MARGINAL LANDS, INDUSTRIAL CROPS AND INNOVATIVE BIO-BASED VALUE CHAINS

Deliverable D1.3

Marginal land Classification and Information System (MIDAS-MLCIS 2) for future options and needs for co-creation of resource efficient biomass value chains with climate mitigation and adaptation and biodiversity conservation and restoration

Funded by the European Union

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082070.

Document summary

Deliverable number	D1.3
Title	Marginal land Classification and Information System (MIDAS-MLCIS 2) for future options and needs for co-creation of resource efficient biomass value chains with climate mitigation and adaptation and biodiversity conservation and resto-ration
Version	First version 31.7.2025, 2nd version 25.11.2025, final version 2.3.2026
Work package n°	1
Lead Beneficiary	WR
Authors	Berien Elbersen, Valentina Jara Rios, Michiel van Eupen & Igor Staritsky , Wouter Meijninger
Submission date	2 March 2026
Dissemination Level	Public
Project acronym and title	MIDAS
Grant Agreement n°	No. 101082070
Project coordinator	Dr. Efi Alexopoulou
Reviewer	Dr. Efi Alexopoulou
Review date	July 2025/February 2026

Statement of Originality
This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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Executive summary

This report presents the second version of a spatial marginal land classification and information systems. The focus in this deliverable is on the crop suitability and crop yield performance in the marginal lands 2020 and 2050. The deliverable also explains the next steps to be taken in WP1 in relation to the further development of the Marginal land Classification and Information System (MIDAS-MLCIS).

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1 Introduction

1.1 Aim and context

This deliverable presents the second version of a spatial marginal land classification and information systems. It is the second Deliverable of work package 1 of MIDAS that has as an overall objective **to improve understanding of the actual and future available marginal land in EU plus UK and Serbia and its potential for "low-ILUC" biomass production and for identification of co-benefits potential risks and upscaling of biomass production with a low potential for ILUC.**

The focus in this deliverable is on the options for crop growth in marginal lands in 2020 and 2050 for the EU27+UK territory taking account of climate change effects. For the crops selected in the MIDAS project crop growth simulation modelling was done taking account of the historic and future climate. In addition, estimates were made of the level at which marginal factors characterising the marginal lands in all location in the EU+UK would negatively affect the yield of the selected crops. The results of this analysis are to be included in the Marginal land Classification and Information System (MIDAS-MLCIS) to inform the end-user about the crop suitability and crop yield performance in marginal lands now and towards 2050. The results presented in this deliverable are preliminary results. Improvements in the crop yield simulations are also to be made after the publication of this Deliverable.

1.2 Outline of report and online product: marginal land classification and information system (MLCIS)

This report consists of 4 chapters including this introductory chapter. Chapter 2 gives a summary overview of the marginal land mapping for 2020 and 2050 based on the most recent updated results in the project. It also explains the presentation of the marginal land mapping in the most recent version of the Marginal land storymap that is published on the MIDAS project website. Chapter 3 presents the methodology and some intermediate results of the mapping of crop suitability and the crop yield simulation approach applied in MIDAS to provide an overview of crop performance in marginal lands. The final chapter 4 discusses next steps planned to finalise the results in WP1.

2 Marginal land mapping results in MLCIS

2.1 Marginal lands 2020

In the former deliverable 1.1 the mapped results were presented of the Marginal land 2020 and the 2050 marginal land locations. Here we summarize first these results.

In MIDAS the marginal land map of EU28 produced in MAGIC was updated and improved. The results of this update are summarized in Table 1 by country. The area share is like in MAGIC, expressed in relation to the historic 'agricultural mask' that consists of all agricultural and semi-natural land cover classes between 1990-2018 (see Annex I).

Table 1 Current land area absolute (km2) and relative (%/ MAGIC historic agricultural land) coverage* by 6 clusters of biophysical constraints making up marginal lands (mapped as severe and severe by pair-wise combination)

km2	1 Climate	2 Wetness	3 Fertility	4 Chemical	5 Rooting	6 Terrain	total marginal (km2)	Total marginal %	not-marginal or sub-severe
Austria	10016	7137	156	260	5433	10568	15684	45%	19191
Belgium	259	140	149	0	118	0	513	3%	16801
Bulgaria	1409	25	139	820	2544	2921	6618	11%	55142
Croatia	86	5340	41	0	4103	869	7958	31%	17719
Czech Rep.	1084	1303	200	52	63	176	2551	6%	42646
Denmark	1	2670	40	0	5048	0	7729	24%	24687
Estonia	4551	5337	14	0	307	0	8159	56%	6495
Finland	34729	9907	12432	0	3963	39	34898	100%	158
France	10562	22456	350	4589	21546	13952	49768	14%	297079
Germany	2699	22528	2418	9	15321	1077	38879	19%	167265
Greece	3384	37	3191	1345	22585	18774	36169	44%	46822
Hungary	0	2995	1365	6076	7113	8	14641	23%	48839
Ireland.	1832	29770	1159	0	3841	642	30322	62%	18762
Italy	7386	4508	2641	1887	10893	20776	34052	19%	140881
Latvia	624	3296	17	0	1266	0	5095	20%	20602
Lithuania	57	1287	361	0	9330	0	10814	28%	27459
Luxembourg	0	0	3	0	127	1	131	9%	1269
Netherlands	0	1739	196	0	1219	0	3061	12%	21800
Poland	767	10844	6176	0	16216	258	30778	17%	153640
Portugal	749	1485	264	1369	9200	2681	12178	24%	39099
Romania	5102	5993	432	5238	36587	6410	42818	30%	98689
Slovakia	1240	467	94	527	3569	890	5315	23%	18210
Slovenia	291	2656	10	22	1972	979	3396	47%	3871
Spain	71283	16703	86341	3396	88301	30522	185854	54%	156850
Sweden	42440	24050	15672	0	6911	2851	48891	71%	20074
UK*	*47097*	*79570*	22294	*0*	*27455*	*6399*	*96365*	58%	*71051*
Total	**247648**	**262243**	**156155**	**25590**	**305031**	**120793**	**732637**	**32%**	**1535101**

** Area refers to total marginal land area in EU+UK (minus Malta & Cyprus) that can be regarded 'agricultural' as it has been in continuous or discontinuous agricultural use (according to Corine Land Cover (CLC)) between 1990 and 2018) (See Annex II)*
***Total marginal land is not equal to the total of all cells per country because the 6 marginal limitations can occur simultaneously in the same location (e.g. steep slope and rooting limitations etc.)*
**** UK is kept in this table for comparison reasons with the original marginal land mapping exercise*

Table 2 Current land area absolute (km2) and relative (%/agricultural land) coverage* by 6 clusters of biophysical constraints making up marginal lands (mapped as severe and severe by pair-wise combination) per environmental region

km2	1 Climate	2 Wetness	3 Fertility	4 Chemical	5 Rooting	6 Terrain	total marginal	%	not-marginal or sub-severe
Alpine	33311	26608	331	27	27133	32002	50985	69%	22979
Atlantic	49881	134401	25895	3364	66672	17580	185346	29%	464703
Continental	7991	46515	10350	12931	74199	8700	136264	20%	556356
Mediterra-nean.	74078	10153	91470	9268	114964	59554	251641	38%	417998
North	82387	44566	28109	0	22063	2957	108401	60%	73065
Total (EU+UK)*	**247648**	**262243**	**156155**	**25590**	**305031**	**120793**	**732637**	**32%**	**1535101**

*EU+UK minus Malta and Cyprus

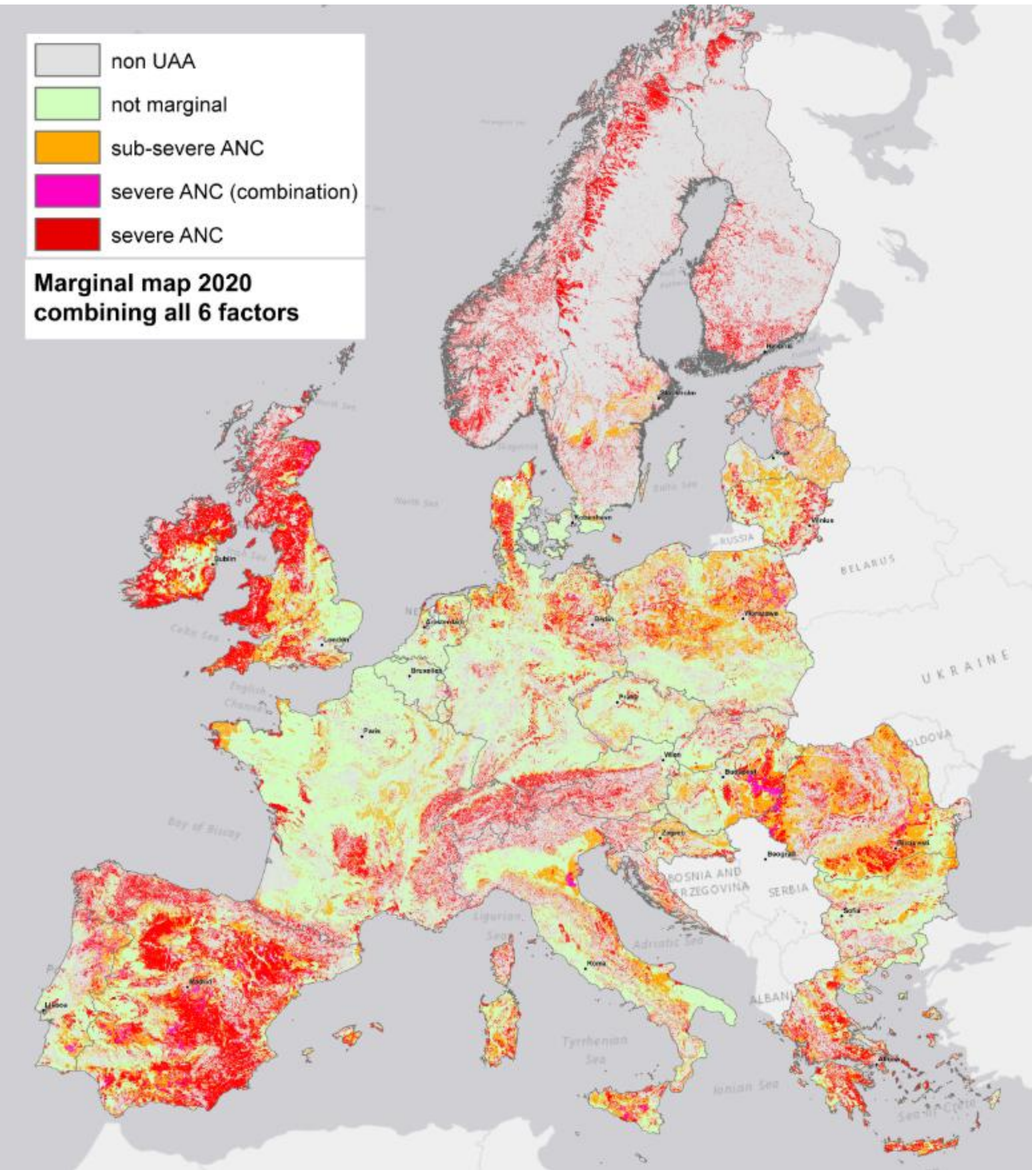

Figure 1 MIDAS marginal area resulting from the combination of 6 clusters of biophysical constraints (mapped as severe and severe by pair-wise combination) for 2020

In the total EU & UK there is more than 732,637 km2 (>74 million ha) of marginal lands which covers 32% of the agricultural area mask used in MAGIC (see Annex I). Countries with the largest absolute area of marginal lands are Finland, Sweden, Ireland, Estonia, Spain and UK. Small area shares of marginal lands are found in Belgium, Czech republic, Luxembourg, Bulgaria, Netherlands and France.

The most dominant marginal factors are rooting, wetness and climate. Rooting is a cluster of a wide range of soil limiting factors and it is therefore not surprising that is covers a large area. Also, the climate limitation of low temperature leading to a short growing season covers a large area in Europe. The latter is responsible together with the wetness limitation for the high marginal land share in the Environmental region North (see Table 2 and Figure 1).

The rooting limitation is more evenly spread over all environmental regions. The continental region has the smallest marginal land share and the largest limiting factor is rooting. In comparison to the other environmental regions the Continental region has the biggest absolute and relative area with chemical limitations. In the Atlantic region the limiting factors covering the largest area are wetness and rooting, but overall, this his region has a low marginal land share. The largest marginal land area in absolute terms, making up more than 25 million hectares is in the Mediterranean region. The marginal land share of this region is 38% which is below the share in the North and the Alpine region, but is high in comparison to the Atlantic and Continental regions. The most dominant marginal factors in the Mediterranean are rooting and fertility but it is also the region with the largest area in the terrain limiting factor.

2.2 Marginal lands in 2050

The area of marginal land that occurs within the agricultural area of the EU27 + UK is slightly decreasing in the period 2020-2050 with 6,385km^2 from 513,521km^2 to 507,136km^2. Interestingly, the total area shares at EU+UK level remains at 32% between 2020 and 2050. However, shifts in marginal land area between 2020 and 2050 within countries and Environmental regions can be big however.

Table 3 Absolute changes in marginal lands 2020-2050

Marginal km2	2020	2050	difference	identical type 2020 - 2050	shift in type 2020 - 2050	only marginal in 2020	only marginal in 2050
EU-27+UK	513521	507136	-6385	376548	86269	50704	44319
North	71069	53210	-17859	29482	23728	17859	0
Alpine	21130	16745	-4385	11754	4948	4428	43
Continental	127333	132548	5215	118710	5677	2946	8161
Atlantic	136486	113105	-23381	95378	17469	23639	258
Mediterranean	157503	191528	34025	121224	34447	1832	35857

Table 4 Relative changes in marginal lands 2020-2050

Marginal % / Current agricultural land	2020	2050	difference	identical type 2020 - 2050	shift in type 2020 - 2050	only marginal in 2020	only marginal in 2050
EU-27+UK	25.9%	25.5%	-0.3%	19.0%	4.3%	2.6%	2.2%
North	49.2%	36.9%	-12.4%	20.4%	16.4%	12.4%	0%
Alpine	48.6%	38.5%	-10.1%	27.0%	11.4%	10.2%	0.1%
Continental	18.7%	19.5%	0.8%	17.5%	0.8%	0.4%	1.2%
Atlantic	22.8%	18.9%	-3.9%	15.9%	2.9%	3.9%	0.0%
Mediterranean	30.4%	36.9%	6.6%	23.4%	6.6%	0.4%	6.9%

Large differences exist within Europe. In Scandinavia (North), Atlantic and Alpine regions the area occupied by marginal land is decreasing mainly due to improving climatic conditions for agricultural practices, while in the Mediterranean the reverse is taking place: an increase of marginal land for the period 2020-2050 with 34,025km^2 (6.6%) due changing climatic conditions and soil fertility (Table 3 and Table 4).

The largest absolute increase in marginal land is expected in Spain and the largest decline in the UK (Figure 2.

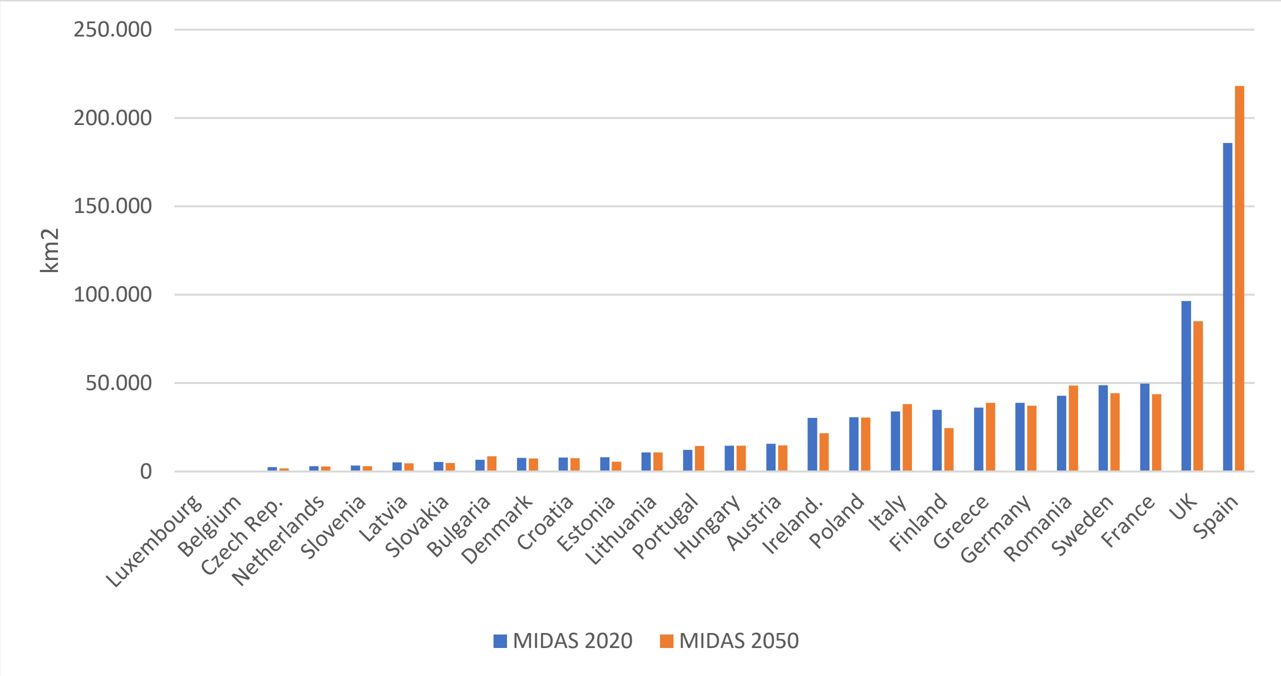

Figure 2 Change in MIDAS marginal land area between 2020 and 2050 per country

2.3 Updated story map on marginal lands

The results of the mapping of marginal lands in 2020 and 2050 are presented in a story map which is accessible with the MIDAS website here: Europe's Marginal lands.

Since the first version was published, some changes were made of which the most important one is the interactive map that enables the user to zoom to specific locations on the map and investigate the changes in marginal land expected between 2020 and 2050 by moving a slider (Figure 3).

Also a 3 dimensional map viewer was added enabling the user to visit any place in the EU on the map and consult the marginal conditions present (Figure 4).

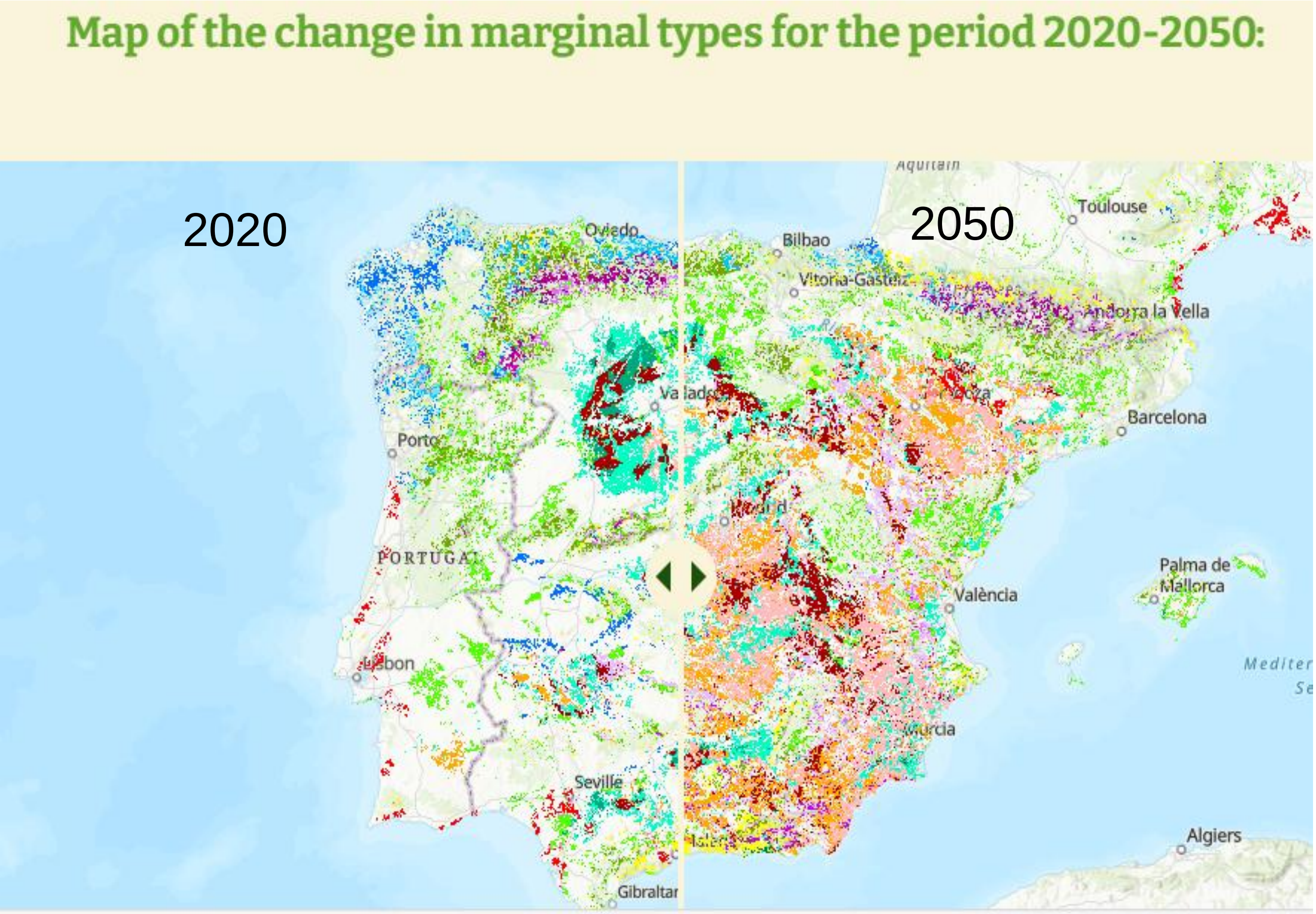

Figure 3 Changes in marginal lands 2020- 2050 (Map viewer Storymap on MIDAS website)

Figure 4 3D map viewer of marginal lands in EU (Map viewer Storymap on MIDAS website)

3 Crops suitable for marginal lands

3.1 Introduction

The maps with marginal lands in 2020 and 2050 tell us where the largest challenges are and will be under influence of climate change, for conventional food production. In these marginal areas there will be a need to either compensate farmers for higher cost and lower returns from their lands in order to prevent land abandonment or to stimulate the development and investments in alternative uses of the land that can be combined with the natural constraints in place. Such alternatives may be the production of non-food biomass to be used as feedstock for the production of bio-chemicals and biomaterials that can replace fossil resources.

This is why in MIDAS the focus is on novel crops providing feedstock for biobased industries and new income opportunities for farmers in marginal lands.

To identify for the mapped marginal lands which MIDAS crops are suitable to grow two activities were performed:
1) the climatic suitability of the different crops has been determined. together with all crop experts in MIDAS and based on a literature review. The information on the climatic requirements per crop has been systematically collected through literature review and through the collection of knowledge from the crop experts participating in MIDAS and doing field trials with all different crops. This resulted in maps showing the climatic suitable area per crop in the EU27 & UK.
2) The experts in WP 1 have estimated based on their field trialing experiences and their scientific reviews of crops what the yield reduction effects are per crop per grouped marginal condition.

3.2 Methodology

The main aim of the methodology is to answer the central research question:
Where in Europe can the crops selected in MIDAS provide viable biomass or seed yields under marginal conditions now and in the future?

The methodology consists of two main steps:
1) Simulating the yield with the Aquacrop model over the whole EU using daily weather data for historic wheather data and for climate change 2050 (SSP285)
2) Applying a spatially explicit crop suitability approach in marginal lands of the EU

Ad 1) Yield simulations with Aquacrop
For the yield crop simulations, the AquaCrop model (Doorenbos and Kassam, 1979) was used. AquaCrop is a crop water productivity model developed by the Land and Water Division of the FAO. The model implementation and post model adaptations were done in a GAMS code.

To assess the yield of biomass crops, the AquaCrop model combines daily weather data with the phenological factors that influence the growth of each specific biomass crop. Since the phenological factors for the newly introduced crops were not initially available, efforts were made to gather this information from various literature references and refined with the help of the crop experts within the project. These experts have large experience with field trials with the specific crops in the EU territory.

Table 5 Overview of crops included in the analysis

Crop	Type (P=Perennial/A=Annual)	Use
Miscanthus	P	Biomass (lignocellulosic)
Switchgrass (Upland & Lowland)	P	Biomass (lignocellulosic)
Giant Reed	P	Biomass (lignocellulosic)
Reed Canary Grass	P	Biomass (lignocellulosic)
Cardoon	P	Biomass & Oilseed
Siberian Elm	P	Biomass (woody/tree)
Seville Lavender	P	Biomass (essential oils/aromatic)
Willow	P	Biomass (short rotation coppice)
Poplar	P	Biomass (short rotation coppice)
Eucalyptus	P	Biomass (woody)
Safflower	A	Oilseed
Industrial Hemp	A	Fiber & Biomass
Crambe	A	Oilseed
Biomass Sorghum	A	Biomass (lignocellulosic)

The AquaCrop approach links crop water use to crop yield, where net biomass production per hectare depends on water productivity and crop water use. The model uses the following formula (Equation 1):

Equation 1. $$B = WP \bullet \sum ETc$$

Where:

- B is the biomass produced cumulatively (Mg ha^{-1}), *data for every Nuts3*
- ETc is the crop evapotranspiration (either mm or m^3 per unit surface), with the summation over the time period in which the biomass is produced and this depends on the number of accumulated days the temperature is above the minimum growing temperature of the crop (°C)
- WP is the water productivity parameter (either kg of biomass per m^2 and per mm, or kg of biomass per m^3 of water transpired).

For each crop, three productivity levels are simulated:

1) The maximum biomass, or potential yield (Bpot), assuming no limits on water and nutrients.
2) A water limited yield (Bwl), assuming that water availability is limited by the soil water balance, driven by precipitation and related crop transpiration before and during the growing season.

3) The attainable yield (Y), which accounts for region- and crop-specific constraints related to climate, management, and land quality.

These relationships are expressed as follows:

$B_{pot} = \Sigma ET0 * Kc * WUE$

$B_{wl} = \Sigma ET0 * Kc * F_{wl} * WUE$

$Y = HI \bullet B$

Where:

B_{pot} is the biomass Potential produced cumulatively (Mg ha^{-1}), *data for every Nuts3*

B_{wl} is the biomass produced under water limitations (Mg ha−1),*data for every Nuts3*

ET0 is the daily evapotranspiration for reference crop, with the summation over the time period in which the biomass is produced in growing season (either mm or m^3 per unit surface), *data for every Nuts3*

Kc Crop coefficient by calculating for each growth stage (*assumed constant value*)

WUE is the water productivity parameter or water use efficiency (either kg of biomass per m^2 and per mm, or kg of biomass per m^3 of water transpired), (*assumed constant value*)

HI is the Harvest index. Ratio of yield to biomass (%), (*assumed constant value*)

F_{wl} reduction factor to water limitation (%) in C3 and C4 photosynthetic system, for every Nuts2-3

Y Yield potential (Mg ha^{-1}), data *for every Nuts3*

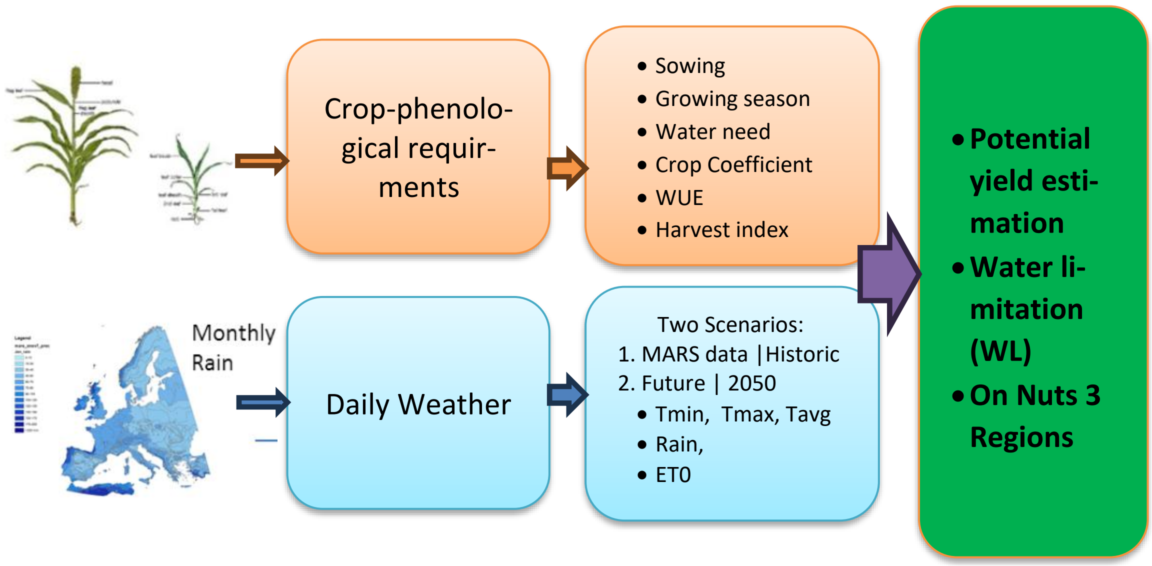

Figure 5. Diagram showing input and output of the crop simulation approach. Source: actualized from (Dees & et al., 2017)

For estimating crop production across all regions, it was essential to gather data on both the phenological requirements of the crops and the daily weather conditions for each scenario. This information serves as the foundation for the crop simulation model. An overview of the model inputs sofar is provided in Figure 5, while the key phenological factors for a selection of the crop are presented in

Table 6.

Table 6. Parameters and factors used sofar for the crop yield simulation in Aquacrop (these factors are still being actualized further!)

Crop	minimun water requirement	Length season	min. start day	Accumulative growing season (fraction)				min. temp (basetemp)	Growing degree days	crop coefficient stage (Kc)				Photosyntetic system	WUE	HI
	mm	day	day	f. initial	f. develop.	f. mid season	f. late season	C°	C°	f. initial	f. develop.	f. mid season	f. late season		g/l	%
miscanthus	500	210	80	0.21	0.34	0.84	1	10	1732	0.48	1.05	1.41	0.95	C4	3.7	0.7
switchgrass	450	210	80	0.18	0.31	0.80	1	10.3	2220	0.50	0.99	1.30	0.80	C4	3.5	0.6
giant reed	400	220	90	0.21	0.32	0.78	1	10	2422	0.54	1.01	1.74	1.18	C3	3.1	0.7
rcg	650	190	80	0.20	0.30	0.80	1	5	1800	0.50	1.00	1.40	1.00	C3	2.2	0.6
cardoon	350	250	90	0.10	0.20	0.80	1	10	2425	0.50	1	1	0.95	C3	3.13	0.6
sorghum	400	115	100	0.15	0.42	0.77	1	10	1415	0.50	0.70	1.2	1.05	C3	4.2	0.6
willow	620	300	80	0.16	0.39	0.84	1	5	2200	0.40	1.00	1.7	0.73	C3	3.3	0.65
poplar	600	300	80	0.16	0.39	0.84	1	7,5	2200	0.30	1.00	1.7	0.5	C3	3.2	0.6

Meteorological Data Source and Scenarios

The model required daily data for the following variables: minimum, average, and maximum temperatures (°C), rainfall (mm), and reference evapotranspiration (ET0, mm). So far historic weather data sourced from the JRC-MARS dataset, provided by the European Commission's Joint Research Centre (JRC). The dataset comprises interpolated data from grid cells of 25x25 km, representing the average conditions over a 10-year period (2005-2015) for each day of the year. These weather data are to be exchanged by more recent weather data 2020-2024 however, but the results presented in this report still refer to the historic data 2005-2015. The data is provided in the form of a GDX file (GAMS Data eXchange) detailing each variable for every NUTS3 region.

For the simulation of future scenarios considering climate change, the following approach was taken:

1. Data Acquisition: Data for each required climate variable was downloaded in the form of geographic maps from the CHELSA V2 dataset (Karger et al., 2017a, 2018) for the year 2050, using the GFDL-ESM4 model under the SSP5-8.5 scenario. CHELSA data provided monthly averages for the period between 2040-2070. These same CHELSA data were also used to map the marginal lands in 2050 (See MIDAS Deliverable 1.1 (Elbersen et al., 2023)
2. ET0 Calculation: To calculate ET0 for the future scenario, an R script was utilized, which processed the climate variables obtained from CHELSA.
3. Annual Average Calculation: The annual average for each climate variable was calculated. Using GIS software, the annual average for Tmin (minimum temperature), Tmax (maximum temperature), and Taverage was determined for each NUTS3 region. For precipitation and evapotranspiration, zonal statistics were performed, with the annual sum used for each variable.
4. Creation of Climate Factors: Since daily weather data for the future climate scenario was not directly available, a climate factor approach was employed. For Tmax, Tmin, and Taverage, the temperature of the future scenario was divided by the temperature of the current scenario. For ET0 and precipitation, a factor was created by subtracting the value of the future scenario from that of the current scenario.
5. Application of Climate Factors: These factors were then applied to the daily weather data from the JRC-MARS dataset for each NUTS3 region using a script written in GAMS. This resulted in a climate file representing the future scenario for the year 2050.

Water-Limited Yield Estimation

The output used for generating results was the water-limited yield, calculated by applying a reduction factor to account for water shortages. In regions such as the Mediterranean and more continental climates of Europe, where crop water requirements often exceed seasonal rainfall (especially during the dry summer months), this shortage can be mitigated by soil water storage, groundwater flow, surface water flow, or irrigation (Elbersen et al., 2016).

To account for variability in water availability during the growing season, we considered water stored in the soil from rainfall events occurring before the season started. This stored water can offset periods of inadequate rainfall during the crop's growth phase. The actual amount of water available to the crop is influenced by several factors, including runoff, soil surface evaporation, and deep percolation. These losses, combined with the uneven distribution of rainfall throughout the season, mean that not all rainfall is accessible to plant roots. Additionally, soil characteristics and terrain features, such as rootable depth, water holding capacity, infiltration rates, and slope, play crucial roles in determining how much rainfall can be effectively utilized by the crop (Elbersen et al., 2016).

To estimate the rainwater available for crop evapotranspiration, a simplified soil water balance model was used. This model assumes that at the start of the growing season, there is an initial 100 mm of soil water available in the rootable zone and that 70% of the seasonal rainfall is effective for crop use (Elbersen et al., 2016). The formula applied is (Equation 2):

Equation 2. Available Water=100 mm+70% of total seasonal rainfall

The reduction factor for yield due to water shortage is calculated as (Equation 3):

Equation 3. Reduction Factor=Available Water/ETc Season

Finally, the water-limited yield is estimated by multiplying the potential yield by the reduction factor. This water-limited yield was then used to generate yield maps for which a selection are already presented in next part of this report.

Ad2) Crop suitability approach

To determine which crops can be effectively grown in different NUTS3 regions, we considered the natural constraining factors that were also used to map the marginal lands and that are potentially limiting crop growth. The approach involves estimating yield reduction levels for each crop when grown under marginal conditions. For this we build on the methodological approach developed in MAGIC project, but here it is refined and the yield reduction levels were revisited and evaluated further .

Yield reduction levels are assigned to each crop based on its response to natural constraints, which define marginal lands. The natural constraining factors used to evaluate crop suitability on marginal lands include:

1. Minimum Length of Growing Season (days): Linked to the base temperature required for crop growth.

2. Tolerance to Killing Frost: The crop's ability to survive varying levels of frost, assuming frost persists for at least 7 consecutive days.
3. Minimum Precipitation During Growing Season: The essential rainfall required for crop growth.
4. Excessive Wetness: Issues related to poor soil drainage and excess soil moisture.
5. Low Soil Fertility: Challenges due to soil acidity, alkalinity, and low organic matter content.
6. Adverse Chemical Conditions: Including salinity and sodicity in soils.
7. Poor Rooting Conditions: Caused by low rootable soil volume and unfavorable soil texture (e.g., coarse sand or heavy clay).
8. Adverse Terrain Conditions: Such as steep slopes, which can hinder crop growth.

The suitability of each crop was mapped assuming that the crop will be able to grow in the holes continent, but not necessarily that it reaches an optimal production level. A draft table listing all limiting factors and their corresponding yield reduction levels is presented here (Table 7).

Table 7 Influence of marginal factors on yield reduction

Marginal climatic factors	Soil moisture	Soil drainage	Soil texture				Shallow rooting depth	Salinity	Sodicity	Acidity	Steep Slope	Threshold of minimal rainfall in growing season (mm)						Killing frost (**)	Length of the growing season (***)
	FC >210d	**Poorly or very poorly drained**	**Coarse material >10%**	**Sand; loamy sand >40%**	**Clay> 50%**	**OM>30 % (30/100 cm)**	**<35cm**	**>3.2 dS/m**	**>4.8 ESP**	**pH< 5.5**	**>12%**	***>1000***	***1000-800***	***800-500***	***500-300***	***300-200***	***< 200***	***(°C)***	***Days***
Common name																			
Upland Switchgrass	2	2	2	3	3	1	2	NA	NA	NA	3	2	2	2	2	1	0	-15	126
Lowland Switchgrass	3	2	2	3	3	1	2	NA	NA	NA	3	2	2	2	1	0	0	-5	200
Camelina (summer-annual)	2	2	1	2	1	1	2	2	NA	NA	1	1	2	2	2	2	2	-10	90
Camelina (winter-annual)	2	2	1	2	1	1	2	2	NA	NA	1	1	2	2	2	2	2	-20	220
Biomass sorghum	1	1	1	2	1	3	2	2	2	2	2	1	2	2	2	1	1	-5	120
Crambe	1	1	2	2	3	NA	2	NA	NA	NA	2	1	1	2	2	2	2	-5	110
Miscanthus	2	2	3	3	1	3	2	2	NA	3	1	2	2	2	1	0	0	-10	135
Giant reed	3	3	2	3	3	NA	1	3	NA	NA	2	**2**	2	2	1	1	0	-5	195
Tall wheatgrass	2	1	3	3	1	NA	2	3	NA	3	2	**2**	2	2	2	2	1	-20	125
Ethiopian mustard (summer annual)	2	1	1	3	3	3	2	2	NA	NA	2	1	1	2	2	2	2	0	140
Reed canary grass	3	2	2	3	2	2	3	3	3	2	3	2	2	1	0	0	0	-20	82
Cardoon	1	1	2	2	2	NA	2	3	3	3	2	2	2	2	2	1	0	0	120
Willow	3	2	3	3	2	2	2	1	3	3	2	2	2	1	1	0	0	-15	180
Poplar	3	1	3	3	3	3	1	2	3	1	2	2	2	1	1	0	0	-15	180
Eucalyptus	3	2	2	3	3	3	2	2	2	3	3	2	2	2	2	1	0	0	180
Siberian elm	2	1	3	3	1	NA	0	2	NA	2	2	2	2	2	2	2	1	-15	150
Sunn hemp	2	1	3	3	2	2	3	1	NA	3	3	2	2	2	2	1	0	0	60

* Yield reduction (YR): 1=75%, 2=50%, 3=25%, 0=unfeasible

** Threshold of minimal rainfall in growing season: No go= 0 = 100% YR; Rainfall meets threshold of crop minimal precipitation need= 1 = 25%YR; Meets well with crop precipitation need = 2 =0%YR

*** Scoring for minimal length of growth season. For annual production seeds: >20% below threshold = 100%YR, 20% meets threshold = 25% YR, 20% above threshold=0% YR. For perennials producing biomass: >20% below threshold = 75%YR, 20% meets threshold = 25% YR, 20% above threshold=0% YR.

Mapping and Calculation Approach

The marginal land maps (see chapter 2 of this report and MIDAS Deliverable 1.1) were overlaid on a mask of agricultural areas in Europe, including land classified in an agricultural land cover class in at least one of the four CORINE Land Cover (CLC) versions (1990, 2000, 2006, 2012)[1] (Elbersen et al., 2022).

To determine which industrial crops could be successfully grown on the mapped marginal lands, a detailed procedure was followed schematized in Figure 6. First, zonal statistics were applied to each map representing a limiting factor. This analysis helped to determine the total area in each NUTS3 region affected by the specific constraint, allowing for the calculation of the percentage of land that was unsuitable for crop growth due to that particular factor.

Next, the yield reduction levels for each crop were applied within these regions, based on the reduction levels established in the MAGIC project. The analysis focused on the highest reduction percentage indicated for each factor, providing a detailed understanding of the potential yield reduction for each crop in each NUTS3 region. To obtain a comprehensive estimate of the yield reduction, all limiting factors were considered together. The approach involved summing the percentage reductions for each crop across all limiting factors within a NUTS3 region (as illustrated in the yellow cell of Figure 6). This cumulative reduction provided a total yield reduction score for each crop in each region.

The methodology was then applied across the entire continent for both current and future scenarios using a GAMS script. This script, previously used in the S2Biom project, was capable of integrating the yield reductions from all limiting factors for each crop in every NUTS3 region. The final output was a total score (the sum of the yield reduction scores) indicating the extent of yield reduction for each crop per region.

Finally, the suitability of each crop was determined by applying a threshold: if the cumulative yield reduction score for a crop exceeded 75% in a given NUTS3 region, the crop was deemed unsuitable for cultivation in that area. This approach ensured that only crops with a reasonable potential for productivity were considered viable under the assessed conditions, providing a robust assessment of crop suitability across varying regions and scenarios.

Specific Considerations and Assumptions made for the suitability calculation

- First, for the "Killing Frost" factor, the number of days per year with temperatures below a critical threshold was calculated for each NUTS3 region under both current and future climate scenarios. Using the data from Table 7, which specifies the critical "killing frost" temperature for each modelled crop, a rule was applied: if there were more than seven days in a year with temperatures below this threshold, the crop was considered unsuitable for that area. Typically, crops cannot survive more than five consecutive days below a certain temperature.
- In cases where yield reduction levels were not available for a particular limiting factor in a specific crop, a minimum yield reduction of 25% was applied. This approach was taken primarily to ensure that the code could run and produce results, though this method will still be improved in the future by obtaining the missing data.

[1] For a detailed description of all CORINE 2012 classes see: http://uls.eionet.europa.eu/CLC2000/classes/index_html

Rooting < 35cm

Reg/Nº	0 - Suitbale	1 - Unsuitbale	% area not suitable	Yiled Reduction of .....? Crop1	Crop2	Crop3	Crop4
Region A	3	6	67%	17%	33%	50%	67%
Region B	7	2	22%	6%	11%	17%	22%
Region C	9	3	25%	6%	13%	19%	25%

A			B		
0	0	1	0	0	1
0	1	1	0	0	0
1	1	1	1	0	
0	0	1	1	1	0
0	0	0	0	0	0

C

Yield Reduction factor per crop		From MAGIC to MIDAS	
Crop1	25% reduction	25%	3
Crop2	50% reduction	50%	2
Crop3	75% reduction	75%	1
Crop4	not suitable	100%	0

Nº of times overlapping limiting factors

S	S	R+S	0	S	R+S
S	R+S	R+S	0	S	S
R+S	R+S	R+S	R	0	0
0	0	R	R	R	0
S	S	S	S	S	S

Sodicity >4.8

Reg/Nº	0 - Suitbale	1 - Unsuitbale	% area not suitable	Yiled Reduction of .....? Crop1	Crop2	Crop3	Crop4
Region A	0	9	100%	25%	50%	75%	100%
Region B	5	4	44%	11%	22%	33%	44%
Region C	6	6	50%	13%	25%	38%	50%

A			B		
1	1	1	0	1	1
1	1	1	0	1	1
1	1	1	0	0	
0	0	0	0	0	0
1	1	1	1	1	1

C

Yield Reduction factor per crop		From MAGIC to MIDAS	
Crop1	50% reduction	50%	2
Crop2	25% reduction	25%	3
Crop3	not suitable	100%	0
Crop4	75% reduction	75%	1

Magic Factors
Score: 1 to 3 [YR=yield (actual)
0= Unfeasible
1= YR>50%;
2= 25%< YR <50%;
3= YR < 25%;

Approach to take...?	
Option1 - Plus	42%
Option2 - Multiply	4%
Option3 - Maximun	25%

Figure 6 Overview of the methodological approach for mapping the crop suitability

- It is also important to note that suitability information is not yet complete and therefore in the next section results are only presented for a subset of crops. Therefore, once the yield simulation data for the remaining crops is modelled, their suitability will be reassessed to ensure more accurate results.
- When applying a yield reduction level for the scoring of the minimum length of the growing season, a distinction is made between annual seed-producing crops and perennial biomass-producing crops. If the length of the growing season falls 30% below the threshold (as specified in Table X), the yield reduction (YR) is set at 100% for annual crops and a less strict 75% for perennials. This is because annual crops that cannot complete their growing season will fail to produce seeds, as they won't reach full development. In contrast, perennials can still generate biomass even if the growing season is shortened.
- Additionally, two extra conditions are used in the total yield reduction calculation: if the percentage of area with steep slopes exceeded 50%, or if the percentage of area with shallow soil depth was greater than 50%, the region was considered unsuitable for crop growth. These conditions further constrain crop suitability in the agricultural land.

The results of the crop suitability analysis, both for the present and future scenarios, are presented as maps in the next results section.

3.3 Results

Here a selection of the draft results is presented. These maps illustrate the areas where each crop is suitable for growth based on the calculated total yield reduction scores in the marginal lands in every Nuts 3 region. The results are preliminary and further improvements are still being made.

First the results of the crop yield simulation is presented. Next is then the presentation of the crop suitability in marginal lands per Nuts3 region expressed in yield reduction classes.

3.3.1 Crop yield simulation results

The following maps display the preliminary yield results under two climate scenarios: the historic and the 2050 following climate change situation in SSP28.5. Results are provided for Miscanthus (Figure 7), Upland Switchgrass (Figure 8), Biomass sorghum (Figure 9) and Safflower (Figure 10). Yields are expressed for the three biomass crops in tons dry mass per hectare per year (tdm/ha/yr) and for Safflower in ton oil seed per hectare per year (ton seed/ha/yr) and represent water-limited yields, with a reduction factor applied to better reflect growth conditions in marginal lands.

Overall, it can be observed that with climate change, yields are expected to decrease in the southern regions of the continent while increasing in central and northern Europe compared to the historic climate scenario.

Currently we are updating the historic weather data with more react (2020-2024) to better reflect the current weather which already changed since 2010 (historic data used and displayed in the maps here.

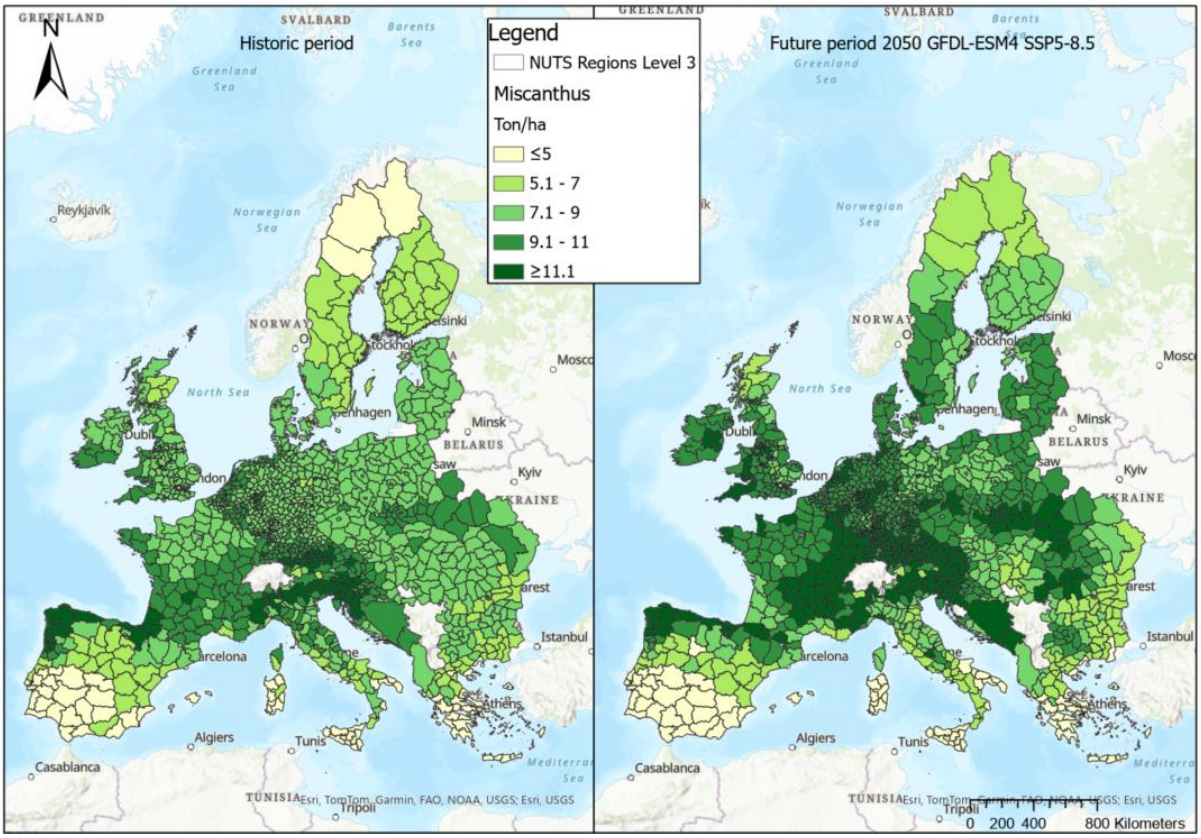

Figure 7 Simulated water limited yield for miscanthus giganteus (tdm/ha/yr) for historic and 2050 climate in SSP28.5 (draft result)

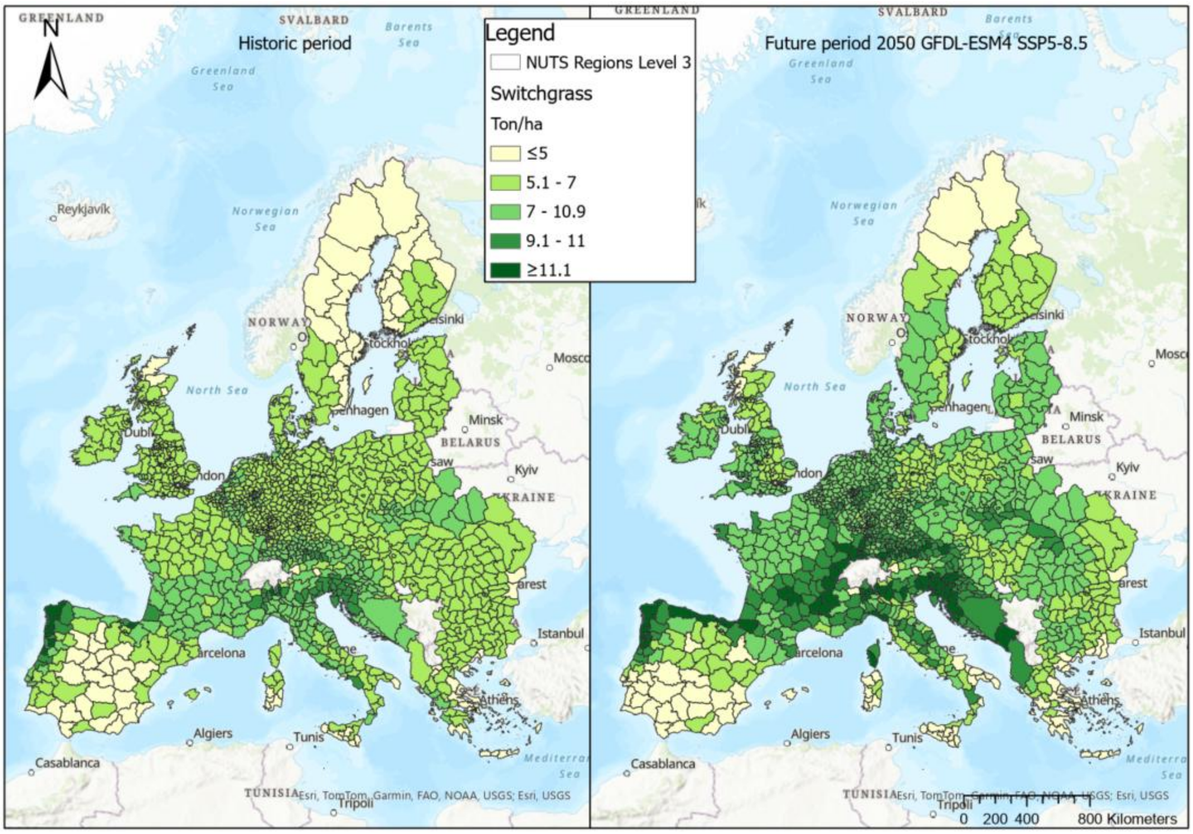

Figure 8 Simulated water limited yield for Switchgrass (upland) (tdm/ha/yr) for historic and 2050 climate in SSP28.5 (draft result)

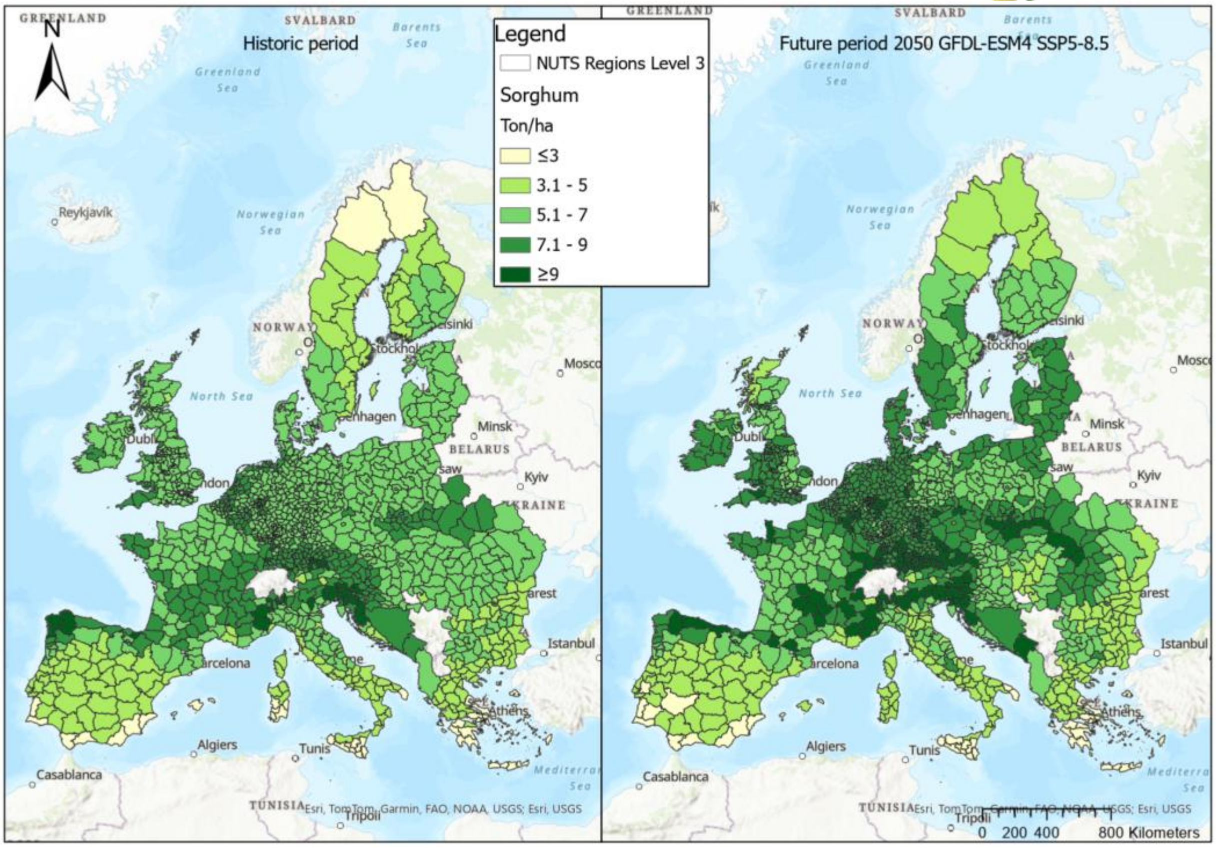

Figure 9 Simulated water limited yield for Biomass sorghum (tdm/ha/yr) for historic and 2050 climate in SSP28.5 (draft result)

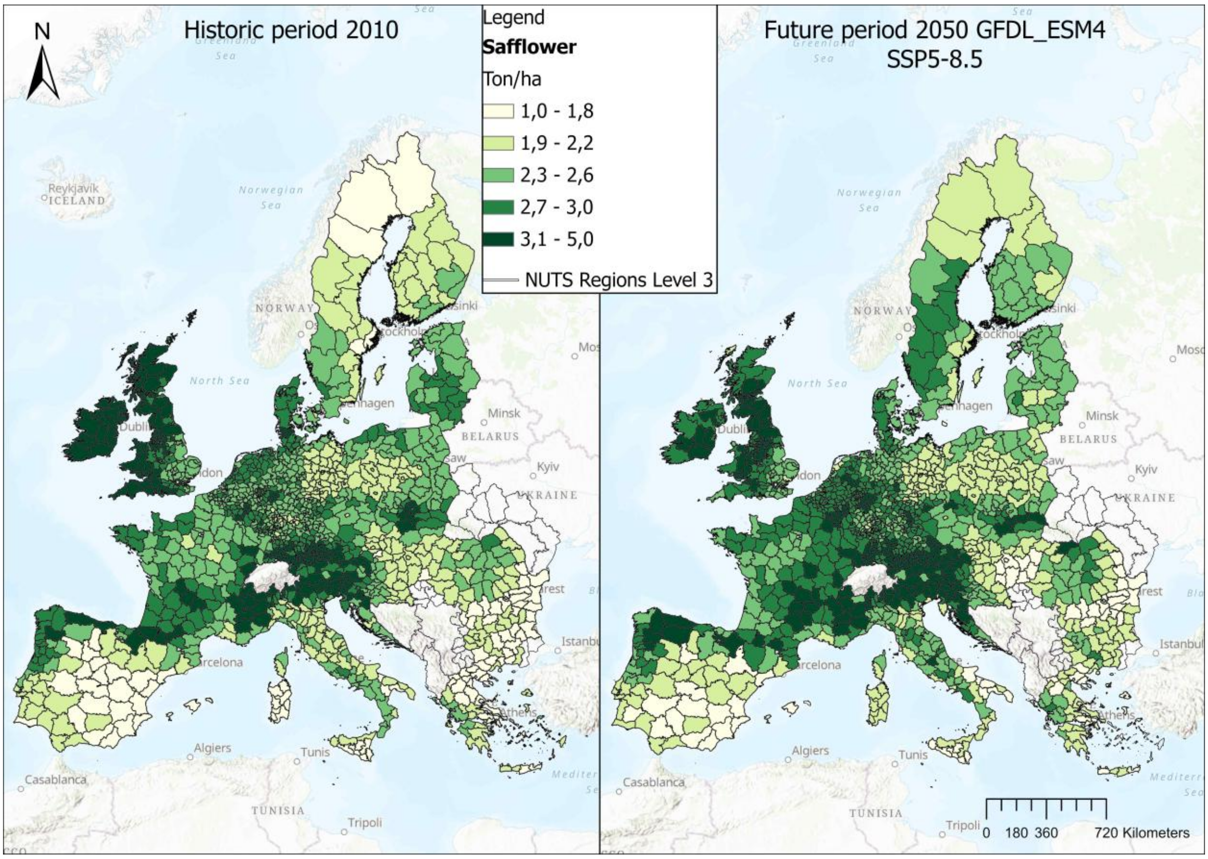

Figure 10 Simulated water limited yield for Safflower (ton oil seeds/ha/yr) for historic and 2050 climate in SSP28.5 (draft result)

3.3.2 Crop suitability in marginal lands

The suitability results presented in this section as maps, are also comparing both modelled scenarios (historic and 2050 SSP28.5). It's important to note that regions where yield reduction exceeds 75% are considered unsuitable for cultivating a particular crop. However, three levels of suitability were established for areas where yield reduction is less severe. If the average yield reduction for a crop is below 45%, these regions, despite being marginal lands, could still be considered suitable for growing that crop.

The classification is further divided into regions where crops experience an average of 45% to 60% yield reduction, and those with an average 60% to 75% reduction. Beyond a 75% reduction, regions are considered unsuitable for cultivation. Regions shown in purple on the maps indicate areas where low temperatures could kill the crops, indicating that are unsuitable for growth.

The same crops that were mapped for yield; Miscanthus, Giant Reed, Reed Canary Grass, Cardoon, Sorghum Biomass, Willow, Poplar, and Eucalyptus are shown for suitability (from Figures 12 to 19). However, Switchgrass requires further refinement to accurately represent the suitability of lowland and upland varieties.

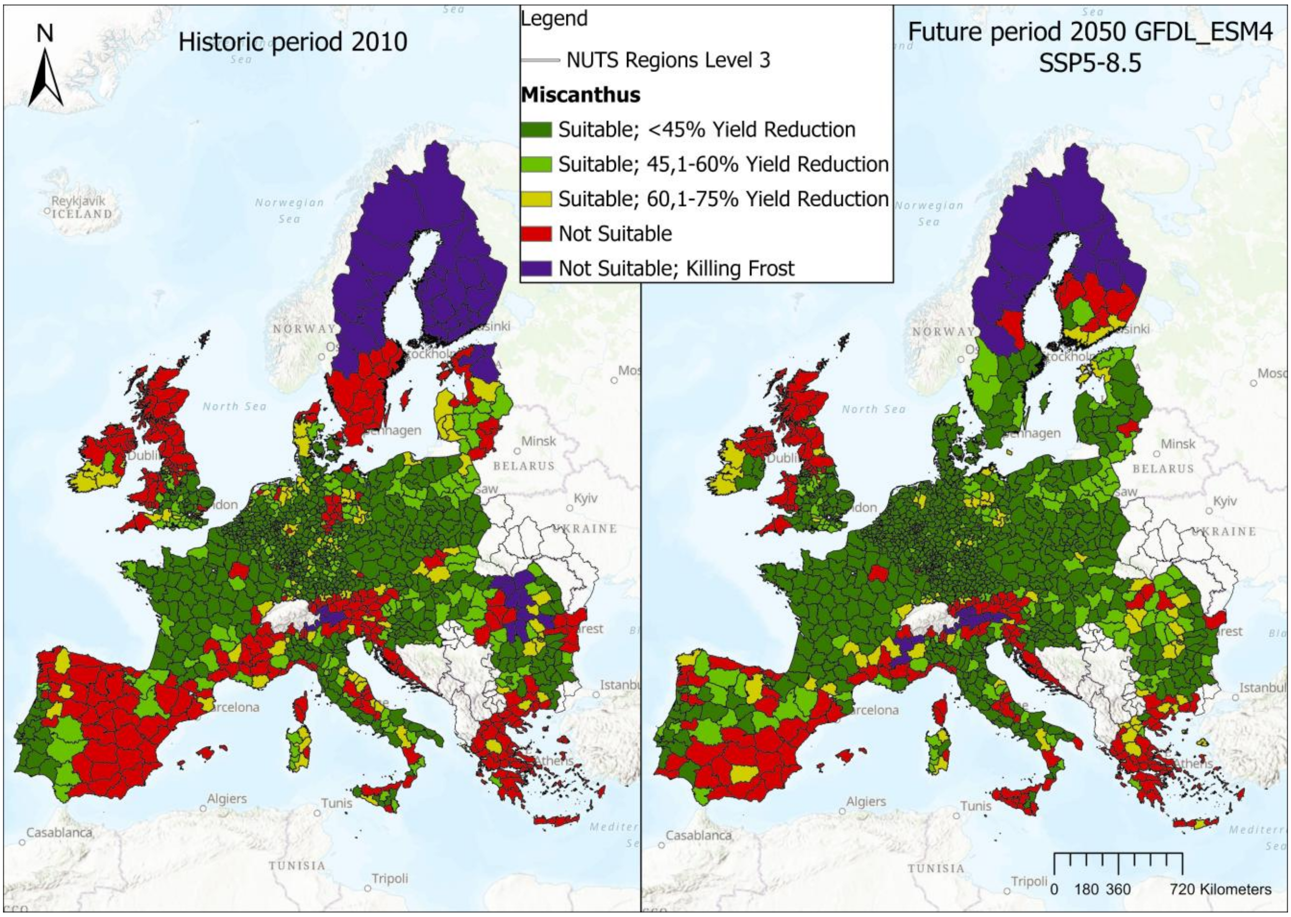

Figure 11 Suitability map for Miscanthus giganteus in marginal lands in historic and 2050 climate in SSP28.5 (draft result)

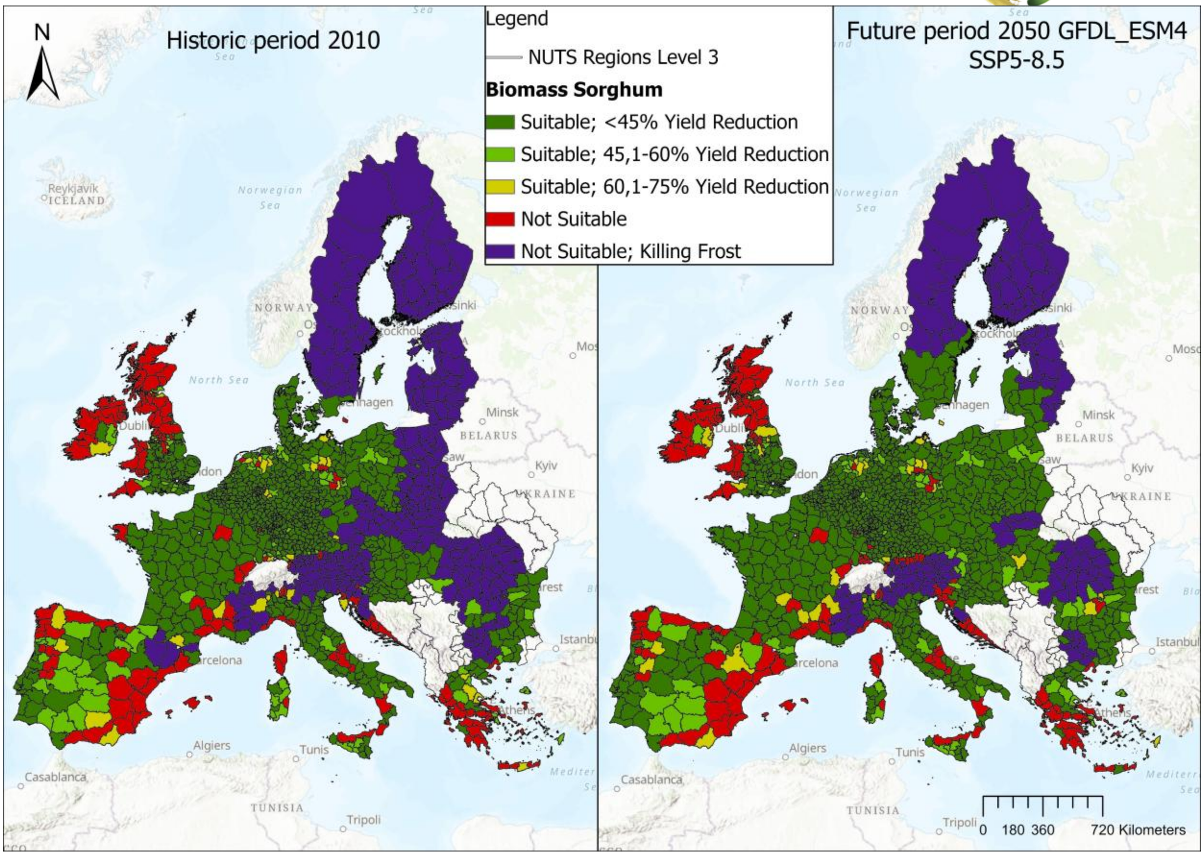

Figure 12 Suitability map for Biomass sorghum in marginal lands in historic and 2050 climate in SSP28.5 (draft result)

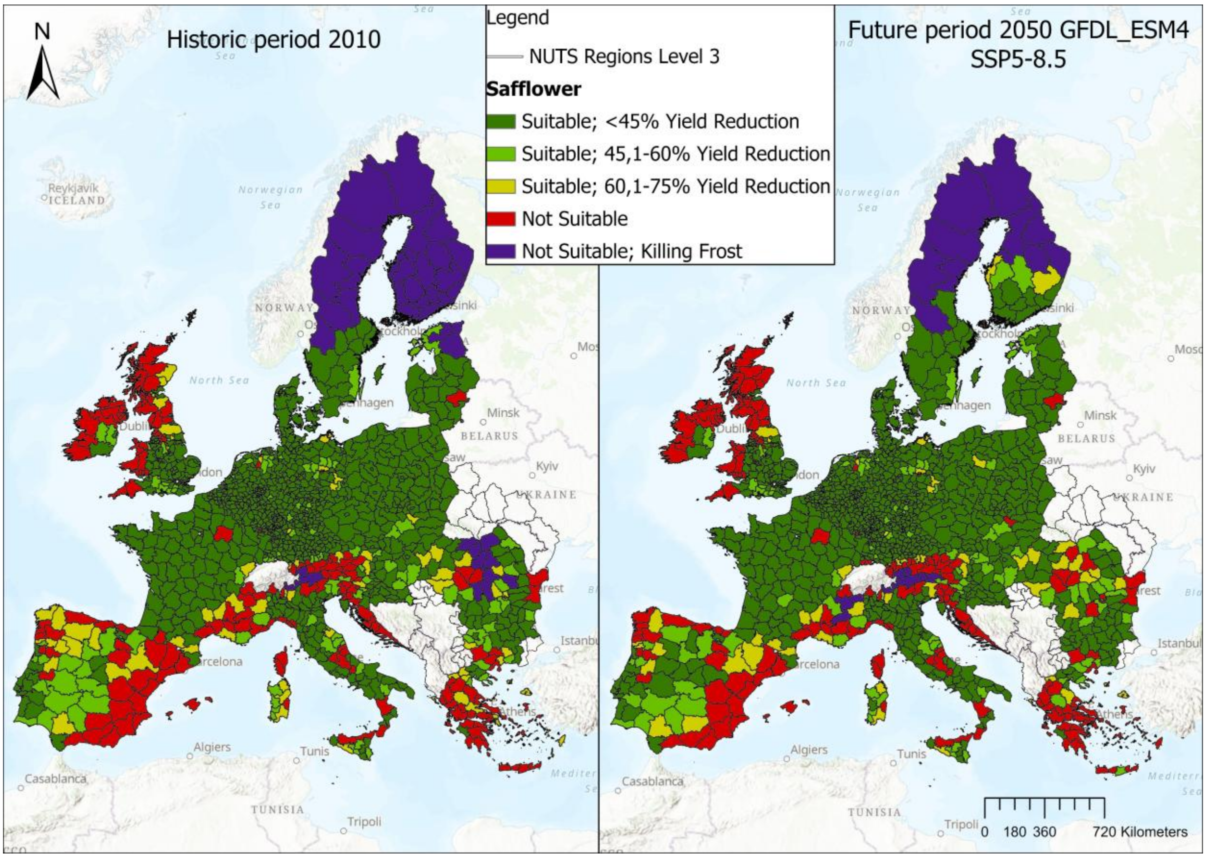

Figure 13 Suitability map for Safflower in marginal lands in historic and 2050 climate in SSP28.5 (draft result)

Overall, the suitability results indicate that in Southern Europe, the modelled crops are generally unsuitable for cultivation when considering the marginality factors used in the analysis. This is particularly evident in Spain and Southern Italy, which appear highly constrained (indicated in red) under both the present and future scenarios, with the future scenario being even more limiting for these regions.

In addition, regions currently unsuitable due to killing frost (in purple) are expected to decrease in future scenarios, which could make more areas of northern Europe suitable for cultivation that were previously unsuitable due to low temperatures. This change suggests that, while southern Europe could face increasing constraints, certain areas in the north could become more favourable for crops as the impact of killing frosts decreases over time.

The results presented in this report are partial and should be interpreted as preliminary and partial. The work is still ongoing and refinement of the crop growth model and suitability methodology is still being done since both the crop growth model and the suitability assessment methodology require further calibration and improvement to yield results that more accurately reflect real-world conditions.

One important observation is that the current model indicates a high degree of unsuitability for most crops in the Mediterranean region. This is largely due to the initial parameters set in the Aquacrop model, which specify a minimum start day for crop growth between day 85 and day 100 of the year. This parameter results in the model missing the rainy season typical of the Mediterranean climate, leading to minimal rainfall during the growing season. Consequently, the crops do not reach the required threshold of minimal rainfall, resulting in low suitability scores for these areas. This issue highlights the need for adjustments in the model to better capture the unique climatic conditions of Mediterranean regions.

Regarding the yield results, it is important to note that the Aquacrop model used in this analysis is simplified. It does not account for factors such as soil characteristics or irrigation (EIP-AGRI Focus Group, 2021), which could potentially provide more precise results for marginal lands if included. Additionally, the climate change scenarios applied in the model are basic and may not fully capture the complexities of future climatic shifts, as they apply the same factors to all days within a region and subsequently adjust daily water availability.

The results show that there is potential for achieving viable yields from marginal lands, though for improving this it could be interesting to consider additional factors such as fertilization or irrigation. Marginal lands may benefit from targeted input applications to sustain yields, particularly if high-value end uses for all crop fractions can be identified (EIP-AGRI Focus Group, 2021). On the other hand, this should not compromise on sustainability. In fact, ideally introduction of these new crops should actually go hand in hand with improving ecosystem delivery such as improving soil health by reducing soil erosion risk and improving SOC levels in soils. This is exactly where the next activities in WP1 will focus on.

4 Next steps

For the crop growth modelling and suitability mapping in marginal lands the next activities are planned until month 46 in the project:

1) Re-model using an actualize climatic data from the las 5 years (2019 to 2023) for a better representation of the actual climate (AGERA5).
2) Calibrate the model for catching better the Mediterranean rainfall seasonality.
3) Refine the phenological data available of the crops and the edaphoclimatic factors (include heat stress in the suitability).
4) Validate the crops outputs against bibliography.
5) All final results will become available online in an interactive tool accessible via the MIDAS website
    - Marginality map – marginal conditions per region
    - Simulated yield maps for all crops
    - Crops suitability according to yield reduction in marginal conditions

Beside work on the crop growth simulation and suitability there is also work being performed in WP 1 on the following:

1. Further characterization of marginal lands in terms of ecosystem services (ESS) in order to identify ESS improvement demands which may be supplied through the wider introduction of MIDAS crops and tested cropping systems. On the other hand, ESS are also mapped to identify area where loss of ESS can occur through the introduction of MIDAS cropping systems. So far 34 ESS have been identified and they are now being mapped and a literature review is being done on how MIDAS cropping systems may help to improve the ESS state and what ESS cannot be combined with MIDAS cropping practices.
2. A further characterization of marginal lands is also made in terms of risk for land abandonment. For these two approaches are followed. The first is based on Radar data and coherence to identify at high spatial resolution whether arable agricultural lands are abandoned. The other approach is aimed at mapping several factors together to come to a spatially explicit indication of the risk for land abandonment of marginal lands over the next years.
3. A separate step that still needs to be implemented over next months is the mapping of marginal lands in Serbia and also the mapping of crop suitability. This will follow a similar method, but some data limitations for the territory need to be addressed which will force us to follow in some cases a more simplified approach.
4. A last activity in WP1 of MIDAS being implemented in the last year of the project is the further socio-economic characterization of the marginal lands in the different Nuts 3 regions of the EU27 & UK and Serbia. A set of socioeconomic KPIs will be used to further characterize the regions, including investment for the region, jobs, potential added value from bio-based products, etc. It will place the development opportunities and needs for introduction of alternative MIDAS production systems in a wider perspective.
5. Finally it is planned to integrate all marginal land specific spatial information into an online consultation tool accessible for end-users online. The tool shows the upscaled results of the project for the whole EU27, UK and Serbia territory. The socio-economic up scaled results will be displayed in the tool in such a way to enable regional and local decision makers to configure value chains that are relevant to their geographical territories and further assess the respective costs and benefits from their implementation.

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Annex I - Agricultural masks used for area share calculation

For the calculation of the relative area shares of the marginal land classes two agricultural masks were used in this report.

1) The MAGIC historic agricultural mask
2) MIDAS 2018 agricultural mask

Ad 1) The so-called MAGIC historic 'agricultural mask' includes all land that was classified in an agricultural land cover class (see Table II.1) in at least one of the four Corine Land Cover (CLC) versions:

CLC 1990

CLC 2000

CLC 2006

CLC 2012

Using this mask also enables to generate comparable statistics for an area of (former) agricultural land including potential abandoned agricultural lands.

Table II.1 CORINE land cover classes (CLC)* agricultural non agricultural

		MAGIC agricultural mask based on CLC 1990, 2000, 2012, 2018		MIDAS 2018 agricultural mask only based on CLC 2018	
CLC-NR	**CLC Description_Level3**	**Grazing**	**Cropping**	**Grazing**	**Cropping**
0	UNCLASSIFIED	No	No	No	No
111	Continuous urban fabric	No	No	No	No
112	Discontinuous urban fabric	No	No	No	No
121	Industrial or commercial units	No	No	No	No
122	Road and rail networks and associated land	No	No	No	No
123	Port areas	No	No	No	No
124	Airports	No	No	No	No
131	Mineral extraction sites	No	No	No	No
132	Dump sites	No	No	No	No
133	Construction sites	No	No	No	No
141	Green urban areas	No	No	No	No
142	Sport and leisure facilities	No	No	No	No
211	Non irrigated arable land	No	**Yes**	No	**Yes**
212	Permanently irrigated land	No	**Yes**	No	**Yes**
213	Rice fields	No	**Yes**	No	**Yes**
221	Vineyards	No	**Yes**	No	**Yes**
222	Fruit trees and berry plantations	No	**Yes**	No	**Yes**

		MAGIC agricultural mask based on CLC 1990, 2000, 2012, 2018		MIDAS 2018 agricultural mask only based on CLC 2018	
CLC-NR	**CLC Description_Level3**	**Grazing**	**Cropping**	**Grazing**	**Cropping**
223	Olive groves	No	**Yes**	No	**Yes**
231	Pastures	**Yes**	No	**Yes**	No
241	Annual crops associated with permanent crops	No	**Yes**	No	**Yes**
242	Complex cultivation patterns	**Yes**	**Yes**	**Yes**	**Yes**
243	Land principally occupied by agriculture- with significant areas of natural vegetation	**Yes**	**Yes**	**Yes**	**Yes**
244	Agro forestry areas	**Yes**	**Yes**	**Yes**	**Yes**
311	Broad-leaved forest	No	No	No	No
312	Coniferous forest	No	No	No	No
313	Mixed forest	No	No	No	No
321	Natural grasslands	**Yes**	No	**Yes**	No
322	Moors and heathland	**Yes**	No	**No**	No
323	Sclerophyllous vegetation	No	No	No	No
324	Transitional woodland shrub	No	No	No	No
331	Beaches- dunes- sands	No	No	No	No
332	Bare rocks	No	No	No	No
333	Sparsely vegetated areas	No	No	No	No
334	Burnt areas	**Yes**	**Yes**	**No**	**No**
335	Glaciers and perpetual snow	No	No	No	No
411	Inland marshes	No	No	No	No
412	Peat bogs	No	No	No	No
421	Salt marshes	No	No	No	No
422	Salines	**Yes**	No	**Yes**	No
423	Intertidal flats	No	No	No	No
511	Water courses	No	No	No	No
512	Water bodies	No	No	No	No
521	Coastal lagoons	No	No	No	No
522	Estuaries	No	No	No	No
523	Sea and ocean	No	No	No	No

*For a detailed description of all CORINE 2012 classes see: http://uls.eionet.europa.eu/CLC2000/classes/index_html

Ad 2) The MIDAS agricultural mask is purely based on the CLC 2018 and only includes agricultural land cover classes (see Table II.1). It is more suitable to apply to be used for comparing the marginal land area changes between 2020 and 2050.

The project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082070.

The consortium