Co-developing an integrated modelling framework for the circular bioeconomy

Assessing technological, societal and policy implications

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The circular bioeconomy is the intersection of bioeconomy and circular economy. It strives towards a more sustainable and resource efficient world with a low carbon footprint. The circular bioeconomy increases the resource efficiency of processes and the use of recycled materials. In addition, fossil carbon is substituted through renewable carbon from biomass produced with agriculture, forestry and the marine environment.

As the above definition illustrates, several interlinked sectors, represented by different scientific disciplines, are involved in studying the bioeconomy. These disciplines use different vocabularies, principles and concepts, which must be aligned to enable a coherent and consistent assessment of future scenarios and potential policies. To this end, around fifteen individuals representing the disciplines engaged in a process of collaborative modelling during workshops and bilateral meetings.

This report describes i) the co-production of the conceptual model of the circular bioeconomy and ii) the transfer of the conceptual model into a modelling framework of existing models, and; iii) the application of one of the computer models within the context of the circular bio-economy, i.e. iClue, in relation to the linked models of the modelling framework.

Keywords: Circular bioeconomy, conceptual modelling, iCLUE

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1 Introduction

In December 2015, the Paris Climate Agreement was signed by 195 countries at the Paris climate summit. In response to the Paris Climate Agreement, the Netherlands launched a vision document "Landbouw, natuur en voedsel, waardevol en verbonden" *("Agriculture, nature and food, valuable and connected")* in 2018. In that vision document, the Dutch Minister of Agriculture Schouten expressed the ambition for a circular agricultural system that is integrated with nature, and which by 2030 should feature as many closed nutrient cycles as possible at local, national and international scales.

A data-driven and evidence-based toolbox is needed to ex-ante understand and assess the implications of potential policies that underpin the realization of this vision. Such a toolbox is aimed at supporting policy makers and stakeholders in the field of the entire bio-economy, including agricultural production for food, fodder, bioplastics and energy; forest products for building material, furniture, paper and energy; climate; bio-diversity; marine resources and; socio-economic developments. Wageningen University and Research (WUR) is creating the toolbox by linking existing models together in a model framework, and to assess the likely results of circular bio-economy scenarios. Figure 1 provides a schematic overview of the model framework.

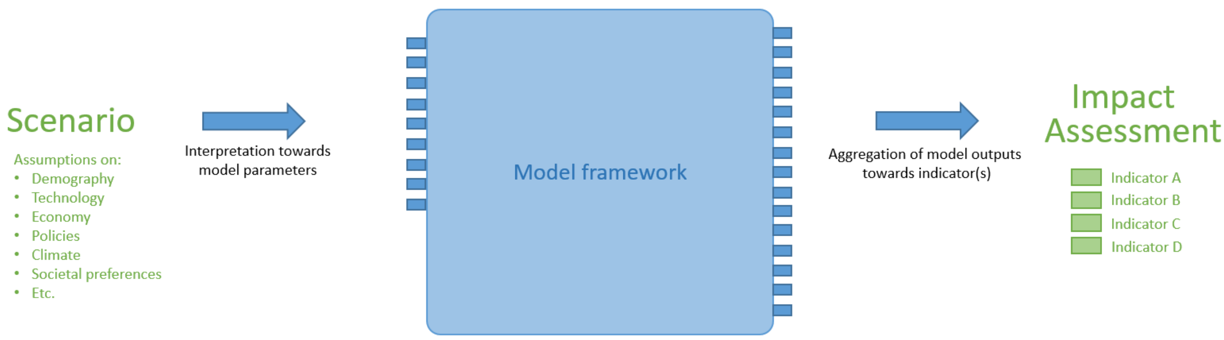


Figure 1 *Schematic representation of the role of the model framework within the context of doing an impact assessment of circular bio-economy scenarios.*

This report describes i) the co-production of the conceptual model of the studied system and ii) the transfer of the conceptual model into a modelling framework of existing models, and; iii) the application of one of the computer models within the context of the circular bio-economy, i.e. iCLUE, in relation to the linked models of the modelling framework.

iCLUE is a land use model that projects land use changes that are a result of climate, socio-economy, dietary and policy drivers. Land use plays a pivotal role in the circular bioeconomy through its role in provisioning services (e.g. food, fibre biomass, fuel and habitat for flora and fauna), regulating services (e.g. climate) and supporting services (e.g. nutrient cycling, soil formation).

Chapter 2 explains the workshops that were used for the co-production of the conceptual model and the model framework (i and ii). Chapter 3 elaborates on the iCLUE model and its integration with the MAGNET model and the Food Safety Model (iii).

2 Framing the circular bioeconomy

2.1 Methods for collaborative modelling

Understanding of the concept of the circular bioeconomy is the first step in the development of the integrated toolbox to assess the future of Europe in a circular bioeconomy between 2020 and 2050. Here, we use the circular bioeconomy definition from Carus and Dammer (2018): *"the circular bioeconomy is the intersection of bioeconomy and circular economy. It strives towards a more sustainable and resource efficient world with a low carbon footprint. The use of additional fossil carbon is avoided, to contribute to climate targets. The circular bioeconomy increases the resource efficiency of processes and the use of recycled materials. In addition, fossil carbon is substituted through renewable carbon from biomass produced with agriculture, forestry and the marine environment."*

As the above definition illustrates, several interlinked sectors, represented by different scientific disciplines, are involved in studying the circular bioeconomy. These disciplines use different vocabularies and principles, which must be aligned to enable a coherent and consistent assessment. To this end, individuals representing the disciplines engaged in a process of collaborative modelling (Figure 2).

Collaborative modelling is a purposeful learning process that incorporates the implicit and explicit knowledge of participants to co-formulate a problem and to create shared and formalized representations of reality (Voinov et al., 2018; Baso-Carrera et al., 2017). Collaborative modelling is rooted in collaborative learning, i.e., an intensive mode of information sharing and knowledge production and that involves the development of relationships. Collaboration is a process the success of which depends on how well that process is organized and managed. Process orchestration overlaps with other methods that together result in social learning, i.e., learning via an interactive process of observation and imitation, which ultimately leads to a convergent change in the participants' perspectives (Verweij, 2021; van der Wal et al., 2016). These other methods include:

- Obtaining a shared system understanding through qualitative modelling. Here concept mapping (Argent et al., 2016; Verweij, 2021) and causal loop diagramming (Lane, 2008) were used to express relationships, highlight key or dominant processes, explore and test ideas and causality, identify knowledge and data gaps, synchronize mental models and build consensus.
- Selecting indicators and building scenarios. In futures studies, scenarios are used as a set of structured conceptual systems of plausible future contexts, often in the form of narrative descriptions (Ramirez et al., 2015; Jetter & Kok, 2014). Within these scenarios, drivers of change (e.g., population trends, consumption patterns), bioeconomy policies and impact indicators (e.g., Green House Gas emissions and land use change) are identified (Smeets & Wetering, 1999). Typically, scenario building involves quantifying the drivers of change.
- Using quantitative modelling to accommodate informed policy-making by testing the likely effects of policies within the scenarios. Testing the policies in different scenarios informs us on their robustness, i.e., 'the capability of policies to maintain functionality and effectiveness in policy goal attainment' (Capano & Woo, 2018).

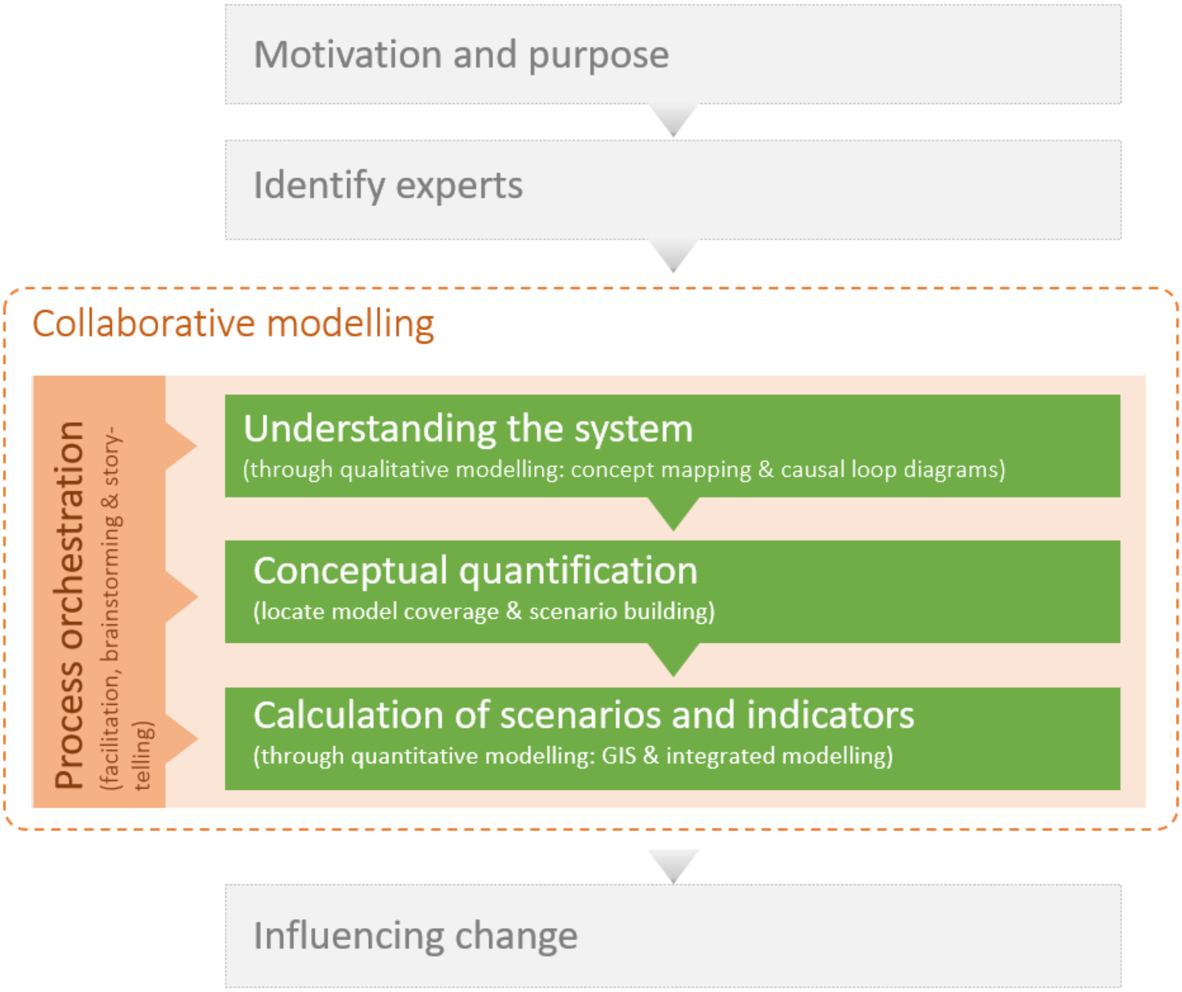


Figure 2 *Collaborative modelling (inspired by Voinov et al., 2018; Foresight4food, 2021; Verweij, 2021). The coloured boxes are included in this study. Green boxes depict the purpose (capitals) and order of activities (follow the arrows between the boxes). Each of the coloured boxes list a number of methods used within this study (in small font between brackets). The orange box 'process orchestration' is used in all green box activities. The grey boxes are excluded from this study, but are nonetheless displayed here to illustrate the full context of typical collaborative modelling studies.*

2.2 Modelling workshops

Within three workshops a shared understanding of the circular bioeconomy was developed with the specific objective to link sectoral models, enabling us to estimate the impacts of potential policies within scenarios of the future. Each of the (mostly existing) sectoral models captures formalized sectoral knowledge. The same group of 17 experts participated in all workshops representing the scientific disciplines of: agro-chains, bio-based products, bio-refinery and value chains, husbandry, economy, food production, food safety, land use, marine (population) ecology, landscape ecology and biodiversity. Two of the workshops were organised online (due to COVID measures), while the third was a hybrid workshop with half of the participants joining online (see Annex 3 for details).

In the first workshop key concepts of circularity were identified, followed by an inventory of strengthening and weakening causal relationships between them. The facilitator used Miro (www.miro.com) as collaboration software, in which he prepared a whiteboard. At the beginning of the workshop each participant was asked to write down countable system variables on Post-its (e.g. 'share of plastics from crops'), with exactly one system variable per note. Then, as different individuals wrote down the same or similar variables, the Post-its were grouped. Grouping took place by all individuals concurrently while in dialogue with each other, under the direction of the facilitator. Groups of Post-its were given names, which sometimes resulted in further break down or aggregation. When Post-it shifts and discussions ceased, the facilitator closed the activity and opened a blank (virtual) whiteboard for creating causal relationships. The facilitator provided an example by copying concepts (both Post-its and group names) from the closed whiteboard and drawing an arrow between them. Two types of arrows were demonstrated: strengthening links (green arrows marked with a '+' sign) and weakening links (red arrow marked with a '-' sign). Strengthening links represent a causal link such as '*if A increases, B increases too*'. Weakening links represent causal links such as if '*A increases, B will decrease*'. Under the direction of the facilitator, all participants were then invited to complete the causal diagram as demonstrated, again during constant dialogue with each other.

The second workshop started with a recapitulation of the resulting causal loop diagram from workshop one. In a plenary meeting the diagram was improved by the facilitator by (re)placing links and semantics of key concepts. Then, in succession, each model-expert drew a boundary around the concepts that were captured by 'their' model. These drawings triggered questions for clarification from other participants, sometimes resulting boundary changes to exclude, or include certain key concepts. At the end of the workshop, the facilitator re-ordered the nodes and boundaries in order to best structure the spaghetti-like structure. This resulting diagram indicates what models exchange what information and were used to plan bilateral meetings between model experts to develop technical data-exchange procedures. After this workshop, the authors developed a model-linking diagram in which only the models, their main purpose and information exchange is visualised. The results of workshop 1 and 2 are graphically summarized in Figure 3. The following models are included within the modelling framework (see for their causal relations '*5. Model framework*' in Figure 3):

- Animal model (MacLeod et al., 2018) – determine land demands for feed and fodder.
- Marine model – estimate seaweed and shellfish production.
- BIOSPACS (Conijn et al., 2018) – determine land demands for agricultural land (e.g. as result of changing diets).
- MAGNET (Doelmand et al., 2018) – determine land demands for agricultural land (e.g. from population growth, tech. innovation and increased consumption patterns).
- Model of the world – determine demands for raw materials and GHG emissions (resp. wood, wheat, sugar cane, fossil resources and CO2 equivalents).
- iCLUE (Verweij et al., 2018) – allocate land demands.
- Food safety model (Liu & van der Fels-Klerx, 2021) – assess risk of mycotoxins in wheat and maize.
- LARCH (Rutter et al., 2014) – assess the biodiversity suitability in terms of habitat size, quality and fragmentation.

The third workshop was used to identify key indicators for measuring the performance of potential policies, technologies and societal choices. Key Performance Indicators are the critical indicators of progress towards an intended result and may be different from the indicators that are produced by the models. At the start of the workshop, all participants individually listed the indicators that were key from their perspective by writing them down on Post-its – with a maximum of seven notes per individual. Then the facilitator gathered all the Post-its, stuck them on the wall, and started grouping them while engaging in plenary dialogue. Notes from the online participants were written down by an assistant and added to the flip-overs on the wall. Group names represented an indicator name (e.g., 'CO2 equivalent', not 'emissions'). The resulting groups were prioritized by handing out three small stickers to each participant, who could then put them on an indicator(group). Participants could decide to put multiple priority stickers on a single indicator or spread them across multiple indicators. The assistant helped the online participants to include their input. Based on the number of stickers, priority indicators were identified by the facilitator. Finally, indicator metrics for the top five indicators were discussed in a plenary and noted by the facilitator. The list below shows the prioritized indicators with their metrics ordered from high to low priority:

1. *Green House Gas emissions* (in tonnes of CO2 equivalents).
2. *Biodiversity* (e.g., as result of habitat loss, contamination and landscape fragmentation).
    - Terrestrial - percentage of total area of (semi-)natural used land and Mean Species Abundance).
    - Marine – percentage of used versus non-used primary production).
3. *Land (and sea) use in relation to yields* (including agriculture for food and non-food, forestry for wood products and biobased intermediates, aquaculture and fisheries).
    - Area and spatial patterns per use class (hotspots and hope-spots).

4. *Resource efficiency* (including nutrients such as N and P, energy, water).
   - External nutrients – tons of (chemical) N/P fertiliser put into the system.
   - Soil degradation – missing model!
   - Water use – in cubic meters.
   - Fossil resources – in Mton of carbon.
5. *Other* (food safety, waste, costs, employment, etc.).
   - Percentage of safely produced food.
   - Intake kCal/person/day.
   - Ratio cereal prices/wages.
   - Number of jobs.
   - GDP.

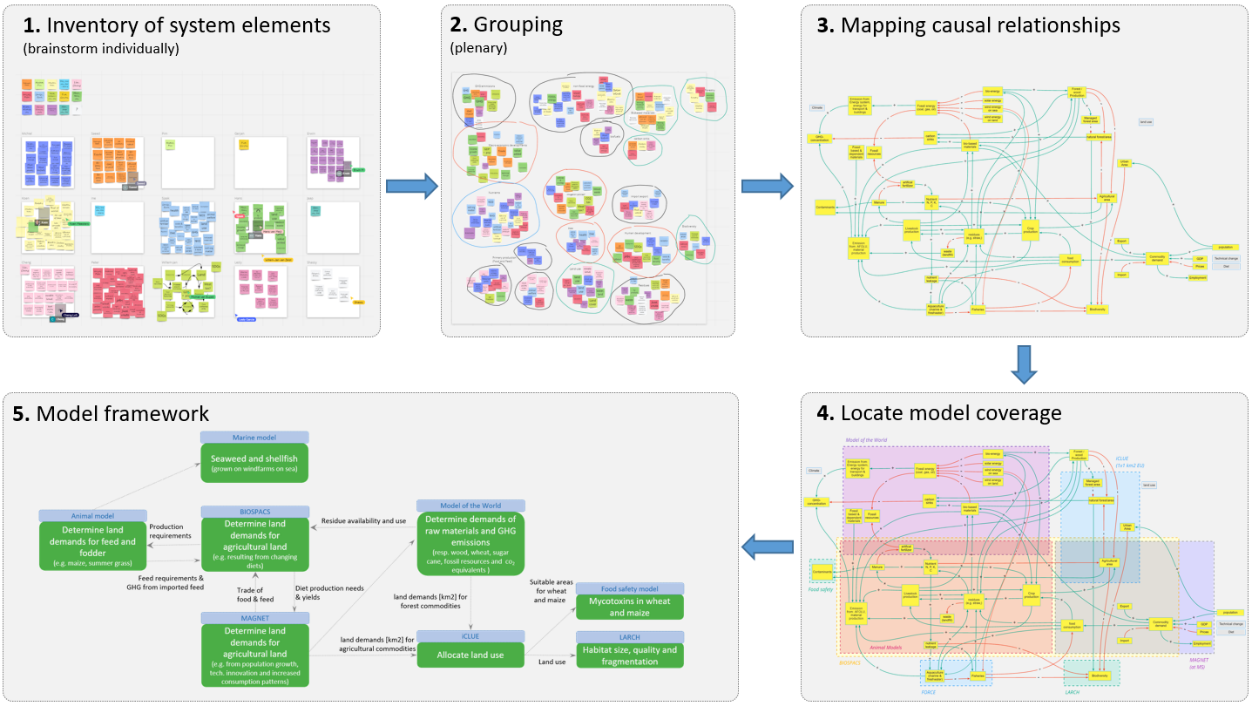


Figure 3 *Overview of the development of the conceptual model and the vision on the integrated toolbox (results of co-producing workshops 1 and 2).*

2.3 Observations

Several observations by participants were made during the workshops. The observations are listed below as feedback on the process and its results:

- [at the end of workshop 1] – 'This is an excellent method for getting an overall understanding of what we as a team see as the bioeconomy. I really like the discussions we are having, very transparent and clarifying';
- [at the end of workshop 1] – 'An important part of the bioeconomy, the forestry sector, is not represented by the available models. It represents material for the paper and pulp industry, timber for construction, a source for renewable energy and is habitat for much of the world's biodiversity'. This omission has been tackled by relying on FAO round wood trend extrapolations. Trend extrapolation is an imbalanced and strong simplification in relation to the models used for other sectors that better represent reality;
- [at the end of workshop 1] – 'models seemingly overlap a lot when looking at system concepts alone. However, they may implement different overall conceptualisations and methodologies. Workshops like this are an efficient and pleasant way of finding (dis)similarities';
- [at the beginning of workshop 2] – 'It is really important to set system boundaries. While we think about circularity on an EU level, there is a lot of material flow from and to the outside, such as food, feed and timber';
- [at the end of workshop 2] – 'Here we found the order of model execution and the conceptualized feedback loops between them. Ideally it would be a model assessment with actual feedback loops between our

models, but given the manual technical interpretations and transformations we need to do, I don't expect this to be feasible';
- [at the end of workshop 3] – 'We ran out of time to locate each of the KPIs on our model framework. Can we calculate all KPIs with our model framework? Isn't our model framework too heavy on other parts, that as they do not result in KPIs? Or do these produce supportive, more detailed indicators?'

3 Land use projections

3.1 Modelling procedure of iCLUE

The iCLUE model is part of the CLUE model family (Kok et al., 2001; Veldkamp & Fresco, 1996; Verburg et al., 2002; Verburg & Overmars, 2009) and simulates land use change by looking at the territorial land use demands (Verweij et al., 2018). The components determining the future allocation of land use are: (i) land use suitability, (ii) the areal demand for every land use class, (iii) conversion rules and (iv) neighbouring land use (see Figure 4).

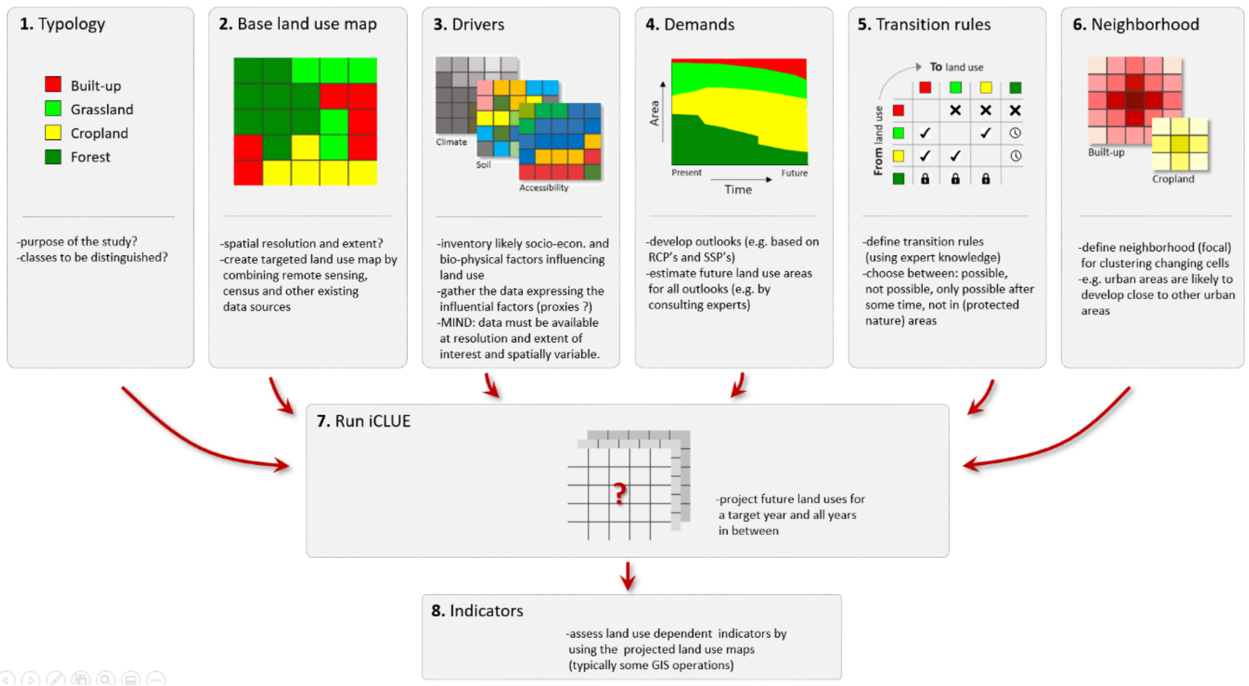


Figure 4 *The iCLUE model and the pre-modelling (1 to 6), model execution (7) and post-modelling (8) steps.*

Firstly, land use suitability is defined as the suitability of a land use class at a specific location, based on the features of that area, i.e., soil, climate, accessibility and terrain. The iCLUE model uses a statistical method, in the form of a stepwise regression, to determine the suitability. Secondly, land use requirements (demands) are calculated for every land use type at the accumulated level for the final year of the modelling timeframe. The demands are calculated using extrapolations or other models. Thirdly, land use type specific conversion settings influence the temporal interactions of the simulations. The specific conversion settings are based on conversion elasticities and land use transition sequences. Conversion elasticity indicates whether the change in land use is likely to change or not; if the value of a cell is 1 the conversion is allowed while a 0 indicates that the conversion is not possible. Examples are shifting cultivation, for which the land is often not used for more than two harvest seasons in a row, or residential areas. The land use transition sequences are defined in a conversion matrix and shows to which other type of land use an area can be changed and to which land use type the area will not be changed. The transition sequence includes: conversion possible, conversion impossible, conversion possible after specified time and conversion (im)possible in specific area. Lastly, the allocation of land is influenced by the land use surrounding the cell. For example, a built-up area is more likely to expand next to an existing built-up area, rather than in a new spots.

3.2 Scenario selection

One scenario was applied in this project to model iCLUE, which hereafter will be called Business-As-Usual (BAU) scenario. BAU is a combination of Shared Socio-economic Pathway 2 (SSP2) and Representative Concentration Pathway 4.5 (RCP 4.5).

The SSP2 scenario originates from the Shared Socio-economic Pathways (SSPs) scenarios, which were developed to characterize a future in which trends in society determine whether mitigation of, or adaptation to, climate change becomes easier or harder (O'Neill et al., 2017). SSP2 is a middle of the road scenario that projects a future in which social, economic and technological developments follow their historical trendlines. In SSP2 some investments are made in renewable energy, but at the same time, the reliance on fossil fuels remains more or less the same. Although there are some environmental regulations which slow the decline of deforestation, environmental degradation continues to take place. The agricultural sector advances at a medium pace with technological innovations. The SSPs do not explicitly take climate change into consideration (O'Neill et al., 2017).

RCP 4.5 is part of the Representative Concentration Pathways (RCPs) that, in contrast to the SSPs, look at the development of greenhouse gas concentrations and the effect thereof on climate change without considering mitigation options (Moss et al., 2010). RCP 4.5 considers an intermediate future, namely that the greenhouse gas emissions peak at 2040 and then begin to decline. This scenario sees the 2050 emission levels decrease by 50% by the year 2100.

3.3 Base land use map

The iClue model requires a land use map describing the current status of the land use over the area of interest (i.e. the Base Map). The base map on a 1 x 1 km grid scale (see Figure 3) used in this study is a combination of the Corine landcover map of 2018[1], the forest management map (Nabuurs et al., 2017) and the agricultural intensity map (Rega et al., 2018) – see Figure 4 and Annex 4. The base map contains the 26 European Union countries with the addition of Norway, the United Kingdom and Switzerland. Malta was not modelled due to data availability issues and therefore Malta's land use situation 2050 remains the same as in 2018 in this model.

[1] Copernicus, https://land.copernicus.eu/pan-european/corine-land-cover/clc2018.

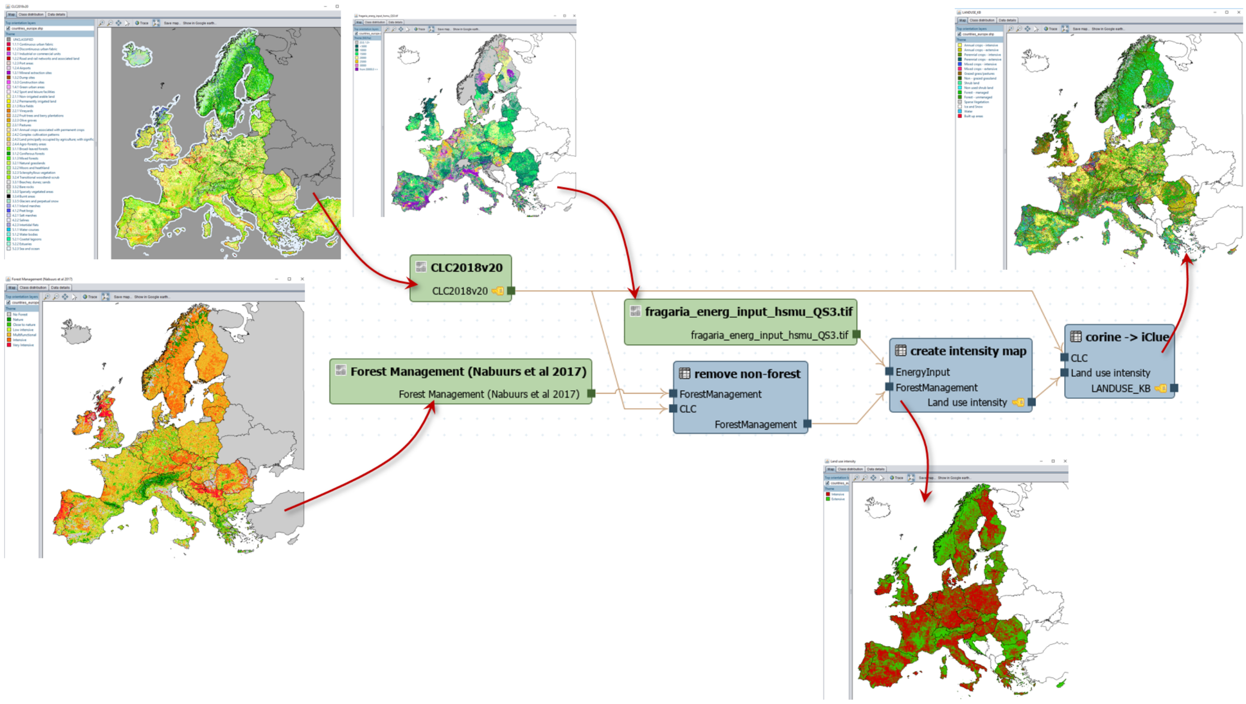


Figure 5 *Workflow for deriving the land use map from existing datasets.*

In order to derive land use indicators, a targeted land use typology was developed to produce results relevant for the study (see Figure 4), of which the distribution in 2018 can be found in Table 1. The land use classes ‘sparse vegetation’, ‘ice and snow’ and ‘water’ were modelled statically, as the classes did not change over time regarding size and location. The suitability variables determining the land use type in every land use cell can be found in Table 2 in Appendix I. The following variables categories were present: soil characteristics, climate characteristics, accessibility characteristics, terrain characteristics and livestock density.

Europe has been modelled with two allocation approaches: on a continental scale (‘*without borders*’-*Europe*) and on a country level (*country-Europe*). In the ‘without borders’-Europe run, iCLUE allocates the areal demands all over Europe, while in country-Europe runs the areal demands are allocated in the respective countries.

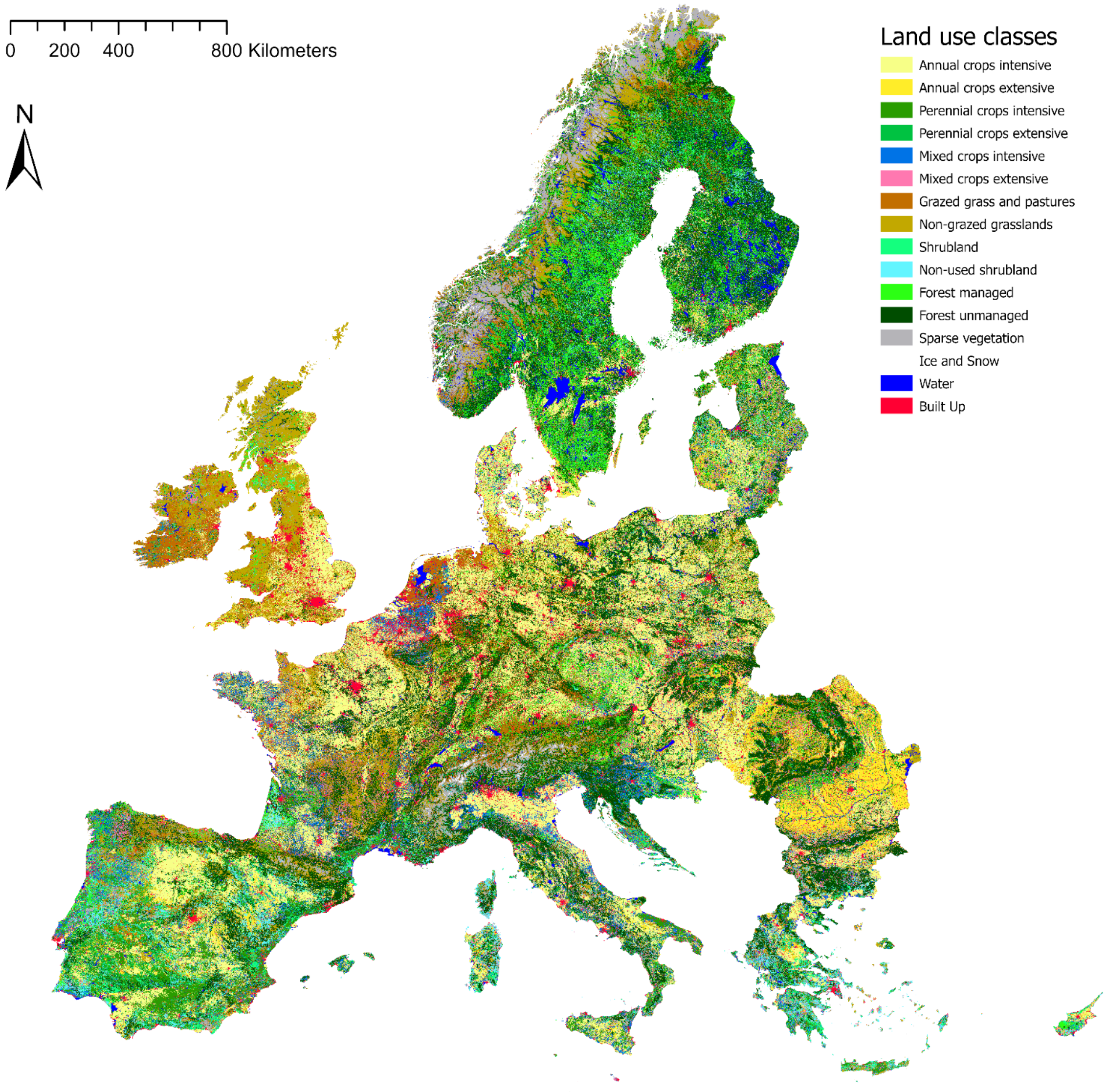


Figure 6 *Europe in 2018.*

Figure 7 *Land use classes.*

Table 1 *Land use distribution in 2018.*

Land use class	**km2**	**Percentage of total (%)**
Forest unmanaged	1129990	24
Annual crops intensive	873807	18
Non grazed grasslands	477612	10
Forest managed	392102	8
Grazed grass pastures	288345	6
Annual crops extensive	241765	5
Built Up	224157	5
Mixed crops intensive	215105	5
Sparse vegetation	171317	4
Non used shrubland	169531	4
Mixed crops extensive	143493	3
Water	134459	3
Shrubland	121133	3
Perennial crops intensive	113026	2
Perennial crops extensive	34240	1
Ice and Snow	5073	0
Total	4735155	100

4 Integration of iCLUE with other models

4.1 Agricultural area demands from MAGNET

The MAGNET model is a global general equilibrium model that simulates the impacts of agriculture, trade, land and bioenergy policies on the global economy[2]. The MAGNET model projected agricultural areal commodity demands for 'without borders'- and 'country-Europe' in 2050 based on the BAU scenario. The agricultural areal commodity demands indicate how much land every agricultural commodity needs in what spatial region (e.g. 'Netherlands' 2,210 km2 of wheat). The areal demands that are projected by MAGNET are provided per statistical region (single number for a country), but without explicit spatial allocation (thousands of cells per country). The iCLUE model therefore takes the projected areal demands from the MAGNET commodities and allocates these demands spatially based on its rules regarding suitability of different landcover types and likelihood of conversion from one land use type to another. iCLUE isn't a specific crop forecasting model, but focusses on land-use change (Verweij et al. 2018), therefore (MAGNET) agricultural commodities need to be converted to their (share of) a specific land use class. The given set of MAGNET commodities can be allocated over different land use classes. For instance, wheat can be grown in a land use classes 'intensive annual crop', 'extensive annual crop', 'intensive mixed crop', or 'extensive mixed crop'. In general, this division is commodity and region specific. Therefore, we developed a distribution key which assessed the amount of areal agricultural commodity present in the different iCLUE land use classes. This key was derived by overlaying spatially downscaled FAO crop statistics[3] as done by MapSPAM[4] with the Corine landcover (CLC) data[5] to their relative distribution in Europe (see Figure 6). With this distribution key, the projected agricultural land use demands were determined.

	iClue land use classes for KB circular economy	Rice (pdr)	Wheat (wht)	Cereals (gro)	Horticulture (hort)	Oilcrops (osd)	Sugar beet and reed (c_b)	OtherCrops (ocrops)	BeefCattle (bfctl)	DairyCows (ctl)	CattleSheepGoatHorse (rmk)	Plantfibers (pfb)	Wol (wol)	Energy (energycrop)
10	Annual crops - intensive	100 %	38%	38%	50%	8%	100%	17%	19%	35%		17%		100%
11	Annual crops - extensive		30%	30%		5%		17%	14%			17%		
20	Perennial crops - intensive				50%	46%		17%	0%			17%		
21	Perennial crops - extensive					27%		17%	8%			17%		
30	Mixed crops - intensive		20%	20%		9%		17%	7%	7%	10%	17%	10%	
31	Mixed crops - extensive		12%	12%		4%		17%	8%		12%	17%	12%	
40	Grazed grass/pastures								31%	58%	21%		21%	
41	Non - grazed grassland								12%		28%		28%	
50	Shrub land										15%		15%	
51	Non used shrub land										14%		14%	
60	Forest - managed													
61	Forest - unmanaged													
70	Sparse Vegetation													
80	Ice and Snow													
81	Water													
90	Built up areas													

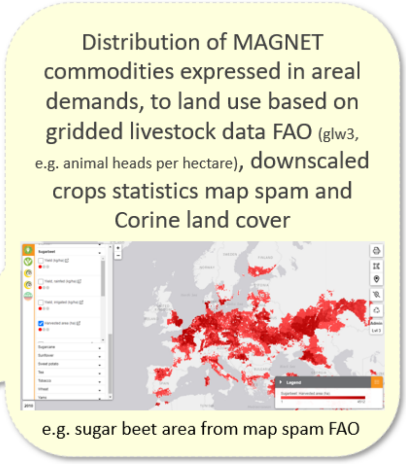


Figure 8 *Distribution key for mapping MAGNET commodities (columns) to iCLUE land use classes (rows) based on related MapSpam data.*

Next to the interpretation of MAGNET commodities to iCLUE land use classes, also the spatial schematisations had to be aligned, e.g. '*Netherlands*' 2210 km2 of wheat, or '*other OECD countries*'

2 MAGNET, https://www.magnet-model.org/
3 FAO, http://www.fao.org/faostat/en/#home
4 MapSPAM, https://www.mapspam.info/
5 Copernicus, https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

185000 km^2 of horticulture. MAGNET groups all '*other OECD countries*' (like Norway and Switzerland) into a single entity which require spatial explicit allocations for iCLUE. iCLUE uses the GADM schematisation (Global Administrative Areas[6]). See Figure 9 for the interpretation of MAGNET regions to GADM regions.

KB1C_CODE	Magnet_NAME	Magnet_NR	iCLUEnr	iCLUEname
AUT	Austria	1	2	Austria
BLG	Bulgaria	3	5	Bulgaria
BLX	**Belgium and Luxemburg**	**2**		
BLX	Belgium and Luxemburg	2	4	Belgium
BLX	Belgium and Luxemburg	2	24	Luxembourg
CZE	Czech Republic	6	8	Czech Republic
DEU	Germany	7	9	Germany
DNK	Denmark	8	10	Denmark
ESP	Spain	9	12	Spain
EST	Estonia	10	11	Estonia
FIN	Finland	11	13	Finland
FRA	France	12	14	France
GBR	United Kingdom	13	39	United Kingdom
GRC	**Greece, Cyprus and Malta**	**4**		
GRC	Greece, Cyprus and Malta	4	7	Cyprus
GRC	Greece, Cyprus and Malta	4	15	Greece
GRC	Greece, Cyprus and Malta	4	28	Malta
HRV	Croatia	5	16	Croatia
HUN	Hungary	14	17	Hungary
IRL	Ireland	15	18	Ireland
ITA	Italy	16	20	Italy
LTU	Lithuania	18	23	Lithuania
LVA	Latvia	17	25	Latvia
NLD	Netherlands	19	29	Netherlands
OECD	Rest of OECD region	32	30	Norway
OECD	Rest of OECD region	32	6	Switzerland
POL	Poland	20	31	Poland
PRT	Portugal	21	32	Portugal
ROU	Romania	22	33	Romania
SVK	Slovakia	23	37	Slovakia
SVN	Slovenia	24	36	Slovenia
SWE	Sweden	25	35	Sweden

Figure 9 *Translation table of MAGNET regions to GADM regions. GADM regions are used by iCLUE.*

4.2 Integration with non-agricultural area demands from FAOSTAT

Non-agricultural land use demands for BAU and forest were derived from projected trends on Copernicus landcover (CLC) statistics[7] combined with expert adjustments for forest areas using FAOSTAT wood production numbers[8]. The BAU trend up to 2050 was based on linear interpolation using 1990, 2000, 2006, 2012 and 2018 CLC datasets. The trend in BAU was checked using ESA's multitemporal global high resolution GHS built-up data dating from 1975-2015 (Florczyk et al., 2019)[9].

[6] Global Administrative Areas (2012). GADM database of Global Administrative Areas, version 2.0. [online] URL: www.gadm.org

[7] The CORINE Land Cover (CLC) inventory was initiated in 1985 (reference year 1990) to standardize data collection on land in Europe to support environmental policy development. Updates were produced in 2000, 2006, 2012 and 2018. Change layers were produced for 2000, 2006, 2012 and 2018. Copernicus, https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

[8] FAOSTAT, European Roundwood production, https://www.fao.org/faostat/en/#data/FO

[9] ESA GHSL datasets https://ghsl.jrc.ec.europa.eu/download.php?ds=bu

Borelli et al. (2016) showed that there is a clear relation between the area of forest cover change and roundwood production in Europe (see Figure 10). This relationship allows us to project the production trends of roundwood (as given by FAOSTAT) as an expected area change of the forest in 2050.

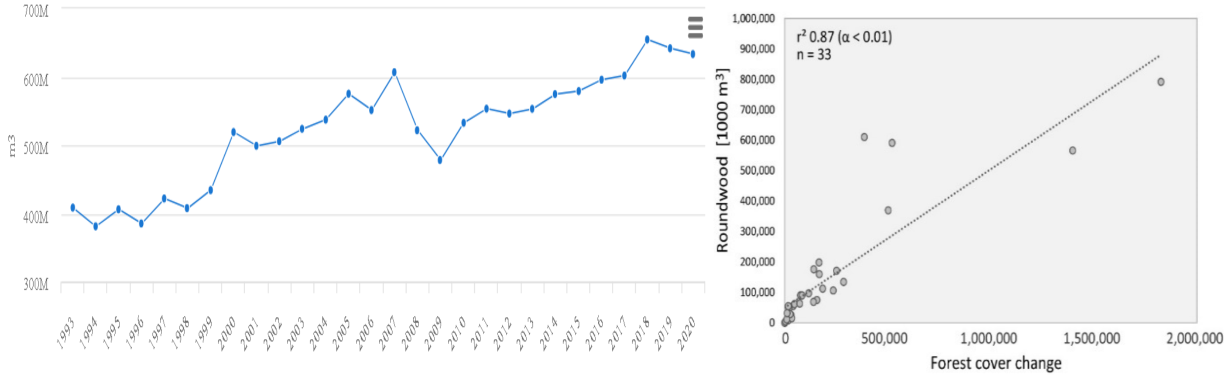


Figure 10 *Left: Volume of Roundwood production in Europe 1993-2019 (FAOSTAT) used for trend analyses; Right: Forest cover changes values versus roundwood production reported by Eurostat in 33 European countries (period 2002–2012) (Borelli et al. 2016).*

Figure 11 shows the derived areal demands with MAGNET commodity demands, as well as the distribution key and trends from FAO statistics for France. The top table contains areal commodity demands from MAGNET (in yellow) that are assigned to the iCLUE land use classes through multiplication with the distribution key. ‘Scenario’ areal demands for forest and built-up areas are also found in the column. These are determined by the linear extrapolation of FAO/CLC trends explained above. Three classes (sparse vegetation, ice and snow and water) are assumed to remain constant in the future.

Applying different base data is typical for cross-sectoral model linking applications and results in mismatches through overshoots and undershoots of the total land demand per country and data-artifacts. Rounding differences are dispatched by the ‘forest unmanaged’ class.

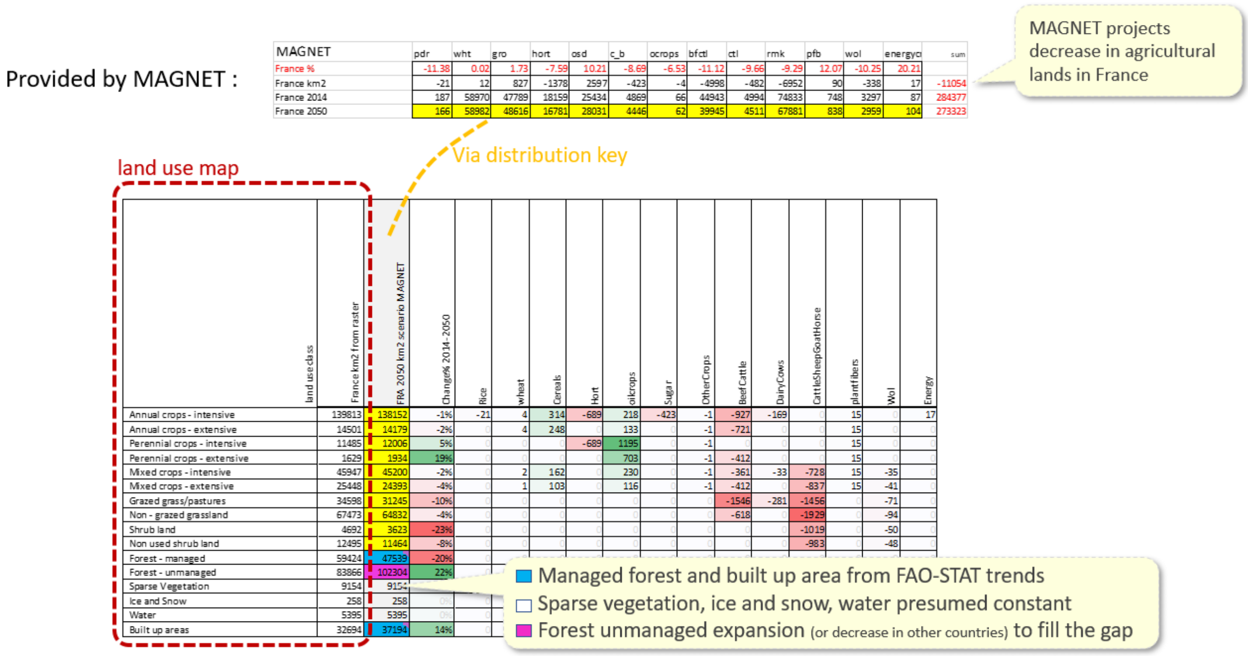


Figure 11 *Determination areal demands with MAGNET commodity demands, the distribution key and trends from FAO/CLC statistics for France. The top table contains areal commodity demands from MAGNET (in yellow) that are assigned to the iCLUE land use classes through multiplication with the distribution key linear extrapolation of FAO trends. The 13 columns on the right display the changes in cells for the commodities.*

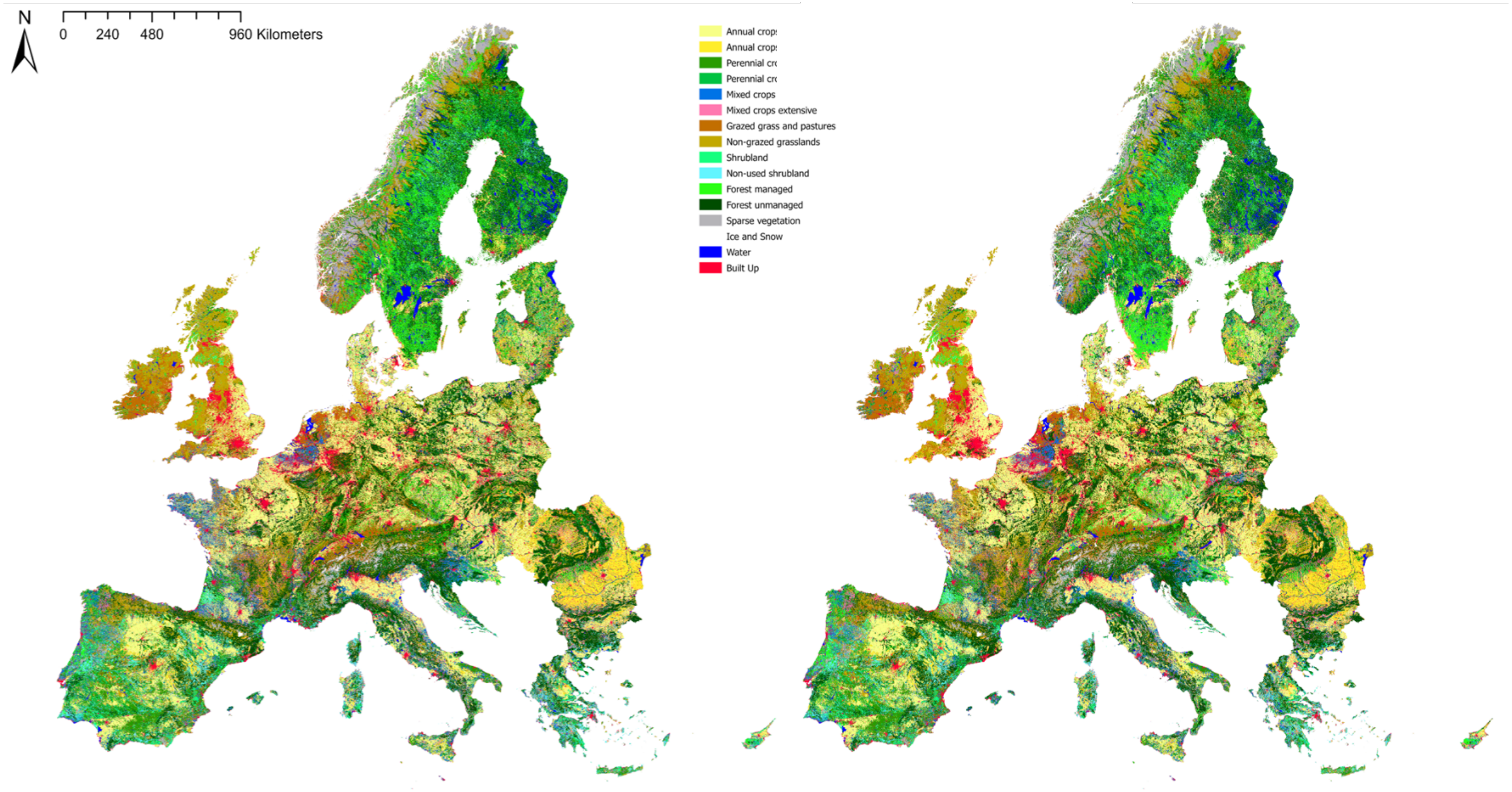


Figure 12 *Land use projections 2050 for 'without borders' Europe and country-Europe. Overall patterns are similar, but differences become apparent in Figure 13.*

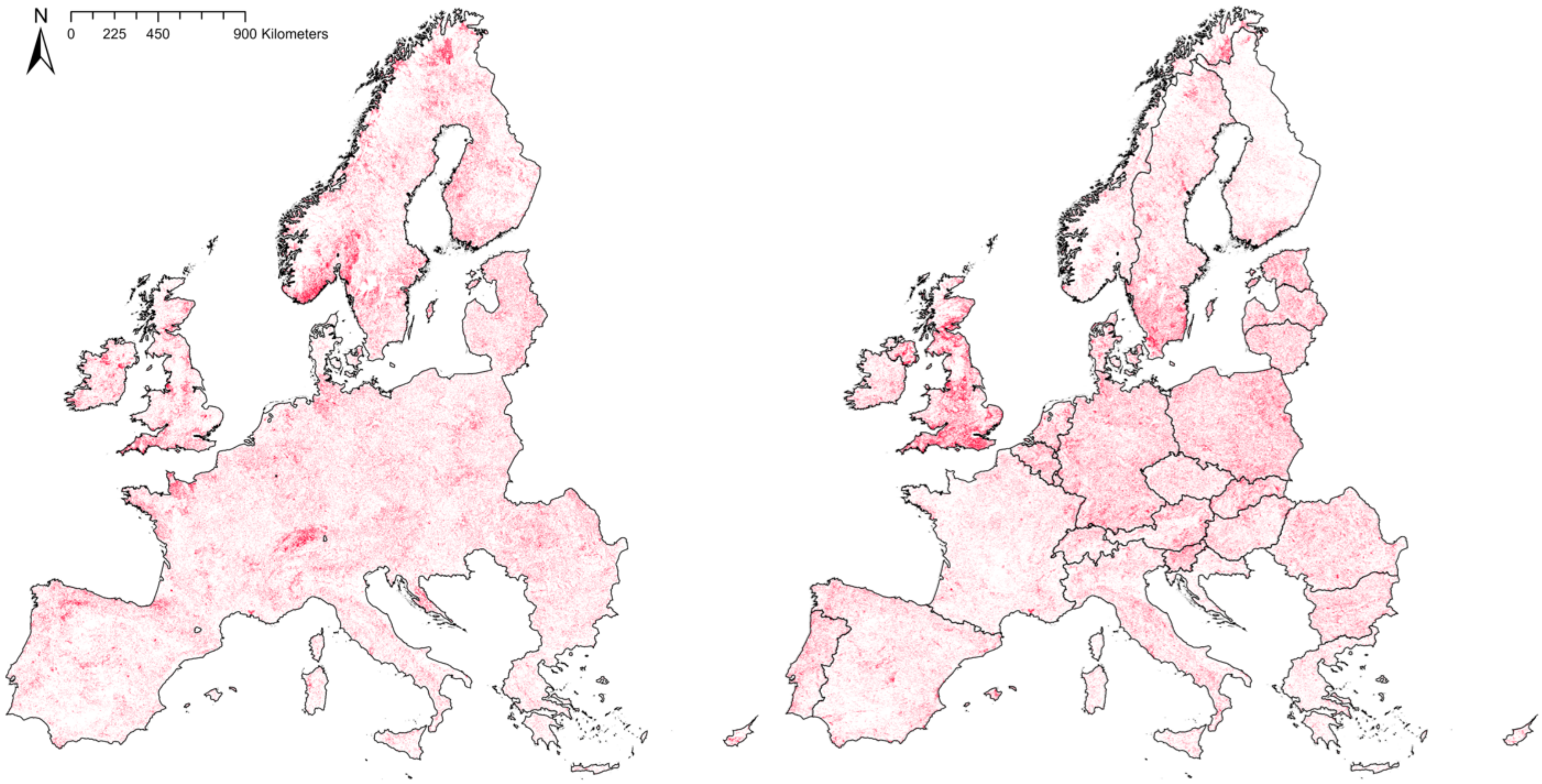


Figure 13 *Differences in 2018 between 'without borders' Europe 2050 (left) and country-Europe 2050: Note the different hotspots of change between both maps, e.g. the deforestation in the south of Norway and the Alps in the left image and a concentration of changes in the UK in the right image. The differences between both maps result from limiting changes within a countries' borders or optimizing land use across Europe given the chosen drivers.*

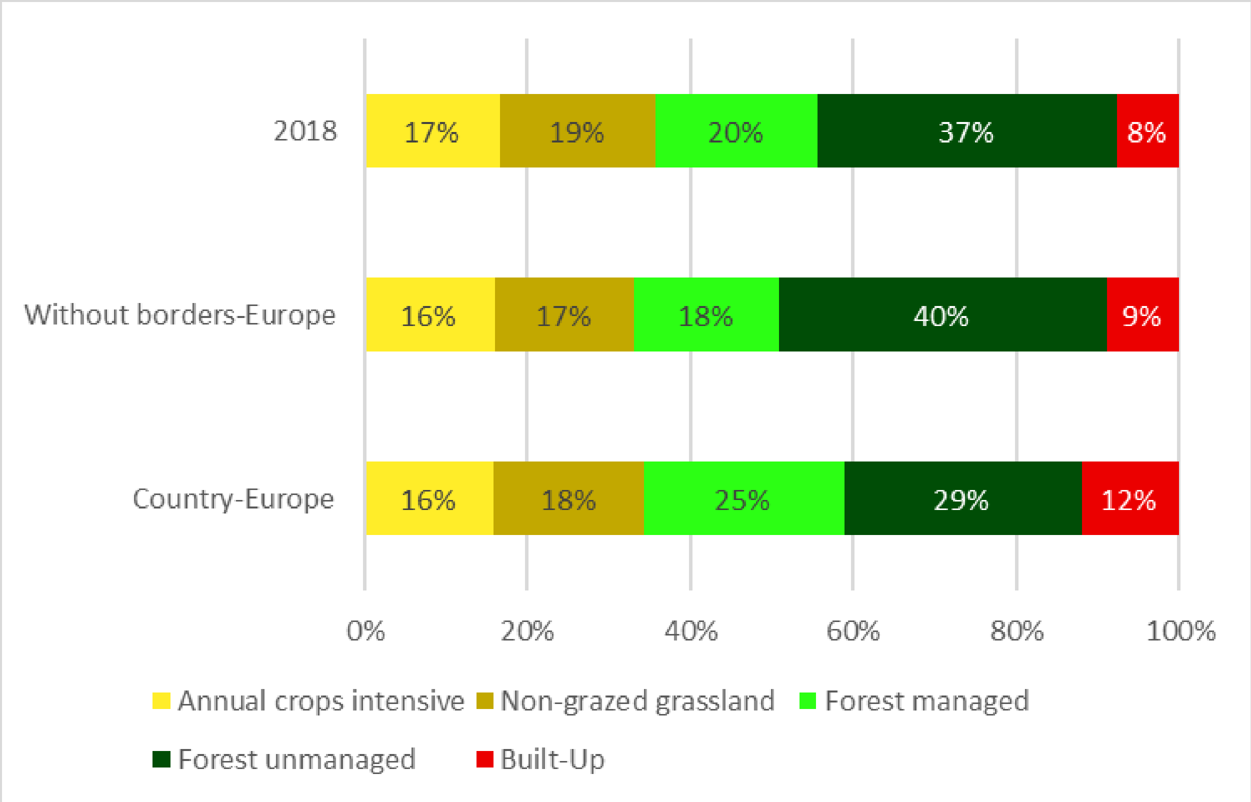


Figure 14 *The land-use distribution of the five largest land use classes in Austria. Austria is used here as an example to illustrate the effects that national policies are projected to have, e.g. Austria is projected to steer towards a growth in managed forests (20% -> 25%) at the cost of unmanaged forests (37% -> 29%), while if Europe were to share land resources, Austria is projected to decrease managed forest and agriculture with a growth in unmanaged forest (37% -> 40%).*

4.3 Integration with Food Safety Model

After connecting iCLUE to the MAGNET model, a connection between iCLUE and the model of Wageningen Food Safety Research (WFSR) was established through soft-linking. In soft-linking isolated models are linked through data file exchange and involves manual edits to the data produced by a model, to be conceptually, methodologically and technically useable as input by another model. The two models were connected to project future wheat and maize cultivation suitability in Europe, based on projected landuse and mycotoxin level change. Climate change is expected to improve growing conditions for mycotoxin producing organisms, which would limit the zones for growing wheat and maize and form a risk for the (European) circular bioeconomy. The starting point for the connection was the Europe 2020 land use map, ‘Without borders’-Europe 2050 and ‘Country’-Europe 2050.

The land use maps do not distinguish between intensively grown crops maize and wheat. Maize and wheat (and other crops) are grouped with the land use types ‘*annual crops - intensive*’ and ‘*mixed crops - intensive*’. To locate areas in which wheat or maize are projected to be grown, the crop projections are overlaid with crop-specific suitability masks (Figure 15).

Initially, the suitability maps for rain-fed winter wheat and rain-fed temperate maize cultivation for 2020 and 2050 were derived from GAEZv3.0 and FAO[10].The suitability maps are based on the climate scenario B1 HADCM3, RCP 4.5[11]. To illustrate these suitability maps, the rain-fed wheat suitability map 2020 and 2050 can be found in Figure 10. The higher the Suitability Index (SI), the higher the suitability of wheat in that area. Although wheat can be very suitable in an area, it does not have to be cultivated at that location. For

[10] IIASA and FAO, https://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/
[11] Copernicus, https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip5-monthly-single-levels?tab=form

both timestamps (historical and future projection), the suitability for wheat is mostly low in southern Europe, whereas eastern Europe contains highly suitable wheat areas.

In the Quickscan environment[12], the present and projected crop suitability was determined through suitable area comparison of 2018 with 2050 (see Figure 17). In addition to the creation of the suitability comparison, the location of cropland in 2018 and 2050 was identified through the overlaying of the land-use map of 2018 with 2050 (see Figure 18). The pie-chart illustrates for 'without borders'-Europe that the majority of cropland in 2018 remains cropland in the projected future. 3% of current cropland disappears between 2018 and 2050, while 2% of newly made cropland will occur by 2050.

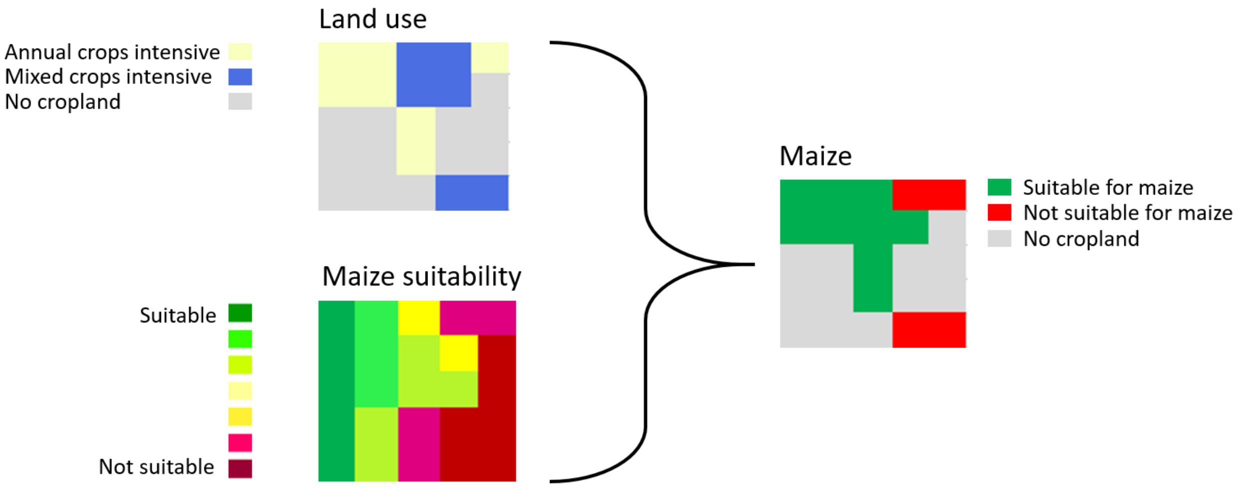


Figure 15 *Schematic representation of identifying projected maize-growing areas by overlaying the projected land use map with the maize suitability map.*

In the end, the combined suitability map and the combined cropland map were put together (see Figure 19, Figure 20, Figure 21 and Figure 22). In general, maize is less suitable throughout Europe than wheat. Although climate change results in some loss of maize suitable areas in France and northern Italy, new suitable areas are projected to occur in Denmark, southern Spain and southern United Kingdom. In most cropland areas wheat is suitable for cultivation in both 2018 and 2050. Mainly in Italy, Spain and small parts of France cropland is not suitable for wheat cultivation at all.

[12] Quickscan, https://www.quickscan.pro/

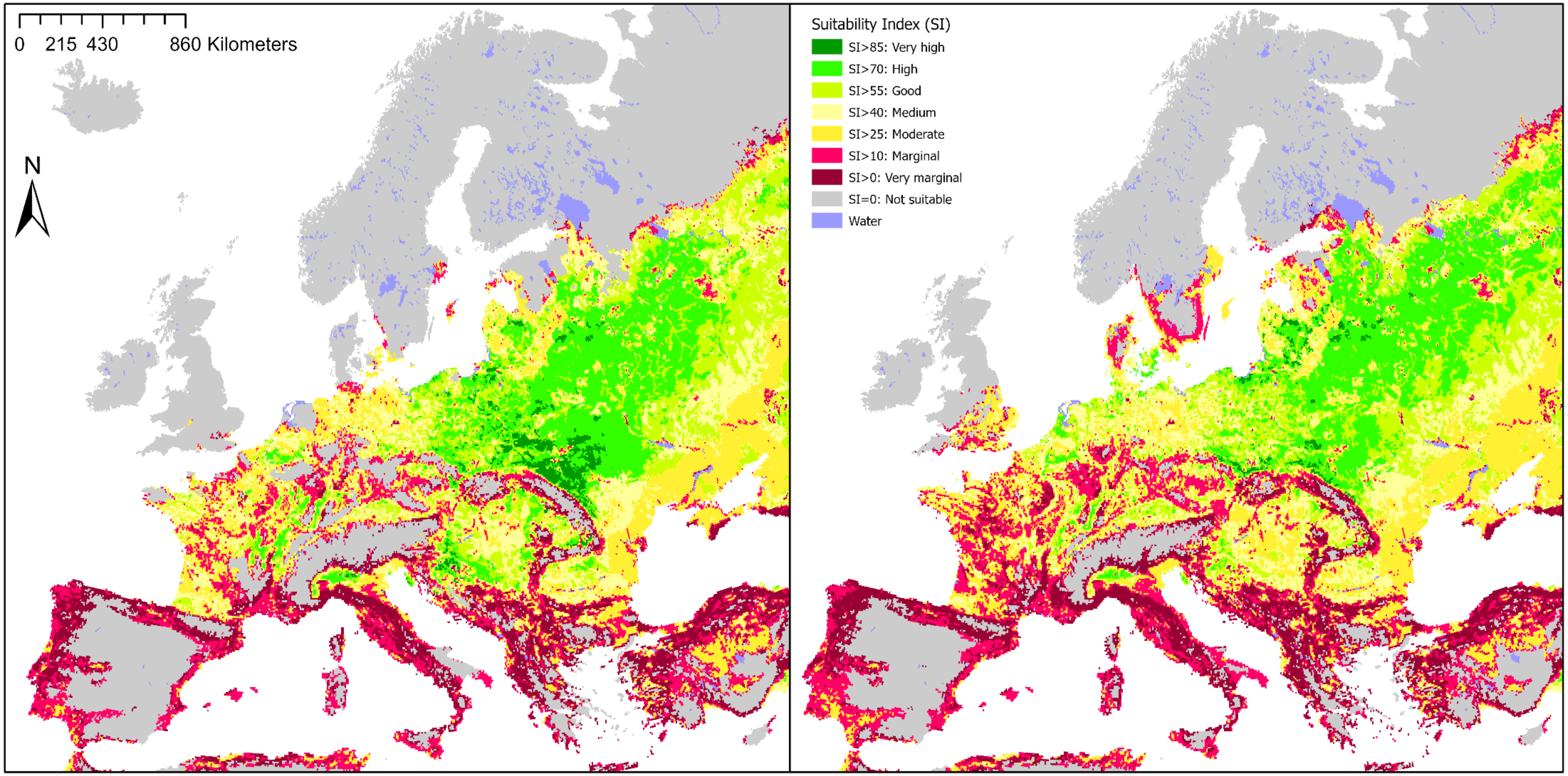


Figure 16 *Suitability map for rain fed winter wheat 2018 (left) and 2050 based on GAEZv3.*

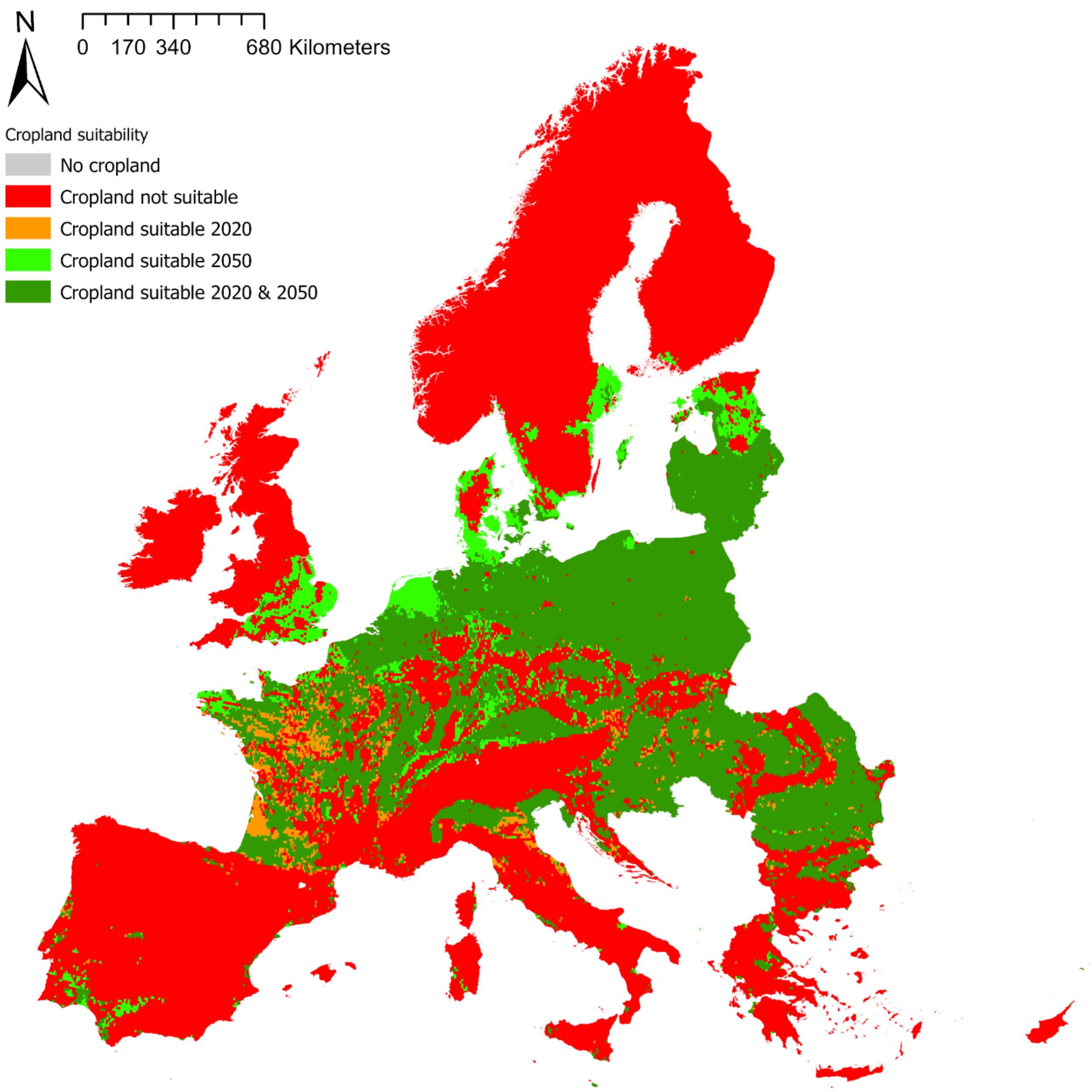


Figure 17 *Suitability rain-fed temperate maize taken from GAEZ v3.*

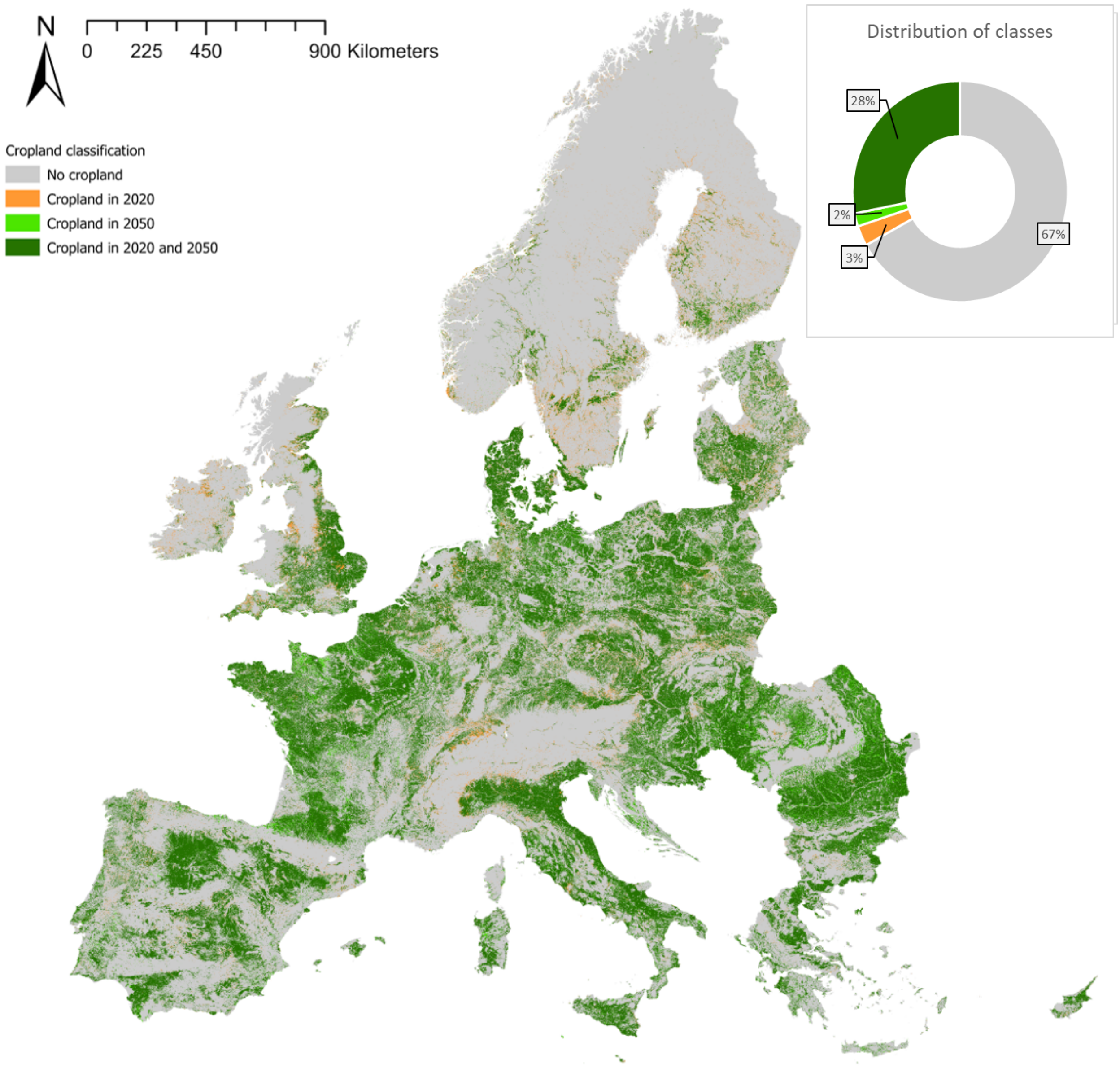


Figure 18 *'Without borders' Europe cropland in 2020 and 2050.*

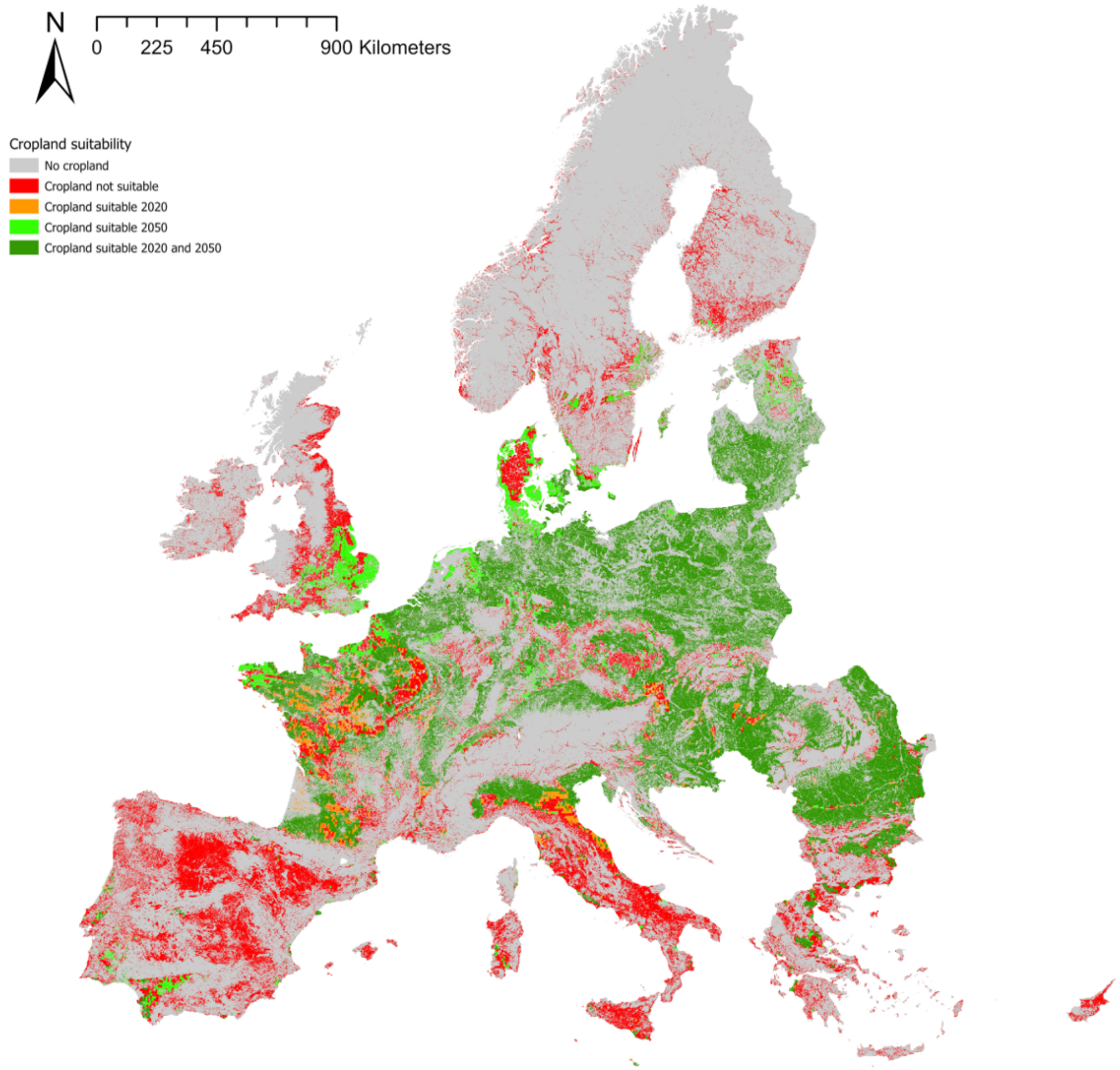


Figure 19 *'Without borders' Europe maize suitable.*

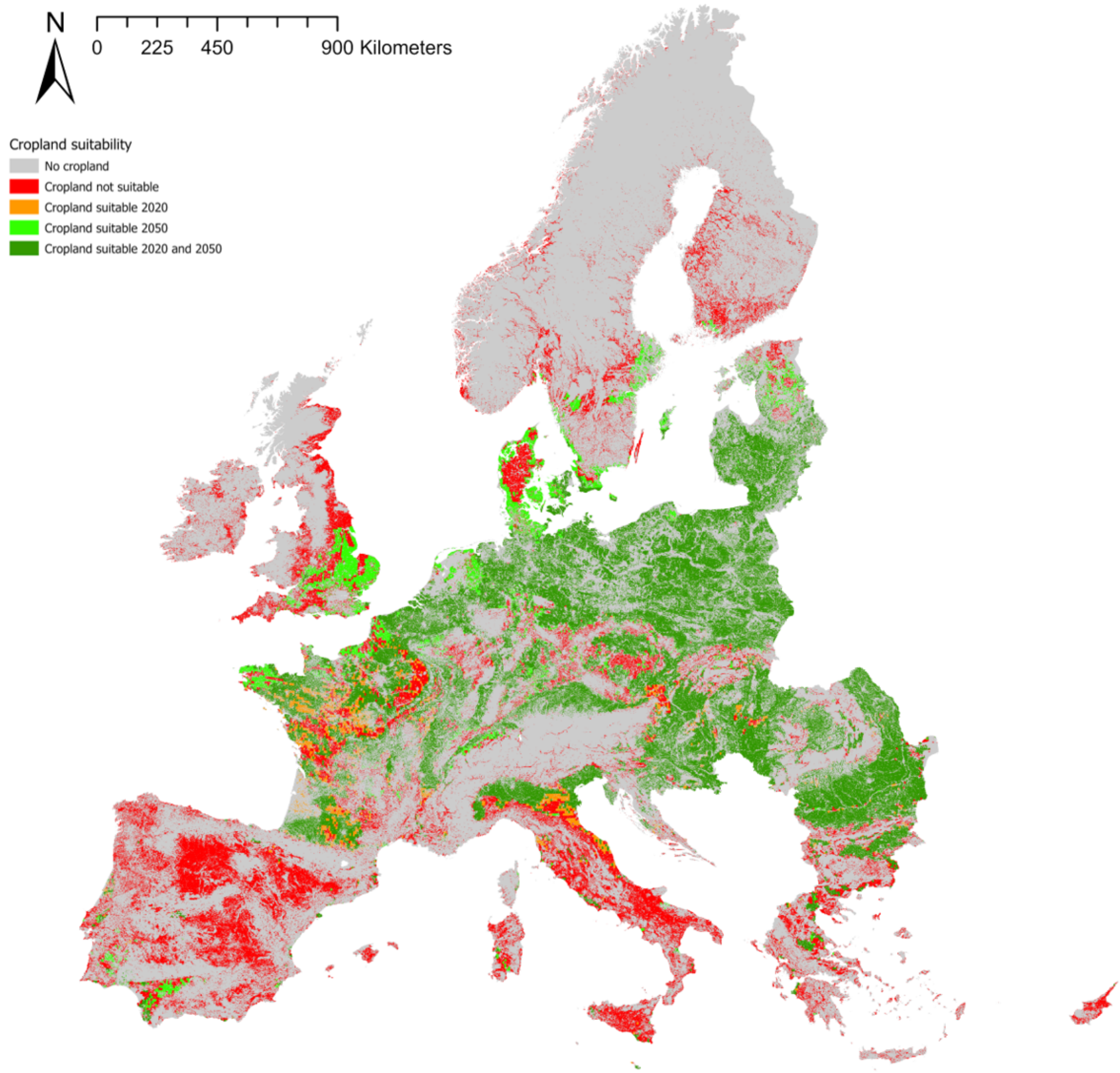


Figure 20 *Country Europe maize suitability.*

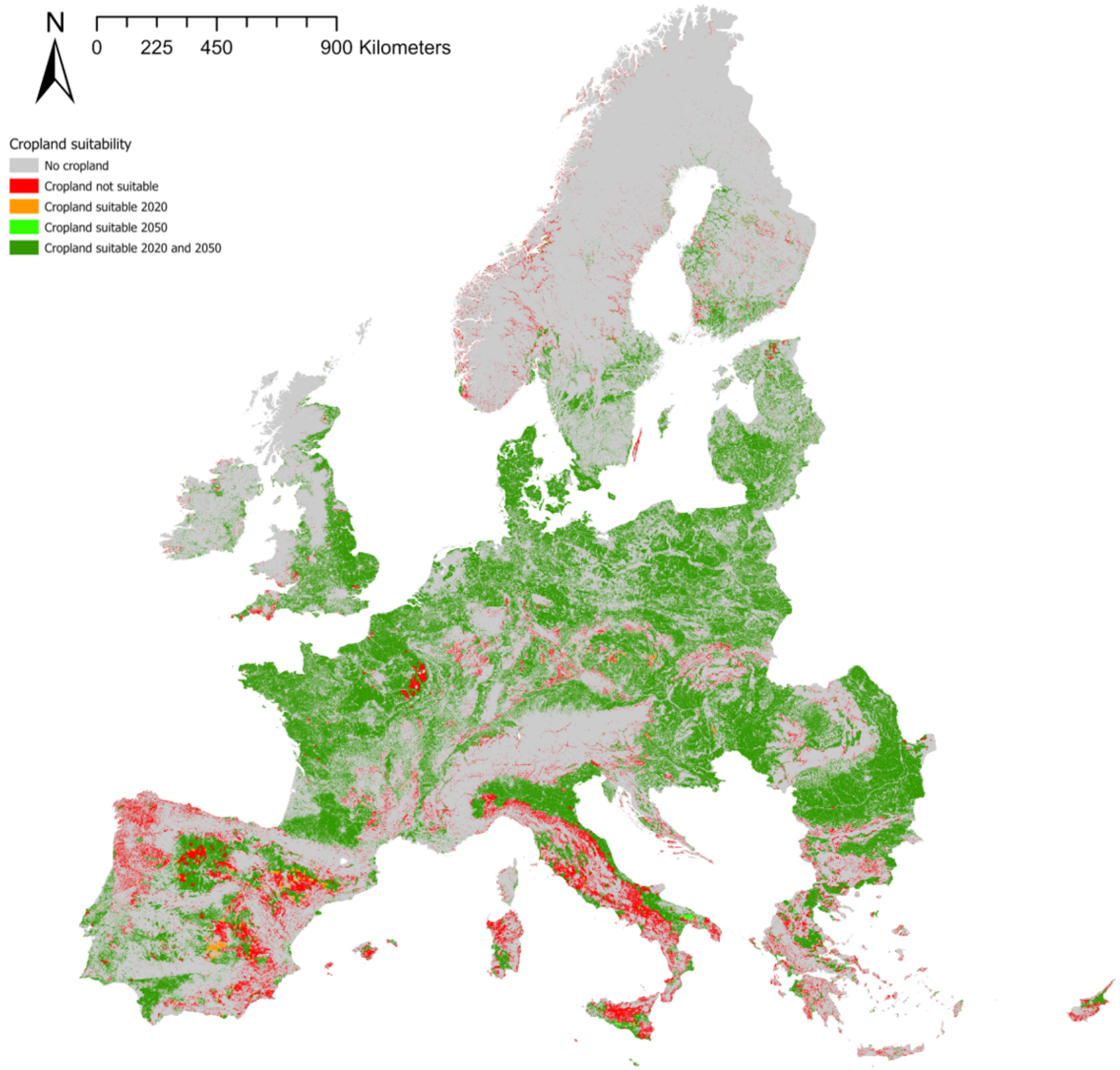


Figure 21 *'Without borders' Europe wheat suitability.*

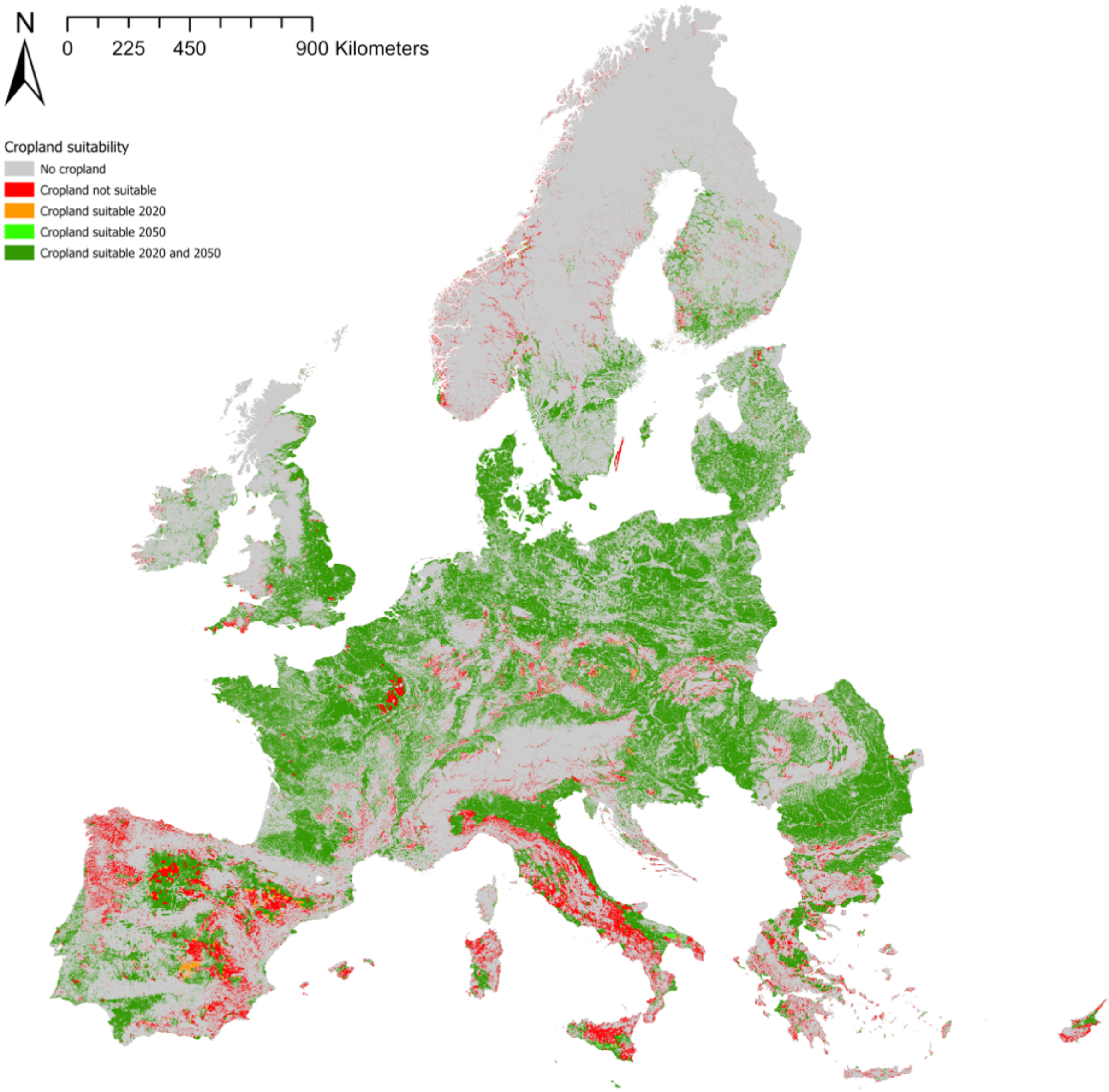


Figure 22 *Country Europe wheat suitability.*

To finalize the connection between iCLUE and the WFSR model, the suitability maps were transformed from 1 x 1 km to 25 x 25 km. The transformation was done through multiple steps. To start, the suitability maps were reclassified to generate for both crops and projections a 2020 and 2050 crop suitability map. Thereafter, these eight developed maps were used as input, together with the MARS-grid to compute zonal statistics tables. The zonal statistics tables showed on a 25 x 25 km scale the percentage of crop suitability in either 2020 or 2050. An example of the resulting wheat suitability map for 2020 without borders can be seen in Figure 23. If the crop suitability of a cell is zero, no cropland occurred in that cell. The zonal statistics tables were shared with WFSR, the tables were used as input for their model on changing mycotoxin levels in wheat and maize.

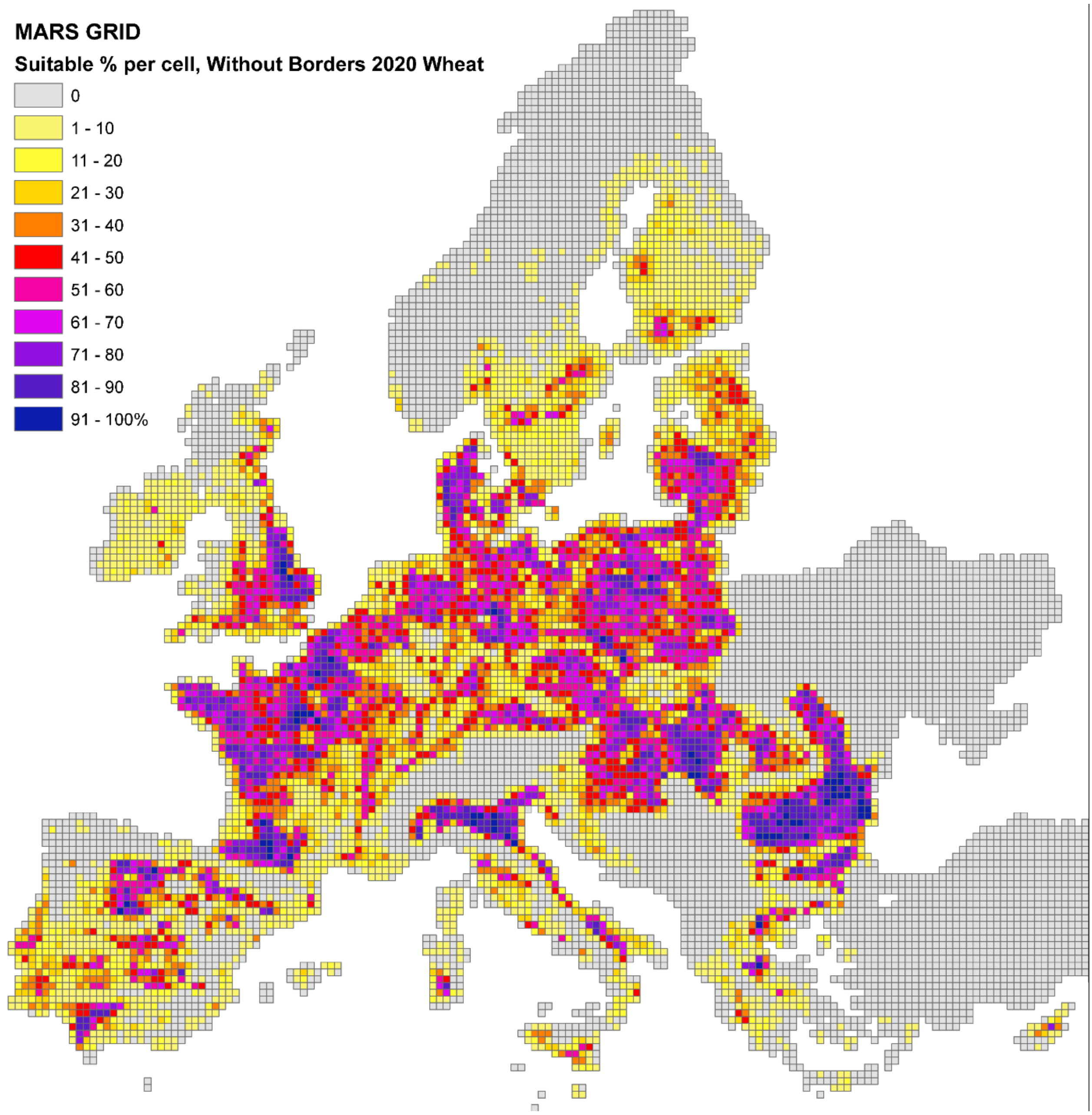


Figure 23 *Wheat suitability 'without borders'-Europe in 2020.*

References

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., Giardino, A., 2017, Collaborative modelling or participatory modelling? A framework for water resources management, Environmental Modelling & Software, 91, pp. 95-110

Borrelli, P., P. Panagos, J. Langhammer, B. Apostol, B. Schütt, Assessment of the cover changes and the soil loss potential in European forestland: First approach to derive indicators to capture the ecological impacts on soil-related forest ecosystems, Ecological Indicators,Volume 60, 2016, Pages 1208-1220, https://doi.org/10.1016/j.ecolind.2015.08.053.

Burkhard, B., Kandziora, M., Hou, Y., & Müller, F. (2014). Ecosystem Service Potentials, Flows and Demands-Concepts for Spatial Localisation, Indication and Quantification. Landscape online, 34.

Capano, G., Woo, J., 2018, designing policy robustness: outputs and processes, policy and society, 37(4), pp. 422-440

Carus, M., & Dammer, L. (2018). The Circular Bioeconomy—Concepts, Opportunities, and Limitations. Industrial Biotechnology, 14(2), 83–91. https://doi.org/10.1089/ind.2018.29121.mca

Conijn, J.G., P.S. Bindraban, J.J. Schröder, R.E.E. Jongschaap, 2018, Can our global food system meet food demand within planetary boundaries? Agriculture, Ecosystems and Environment 251, p.244-256

Doelman, J. C., Stehfest, E., Tabeau, A., van Meijl, H., Lassaletta, L., Gernaat, D. E., Hermans, K., Harmsen, M., Daioglou, V., Biemans, H., van der Sluis, S., & van Vuuren, D. P., 2018, Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation. Global Environmental Change, 48, pp. 119–135

Jetter, A. Kok, K., 2014, Fuzzy Cognitive Maps for future studies -- a methodological assessment of concepts and methods, Futures, 61, pp. 45-57

Kapsalis, V. C., Kyriakopoulos, G. L., & Aravossis, K. G. (2019). Investigation of Ecosystem Services and Circular Economy Interactions under an Inter-organizational Framework. Energies, 12(9), 1734

Kok, K., Farrow, A., Veldkamp, A., & Verburg, P. H. (2001). A method and application of multi-scale validation in spatial land use models. Agriculture, Ecosystems and Environment, 85(1–3), 223–238.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: the concept and its limitations. Ecological economics, 143, 37-46

Lane, D., 2008, The emergence and use of diagramming in system dynamics: a critical account Systems Research & Behavioural Science, 25 (1), pp. 3-23

Liu, C., van der Fels-Klerx, 2021, Quantitative modelling of climate change impacts on mycotoxins in cereal grains: a review, Toxins, 13, 276

Martins, N. O. (2016). Ecosystems, strong sustainability and the classical circular economy. Ecological economics, 129, 32-39

Macleod, M., Vellinga, T., Opion, C., Falcucci, A., Tempio, G., Henderson, B., Makkar, H., Mottet, A., Robinson, T., Steinfeld, H., Gerber, P., 2018, Invited review: A position on the Global Livestock Environmental Assessment Model (GLEAM), Animal, 12, pp. 383-397

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. In Nature (Vol. 463, Issue 7282, pp. 747–756). Nature Publishing Group.

Nabuurs, G. J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M., & Ollikainen, M. (2017). By 2050 the mitigation effects of EU forests could nearly double through climate smart forestry. Forests, 8(12), 484.

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42, 169–180.

Ramirez, R., Mukherjee, M., Vezzoli, S., Matus Kramer, A., 2015, sccenarios as a scholarly methodology to produce "interesting research", Futures, 71, pp. 70-87

Rega, C., Short, C., Pérez-Soba, M., & Luisa Paracchini, M. (2018). A classification of European agricultural land using an energy-based intensity indicator and detailed crop description. Landscape and Urban Planning, 198(March).

Rutter, S., Vos, C., van Eupen, M., Ruhmkorf, H., 2014, Transboundary ecological networks as an adaptation strategy to climate change: The example of the Dutch – German border, Basic and applied ecology, 15*8), pp. 639-650

Smeets, E., Weterings, R., Environmental indicators: typology and overview, 1999, EEA technical report no.25

Van der Wal, M., de Kraker, J., Kroeze, C., Kirschner, P., Valkering, P., 2016, Can computer models be used for social learning? A serious game in water management, Environmental modelling & software, 75, pp. 119-132

Veldkamp, A., & Fresco, L. O. (1996). CLUE: A conceptual model to study the conversion of land use and its effects. Ecological Modelling, 85(2–3), 253–270.

Verburg, P. H., & Overmars, K. P. (2009). Combining top-down and bottom-up dynamics in land use modeling: Exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecology, 24(9), 1167–1181.

Verburg, P. H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., & Mastura, S. S. (2002). Modeling the Spatial Dynamics of Regional Land Use: The CLUE-S Model. Environmental Management, 30(3), 391–405.

Verweij, P., Cormont, A., Kok, K., van Eupen, M., Janssen, S., te Roller, J., de Winter, W., Pérez-Soba, M., & Staritsky, I. G. (2018). Improving the applicability and transparency of land use change modelling: The iCLUE model. Environmental Modelling and Software, 108(7), 81–90.

Verweij, P., 2021, Collaboration tools for land use policy development, chapter 6 synthesis and recommendations, PhD thesis, Wageningen University, The Netherlands

Voinov, A., Jenni, K., Gray, S., Kolongani, N., Glynn, P., Bommel, P., Prell, C., Zellner, M., Paolliso, M., Jordan, R., Sterling, E., Schmitt Olabisi, L., Giabbanelli, P., Sun, Z., Le Page, C., Elsawah, S., BenDor, T., Hubacek, K., Laursen, N., Jetter, A., Basco-Carrera, L., Singer, A., Young, L., Brunacini, J., Smajgl, A., 2018, Tools and methods in participatory modeling: Selecting the right tool for the job, Environmental Modelling & Software, 109, pp. 232-255

Wojtach, A. (2016). Ecosystem services in the circular economy, EKONOMIA I ŚRODOWISKO, 4 (59)
http://ekonomiaisrodowisko.pl/uploads/eiś%2059/08_wojtach.pdf

Annex 1 Drivers used in iCLUE modelling

Variable used	Title	Unit	Reference basic data used	Link
ACC_Cities_2015	Travel time to major cities	minutes	Nelson, A. (2008). *Travel time to major cities: A global map of Accessibility.* Office for Official Publications of the European Communities.	http://bioval.jrc.ec.europa.eu/products/gam/download.htm
bio_12	Annual Precipitation	millimetres	Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25(15), 1965–1978.	
bio_7	Temperature Annual Range	°C		
cattle_etrs	Cattle density	nr/km2	Food and Arigculture Organization of the United Nations. (2007). *Gridded Livestock of the World 2007*. http://www.fao.org/docrep/010/a1259e/a1259e00.HTM	http://www.fao.org/docrep/010/a1259e/a1259e00.HTM
Distance_distcities	Distance to cities	meters	ESRI 2012 World Administrative Divisions; first-level administrative divisions of the world. Redlands, California, USA	http://www.esri.com/
Distance_distcoast	Distance to coasts	meters		
Distance_distrivers	Distance to rivers	meters		
Distance_distroads	Distance to roads	meters		
Distance_distwpda	Distance to protected areas	meters	UNEP, & IUCN. (n.d.). World Database on Protected Areas (WDPA).	https://www.protectedplanet.net/en
dtm_1km	Elevation	meters	EUdem 25m resampled	
dtm_1km_slope_perc_mean	Slope	%		
ECEARTH_CCLM_drought_index2018	Drought index	Index	EC-EARTH-CCLM	
ECEARTH_CCLM_length_growing_season_2018	Length of growing season	Days		
ESAWATER_&_JRC_Lisflood_2025_2Yrs_Return_ND	Water depth 2 years return period for 2025	meters	European Commission. (2020, April). *LISFLOOD - a distributed hydrological rainfall-runoff model.* https://ec-jrc.github.io/lisflood-model/	https://ec-jrc.github.io/lisflood-model/
FARO_acc	Access to services	Minutes	van Eupen, M., Metzger, M., Pérez-Soba, M., Verburg, P., van Doorn, A., & Bunce, R. (2012). A rural typology for strategic European policies. *Land Use Policy*, *29*(3), 473–482. https://doi.org/10.1016/j.landusepol.2011.07.007	
GlobalEquilibriumWaterTableDepth_m_Fan_MiguezMacho_2013_100x100m	Ground water depth	Meters	Fan, Y., Li, H., & Miguez-Macho, G. (2013). Global Patterns of Groundwater Table Depth. *Science*, *339*(6122), 940–943. https://doi.org/10.1126/science.1229881	

Variable used	Title	Unit	Reference basic data used	Link
goat_etrs	Goat density (one of the proxies for extensive farming)	nr/km2	Arigculture and Consumer Protection Department. (2012). *Global Livestock Production and Health Atlas (GLiPHA)* [Dataset]. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/againfo/home/en/news_archive/AGA_in_action/glipha.html	http://www.fao.org/ag/againfo/home/en/news_archive/AGA_in_action/glipha.html
GPW_2018	Gridded Population of the World (GPW), v4	People/km2	Center for International Earth Science Information Network. (2016). *Gridded Population of the World, Version 4* (GPWv4) (Version 4) [Dataset]. Columbia University. https://doi.org/10.7927/H4F47M2C	https://sedac.ciesin.columbia.edu/data/collection/gpw-v4
LandscapeMosaicPercNatural_km2	Percentage natural land use Corilis (focal CLC) layers EEA	% natural land use	European Environmental Agency. (2008). *Green potential background* [Dataset]. European Environmental Agency. https://www.eea.europa.eu/data-and-maps/data/green-potential-background-1	https://www.eea.europa.eu/data-and-maps/data/green-potential-background-1
MarginalImproved_2019_Perc_EU2	Marginal agricultural areas Europe MAGIC project	% marginality	Elbersen, B. S., van Eupen, M., Boogaard, H. L., Mantel, S., Verzandvoort, S. J. E., Mücher, C. A., Ceccarelli, T., Elbersen, H. W., Bai, Z., Iqbal, Y., Cossel, M., MCallum, I., Carrasco, J., Ramos, C., Monti, C. D., Scordia, D., & Eleftheriadis, I. (2018, July). *Deliverable 2.6 Methodological approaches to identify and map marginal land suitable for industrial crops in Europe.* https://doi.org/10.5281/zenodo.3539311	
NDEP_LAEA_1km	Dry deposition of oxidized nitrogen per m2 grid - DDEP_OXN_m2Grid	nitrogen per m2	The Norwegian Meteorological Institute. (2018). *EMEP MSC-W modelled air concentrations and depositions* [Dataset]. The Norwegian Meteorological Institute. https://www.emep.int/mscw/mscw_moddata.html	https://www.emep.int/mscw/mscw_moddata.html
Soilgrids_ACDWRB_M_ss_250m_ll	Grade of sub-soil being acid	grade		
Soilgrids_AWCh2_M_sl1_250m_ll	Available soil water capacity (volumetric fraction) with FC = pF 2.3	percentage		
Soilgrids_AWCtS_M_sl1_250m_ll	Saturated water content for soil	percentage	ISRIC. (n.d.). *Soilgrids database*. ISRIC.	http://soilgrids.org/index.html
Soilgrids_BDRICM_M_250m_ll	Absolute depth to bedrock	centimetres		
Soilgrids_BDRLOG_M_250m_ll	Probability of occurrence of R horizon in soil	percentage		
Soilgrids_BDTICM_M_250m_ll	Absolute depth to bedrock	centimetres		
Soilgrids_BLDFIE_M_sl1_250m_ll	Bulk density of fine earth	kg/m3		

Variable used	Title	Unit	Reference basic data used	Link
Soilgrids_CECSOL_M_sl1_250m_ll	Cation Exchange Capacity of soil	cmolc/kg		
Soilgrids_CLYPPT_M_sl1_250m_ll	Weight percentage of the clay particles (<0.0002 mm)	percentage		
Soilgrids_CRFVOL_M_sl1_250m_ll	Volumetric percentage of coarse fragments (>2 mm)	percentage		
Soilgrids_HISTPR_250m_ll	Histosols probability cumulative	percentage		
Soilgrids_OCDENS_M_sl1_250m_ll	Soil organic carbon density in kg per cubic-m	kg/m3		
Soilgrids_OCSTHA_M_30cm_250m_ll	Soil organic carbon stock in tons per ha	ton/ha		
Soilgrids_ORCDRC_M_sl1_250m_ll	Soil organic carbon content (fine earth fraction) in g per kg	permille		
Soilgrids_PHIHOX_M_sl1_250m_ll	Soil pH x 10 in H2O	pH		
Soilgrids_SNDPPT_M_sl1_250m_ll	Sand content (50-2000 micro meter) mass fraction in %	percentage		
Soilgrids_TAXNWRB_250m_ll	World Reference Base legend	-		
Soilgrids_TAXOUSDA_250m_ll	Keys to Soil Taxonomy suborders	-		
Soilgrids_WWP_M_sl1_250m_ll	Available soil water capacity (volumetric fraction) until wilting point	percentage		

Annex 2 iCLUE parameter file

property file uses key=value notation. The symbol '=' cannot be used for other purposes
key cannot contain any white spaces. Use camel casing instead
key uses namespace notation (a '.' between key-parts) to denote a hierarchical relation
a value can contain white spaces
in value the symbol ',' is used to separate list elements. It can therefore not be used for other purposes

# Baseline landuse map and year that the map represents
Baseline.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\Europe_KBNEW2018i.tif
Baseline.year=2018

Landuse classes
code in map file, colour code in hex rgb, ease of change, initial age in years, demand deviation type, demand deviation amount
colour examples: (red ff0000), (green 00ff00), (blue 0000ff), (yellow ffff00), (white ffffff), (black 000000), (grey aaaaaa), (orange ffaa00), (purple aa00ff)
see also: http://www.color-hex.com/color-names.html
ease of change: {'Very easy', 'Easy', 'Hard', 'Very hard', 'Cannot change'}
demand deviation type: {'AbsoluteDeviation' [cell count], 'PercentageDeviation' [0..100]}.
Example 1: LanduseClass.Forest=10001,38a800,Hard,100,AbsoluteDeviation,2047
Example 2: LanduseClass.Urban=10002,38a800,Very easy,22,PercentageDeviation,15

LanduseClass.AnnualCrops_int=10,ffff66,Very easy,0,PercentageDeviation,3
LanduseClass.AnnualCrops_ext=11,ffffb3,Very easy,0,PercentageDeviation,3
LanduseClass.PerrenialCrops_int=20,ff99dd,Easy,5,PercentageDeviation,3
LanduseClass.PerrenialCrops_ext=21,ffe7f7,Hard,5,PercentageDeviation,3
LanduseClass.MixedCrops_int=30,ff9d26,Very easy,3,PercentageDeviation,3
LanduseClass.MixedCrops_ext=31,ffd326,Very easy,3,PercentageDeviation,3
LanduseClass.GrazedGrasslandAndPastures=40,26ffd3,Very easy,0,PercentageDeviation,3
LanduseClass.NonGrazedGrassland=41,afffef,Very easy,15,PercentageDeviation,3
LanduseClass.Shrubland=50,c1cd9f,Easy,15,PercentageDeviation,3
LanduseClass.UnusedShrubland=51,67773d,Easy,30,PercentageDeviation,3
LanduseClass.ForestManaged=60,00cc00,Very easy,100,PercentageDeviation,3
LanduseClass.ForestUnmanaged=61,002e00,Very easy,100,PercentageDeviation,3
LanduseClass.SparseVegetation=70,ab9fcd,Cannot change,0,PercentageDeviation,20
LanduseClass.IceAndSnow=80,ab9fcd,Cannot change,0,PercentageDeviation,20
LanduseClass.Water=81,0000ff,Cannot change,50,AbsoluteDeviation,0
LanduseClass.BuiltUp=90,ff0000,Very easy,100,PercentageDeviation,10

Administrative units map and list of unit name and unit code
Example: AdministrativeUnits.filename=D:\\clue\\Europe\\masker
Example: AdministrativeUnit.Netherlands=1
Example: AdministrativeUnit.Belgium=2

AdministrativeUnits.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_Countries2.tif
#AdministrativeUnits.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_Mask_01.tif

AdministrativeUnit.EuropeTotal=1

```
# AdministrativeUnit.Austria=2
# AdministrativeUnit.Belgium=4
# AdministrativeUnit.Bulgaria=5
# AdministrativeUnit.Croatia=16
# AdministrativeUnit.Cyprus=7
# AdministrativeUnit.CzechRepublic=8
# AdministrativeUnit.Denmark=10
# AdministrativeUnit.Estonia=11
# AdministrativeUnit.Finland=13
# AdministrativeUnit.France=14
# AdministrativeUnit.Germany=9
# AdministrativeUnit.Greece=15
# AdministrativeUnit.Hungary=17
# AdministrativeUnit.Ireland=18
# AdministrativeUnit.Italy=20
# AdministrativeUnit.Latvia=25
# AdministrativeUnit.Lithuania=23
# AdministrativeUnit.Luxembourg=24
# AdministrativeUnit.Malta=28
# AdministrativeUnit.Netherlands=29
# AdministrativeUnit.Norway=30
# AdministrativeUnit.Poland=31
# AdministrativeUnit.Portugal=32
# AdministrativeUnit.Romania=33
# AdministrativeUnit.Slovakia=37
# AdministrativeUnit.Slovenia=36
# AdministrativeUnit.Spain=12
# AdministrativeUnit.Sweden=35
# AdministrativeUnit.Switzerland=6
# AdministrativeUnit.UnitedKingdom=39

# Demands
# line with sequence of landuse classes
# line with same sequence of landuse demands per year
# Example: LanduseDemands.sequence=Forest,Urban
# Example: LanduseDemand.Netherlands.2050=530787,132460
# Example: LanduseDemand.Belgium.2050=400,100

LanduseDemands.sequence=AnnualCrops_int,AnnualCrops_ext,PerrenialCrops_int,PerrenialCrops_ext,
MixedCrops_int,MixedCrops_ext,GrazedGrasslandAndPastures,NonGrazedGrassland,Shrubland,UnusedShrubl
and,ForestManaged,ForestUnmanaged,SparseVegetation,IceAndSnow,Water,BuiltUp
LanduseDemand.EuropeTotal.2050=849061,234018,109432,36351,206230,135235,270380,442330,
114460,162547,475270,1089761,171971,5073,132399,300402

#LanduseDemand.Austria.2050=10455,2329,513,93,2745,2910,2930,12158,0,357,16019,18796,5567,333,
722,8011
#LanduseDemand.Belgium.2050=5814,370,0,8,6025,877,2994,556,41,45,769,3098,12,0,230,9822
#LanduseDemand.Bulgaria.2050=16310,21397,633,463,2159,10361,442,7372,579,6638,768,36521,542,0,
978,5800
#LanduseDemand.Croatia.2050=5987,28,410,287,12088,595,4507,875,6546,1135,5487,14820,720,0,566,
2465
#LanduseDemand.Cyprus.2050=1739,900,307,109,767,604,119,120,1277,208,1253,382,191,0,41,1227
#LanduseDemand.CzechRepublic.2050=25583,1887,356,65,3215,3489,3134,4728,277,1215,14766,12624,4
,0,632,6908
#LanduseDemand.Denmark.2050=23319,2689,0,0,2682,1076,40,833,377,354,2363,4504,102,0,780,3923
#LanduseDemand.Estonia.2050=3309,3348,0,0,582,3565,555,4706,202,3666,13575,7810,46,0,2088,1937
```

#LanduseDemand.Finland.2050=11780,4998,1,9,6205,4939,20397,8119,15259,12223,62744,150646,1971,0,31888,6653
#LanduseDemand.France.2050=138146,14185,12007,1944,45202,24399,31252,64840,3623,11500,13797,137625,9165,258,5414,35676
#LanduseDemand.Germany.2050=120146,10286,2111,623,0,0,43063,21352,14,425,24434,88400,262,1,4864,41749
#LanduseDemand.Greece.2050=17629,3393,8135,2536,10921,7544,2619,8169,13127,20802,2109,23705,3480,0,1682,6147
#LanduseDemand.Hungary.2050=42278,2223,1400,479,2485,788,2630,6864,2240,1783,2459,17445,35,0,1782,8129
#LanduseDemand.Ireland.2050=2479,58,0,0,2340,2575,30171,19047,1068,713,2659,3735,918,0,1439,2726
#LanduseDemand.Italy.2050=68049,11286,17032,4777,29738,14651,3496,8675,5793,13527,7708,78641,15422,393,3013,18501
#LanduseDemand.Latvia.2050=3986,7109,0,0,1373,5105,693,7004,92,9985,11230,15091,65,0,1358,1484
#LanduseDemand.Lithuania.2050=13012,9017,47,95,4271,5846,436,3703,63,2460,9243,12863,39,0,1313,2481
#LanduseDemand.Luxembourg.2050=444,5,0,8,456,24,378,19,1,1,66,779,0,0,7,401
#LanduseDemand.Malta.2050=0,4,0,0,71,72,0,0,9,41,0,0,5,0,1,100
#LanduseDemand.Netherlands.2050=5743,326,0,0,6084,155,10167,519,0,0,619,3680,111,0,3350,6613
#LanduseDemand.Norway.2050=5271,522,18,8,8738,2419,38657,30079,6327,335,50854,56807,103466,2804,13887,3157
#LanduseDemand.Poland.2050=120071,9263,1626,523,12103,6392,9034,18934,3386,1554,17143,82424,152,0,4818,24511
#LanduseDemand.Portugal.2050=4428,4304,6598,6966,10874,4956,2026,4203,6503,11540,9425,10009,1250,0,1274,4475
#LanduseDemand.Romania.2050=17853,68746,3971,3778,4083,12811,4194,29060,1783,1740,14702,56633,302,0,4077,14659
#LanduseDemand.Slovakia.2050=9804,5839,357,124,691,3308,208,2729,213,1203,4468,15667,116,0,333,3952
#LanduseDemand.Slovenia.2050=921,33,292,28,4112,197,1167,226,415,30,1531,10103,267,0,83,868
#LanduseDemand.Spain.2050=96741,26012,53447,13404,21756,10722,23223,37918,36772,33082,15681,96638,7640,3,4266,21203
#LanduseDemand.Sweden.2050=18214,11187,0,0,2547,4160,3712,58113,7263,23026,151319,111811,11099,260,36859,10067
#LanduseDemand.Switzerland.2050=5909,95,171,24,1733,43,8281,611,1209,84,3128,7587,6068,1021,1430,3906
#LanduseDemand.UnitedKingdom.2050=53677,12179,0,0,184,645,19855,80798,0,2869,14951,10919,2954,0,3224,42851

#Drivers
#Can be ‘Constant’, or ‘Dynamic’ driver. Dynamic drivers change over time
#For every driver:
#line 1: DataType= {‘Qualitative’, ‘Quantitative’}
#line 2: filename=full path
#line 3 etc: class.className=class code in map file, class colour in hex rgb
#the following 4 examples illustrate: 1. qualitative constant driver, 2. quantitative constant driver, 3. qualitative dynamic driver, 4. quantitative dynamic driver
Example 1: ParameterMap.Constant.EcoRegions.DataType=Qualitative
Example 1: ParameterMap.Constant.EcoRegions.filename=D:\\clue\\Mexico\\wwf_ecoregion
Example 1: ParameterMap.Constant.EcoRegions.class.Boreal=204,ffaa5b
Example 1: ParameterMap.Constant.EcoRegions.class.Pannonioal=205,22e4ff
Example 1: ParameterMap.Constant.EcoRegions.class.Tundra=206,ffff00

ParameterMap.Constant.emis_NDEP.DataType=Quantitative

ParameterMap.Constant.emis_NDEP.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_2017met_2016emis_NDEP_LAEA_1km2.tif

ParameterMap.Constant.ACC_Cities_2015.DataType=Quantitative
ParameterMap.Constant.ACC_Cities_2015.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_ACC_Cities_2015.tif

ParameterMap.Constant.bio_12.DataType=Quantitative
ParameterMap.Constant.bio_12.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_bio_12.tif

ParameterMap.Constant.bio_7.DataType=Quantitative
ParameterMap.Constant.bio_7.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_bio_7.tif

ParameterMap.Constant.cattle_etrs.DataType=Quantitative
ParameterMap.Constant.cattle_etrs.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_cattle_etrs.tif

ParameterMap.Constant.dtm_1km.DataType=Quantitative
ParameterMap.Constant.dtm_1km.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_dtm_1km.tif

ParameterMap.Constant.dtm_1km_slope_perc_mean.DataType=Quantitative
ParameterMap.Constant.dtm_1km_slope_perc_mean.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_dtm_1km_slope_perc_mean.tif

ParameterMap.Constant.ECEARTH_CCLM_drought_index2018.DataType=Quantitative
ParameterMap.Constant.ECEARTH_CCLM_drought_index2018.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_ECEARTH_CCLM_drought_index2018.tif

ParameterMap.Constant.ECEARTH_CCLM_length_growing_season_2018.DataType=Quantitative
ParameterMap.Constant.ECEARTH_CCLM_length_growing_season_2018.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_ECEARTH_CCLM_length_growing_season_2018.tif

ParameterMap.Constant.ESAWater_&_JRC_Lisflood_2025_2Yrs_Return_ND.DataType=Quantitative
ParameterMap.Constant.ESAWater_&_JRC_Lisflood_2025_2Yrs_Return_ND.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_ESAWater_&_JRC_Lisflood_2025_2Yrs_Return_ND.tif

ParameterMap.Constant.FARO_acc.DataType=Quantitative
ParameterMap.Constant.FARO_acc.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_FARO_acc.tif

ParameterMap.Constant.GlobalEquilibriumWaterTableDepth_m_Fan_MiguezMacho_2013_100x100m.DataType=Quantitative
ParameterMap.Constant.GlobalEquilibriumWaterTableDepth_m_Fan_MiguezMacho_2013_100x100m.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_GlobalEquilibriumWaterTableDepth_m_Fan_MiguezMacho_2013_100x100m.tif

ParameterMap.Constant.goat_etrs.DataType=Quantitative
ParameterMap.Constant.goat_etrs.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_goat_etrs.tif
ParameterMap.Constant.GPW_2018.DataType=Quantitative

ParameterMap.Constant.GPW_2018.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_GPW_2018.tif

ParameterMap.Constant.LandscapeMosaicPercNatural_km2.DataType=Quantitative
ParameterMap.Constant.LandscapeMosaicPercNatural_km2.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_LandscapeMosaicPercNatural_km2.tif

ParameterMap.Constant.MarginalImproved_2019_Perc_EU2.DataType=Quantitative
ParameterMap.Constant.MarginalImproved_2019_Perc_EU2.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\EU_ETRS_MarginalImproved_2019_Perc_EU2.tif

ParameterMap.Constant.Soilgrids_ACDWRB_M_ss_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_ACDWRB_M_ss_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_ACDWRB_M_ss_250m_ll.tif

ParameterMap.Constant.Soilgrids_AWCh2_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_AWCh2_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_AWCh2_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_AWCtS_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_AWCtS_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_AWCtS_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_BDRICM_M_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_BDRICM_M_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_BDRICM_M_250m_ll.tif

ParameterMap.Constant.Soilgrids_BDRLOG_M_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_BDRLOG_M_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_BDRLOG_M_250m_ll.tif

ParameterMap.Constant.Soilgrids_BDTICM_M_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_BDTICM_M_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_BDTICM_M_250m_ll.tif

ParameterMap.Constant.Soilgrids_BLDFIE_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_BLDFIE_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_BLDFIE_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_CECSOL_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_CECSOL_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_CECSOL_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_CLYPPT_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_CLYPPT_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_CLYPPT_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_CRFVOL_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_CRFVOL_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_CRFVOL_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_HISTPR_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_HISTPR_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_HISTPR_250m_ll.tif
ParameterMap.Constant.Soilgrids_OCDENS_M_sl1_250m_ll.DataType=Quantitative

ParameterMap.Constant.Soilgrids_OCDENS_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_OCDENS_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_OCSTHA_M_30cm_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_OCSTHA_M_30cm_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_OCSTHA_M_30cm_250m_ll.tif

ParameterMap.Constant.Soilgrids_ORCDRC_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_ORCDRC_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_ORCDRC_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_PHIHOX_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_PHIHOX_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_PHIHOX_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_SNDPPT_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_SNDPPT_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_SNDPPT_M_sl1_250m_ll.tif

ParameterMap.Constant.Soilgrids_TAXNWRB_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_TAXNWRB_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_TAXNWRB_250m_ll.tif

ParameterMap.Constant.Soilgrids_TAXOUSDA_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_TAXOUSDA_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_TAXOUSDA_250m_ll.tif

ParameterMap.Constant.Soilgrids_WWP_M_sl1_250m_ll.DataType=Quantitative
ParameterMap.Constant.Soilgrids_WWP_M_sl1_250m_ll.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Soilgrids_WWP_M_sl1_250m_ll.tif

ParameterMap.Constant.Distance_distcities.DataType=Quantitative
ParameterMap.Constant.Distance_distcities.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Distance_distcities.tif

ParameterMap.Constant.Distance_distcoast.DataType=Quantitative
ParameterMap.Constant.Distance_distcoast.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Distance_distcoast.tif

ParameterMap.Constant.Distance_distrivers.DataType=Quantitative
ParameterMap.Constant.Distance_distrivers.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Distance_distrivers.tif

ParameterMap.Constant.Distance_distroads.DataType=Quantitative
ParameterMap.Constant.Distance_distroads.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Distance_distroads.tif

ParameterMap.Constant.Distance_distwpda.DataType=Quantitative
ParameterMap.Constant.Distance_distwpda.filename=E:\\QUICKScanCloud\\QUICKScan2018\\KB_QS_iCLUE_Global\\EU_dataMartin\\EU_Tifs_iClueKB2\\Distance_distwpda.tif

Suitability calculation
line 1: Method={StepwiseRegression, FunctionDictionary} TODO: Is FunctionDictionary a self-explanatory term? may-beUserDefinedFunctionList,
line 2: depending the method

```
# line 2: StepwiseRegression.SampleSizePercentage=decimal number between 0..100 (percentage of the number of cells for each land use class that'll be used to do the regression upon)
# line 3: StepwiseRegression.CorrelationThreshold=decimal number between 0..1 (drivers are being correlated for each landuse. If drivers are highly correlated (above threshold), the the driver with the lowest correlation with the landuse class is omitted)
# line 4: StepwiseRegression.ExportFileName=d:\\path\\filename.prop
# Example: Suitability.Method=StepwiseRegression
# Example: Suitability.StepwiseRegression.SampleSizePercentage=7.5
# Example: Suitability.StepwiseRegression.CorrelationThreshold=0.85
# line 2: FunctionDictionary.<adminUnit>.<landuseClass>.<FunctionConstant>= decimal number between -1..1 (constant value in function)
# line 3: FunctionDictionary.<adminUnit>.<landuseClass>.<FunctionCoefficient>.<Driver>= decimal number between -1..1 (coefficient value in function for quantitative driver)
# line 4: FunctionDictionary.<adminUnit>.<landuseClass>.<FunctionCoefficient>.<Driver>.class.<className>= decimal number between -1..1 (coefficient value in function for qualitative driver)
# line 5: etc. for driver and landuse class

Suitability.Method=StepwiseRegression
Suitability.StepwiseRegression.SampleSizePercentage=30
Suitability.StepwiseRegression.CorrelationThreshold=0.85

# Conversion
# choose from the options: {'always', 'never', 'years,7'}
# default is 'always' (no need to include a land use conversion that can take place always)
# Example 1: Conversion.Urban.Forest=never
# Example 2: Conversion.Forest.Urban=years,15
# Example 3: Conver-si-on.Forest.Arable=location,E:\\UserData\\Minatura\\iCLUE\\Hungary\\1000m\\ShamimHasan\\data\\n2000_cdda_ndv2.tif

Conversion.BuiltUp.UnusedShrubland=never
Conversion.BuiltUp.Shrubland=never
Conversion.BuiltUp.NonGrazedGrassland=never
Conversion.BuiltUp.ForestManaged=never
Conversion.BuiltUp.AnnualCrops_int=never
Conversion.BuiltUp.AnnualCrops_ext=never
Conversion.BuiltUp.PerrenialCrops_int=never
Conversion.BuiltUp.PerrenialCrops_ext=never
Conversion.BuiltUp.MixedCrops_int=never
Conversion.BuiltUp.MixedCrops_ext=never
Conversion.BuiltUp.GrazedGrasslandAndPastures=never
Conversion.BuiltUp.ForestUnmanaged=never

# Target time
# define until what time land use allocation calculations take place
# Example: TargetTime=2030

TargetTime=2050
```

Annex 3 workshop slides and participants

Workshop 1 – capturing our understanding of the system through conceptual modelling
Date: March 5th 2021
Venue: microsoft teams and Miro
Participants: Peter Verweij, Saeed Moghayer, Pim Mostert, Sjaak Conijn, Liu Cheng, Michiel van Eupen, GerJan Piet, Lesly Garcia Chavez, Koen Meesters, Willem-Jan van Zeist, Jaap van der Meer, Shassy Cahyani

Objective

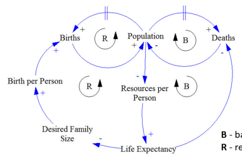
- Generate shared understanding of circular economy
- Define conceptual links (as prelude to practical data exchange protocols)

Modelling Systems (1/4)
Definitions

- A **system is** a cohesive conglomeration of **interrelated and interdependent parts** that is either natural or man-made
- Every system is **delineated by** its **spatial and temporal boundaries**, surrounded and **influenced by its environment**, described by its structure and purpose or nature and expressed in its functioning
- Changing one part of the system usually affects other parts and the whole system, with **predictable patterns of behaviour**

Modelling systems (2/4)
Causal Loop Diagrams

'a causal diagram that aids in visualizing how different variables in a system are interrelated'

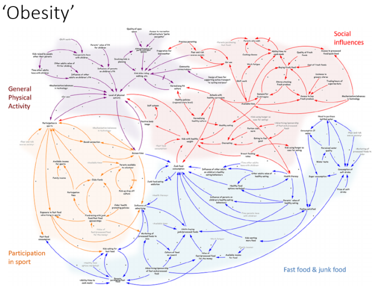


Variabelen:
- telbaar ('1,2,3') en
- ordinaal ('weinig, veel, matig')

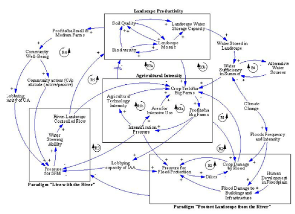
B - balancing
R - reinforcing

The diagram consists of a set of nodes and edges.
Nodes represent the variables and edges are the links that represent a connection or a relation between the two variables

Modelling Systems (3/4)
Example 'Obesity'



Modelling Systems (4/4)
Positioning models



Variabelen:
- telbaar ('1,2,3') en
- ordinaal ('weinig, veel, matig')

B - balancing
R - reinforcing

Method workshop 1
case3 – 'Impact of circular bio-economy on emission, biodiversity...?'

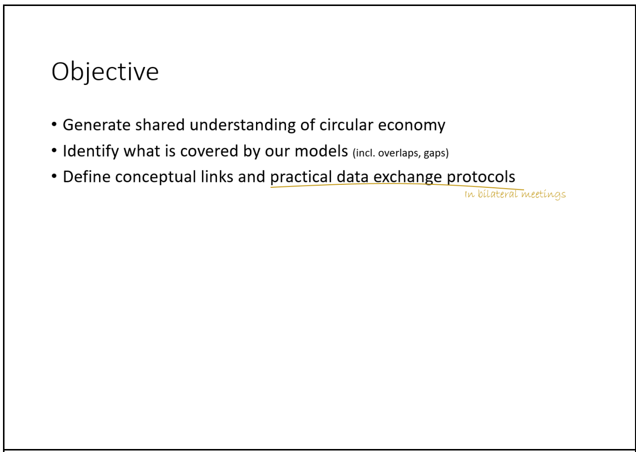
- *[individually, 5 min.]*
  Inventory of countable system variables
  (e.g. 'percentage renewables', 'food production', 'import/export', 'energy use per person', 'area of timber grown', 'amount of waste re-used')

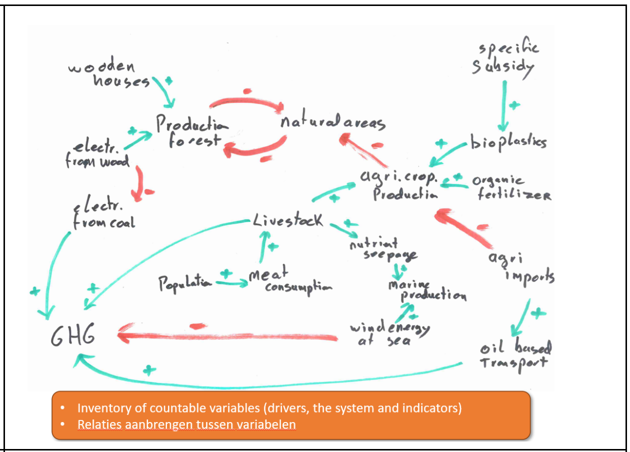
- *[plenairy, 30 min.]*
  grouping of system variables
- *[plenairy, 30 min.]*
  Draw relations between variables
  (including '**B**' – balancing , '**R**' – reinforcing)
- *[plenairy, 10 min.]*
  Where do the models fit?

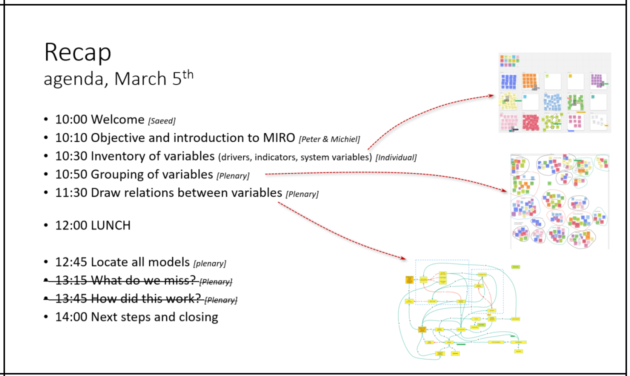
Results

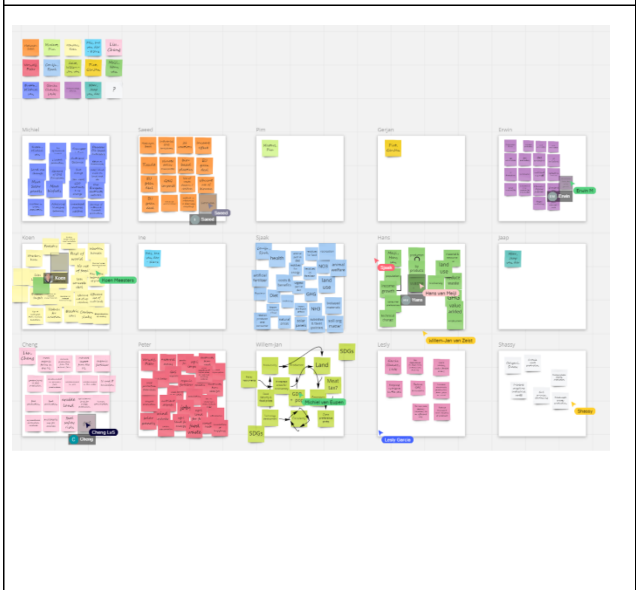

Michiel
Saeed
Pim
Gerjan
Erwin
Koen
Ine
Sjaak
Hans
Jaap
Cheng
Peter
Willem-Jan
Lesly
Shassy
Case III Circ. economy
GHG-emmisions
non-fossil energy
Forestry
Biobased materials
biofuels
carbon sinks
Macro-economic developments
Nutrients
Mitigation policies?
import export
Biodiversity
Diets
Human development
Primary production
(Food and Feed)
Land-use
Residues

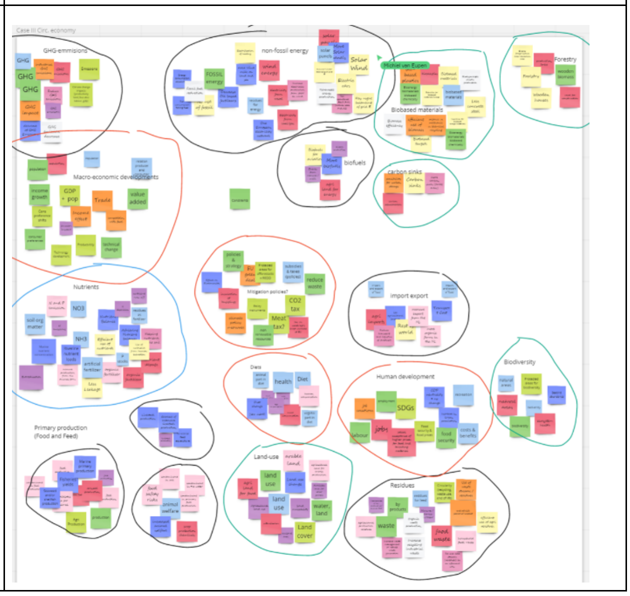
Workshop 2 – model framework within conceptual model
Date: March 18th 2021
Venue: microsoft teams & Miro
Participants: Peter Verweij, Saeed Moghayer, Pim Mostert, Sjaak Conijn, Liu Cheng, Michiel van Eupen, GerJan Piet, Lesly garcia Chavez, Koen Meesters, Willem-Jan van Zeist, Jaap van der Meer, Shassy Cahyani

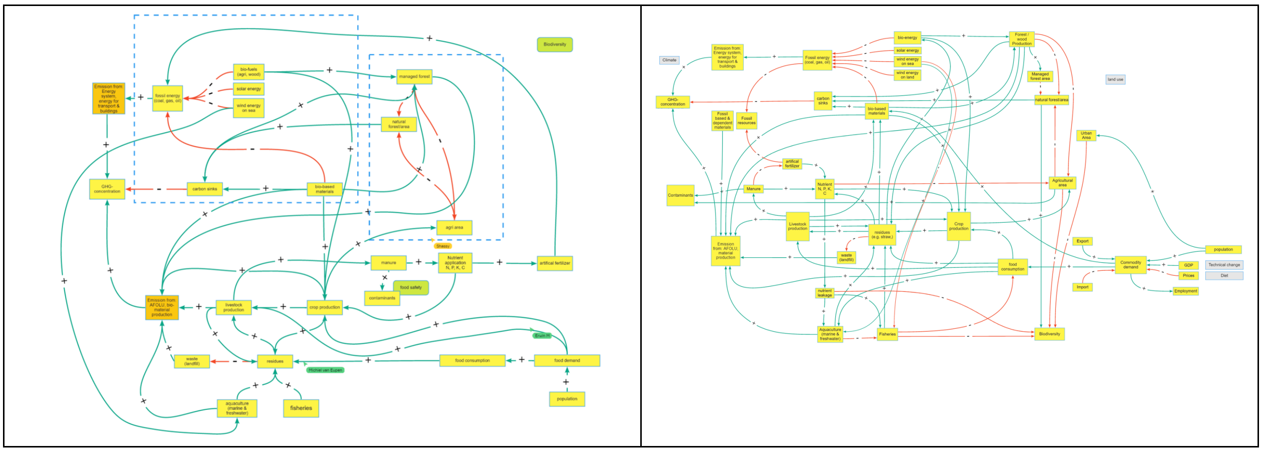




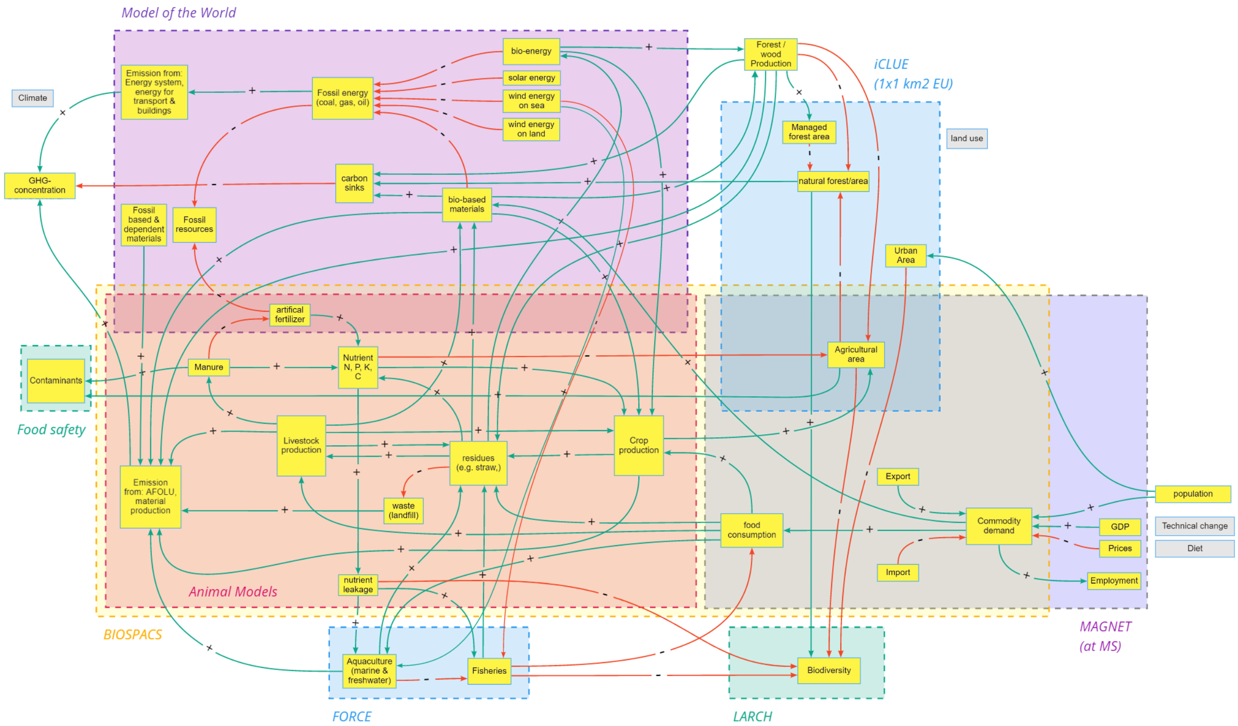


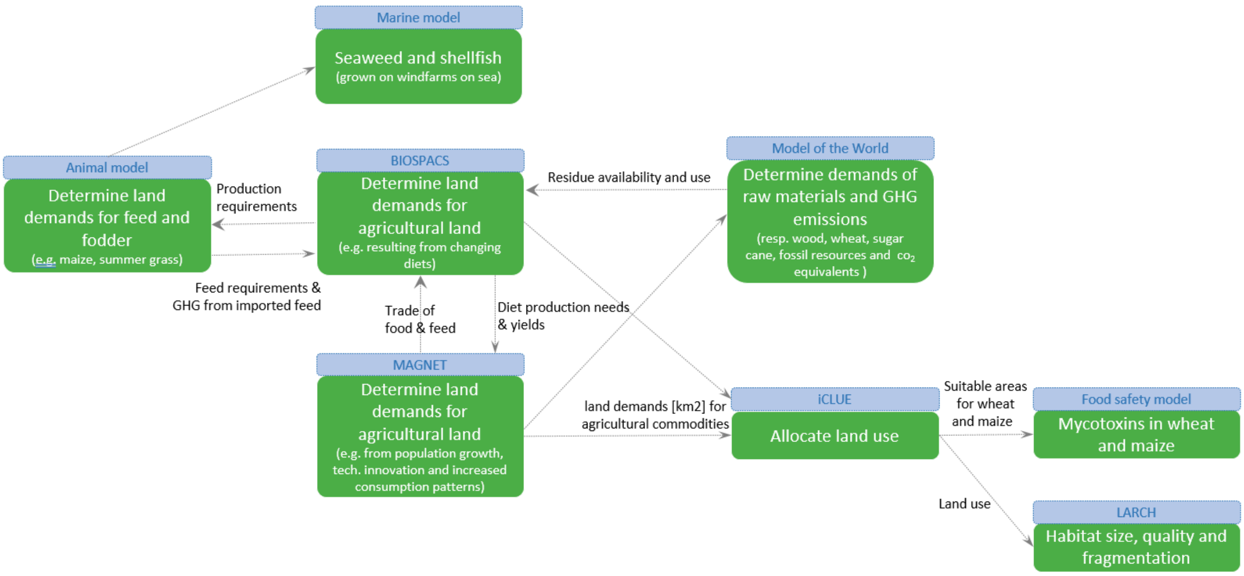






Results


Model of the World
Emission from: Energy system, energy for transport & buildings
Fossil energy (coal, gas, oil)
bio-energy
solar energy
wind energy on sea
wind energy on land
Forest / wood Production
iCLUE (1x1 km2 EU)
Climate
GHG-concentration
carbon sinks
bio-based materials
Managed forest area
land use
natural forest/area
Fossil based & dependent materials
Fossil resources
Urban Area
artifical fertilizer
Contaminants
Food safety
Manure
Nutrient N, P, K, C
Agricultural area
Livestock production
residues (e.g. straw,)
Crop production
Emission from: AFOLU, material production
waste (landfill)
Export
food consumption
Commodity demand
population
GDP
Technical change
Prices
Diet
Import
Employment
nutrient leakage
Animal Models
BIOSPACS
MAGNET (at MS)
Aquaculture (marine & freshwater)
Fisheries
Biodiversity
FORCE
LARCH


Marine model
Seaweed and shellfish (grown on windfarms on sea)
Animal model
Determine land demands for feed and fodder (e.g. maize, summer grass)
Production requirements
Feed requirements & GHG from imported feed
BIOSPACS
Determine land demands for agricultural land (e.g. resulting from changing diets)
Residue availability and use
Model of the World
Determine demands of raw materials and GHG emissions (resp. wood, wheat, sugar cane, fossil resources and co2 equivalents)
Trade of food & feed
Diet production needs & yields
MAGNET
Determine land demands for agricultural land (e.g. from population growth, tech. innovation and increased consumption patterns)
land demands [km2] for agricultural commodities
iCLUE
Allocate land use
Suitable areas for wheat and maize
Food safety model
Mycotoxins in wheat and maize
Land use
LARCH
Habitat size, quality and fragmentation

Workshop 3 – measuring the performance of the circular economy

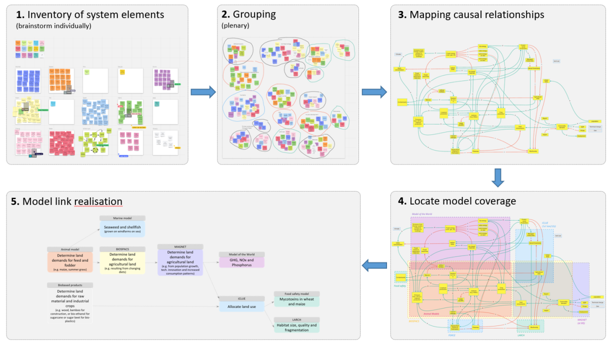
Date: October 11th 2021

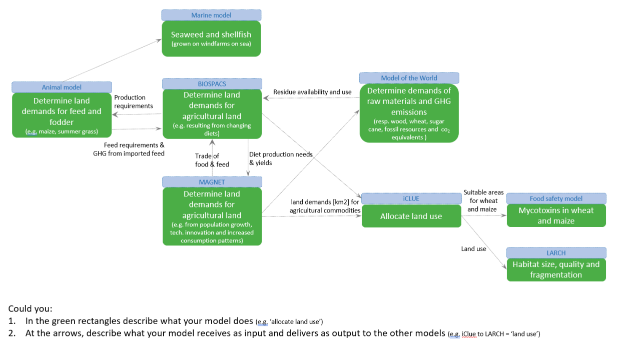
Venue: hybrid, Microsoft teams & GAIA building room 2, Wageningen

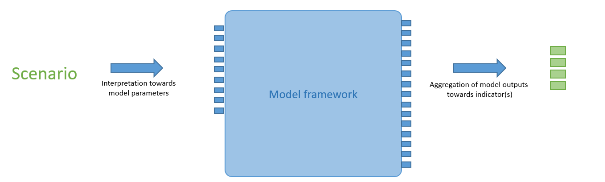
Participants: Peter Verweij, Michiel van Eupen, Saeed Moghayer, Pim Mostert, Liu Cheng, Sjaak Conijn, Lesly Garcia Chavez, GerJan Piet, Koen Meesters, Willem-Jan van Zeist, Jaap van der Meer, Ine van der Fels Klerx, Zuzana Kristova, David Cui, Marlous Focker, Charlotte van Haren, Petros Panteleon

Agenda

- 12:30 Welcome and introduction by project coordination *[Saeed]*
- 12:45 Workshop approach *[Peter]*
- 13:00 Inventory key performance indicators
- 14:00 Break
- 14:20 Prioritizing key performance indicators
- 15:15 Link key performance indicators to model framework
- 16:30 Closing *[Saeed]*







Measuring the performance of the circular bio-economy

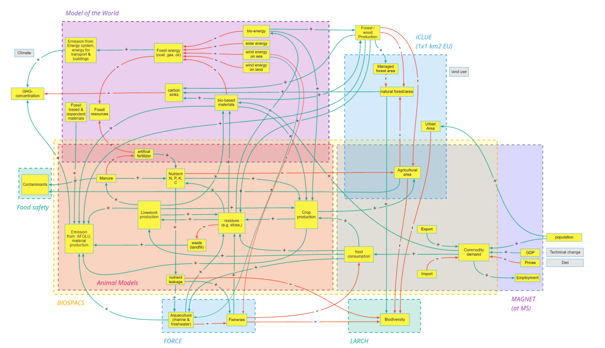
- *[individual, 10 minutes]* write down performance indicators on sticky notes
  - One indicator per sticky note
  - Max. of 7 indicators
- *[all, 20 minutes]* put sticky notes on wall and group them together
  - A group represents a single key performance indicator
    (e.g. '*CO2 equivalent*', not '*emissions*')
- *[plenary, 20 minutes]* reflect on and name groups (facilitated by Michiel)
  - If necessary, split and merge groups

Prioritize performance indicators

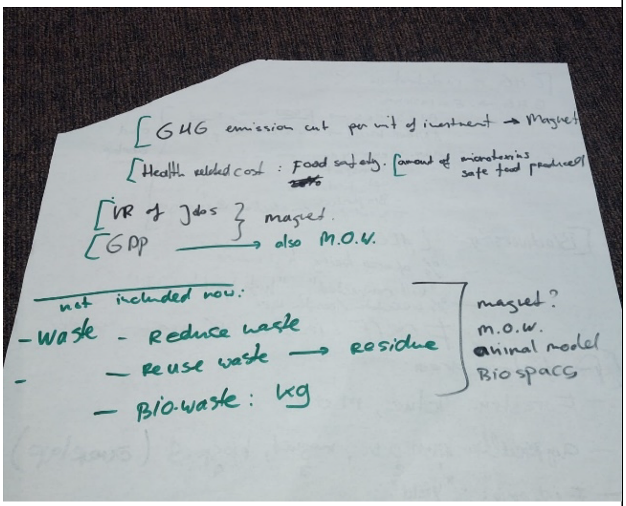
- *[individual, 10 minutes]* put stickers on (grouped) key performance indicators
  - 3 stickers per person
  - You can put multiple stickers on a single indicator
- *[plenary, 10 minutes]* rank indicators
- *[plenary, 30 minutes]* Define metrics for priority indicators

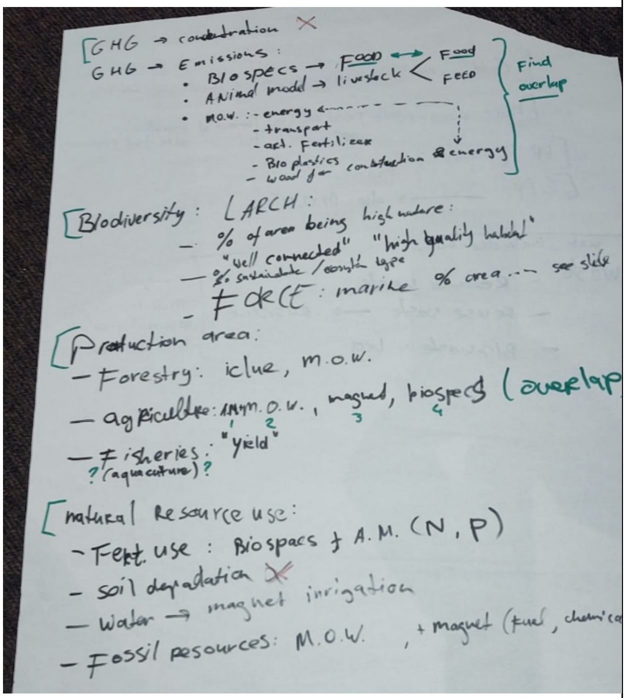
Link key performance indicators to model framework

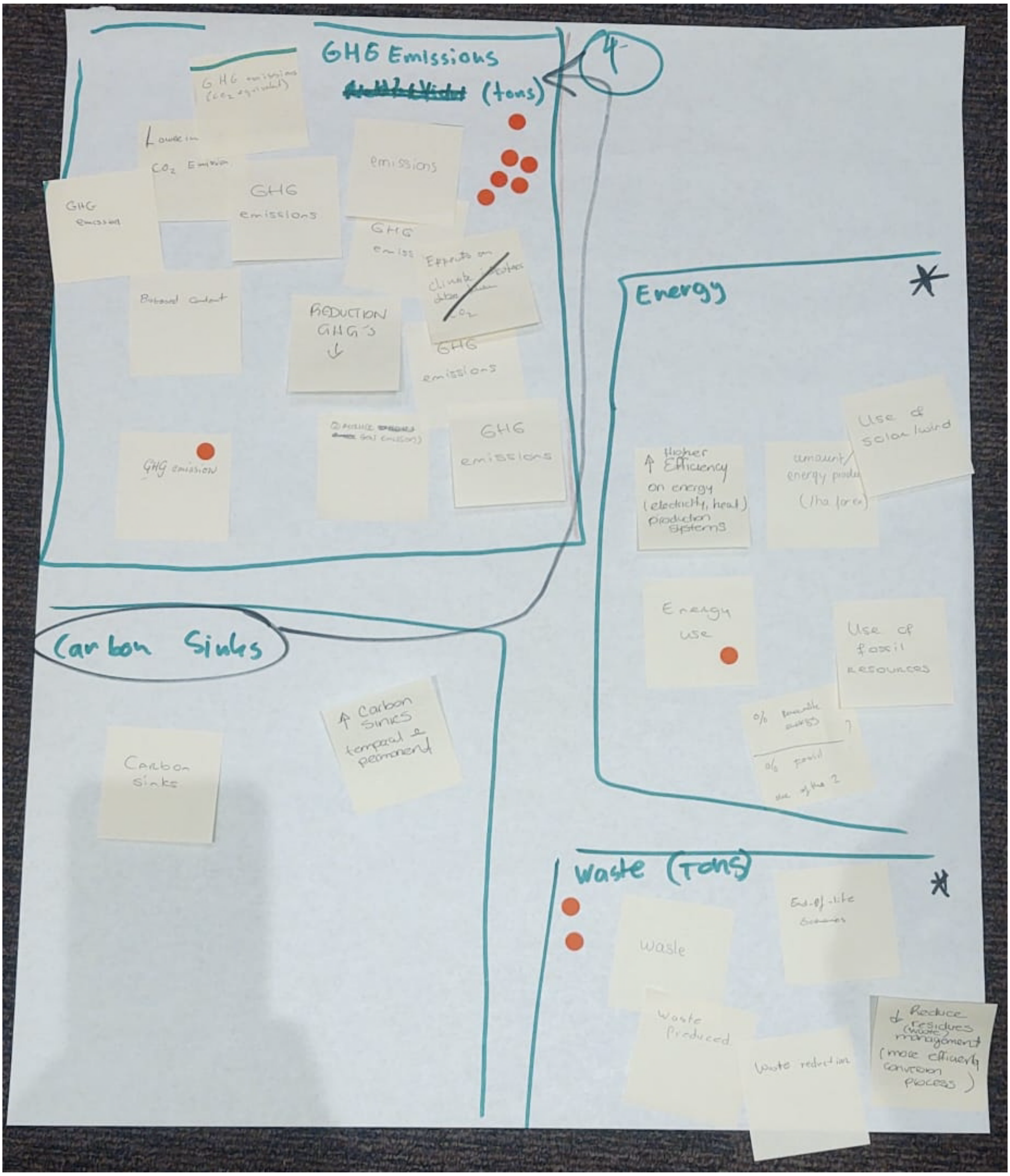
- *[plenary,]* locate each of the KPI's in the framework
  - Multiple models deliver the same KPI?
  - What models are involved to calculate the KPI?
- [Groups,] what data is exchanged between models

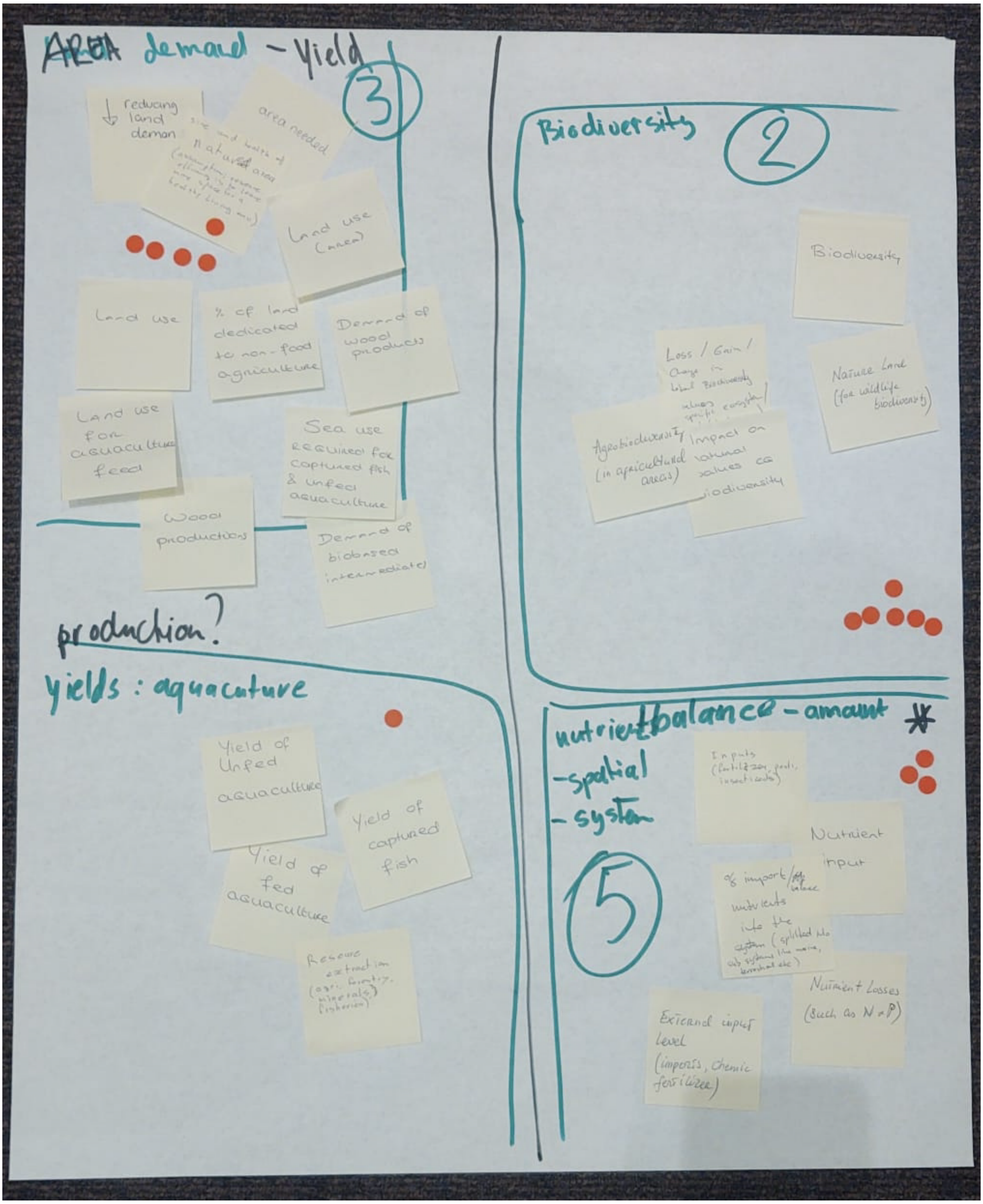


Results

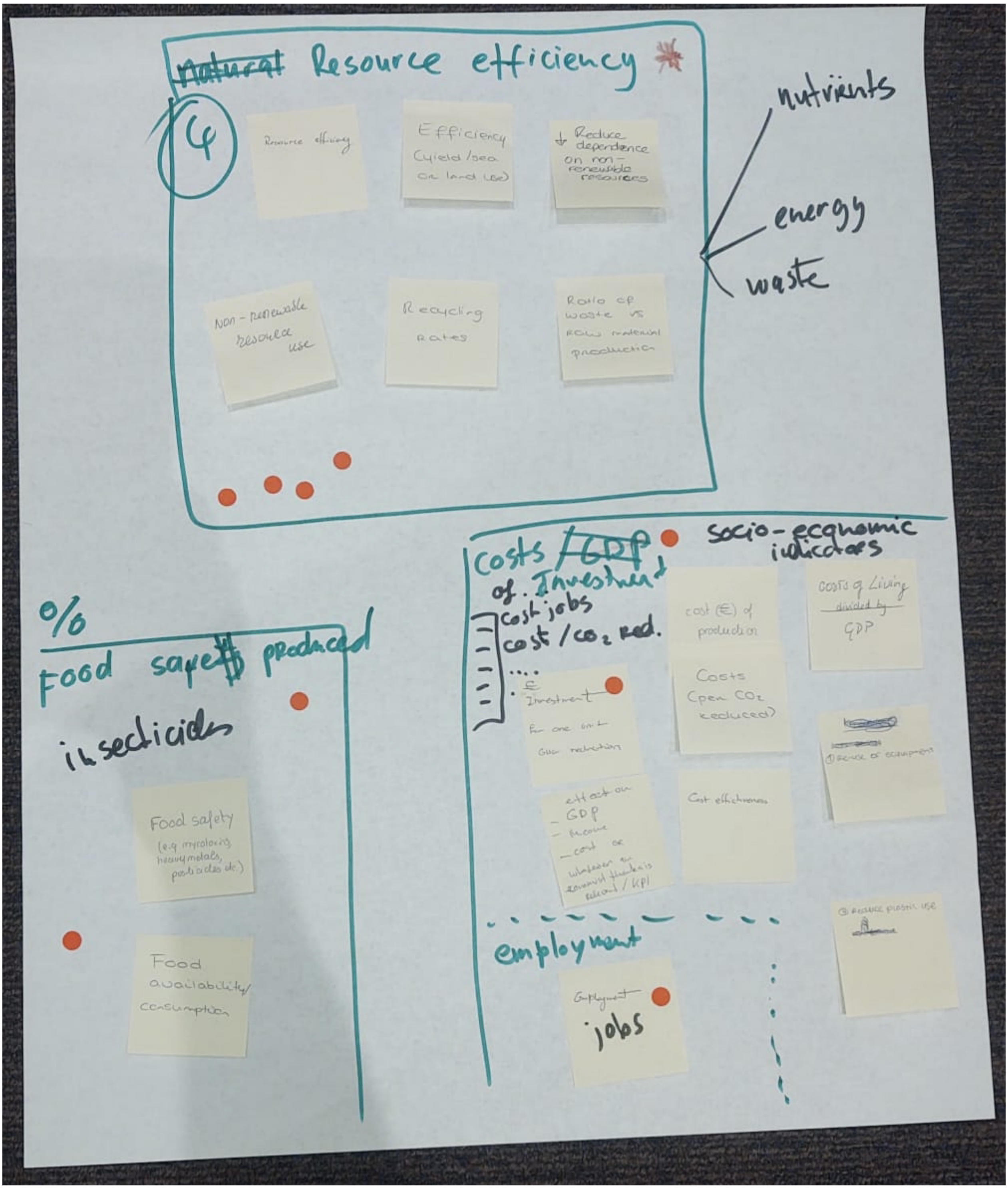

GDP → also M.O.W.
not included now:
- Waste - Reduce waste
- Reuse waste → Residue
- Bio-waste : kg
magnet?
m.o.w.
animal model
Biospecs


Find overlap
Biodiversity:
Production area:
- Forestry: iclue, m.o.w.
natural Resource use:
- Fert. use : Biospecs + A.M. (N, P)
- soil degradation
- water → magnet irrigation
- Fossil resources: M.O.W.


GHG Emissions
(tons)
4
emissions
GHG emissions
GHG emission
REDUCTION GHG'S
Energy
Higher Efficiency on energy (electricity, heat) production systems
Use of solar/wind
Energy use
Use of fossil resources
Carbon Sinks
Carbon sinks
Carbon sinks temporal & permanent
Waste (Tons)
Waste
Waste Produced
Waste reduction
Reduce residues (waste management) (more efficiently conversion process)



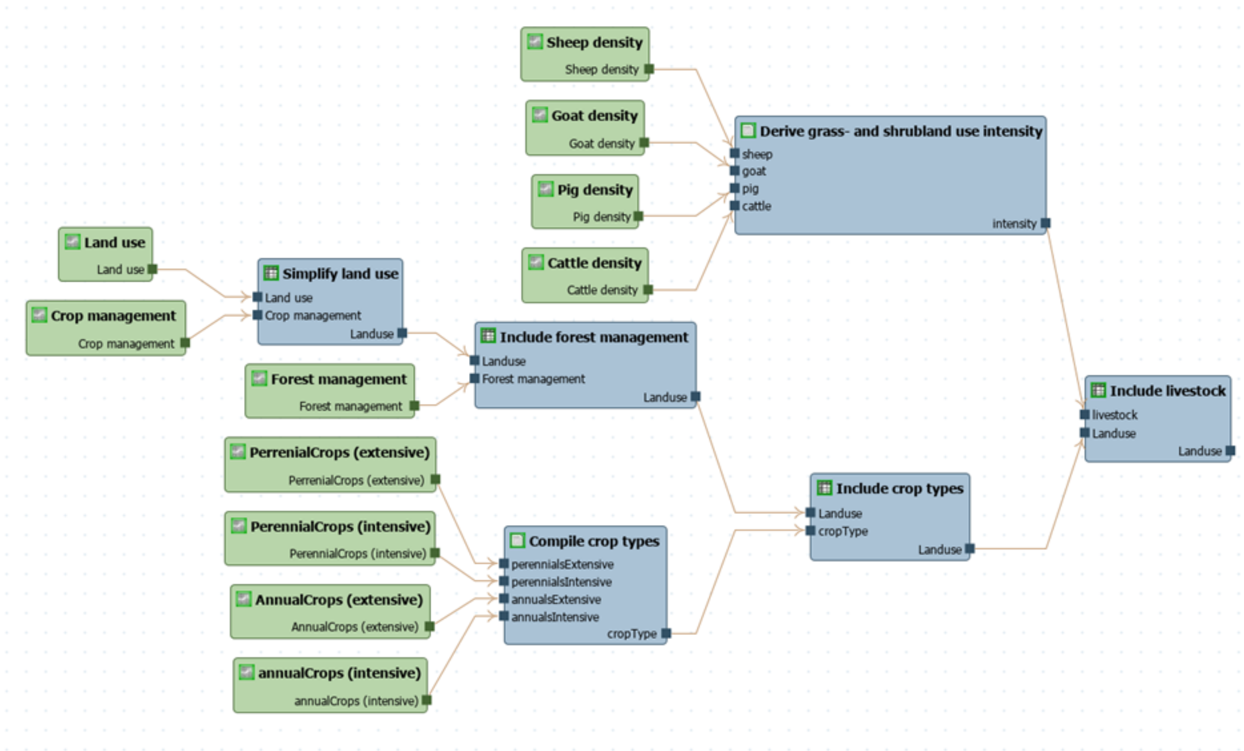
AREA demand - yield
3
reducing land deman
area needed
Land use (area)
Land use
% of land dedicated to non-food agriculture
Demand of wood production
Land use for aquaculture feed
Sea use required for captured fish & unfed aquaculture
Wood production
Demand of biobased intermediates
Biodiversity
2
Biodiversity
Nature Land (for wildlife biodiversity)
Agrobiodiversity (in agricultural areas)
production?
yields : aquaculture
Yield of Unfed aquaculture
Yield of captured fish
Yield of fed aquaculture
nutrient balance - amount
- spatial
- system
5
Nutrient input
Nutrient Losses (Such as N & P)
External input level (imports, chemic fertilizer)


Natural Resource efficiency
4
Resource efficiency
Efficiency (yield/sea or land use)
Reduce dependence on non-renewable resources
nutrients
energy
waste
Non-renewable resource use
Recycling rates
Ratio of waste vs raw material production
costs / GDP
of. Investment
cost jobs
cost / CO2 red.
socio-economic indicators
cost (€) of production
Costs of Living divided by GDP
Investment for one unit GHG reduction
Costs (per CO2 reduced)
effect on GDP
Cost efficiency
employment
jobs
%
Food safety produced
insecticides
Food safety (e.g. mycotoxins, heavy metals, pesticides etc.)
Food availability/consumption

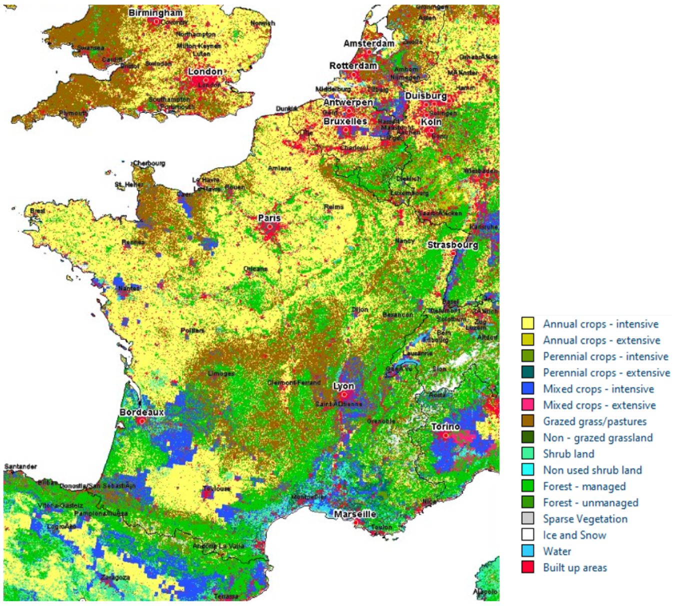
Annex 4 Baseline land use map

Author: Martin Jancovic & Michiel van Eupen

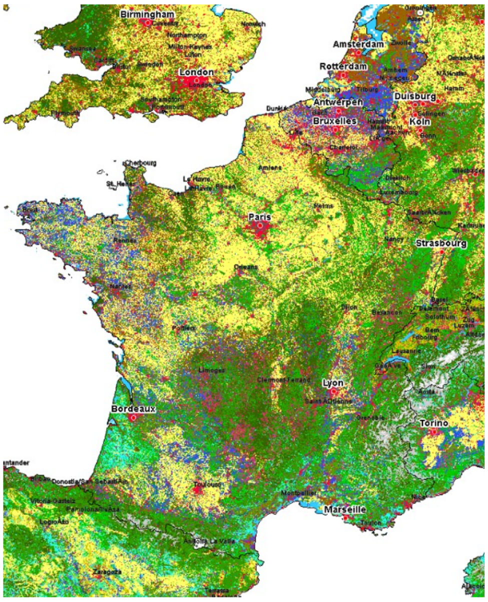
A land use map is the basis on which land use projections with the iCLUE model are carried out. Since the economy involves the entire globe, societal, technological and policy developments impact the globe in general and global land use in particular. The context of this study, however, focuses on Europe. Therefore, two land use maps were created, one based on available global datasets and one based on available European datasets. For both maps the same land use typology was used. The below figures illustrate the workflow for deriving the global land use map, and a visual comparison of the implications of using these different datasets by zooming in to the sample region of France.



Derived from global datasets



Derived from EU datasets



For the land use classification a draft ecosystem service (ESS) assessment has been made; ESS delivery (from '0 - low' in white to '5 - high' in dark red) and relevance of the ESS for the bioeconomy (Burkhard et al., 2014; Korhonen et al., 2018; Martins, 2016; Kapsalis et al., 2019; Wojtach, 2016; O'Neill et al., 2017).

GLC avg. 2012	Regulating service (potential)	Global climate regulation	Local climate regulation	Air quality regulation	Water flow regulation	Water purification	Nutrient regulation	Erosion regulation	Natural hazard regulation	Pollination	Pest and disease control	Regulation of waste
ESS relevant for Bioeconomy		high	high	high	low	medium	medium	low	medium	low	low	high
Annuals Intensive		1	2	1	1	0	1	0	1	1	2	2
Annuals Extensive		1	2	1	2	0	2	1	1	2	3	2
Perennials Intensive		2	2	1	1	1	1	1	1	3	2	2
Perennials Extensive		2	2	2	2	1	2	2	1	4	3	2
Mixed intensive		1	2	1	1	0	1	2	1	1	2	2
Mixed extensive		2	3	2	2	2	2	3	1	3	3	3
Grazed grass/Pastures		2	1	0	1	0	1	1	1	0	2	4
Non - grazed grassland		5	2	0	1	3	4	5	1	1	1	2
Shrubland		1	2	1	1	1	1	1	1	1	1	2
Non - used shrubland		2	3	1	1	2	2	2	1	2	2	3
Forest managed		5	5	5	3	5	5	5	4	4	4	4
Forest unmanaged		5	5	5	4	5	5	5	5	5	5	5
Ice and Snow		3	4	0	5	0	0	0	0	0	1	1
Sparse vegetation		0	1	0	0	1	1	1	1	0	1	1
Water		2	2	0	3	2	3	1	3	0	3	4
Built up areas		0	0	0	0	0	0	1	0	0	1	0

GLC avg. 2012	Provisioning service (potential)	Crops	Biomass for energy	Fodder	Livestock (domestic)	Fibre	Timber	Wood Fuel	Fish, seafood & edible algae	Aquaculture	Wild foods & resources	Biochemicals & medicine	Freshwater	Mineral resources*	Abiotic energy sources*
ESS relevant for Bioeconomy		high	medium	high	high	high	high	medium	medium	high	low	low	high	high	high
Annuals Intensive		5	3	4	0	4	0	0	0	0	1	2	0	0	1
Annuals Extensive		4	3	3	0	3	0	0	0	0	2	1	0	0	1
Perennials Intensive		4	1	1	0	0	2	2	0	0	0	2	0	0	0
Perennials Extensive		3	1	1	0	0	1	1	0	0	1	1	0	0	0
Mixed intensive		4	2	3	1	4	1	2	0	0	1	2	0	0	2
Mixed extensive		2	3	2	2	3	2	1	0	0	2	1	0	0	1
Grazed grass/Pastures		0	1	5	5	0	0		0	0	2	0	0	0	5
Non - grazed grassland		0	1	2	3	0	0	0	0	0	5	1	0	0	2
Shrubland		0	1	1	2	1	1	1	0	0	1	1	0	0	1
Non - used shrubland		0	1	1	1	1	1	2	0	0	1	2	0	0	1
Forest managed		0	1	1	1	1	5	5	0	0	5	3	0	0	0
Forest unmanaged		0	0	0	0	0	0	0	0	0	2	2	0	0	0
Ice and Snow		0	0	0	0	0	0	0	0	0	0	0	5	0	0
Sparse vegetation		0	0	0	0	0	0	0	0	0	1	0	0	0	1
Water		0	1	1	0	0	0	0	2	5	3	1	4	0	1
Built up areas		0	0	0	0	0	0	0	0	0	0	0	0	0	1

GLC avg. 2012	Cultural services (potential)	Recreation & tourism	Landscape aesthetics & inspiration	Knowledge systems	Religious & spiritual experience	Cultural heritage & cultural diversity	Natural heritage & natural diversity
ESS relevant for Bioeconomy		low	medium	medium	low	low	medium
Annuals Intensive		1	1	2	0	3	0
Annuals Extensive		2	2	3	0	4	1
Perennials Intensive		3	2	2	0	4	0
Perennials Extensive		4	3	3	1	5	1
Mixed intensive		2	2	2	0	3	1
Mixed extensive		3	3	3	1	3	2
Grazed grass/Pastures		2	2		0	3	1
Non - grazed grassland		3	4	5	1	3	3
Shrubland		2	3	3	1	2	3
Non - used shrubland		3	4	4	1	2	4
Forest managed		5	5	5	3	4	5
Forest unmanaged		5	5	5	5	5	5
Ice and Snow		5	5	4	0	0	1
Sparse vegetation		1	1	3	0	2	1
Water		3	3	4	1	3	3
Built up areas		1	1	1	0	1	0

Wageningen Environmental Research
P.O. Box 47
6700 AA Wageningen
The Netherlands
T 0317 48 07 00
wur.eu/environmental-research

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The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 6,800 employees (6,000 fte) and 12,900 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.

To explore the potential of nature to improve the quality of life

Wageningen Environmental Research
P.O. Box 47
6700 AB Wageningen
The Netherlands
T +31 (0) 317 48 07 00
wur.eu/environmental-research

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