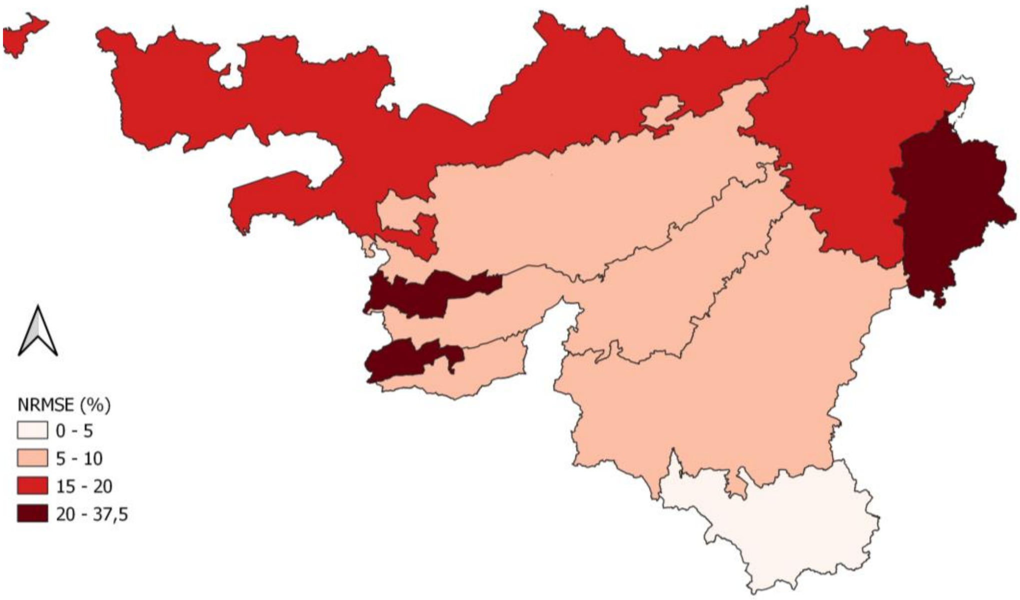


Figure 22. Normalised RMSE (by range) regarding the projection of the numbers of farms in 2020 by agricultural regions in Wallonia. The number of farms is the average of 80 runs and are compared to official statistics by farm size categories.

2.1.2. Land use

As per the model construction, there is no parameter which influence's can be studied through a sensitivity analysis. The land use decisions are based on potential land use profitability and subsidies conditionalities. We anyway calculated the average of the outputs of the 20 runs of each scenarios (four), which lead to 80 model runs, in the year 2020 and compared the projected crop repartitions by agricultural regions to the official statistics from 2020, by calculating normalized RMSE (Figure 23). The high Ardennes, Ardennes, Fagnes, with values of 50.3%, 33.7% and 30.8% respectively, presented the highest NRMSE. Figure 24 displays the projected future crop repartition of four agricultural regions. The region "Hautes Ardennes" is not represented as the model projections did not support any crop.

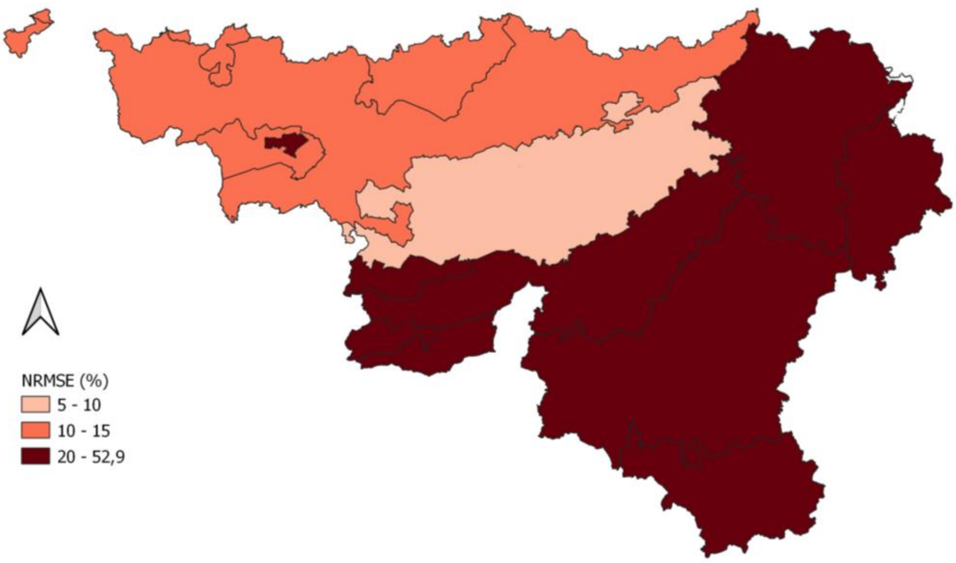


Figure 23. Normalised RMSE (by range) regarding the projection of the areas of the different crop categories in 2020 by agricultural regions in Wallonia. The areas are the average of 80 runs and are compared to official statistics of year 2020.

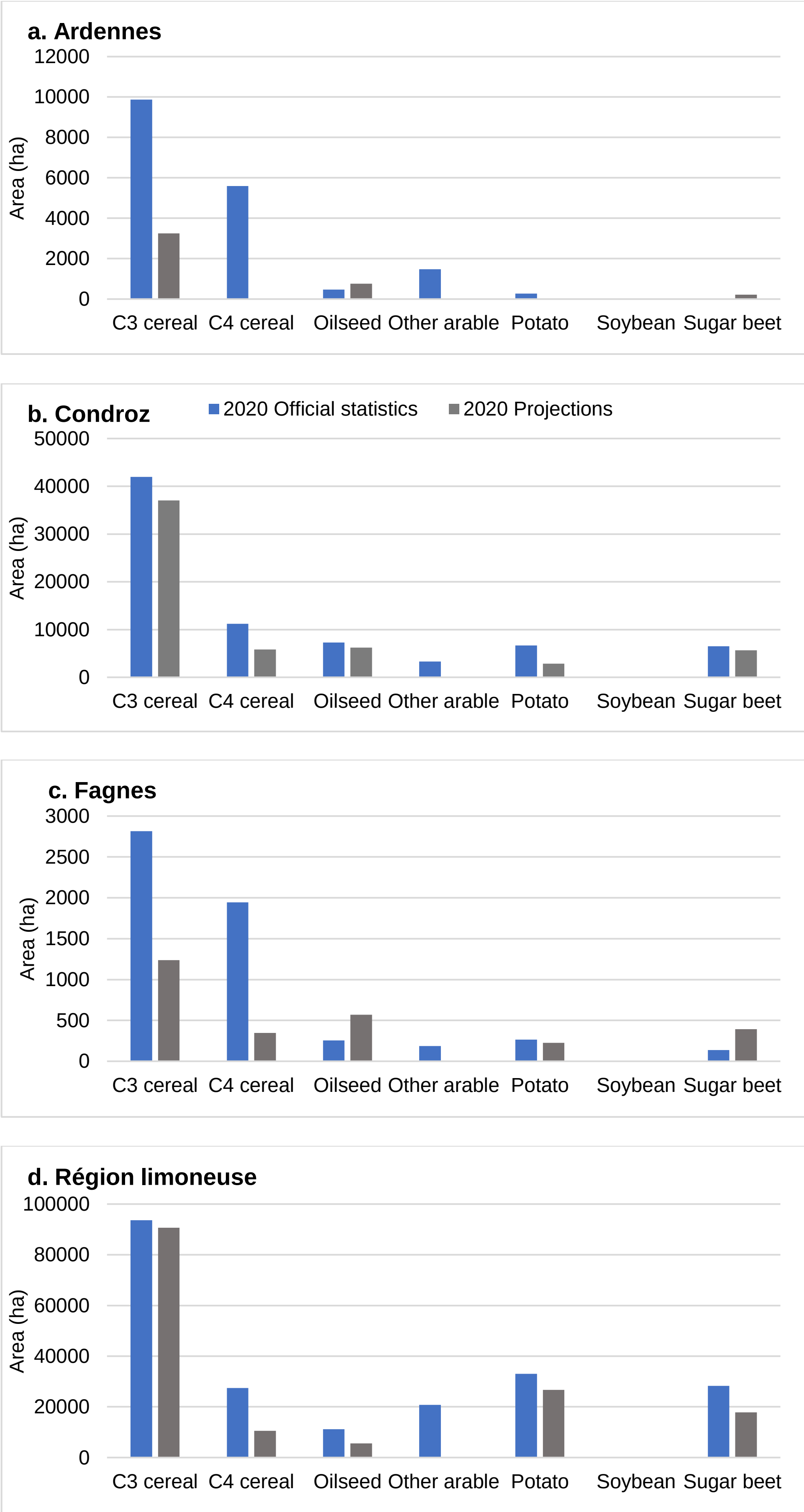


Figure 24. Average crop land use projections of 80 model runs in 2020 by agricultural regions in Wallonia.

Evaluating the accuracy of the projections of the future crop repartitions in Wallonia by crop, C3 cereal, potato and sugar beet total areas are the closest to the actual 2020 crop repartition (Table 7), as in agreement with the projected crop repartition in the Condroz region and the "Région limoneuse" (Figure 24 b. and d.).

Table 7. Normalised RMSE regarding the projection of the areas of the different crop categories in 2020 in Wallonia. The projected areas are the average of 80 runs and are compared to official statistics of year 2020.

Land use categories	NRMSE (%)
C3 cereal	3,5
C4 cereal	23,2
Oilseed	17,2
Other arable	32,3
Potato	7,1
Soybean	42,8
Sugar beet	13,1

2.2. Projections

2.2.1. Farms distributions

In 2070, all farm size categories are affected by a decrease in the number of farms (Figure 25), and the same pattern is observed for each agricultural regions. As per the chosen successor rate, the GE scenarios a drastic decrease in the total number of farms, between 77 and 81% in 2070, which is coherent with the current annual decrease in the number of farms of 2-3% (as discussed in 2.1.1. section) which should lead to a loss of 80% of the farms by 2070.

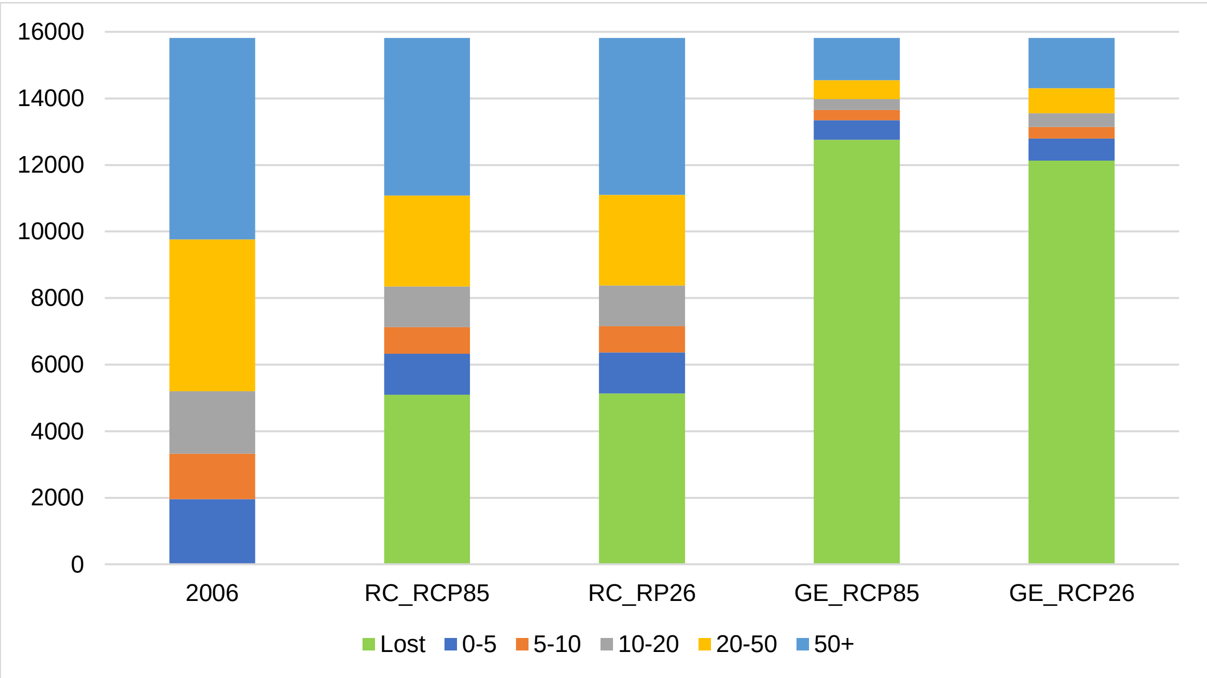


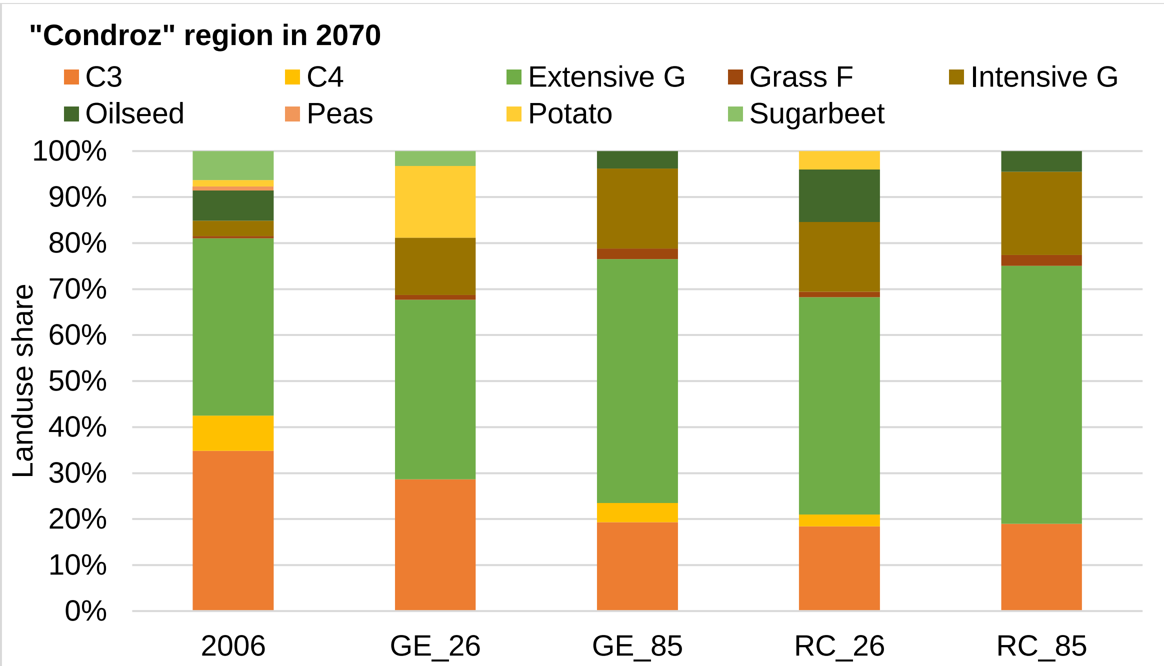
Figure 25. Projected numbers of farms by farm size categories in 2070 by scenarios: Regional Communities (RC), Global Economy (GE), and climate forcing scenarios (RCP8.5 and RCP2.6).

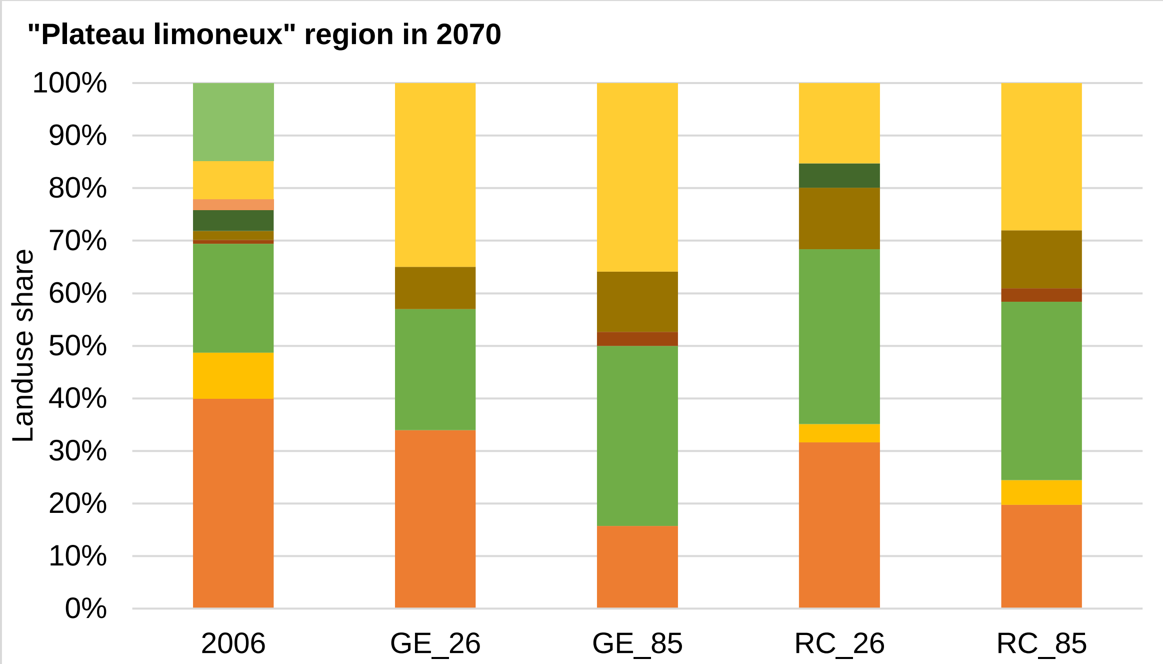
2.2.2. Land uses in average

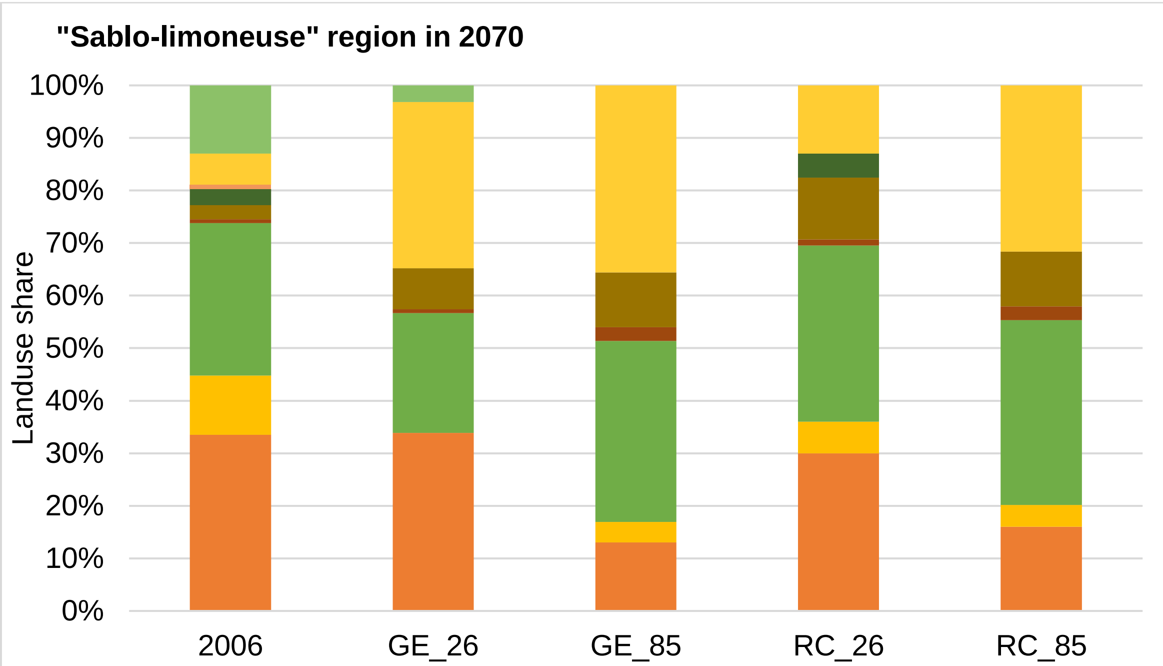
In 2070, the model projects a global decrease in C4 areas between 69 and 98 % for all scenarios with a complete disappearance in most agricultural regions under the GE_RCP26 scenario (Figure 26). The C4 category indeed presents the lowest yield increase under the RCP2.6 climate forcing scenario and only a small portions remain in 2070 in the “Lorraine” and “Fagnes” agricultural regions. On the other hand, soybean presents the highest yield increase in both climate forcing scenarios but the cultivated areas do not expand in Wallonia, only a small surface is dedicated to this crop in the “Ardennes” region (between 127 and 177 ha, depending on the scenario). Regarding soybean, despite a great potential, it seems that the historical crop sequence have a larger influence on the future crop decisions than the economic profitability parameter. Eventually, the projections also suggest that cultivated areas with C4 cereals or sugarbeet decrease in favor to the potato crop in the central region of Belgium (“Plateau limoneux” and “region sablo-limoneuse”) while it is climate-dependent in the “Condroz” region. Cultivated areas with C3 cereal tend to decrease more under climate forcing RCP8.5 scenario, although the yield change is larger, in favor to the extension of pastures in the concerned agricultural regions (“Fagne”, “Famenne”, “Lorraine”, “Pays de Herve”, “Hautes Ardennes”, “Ardennes”).

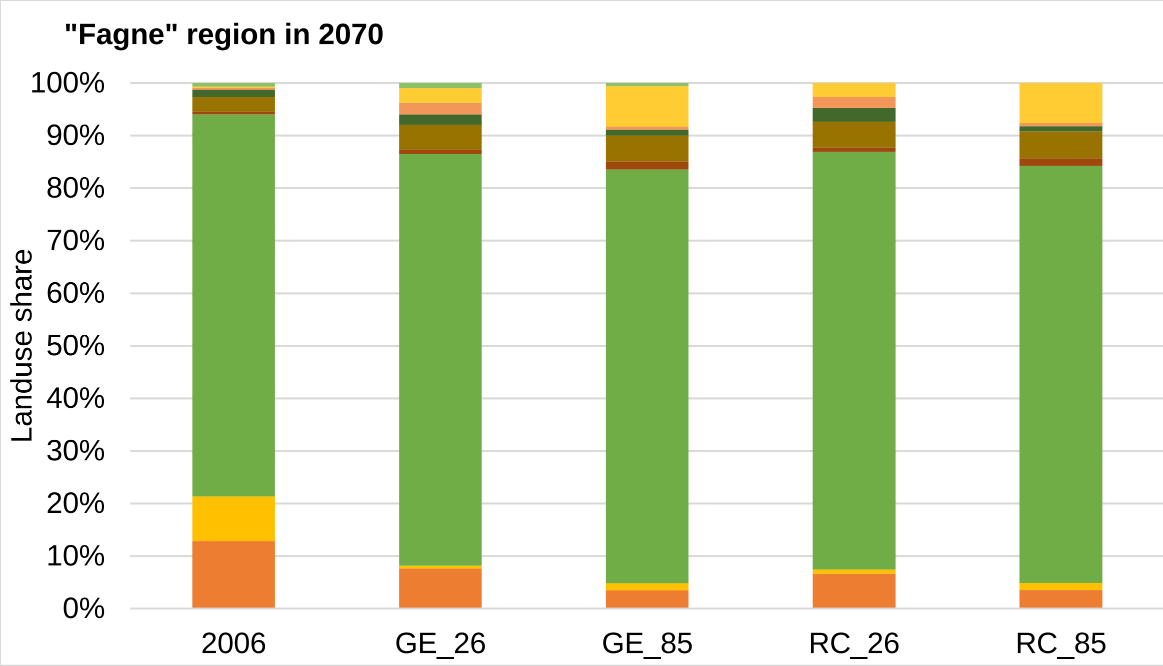
Table 8. Projected changes in Wallonia crop yields in percent for the period 2041-2070 relative to the period 1991-2020 under the RCP 2.6 and RCP8.5 climate forcing trajectories. Table adapted from MAPPY D2.4.

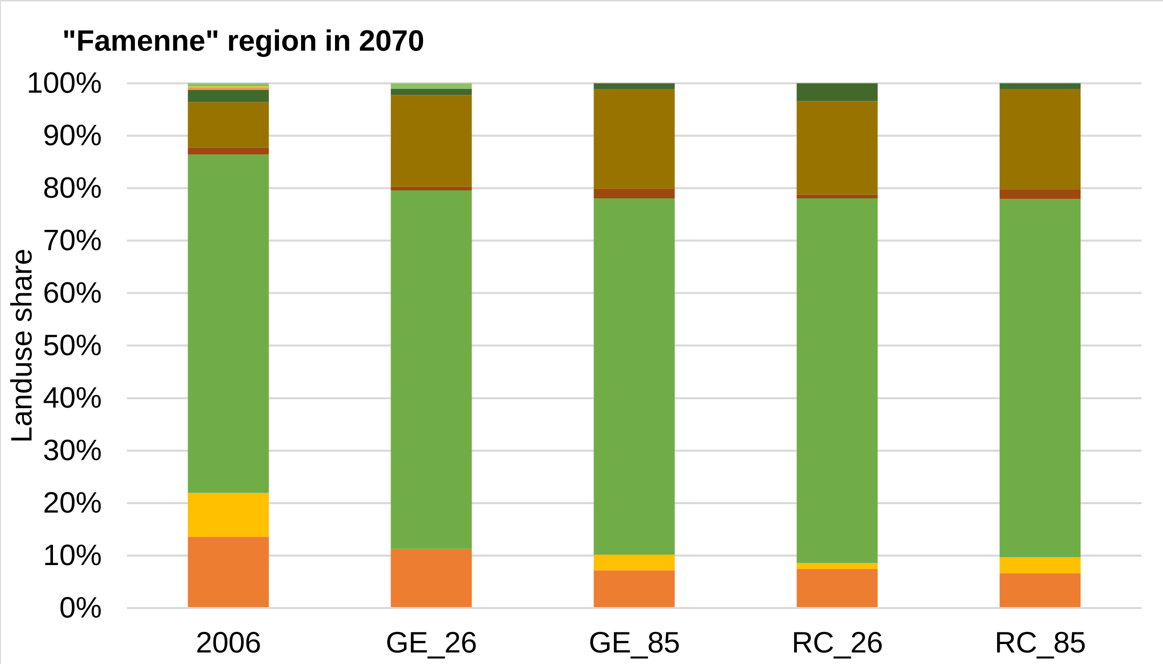
Crop	Yield change (%) RCP 2.6	Yield change (%) RCP 8.5
C3	31	37
C4	7.4	14
Oilseed	22	23
Sugar beet	30	23
Soybean	33	43

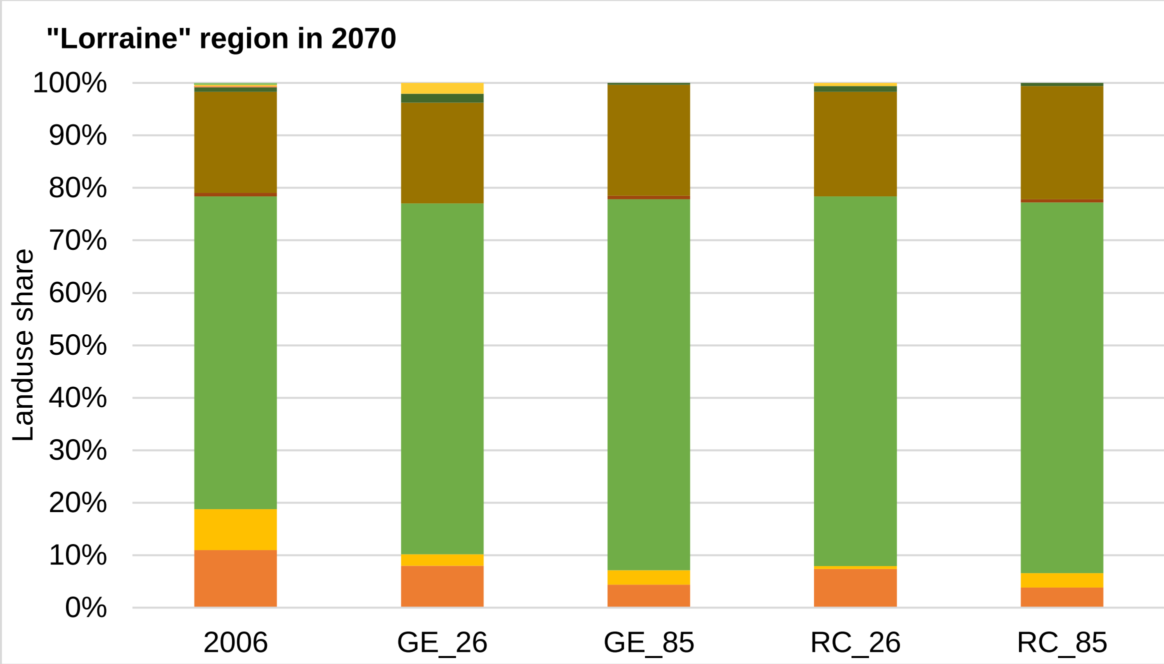


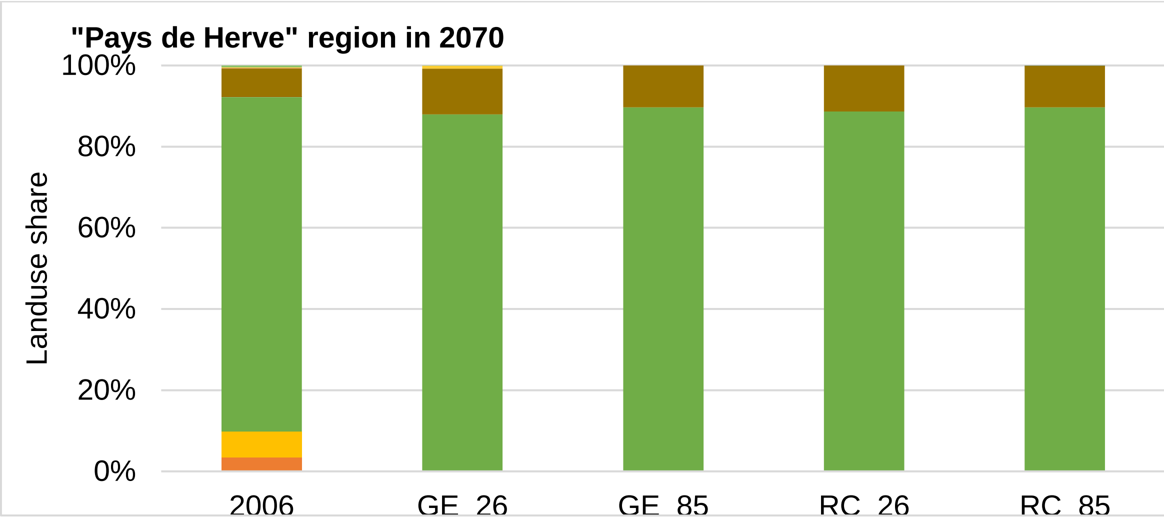

"Plateau limoneux" region in 2070
Landuse share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
GE_26
GE_85
RC_26
RC_85

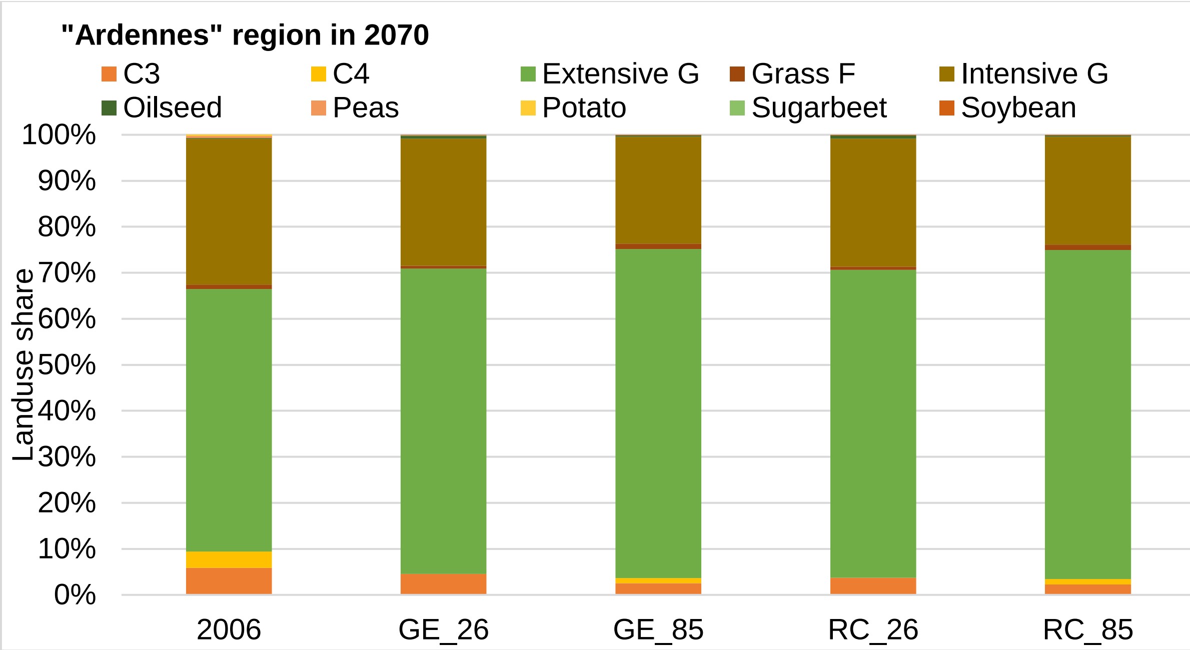

"Sablo-limoneuse" region in 2070
Landuse share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
GE_26
GE_85
RC_26
RC_85


"Fagne" region in 2070
Landuse share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
GE_26
GE_85
RC_26
RC_85


"Famenne" region in 2070
Landuse share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
GE_26
GE_85
RC_26
RC_85


"Lorraine" region in 2070
Landuse share
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2006
GE_26
GE_85
RC_26
RC_85


"Pays de Herve" region in 2070
Landuse share
100%
80%
60%
40%
20%
0%
2006
GE_26
GE_85
RC_26
RC_85



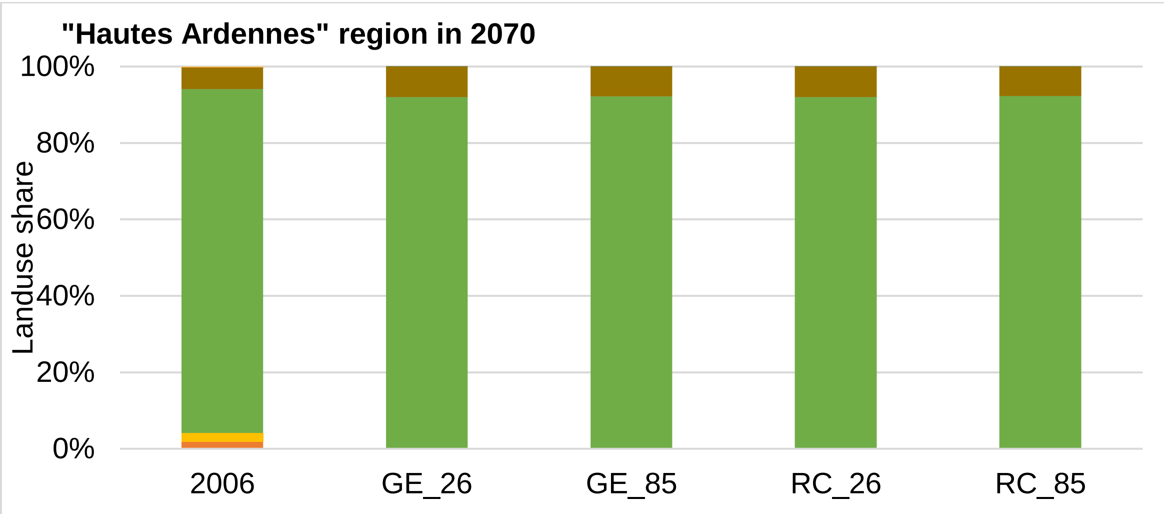


Figure 26. Projected landuse share in 2070 for the agricultural regions of Wallonia by scenarios. Regional Communities (RC), Global Economy (GE), and climate forcing scenarios (RCP8.5 and RCP2.6).

2.2.3. Most recurrent land use

Computing the most recurrent land use, it is possible to extract precise spatial land use information that will be use in WP5. Frequencies range from 0.15 to 1 with a median of 0.9 (Figure 27). We combined the 270226 agricultural parcels with Corine database 2006 in order to have a continuous layer across Wallonia, and the data were rasterized to fit the standard 3x3 km² MAPPY grid. Results from WP3 (mass of carbon and LAI of forest) were also added to each cell. The data were delivered to WP6 in the form of csv file.

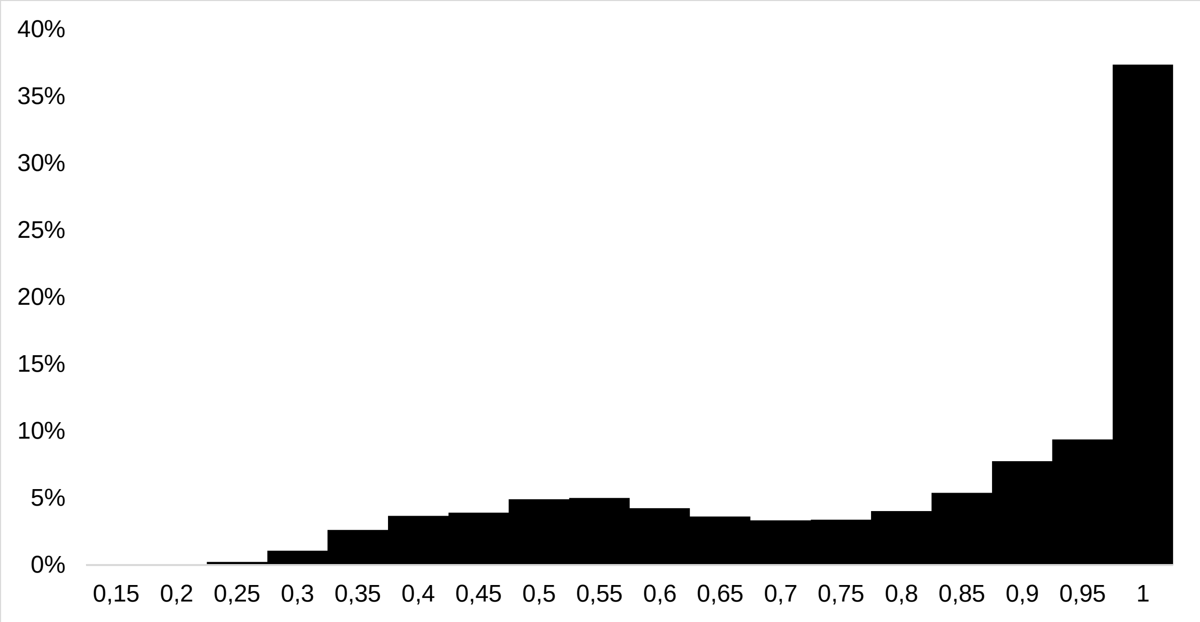


Figure 27. Histogram of the frequencies of land use probabilities by agricultural parcels in 2070 for the GE_RCP2.6 scenario.

2.3. Landscape diversity

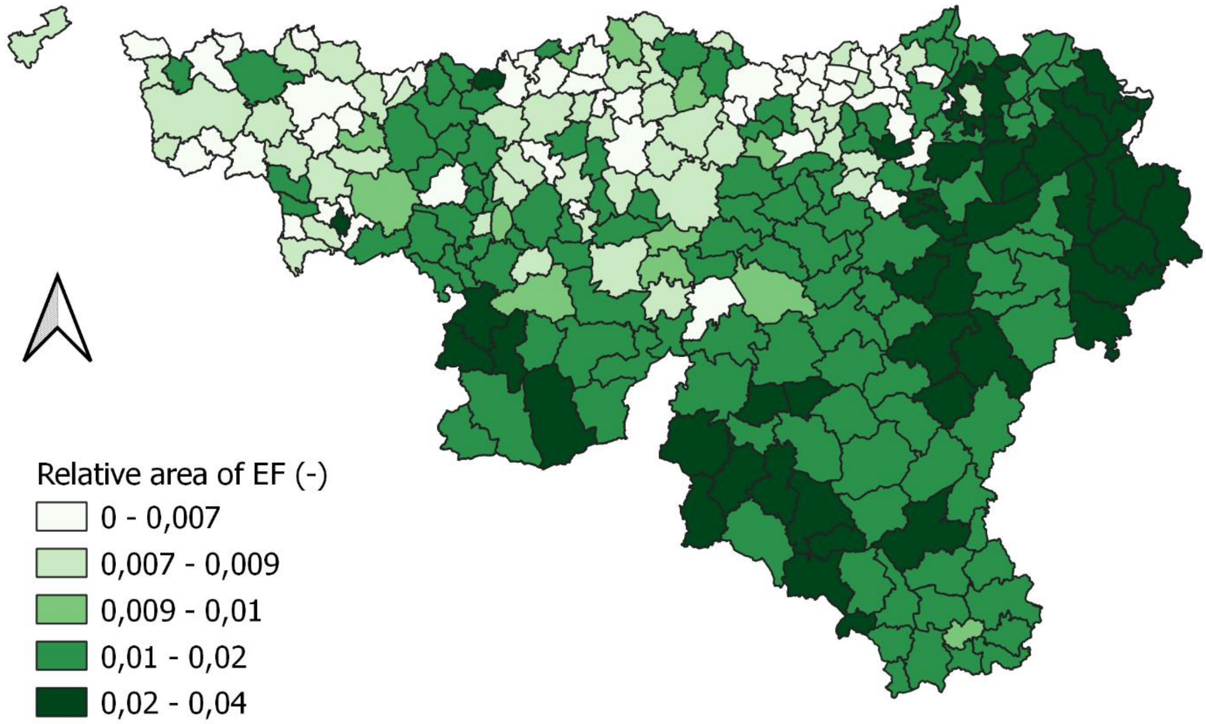
2.3.1. Land abandonment

In 2070, in average, the land abandonment was similar between climate forcing scenarios (RCP8.5 and RCP2.6) for each economic scenarios. For both scenarios, the “Hautes Ardennes” agricultural region presents the highest rate of land abandonment (7 and 5% for, respectively, the GE and RC scenario), followed by the “Ardennes” region (4 and 2%) while the other regions present a rate around 3% in the GE scenarios and between 1 to 2% in the RC scenarios.

The fate of abandoned parcels was developed along three scenarios. The “Baseline” scenario would consider that the abandoned parcels would remain fallow or set-aside land while the “Forest” scenario convert the parcels into “afforested” land. Finally, the “Urban” scenario converted the abandoned parcels into urban areas if the ratio of urban areas over the total area of the Mappy grid pixel (3 km x 3 km) was above 2%, otherwise it would remain fallow.

2.3.2. Ecological features distribution

An important land use characteristic to the distribution of pollinators is the spreading of ecological features across the region. The average area of ecological feature for each parcels was also provided to WP5. The average ecological areas by municipalities are similar between climate forcing scenario, differences emerging from the random allocation of ecological features within a farm, and only the projection from the RCP2.6 climate forcing scenarios are presented (Figure 28).



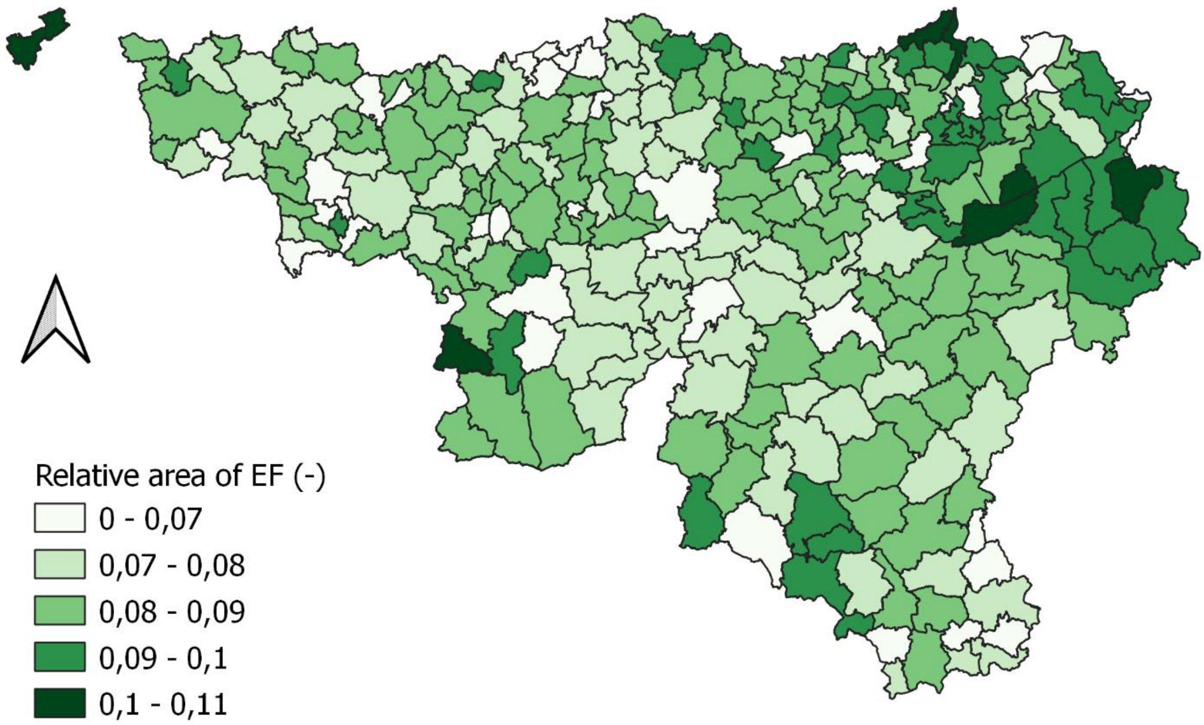


Figure 28. Relative area of ecological feature (-) by municipality in 2070 across Wallonia, by economical scenario under the RCP 2.6 climate forcing scenario. Upper map: GE scenario. Lower map: RC scenario.

2.3.3. Diversity indexes

The structure of the landscape can be assessed through the computation of the Shannon and Simpson indexes, quantifying, respectively, the richness and the evenness of diversity (Nagendra, 2002). It was expected that the RC scenario would lead to a more diverse landscape as the rules intends to keep more small farms that must comply with crop diversity, but those are however lower than the GE values for the same climate forcing scenario (Figure 29). Exclusively is the Shannon index for the RC scenario higher than the GE's value under the RCP2.6 climate forcing scenario in 2070, coming from the higher index values of the three main crop regions of Wallonia (Table 9, *Plateau limoneux*, *region sablo-limoneuse* and *Condroz*). Focusing on those three regions, differences in index values between economical scenarios are more pronounced for the RCP2.6 climate forcing scenarios then the RCP 8.5 (Table 9 and 10).

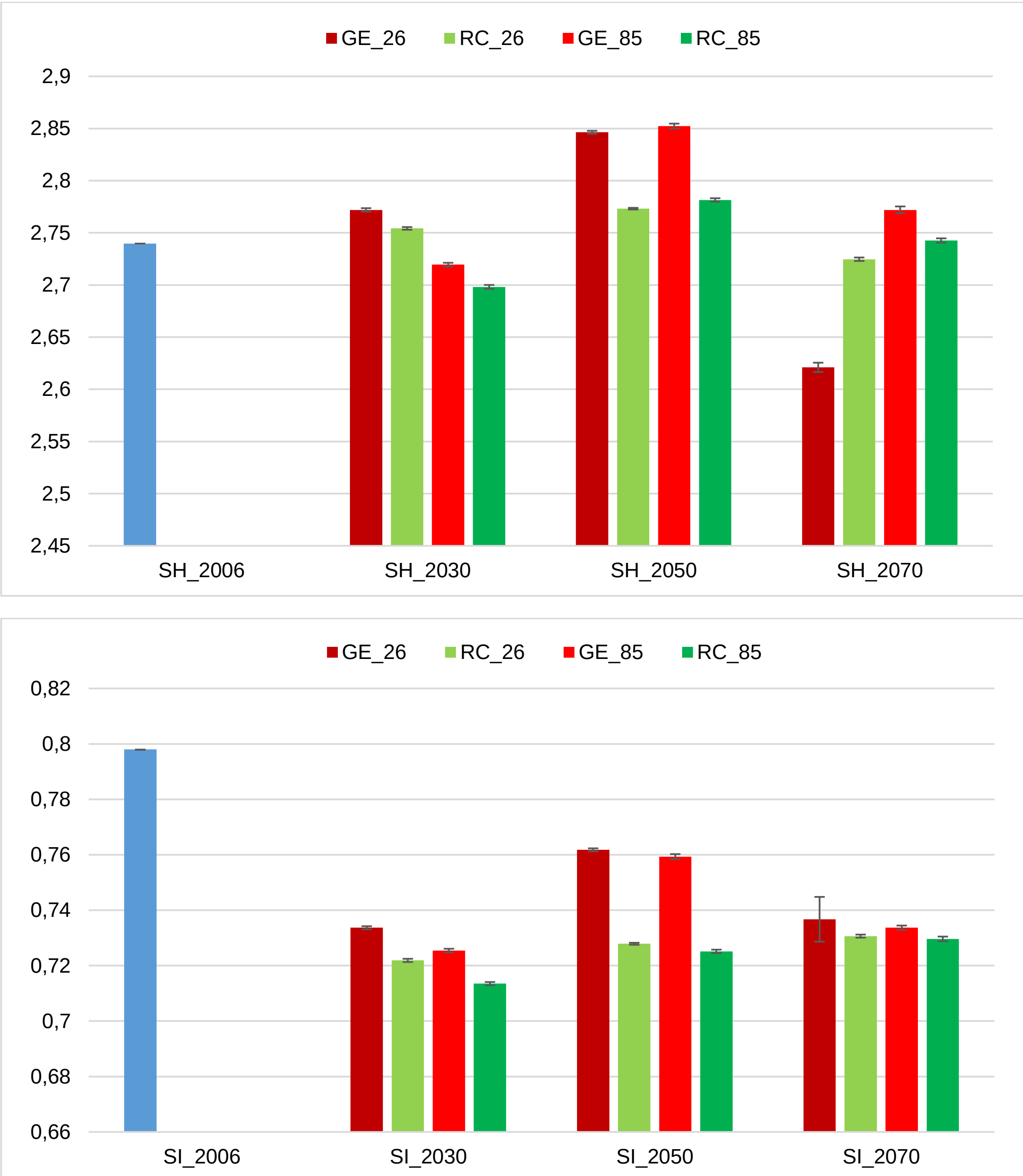


Figure 29. Evolution of Shannon (Upper graph) and Simpson (Lower graph) index from 2006 to 2070 by scenarios for the Wallonia region.

Table 9. Shannon index in 2070 by agricultural regions and scenarios. Regional Communities (RC), Global Economy (GE), and climate forcing scenarios (RCP8.5 and RCP2.6).

	2006	GE_RCP26	RC_RCP26	GE_RCP85	RC_RCP85
Famenne	2,37	2,30	2,27	2,45	2,37
Pays de Herve	1,85	2,06	1,97	2,09	1,98
Plateau limoneux	2,92	2,71	2,92	2,95	2,95
Ardennen	2,10	2,21	2,17	2,22	2,15
Lorraine	2,44	2,36	2,31	2,44	2,37
Fagne	2,19	2,57	2,51	2,51	2,42
Sablo-limoneuse	2,89	2,70	2,89	2,94	2,90
Hautes Ardennes	1,52	1,83	1,76	1,84	1,75
Condroz	2,63	2,57	2,70	2,81	2,76

Table 10. Simpson index in 2070 by agricultural regions and scenarios. Regional Communities (RC), Global Economy (GE), and climate forcing scenarios (RCP8.5 and RCP2.6).

	2006	GE_RCP26	RC_RCP26	GE_RCP85	RC_RCP85
Famenne	0,61	0,63	0,66	0,58	0,61
Pays de Herve	0,37	0,52	0,52	0,45	0,44
Plateau limoneux	0,80	0,76	0,81	0,80	0,81
Ardennen	0,57	0,63	0,62	0,59	0,57
Lorraine	0,69	0,66	0,68	0,62	0,63
Fagne	0,54	0,65	0,65	0,60	0,59
Sablo-limoneuse	0,80	0,76	0,81	0,79	0,79
Hautes Ardennes	0,22	0,47	0,48	0,41	0,40
Condroz	0,70	0,73	0,76	0,72	0,73

Conclusion

This deliverable provides results of the land use change model developed in the frame of the MAPPY project for two case studies of the project. Given the complexity and labor intensity necessary for the model construction, the future land use of the other four case studies was not projected. We intended to present factual results that should be interpreted in parallel with the final results of the WP5 (pollinators spreading) and WP6 (socio-economic impacts).

In order to evaluate the the impact of agricultural practices and policy incentives on the agricultural landscape and pollinators distribution, we used and agent-based model to simulate the yearly behavior of individual farmers across the studied region. This model presents two major components. On one hand, farmers age and the future of their farm depends on whether the farmer has a successor or not. It should influence the spatial crop diversity as, per the model rule, one farm should present a minimal number of crop. On the other hand, farmers take yearly decision on the future use of each of their parcel. Those decisions are based on the economic profitability of the crop (from the projected yields, depending on climate forcing scenarios RCP8.5 and RCP2.6), on traditional agricultural sequence , and on the agricultural policies in place that comply the farmers with specific agricultural rules. This last set of rules are developed along two contrasting scenarios: the Regional Communities scenario (RC) that should promote farm succession, crop diversity and the implementation of ecological features, and the Global Economy scenario (GE).

As an agent-based model is a stochastic model, the results were evaluated by averaging the outputs of the multiple runs. For the project needs, we however also calculated the frequency of each land use category by parcels and selected the most frequent one by parcels as input for WP5.

For the Austrian case study, we could compare the 2020 projected land use to the actual observations and the resulting normalized RMSE were satisfactory with values between 5 and 10% depending on the municipality. In Belgium, we could compare both the 2020 projected farm distribution and 2020 projected land use with observations. the projected farm distribution present a NRMSE between 5 and 20%, depending on the agricultural region. The projected land use present a NRMSE between 5 and 50% depending on the agricultural region. The highest NRMSE are for the less dominant land use (soybean) and the “other arable” land use that disappear in all scenarios.

Finally, we can draw some general results from the functioning of the model:

- Future farm distribution is largely dependent on the economic scenario, and not at all on the climate scenario.
- Crop land use change in 2070 are in line with the yield change while grassland changes depends mostly on economic scenarios. Although it is difficult to implement a new crop (such as soybean in Belgium) due to the influence of the historical crop sequence on the next crop decision.
- Land abandonment rate depends on the economic scenario and repartition vary a little between climatic scenarios due to the stochastic nature of the model.
- The diversity of the landscape, assessed through the Shannon and Simpson indexes, is more impacted by the climatic scenario than by the economic scenario. As per the index calculation, crop-dominant regions present higher diversity indexes.

References

Beckers, V., Beckers, J., Vanmaercke, M., Van Hecke, E., Van Rompaey, A., and Dendoncker, N. 2018. Modelling farm growth and its impact on agricultural land use: a country scale application of an agent-based model. Land, 7, 109.

Herzfeld, T., Heinke, J., Rolinski, S., Müller, C., 2021. Soil organic carbon dynamics from agricultural management practices under climate change. Earth Syst. Dynam. 12, 1037-1055.

Jacquemin, I., Dury, M., Henrot, A.-J., Beckers, V., Berckmans, J., Dendoncker, N., Hamdi, R., Hambuckers, A., Tychon, B., Francois, L., 2020. High-resolution simulations of natural and agricultural ecosystems over Belgium with the CARAIB Dynamic Vegetation Model. Geo-Eco-Trop 44(4):541-552

Nagendra, H. 2002. Opposite trends in response for the Shannon and Simpson indices of landscape diversity. Applied Geography. 22, 175-186.

Lutz, F., Herzfeld, T., Heinke, J., Rolinski, S., Schaphoff, S., von Bloh, W., Stoorvogel, J.J., Müller, C., 2019. Simulating the effect of tillage practices with the global ecosystem model LPJmL (version 5.0-tillage). Geosci. Model Dev. 12, 2419-2440.

von Bloh, W., Schaphoff, S., Müller, C., Rolinski, S., Waha, K., Zaehle, S., 2018. Implementing the nitrogen cycle into the dynamic global vegetation, hydrology, and crop growth model LPJmL (version 5.0). Geoscientific Model Development 11, 2789-2812.