Land use potentials and land use requirement scenarios for 2050

Deliverable 3.2 of the project

BioTransform.at

Using domestic land and biomass resources to facilitate a transformation towards a low-carbon society in Austria

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Abstract

The following description is based on the sub study report 5b "Agricultural land use potentials of Austria and simulation of production scenarios till 2050" (Schaumberger *et al.*, 2011), which was carried out within the framework of the "Save our Surface" study (SOS, 2011). The climatological and location-related input parameters are equal to those of the SOS project. The algorithms used for the computation of the land use potentials and for the requirement scenarios had to be adapted to the different assumptions and different simulated crops of the current project. The calculated land use potentials are, among others, supplied in Excel sheet format for further processing. A representative climate model was used for the graphical representation of the production scenarios for the 2015 decade (period 2041-2050).

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1 Introduction

1.1 The project “BioTransform.at”

In the context of the EU’s climate and energy targets as well as its ambitions to establish a bioeconomy until 2050, biomass will be of crucial importance; for reducing greenhouse gas (GHG) emissions and the dependence on fossil resources in energy supply as well as for replacing energy- and carbon-intensive products.

The core objective of the project “BioTransform.at” was to develop transformation pathways towards a low-carbon bioeconomy in Austria in 2050, considering all relevant types of biomass supply and use and a complete representation of the energy sector. Such transformation scenarios are presented in Deliverable 5.2 of the project.

1.2 Aim of this report

The structure of agricultural land use is a main determinant for biomass supply and subject to constraints imposed by natural conditions and requirements of crops. To be able to derive realistic and feasible scenarios for agricultural land use, it is necessary to analyse these parameters on a regionally disaggregated scale and determine supply potentials and limits for the various crops. This report presents the methodological approach and material used for deriving such data (section 2), which have subsequently been implemented in the “overall model” applied in work package 5. More specifically, “classes” of agricultural land have been derived, which are characterized by their share in total agricultural land in Austria by their suitability for crop types.

The overall model has been used to derive scenarios towards a low-carbon bioeconomy (see Del. 5.2). The structure of agricultural land use (crop shares) is an endogenous model result. Due to the “agricultural land classes” implemented in the model, it is ensured that domestic supply potentials are not exceeded in the scenarios and crop shares are in accordance with natural conditions and crop requirements.

Based on the supply quantities in the scenarios, maps for land use distribution have been prepared, illustrating how these quantities could be supplied in an optimal way (section 3). Furthermore, “conflict potentials” are shown in the form of maps, providing insight into the regional distribution of agricultural land with high suitability for many crop types.

2 Material and methods

2.1 Location-related parameters

The temperature and precipitation data were extracted from the two climate scenarios ETHZ and METNO of the Wegener Center in Graz (Austria) at a spatial resolution of 1000 meters (Beham *et al.*, 2009). The data for the soil parameters (soil value, soil depth, pH-value and soil water conditions) derived from the Austrian Soil Map (eBod) at a spatial resolution of 500 meters in TIFF format. The orographic slope was computed using a DEM with a spatial resolution of 50 meters.

Two climate scenarios were chosen for the current study: the ETHZ-CLM_HadCM3Q0 scenario with a meteorological hot and dry trend (ETHZ) and the METNO-HIRHAM4_BCM scenario with a meteorological cool and wet trend (METNO). Both modelling results show a strong resilient increase in air temperature and a less pronounced increase in winter precipitation, but do not allow reliable conclusions about climatological changes for all months of the year other than the winter months (Beham *et al.*, 2009).

All computations are based on average temperatures and average precipitation values for the period 2041-2050. The average values for the 10-year period are computed using the mean annual precipitation sums as well as the mean temperature values of the vegetation period.

In this study the simulations and graphical representations of the results are mainly based on the METNO scenario.

2.2 Climate and soil requirements of plants

The model to calculate the crop's land use potential implements the most important plant requirement parameters based on information with the widest possible coverage. The definition of the plant requirements has been worked out after thorough literature research and in consultation with crop farming specialists. The requirements are furthermore based on the EcoCrop database developed and kept by the FAO, which defines the requirements of many different agricultural plants (FAO, 2004). Some additional parameters are included due to expert's recommendations and adapted to Austrian conditions as well as to existing spatial location-related parameters. Because of missing availability of some spatial data, requirement parameters are limited to temperature, precipitation, soil value, soil depth, pH-value, soil water conditions and orographic slope.

The EcoCrop database gives rather rough indications of the plant's requirements due to the fact, that the complete range of requirement variabilities of different crop types has to be incorporated in a limited number of definitions. The assessment of spatial distribution therefore is often hampered by inaccurate information.

Table 1 shows a comparison between the crops used in the SOS project and the crops used within the current project. 13 less significant SOS crop types were left unconsidered and the short-rotation wood plant type has been added to form the crop basis for the simulations of the production scenarios. Furthermore, several crop types have been regrouped in the current project before carrying out the calculations.

Table 1: Crops used in the SOS project and in the "BioTransform" project

"Save our Surface"	"BioTransform"
Field beans	
Mountain pastures and steep slope meadow	
Other cereals	Other cereals
Corn-Cob-Mix	
Permanent grassland	
Permanent pastures	
1-cut meadow	
Potatoes	Potatoes
Grassland - extensive cultivation	Grassland - extensive cultivation
Green beans	
Fodder beet	Fodder beet
Barley	Barley
Green peas	
Oat	Oat
Hard wheat	Hard wheat
Areas of herding	
Grassland - intensive cultivation	Grassland - intensive cultivation
Grass-clover	Grass-clover
Grain peas	Grain peas
Corn maize	Corn maize
Alfaalfa	Alfaalfa
Multi-cut meadow	
Mixed cereals	Mixed cereals
Oil squash	Oil squash
Rape and turnip rape	Rape and turnip rape
Rice	
Rye	Rye
Red clover and other clover types	Red clover and other clover types
Maize and fodder maize	Maize and fodder maize
Soybeans	Soybeans
Sunflower	Sunflower
Other legumes	
Other fodder crops	Other fodder crops
Triticale	Triticale
Temporary grassland	Temporary grassland
Common wheat	Common wheat
Sweet corn	
Sugar beet	Sugar beet
	Short-rotation wood

2.3 Model development

The aim of the land use potential modelling attempts is to reproduce reality as good as possible. However, a distinct or "sharp" definition of optimum location conditions for plants can't be provided. Assessments of the optimum location conditions have to be made instead, requiring the consideration of certain uncertainties to prevent computational discontinuities and allowing the approximate description of natural transition zones. A model is therefore needed, which meets these requirements. A thorough literature research unveiled that the concept of fuzzy logic is ideally suited for the topical problem of this analysis and that it has been successfully applied on other similar tasks (de la Torre *et al.*, 2005; Jusoff, 2009; Moreno, 2007; O'Brien *et al*., 2004; Torbert *et al*., 2008).

Fuzzy logic defines fuzzy sets of elements, which are not allocated on the basis of simple and discrete decisions. The allocation of elements to a set does not rely on the boolean variables YES and NO but on a continuous range of values such as 0 to 1 – with 0 representing no association to the set and 1 representing full association to the set. The degree of association can be expressed by mathematical functions of different complexity (Kruse et al., 1994). The fuzzy logic methodology is well suited for the computation of land use potentials due to the fact, that the location suitability of a plant is ambiguous because of the uncertainties of location conditions and plant requirements.

Based on the theory of Fuzzy logic, allocation functions and requirement functions are expressed as trapezoid functions.

These functions allow an appropriate mathematical description of the information contained in the EcoCrop database, which defines the plant requirements using optimal and absolute value ranges per location parameter. The absolute threshold values are related to the minimum requirements of the vegetation, which extend till the optimum threshold values.

The suitability of a plant in relation to a particular location parameter is expressed by the allocation function with a value range of 0 to 1 – with 0 representing no potential and 1 representing high potential of suitability. The trapezoid function used in this analysis is defined by four values - minimum and maximum threshold values of an absolute and an optimal value range as depicted in figure 1. The x-axis indicates the information of the chosen parameter such as the precipitation sum.

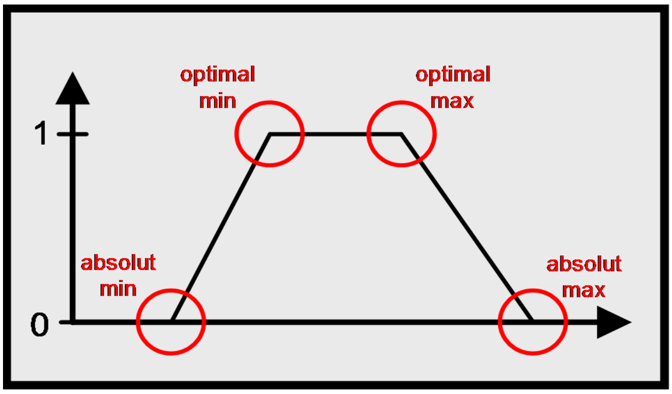

Figure 1: Allocation function – suitability of a crop type with respect to a particular location parameter

Figure 2 shows a graphical representation of the land use potential calculation method. An Excel sheet with plant specific information is used as input data file for the calculation process. The lines of the table define the crop type used in the analysis and the columns contain the threshold values of the trapezoid function for each location parameter. All calculations are carried out on the region of interest, which is split up into a spatial grid with a predefined resolution. The table's data are thus used to value each pixel (location) of each location parameter grid. Computationally, the table is processed in a top-down manner allowing each crop to be taken into account by the algorithm used in the analysis. The land use potential values are calculated for each crop and location. Based on the results, the corresponding location parameter grids are then linked with logical AND and MINIMUM operators in accordance with the Fuzzy Logic method. The processing results are land use potential values for all crops and all location parameters, which are included in the source table.

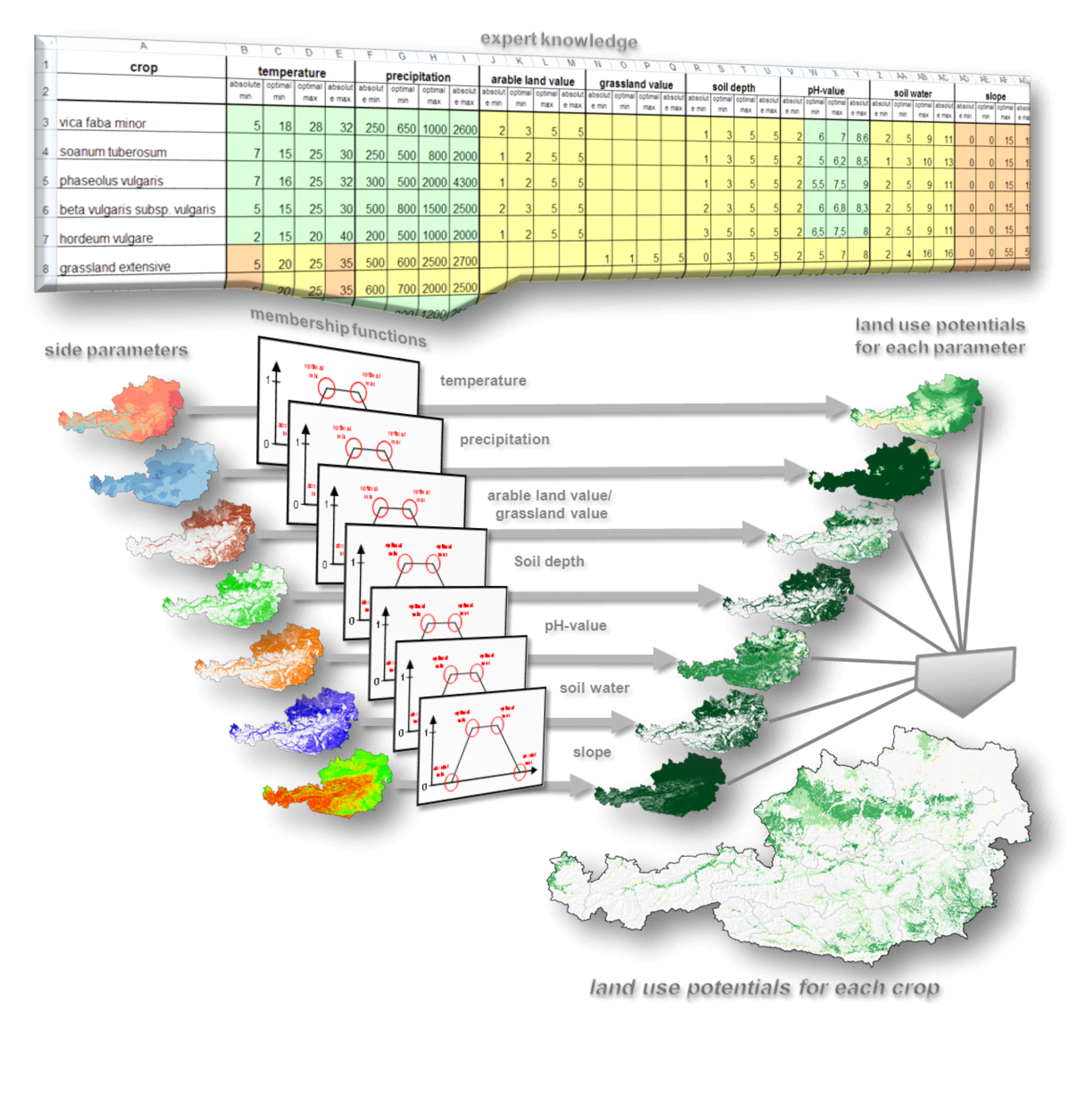

Figure 2: Calculation sequence for the determination of land use potentials

One advantage of this approach is the potential combination of different parameters with varying units and value ranges. From the crop's perspective, units and values of parameters such as temperature [°C] or precipitation sum [mm] are thus transformed into uniform and comparable dimensions using suitable allocation functions.

The spatial resolution of the land use potential calculations depends on the grid resolution of the location parameter surfaces, which were available in a grid resolution of 500 meters. Thus land use potential results could also be generated down to a spatial resolution of 500 meters.

2.4 Computer program implementation

A software package was developed to calculate the land use potentials of selected crops. The software allows the comparison of the requirements of important agricultural plants to climatological, pedological and topographical site-related conditions.

The algorithms are implemented in the object oriented computer programming language JAVA. Object oriented programming supports the simulation and model-based description of behaviour and interactions of real objects. A graphical user interface was furthermore created to facilitate the use of this newly developed geo-information system for users without particular proficiency. The visualisation of geodata and of some useful functions was implemented using publicly available free program libraries instead of reinventing the wheel. The challenge was to combine the already existing components with new algorithms to optimally support the project's tasks.

The most important function of the program is the computation of land use potentials. For this purpose, file paths to the input grids and input information files of the location parameters have to be entered via the graphical user interface. The processing methods are selected subject to the Fuzzy Logic allocation functions and the information about the crop's requirements. The requirements are specified as allocation functions with the help of separate input masks. The functions are then saved in a text file. With the help of this text file, all land use potential values of all crops can be calculated in a single processing step. The calculation period is set to 2041-2050.

2.5 Spatial simulation of demand and production scenarios

The spatial effects of various demand and production scenarios can be identified based on the results of the land use potential calculations for each crop. For this purpose, an algorithm is needed that allocates suitable locations (pixels) to individual crops in accordance with the relevant scenario.

The algorithm developed for this purpose allocates the current pixel to that crop, which shows the largest relative difference between the actual yield value of a pixel (allocated previously) and the target yield of a specific crop. The allocation occurs gradually, such as the allocation of land use potentials, which occurs in ten steps (1.0-0.9, 0.9-0.8, 0.8-0.7, ..., 0.1-0.0). This prevents low land use potential values to be allocated too early. The scanning order of the individual pixels is randomised to ensure an equal spatial distribution in the decision process of assigning pixels to values.

Crop rotation is taken into consideration when allocating crop types to locations. Locations suited for the cultivation of cereal plants or other "principal plants" like potatoes, for example, are weighted with 75% per year. In the remaining time of the year (25%), "secondary plants" like field forage are allocated. That way each crop type is assigned an annual weight factor. In reality, crop rotation starts only several years after the planting of the principal crop. The use of weighting factors between principal and secondary plants, as implemented in the model, represents the planting time interrelation, extended to several years, in a simplified way.

Well-defined demand and production scenarios provide the input data (value of demand and target crop yield) for the execution of the allocation processes. Appropriate scenarios are developed based on yield values per hectare and crop type, which in turn are specified using actual statistical data. For three different scenarios, as defined in the actual project, individual calculations are carried out, resulting in three different outputs. The scenarios are named "Reference scenario", "Intensive scenario" and "Alternative scenario" and are described in a different deliverable of the project.

The input data for the simulation of the three scenarios can be summed up as follows:

- Excel tables or CSV tables supply the information about year, crop type and demand [tons of dry matter]
- Individual tables for each crop type supply the information about crop yield per hectare and are updated during the calculation process

3 Results

3.1 Demand and production in 2050

The simulation results of each scenario are made available in the form of spatial geodata files and map displays as well as in the form of numerical values in Excel files. The numerical results include annual average values of the total crop yield, which are required to satisfy the demands postulated in the different production scenarios, as well as potential deviations therefrom for each crop type and for the period 2041-2050. The map displays show the optimum spatial distribution of crops, which best satisfy the postulated demands, in accordance with the crop's land use potentials.

Figures 3 - 5 show the computation results for the different production scenarios of the “principal plants” allowing the visualisation of land use requirements and their spatial extents. Figure 6 shows an example of the computation results for the “reference” production scenario of the “secondary plants” after the crop rotation.

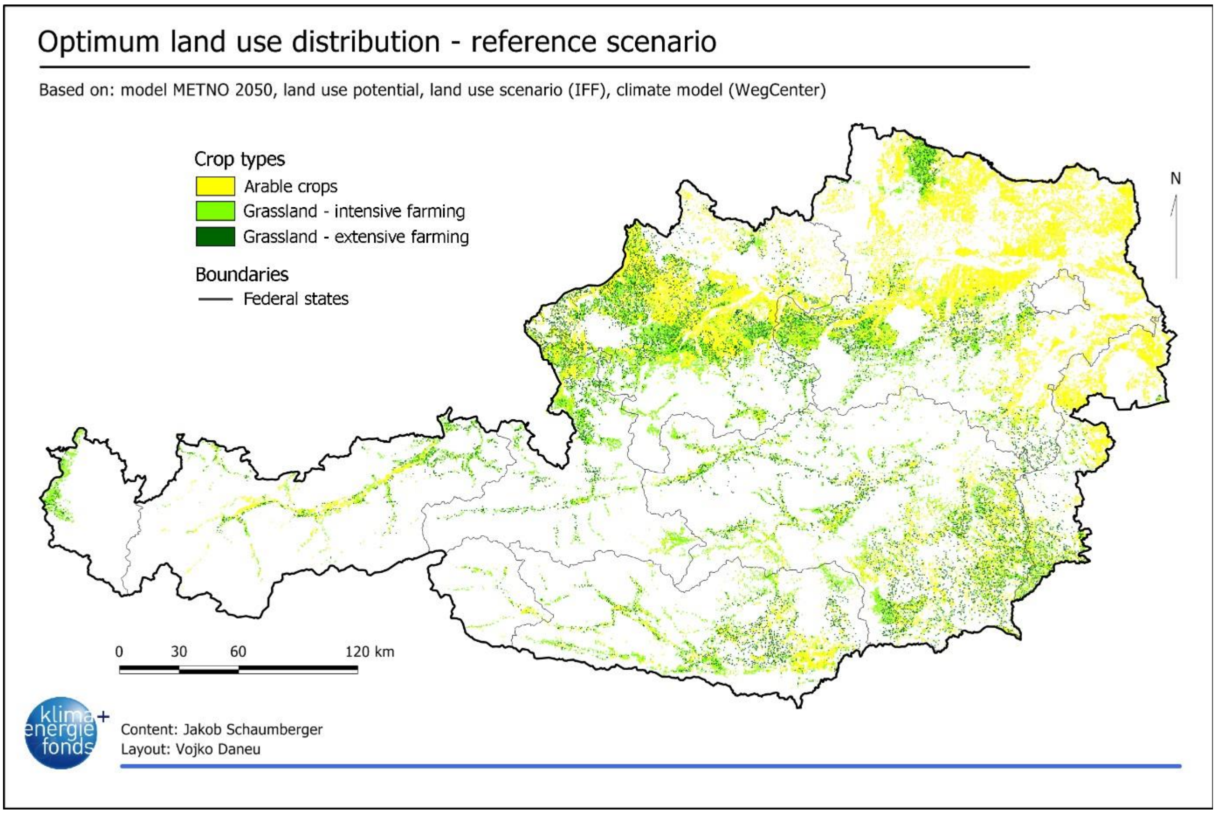

Figure 3: Optimum land use distribution for the period 2041-2050 based on the reference production scenario of the “principal plants”

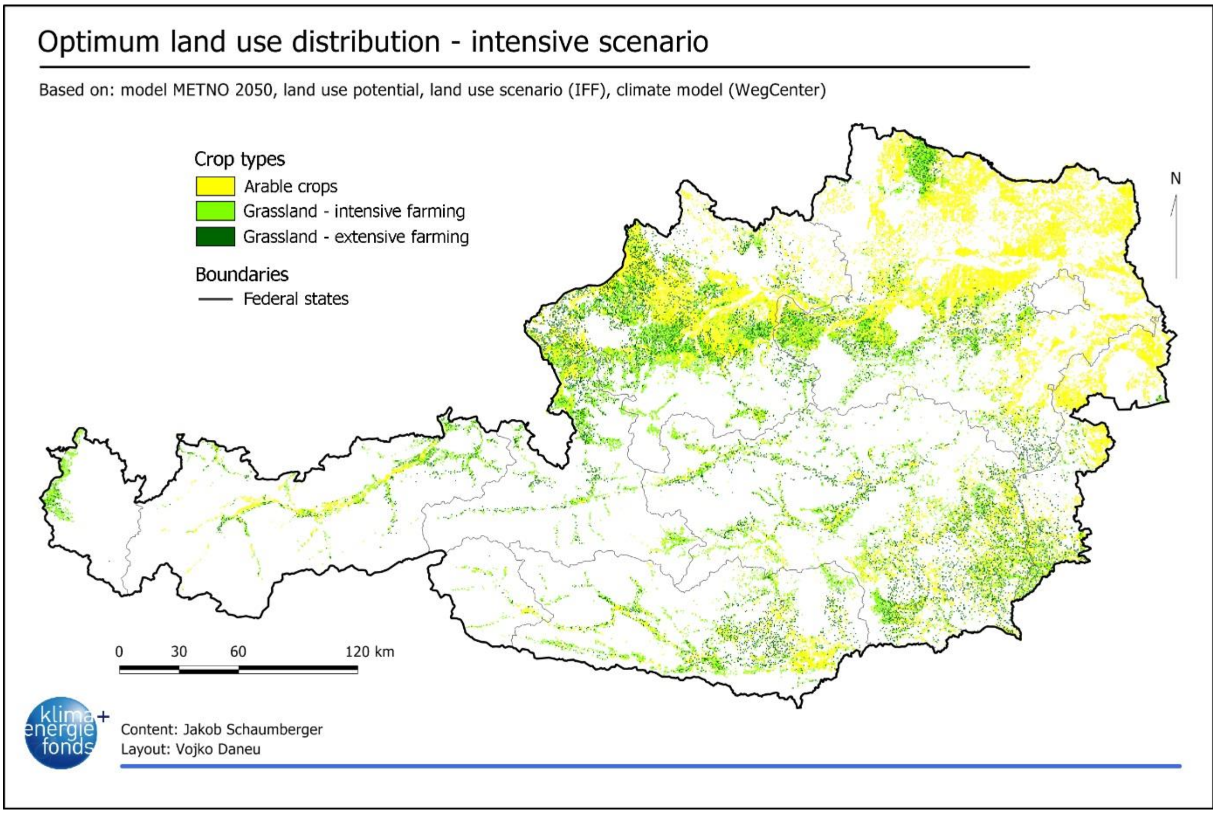

Figure 4: Optimum land use distribution for the period 2041-2050 based on the intensive production scenario of the "principal plants"

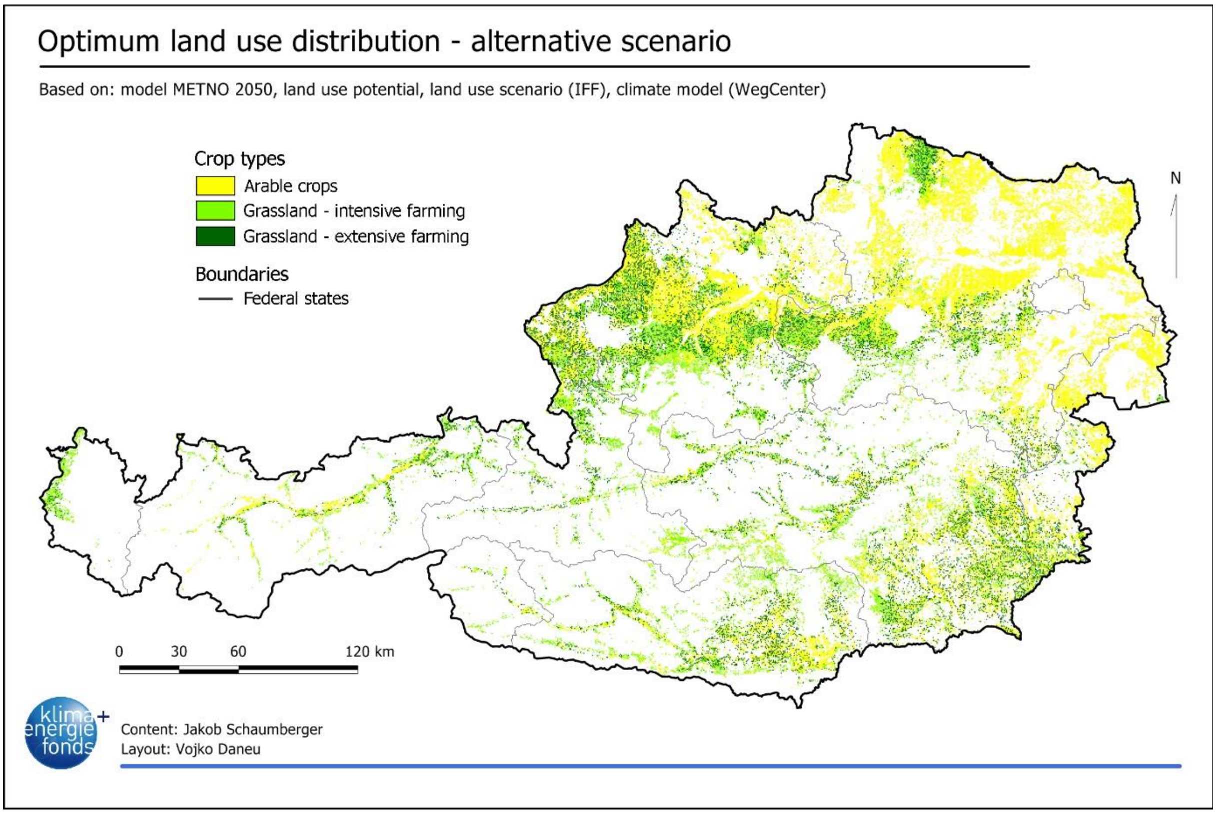

Figure 5: Optimum land use distribution for the period 2041-2050 based on the alternative production scenario of the "principal plants"

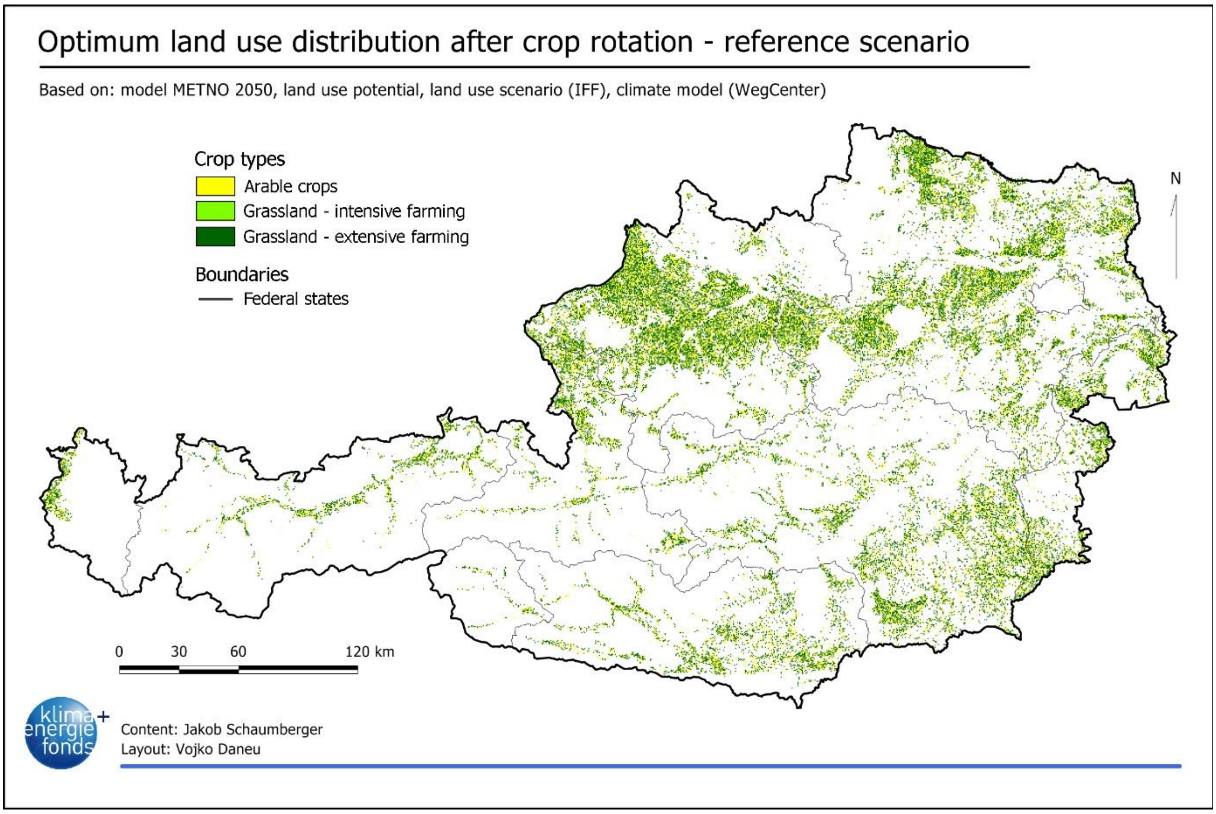

Figure 6: Optimum land use distribution for the period 2041-2050 based on the reference production scenario of the "secondary plants" after the crop rotation

3.2 Conflict potentials

Within the scope of the current project the term "conflict potential" is defined as potential of conflict, which arises, if several crops with high values of land use potential compete for the same location. Such valuable locations can be cultivated with various different crops - the decision in favour of a particular crop will prevent the cultivation of another crop. If cultivation area is scarce then a conflict situation is created particularly in this area.

The conflict potential at a particular location is calculated adding up the land use potential values of all crops, which can be cultivated at the location, within the period 2041-2050 for both climate scenarios ETHZ and METNO. Locations which host many crops with high land use potential show a high/very high conflict potential as depicted in figure 7 in red or purple colour.

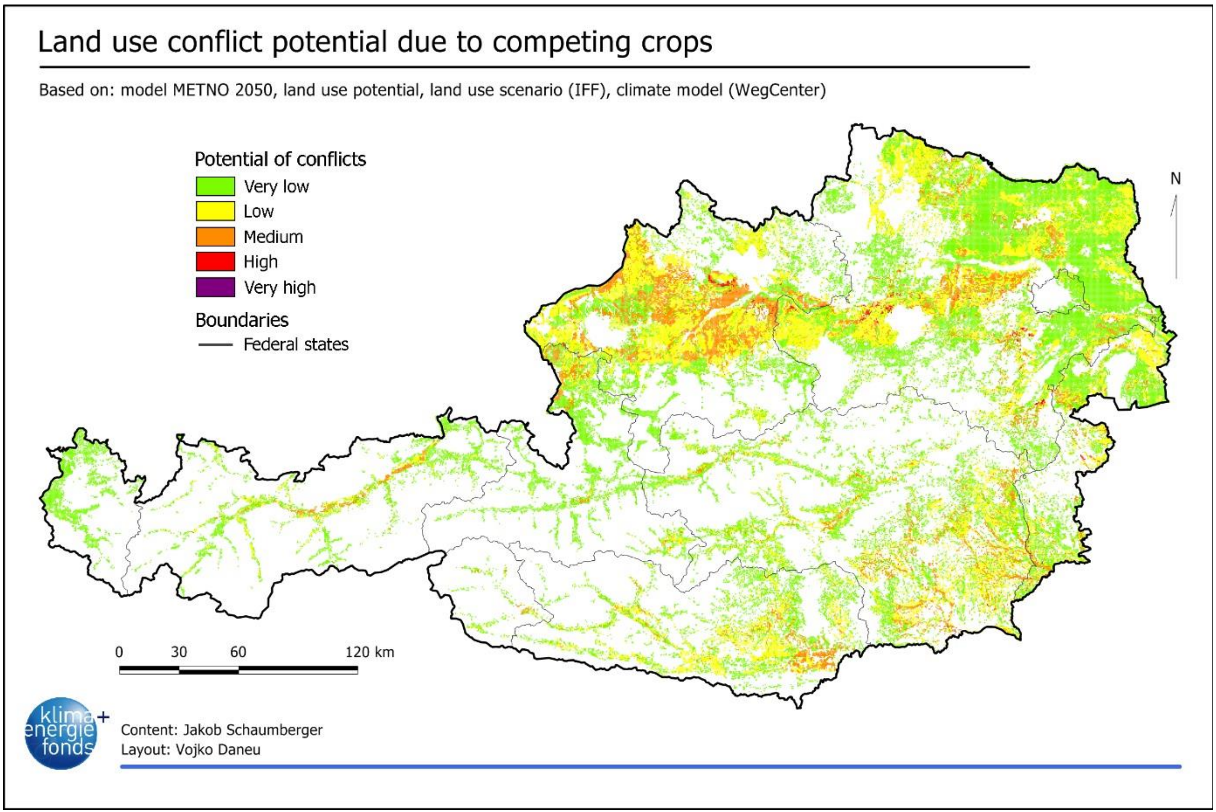

Figure 7: Land use conflict potential for the period 2041-2050 (climate scenario METNO 2050)

3.3 Space consumption of urban areas

Within the current project, assumptions about the loss of agricultural land due to the extension of urban areas and with regard to the demand and consumption of agricultural land within the period 2041-2050 have been worked out and are summed up in table 2.

Table 2: Loss of agricultural land for the period 2041-2050 and for the three different production scenarios due to the extension of urban areas

Loss of agricultural land due to the extension of urban areas (reference year: 2010)	Reference scenario in 1000 hectares	Intensive scenario in 1000 hectares	Alternative scenario in 1000 hectares
Arable land	192,73	192,73	72,27
Grassland: intensive cultivation	161,21	161,21	60,45
Grassland: extensive cultivation	207,88	207,88	77,95

Figures 8 – 10 show the results of GIS simulations, carried out to visualize the effects of the predicted extension of urban areas on agricultural land distribution for the three demand and production scenarios. Based on a data set of Austrian localities of 2016 (Statistics Austria, 2016), GIS overlay analysis has been performed by gradually and uniformly extending urban areas to sizes, which approximately reproduce the agricultural land loss values of table 2. In all three cases distinct land loss effects can be visualized, which are particularly pronounced in the reference and intensive scenarios.

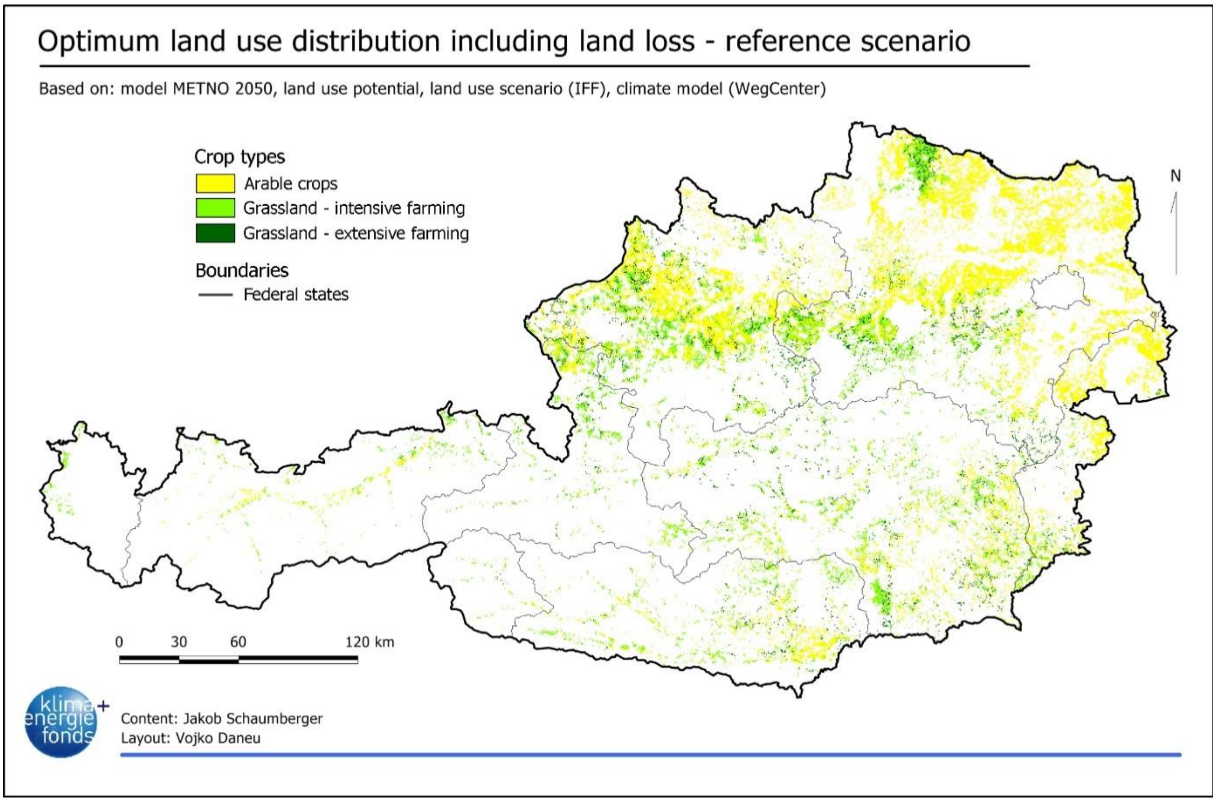

Figure 8: Optimum land use distribution for the period 2041-2050 based on the reference production scenario of the "principal plants" and after elimination of agricultural land due to the predicted extension of urban areas

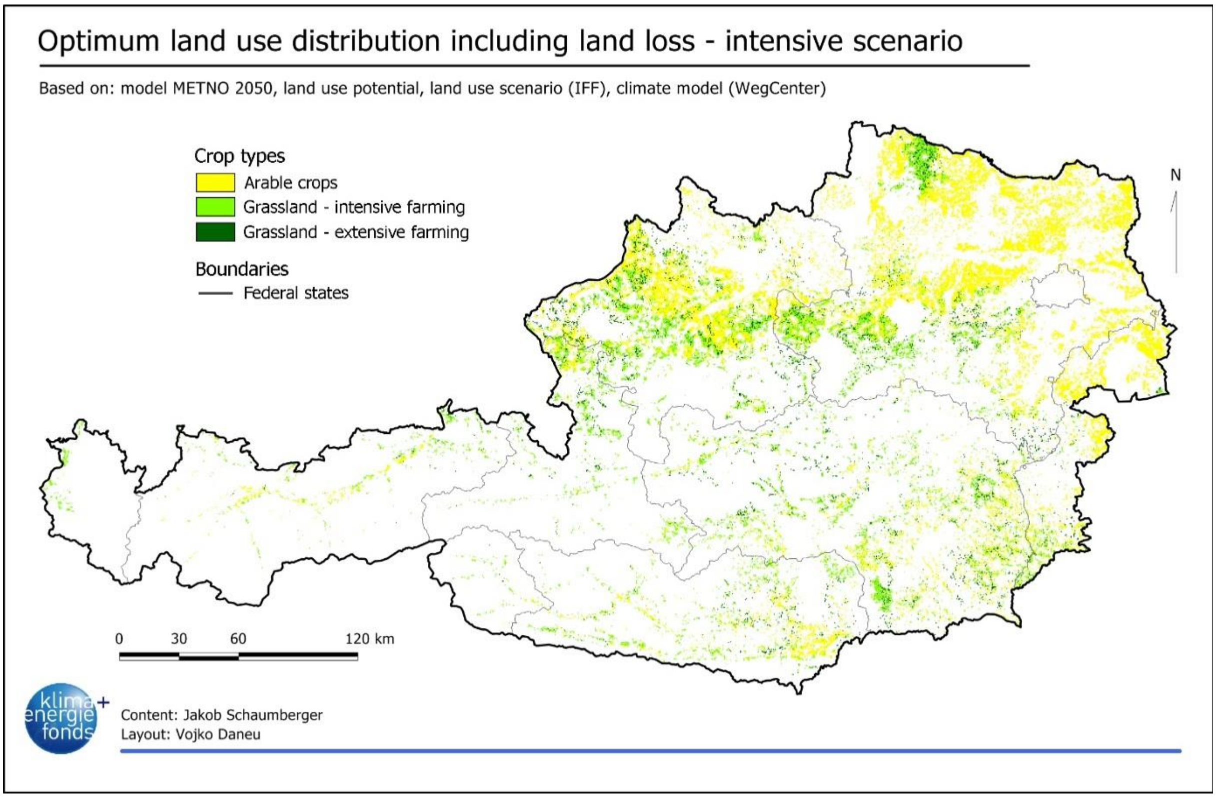

Figure 9: Optimum land use distribution for the period 2041-2050 based on the intensive production scenario of the "principal plants" and after elimination of agricultural land due to the predicted extension of urban areas

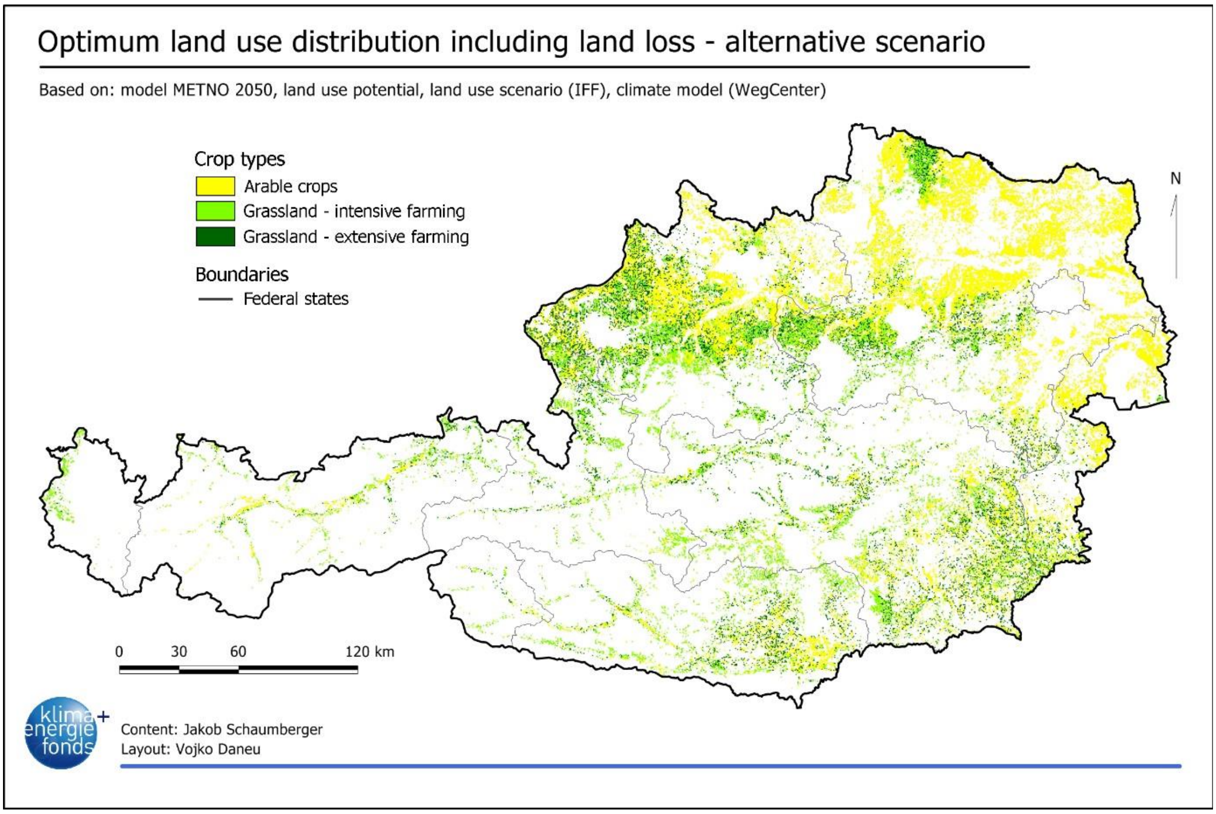

Figure 10: Optimum land use distribution for the period 2041-2050 based on the alternative production scenario of the "principal plants" and after elimination of agricultural land due to the predicted extension of urban areas

4 References

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5 Annex

5.1 List of figures

5.2 List of tables