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Ponderful

PONDS FOR CLIMATE



Deliverable 3.9

Protocol for local land use projections

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1. Executive Summary

This deliverable outlines the protocol to project land use change in the vicinity of ponds at a local scale. To this purpose, we have extended the GLOBIO 4 model's land-use allocation method to further downscale land use projections at a spatial resolution of 10 m. Instead of directly using the Land Use Harmonization v2 (LUH2) data, which have a coarse spatial resolution (0.25°) and tend to underestimate the spatial heterogeneity of land-use patterns at local to regional scales, we have used the 100 m land use projection dataset from deliverable 3.7 as the starting point for further local downscaling.

2. Introduction

Small bodies of water, especially ponds, have characterised much of the European landscape for many centuries (Hill et al., 2018). Ponds rank quite highly for wildlife resource provision when compared to other bodies of water (Biggs et al., 2005; Boix et al., 2012). Ponds are important not only for the wildlife they support, but also for their historical and cultural significance as distinctive elements of local landscapes, their visual attraction, and the understanding that they can help locals maintain a connection to nature (Boix et al., 2012). However, due to changes in land use, such as urbanisation and agricultural intensification, pond numbers have been declining steadily over the past century. In some countries, this loss has reached 90 percent, while it has exceeded 50 percent in most of western Europe (Indermuehle et al., 2008).

Land use and land cover (hereinafter LULC) are two interchangeable terms that are frequently used synonymously in the scientific literature (Jamal & Ahmad, 2020). The interaction of environmental, institutional, and socioeconomic elements and human exploitation of those factors over time and space determines the LULC pattern of every location or situation (Jamal & Ahmad, 2020). While land use refers to human activities in which land resources are used solely to produce goods or services, land cover refers to the physical qualities that cover the surface of the planet, such as plant, soil, water, and artificial structures (Jamal & Ahmad, 2020).

To analyse the relationship between land use changes and their effects on freshwater biodiversity, information on land cover and land use is required at a range of spatial and temporal scales, from local to global. Shared Socioeconomic Pathways (SSPs) are widely used to assess the impact and risk of land use change, climate change, energy consumption and human health in a future world (Chen et al., 2020; Dellink et al., 2017; Riahi et al., 2017). However, most of the current research on SSPs is conducted on a global scale, and the availability of future scenarios at local to regional scales is scarce. The spatial resolution of existing global land use projections (e.g., 0.25° × 0.25° in the LUH2 dataset) is too coarse to meet the needs of local research and decision-making (Hurtt et al., 2011; Liao et al., 2020). Hence, it is necessary to develop local scale SSPs for localised LULC projections, which is vital for spatial planning and ecological risk assessments to inform management and support decision-making.

Our first attempt at downscaling the global LUH2 data is described in Deliverable 3.7, where we focussed on downscaling three future SSP scenarios at 100 m resolution: Sustainable Development (SSP1), Regional Rivalry (SSP3), and Fossil-fuelled Development (SSP5), for the 2050 period. The sustainability scenario is characterized by a relatively low population growth, low consumption due to less resource-intensive lifestyles (e.g., a decrease in meat consumption) and more resource- efficient technologies, combined with improved technologies, increased regulation of land-use changes due to expansion of the protected area network, and significant progresses in agricultural productivity, permitting for reforestation (Schipper et al., 2020). The regional rivalry scenario is characterised by high population expansion, resource intensive consumption, low agricultural productivity, and limited regulation of land use change, resulting in ongoing deforestation (Schipper et al., 2020). Finally, the fossil-fuelled development scenario is characterised by low population increase, significant economic growth, a consumption-oriented and energy-intense society, and highly intensive agricultural practises that result in reduced deforestation (Schipper et al., 2020).

Following the biodiversity model intercomparison protocol, we had mixed the SSPs with climate projections based on the Representative Concentration Pathways (RCPs; refer to deliverable 3.7 for more information) so that the combinations encompassed a broad range of land use and climate change (Kim et al., 2018). SSP1 (moderate land use pressure) was linked with RCP2.6 (low level of climate change), SSP3 (high land use pressure) with RCP6.0 (moderate level of climate change), and SSP5 (moderate land use pressure) with RCP8.5 (high level of climate change). The SSP3xRCP6.0 and SSP5xRCP8.5

combinations reflect the scenarios that include only minor or no climate change mitigation policies (Kim et al., 2018).

Deliverable 3.7, however, was completed only at the national level. For applications at the local level, especially to assess the impacts on pondscapes, LULC projections at a finer spatial resolution would be required. As a result, in this deliverable, we have focussed on developing a protocol for local LULC projections at 10 m spatial resolution. Our goal is to widen the application of SSP scenarios at the scale that is more relevant for supporting the state and local governments' policies (Chen et al., 2020; Huang et al., 2020). In this deliverable, we have extended the GLOBIO model's land-use allocation method to downscale coarse resolution land use projections to a spatial resolution of 10 m. The GLOBIO model was developed in cooperation with multiple partners by PBL Netherlands Environmental Assessment Agency and is intended to inform and support policymakers by quantifying global human impacts on biodiversity and ecosystems (Nellemann et al., 2001). The model is linked to PBL's IMAGE model, which is an integrated assessment model that simulates the global environmental effects of human activities. The IMAGE-GLOBIO framework has been widely applied to environmental assessments in recent years, including for the Convention on Biological Diversity (CBD) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)(Schipper et al., 2020).This model is capable of downscaling (or spatially allocating) low-resolution land-use data (regional totals or 'claims') to a global high-resolution discrete land-use map that is compatible with the GLOBIO 4 model environment.

3. Methods

Study area

Our chosen study area, Hasselt, has a population of 68,000 and is located 70 kilometres east of Brussels in the Maas-Rhine region of Belgium (Figure 1). Hasselt was selected as the study area for this deliverable because this administrative region contains a high density of ponds and is representative of the scale at which the pond conservation efforts are likely to be planned and implemented.

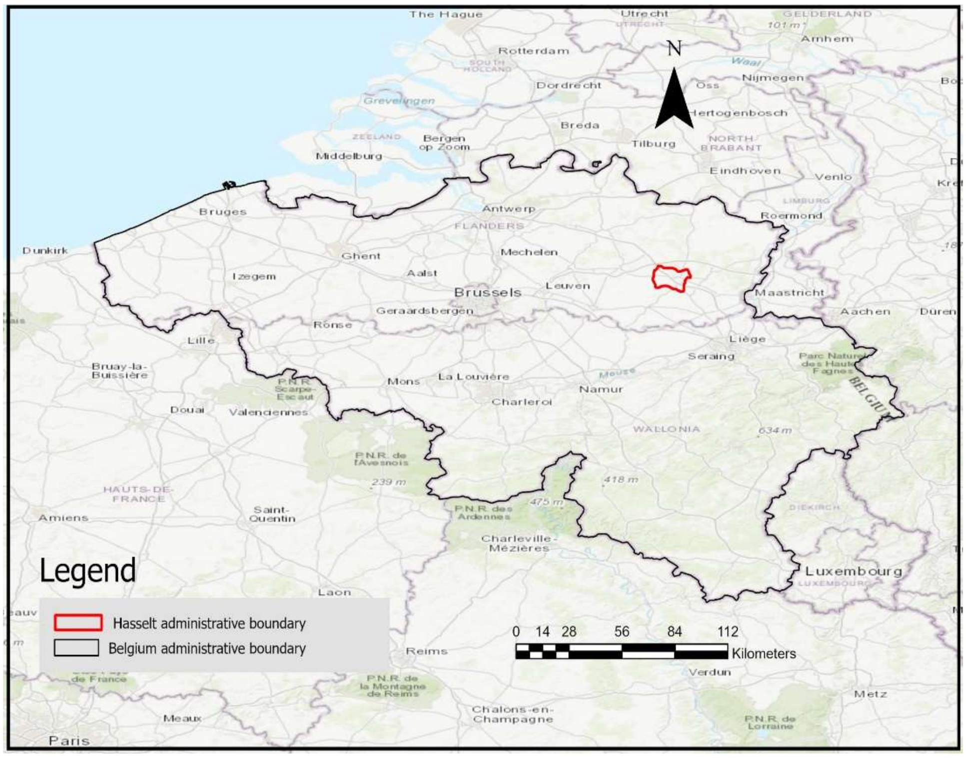

Figure 1. Location of Hasselt in Belgium

GLOBIO Land Use Allocation module

The Discrete Land-use Allocation module is a GLOBIO 4 pre-processing module that can be run in the GLOBIO 4 framework. We have extended a routine to downscale land-use data to discrete maps with a spatial resolution of 10 meter. This improves the ability to account for spatial heterogeneity as well as ecological consequences that are influenced by the landscape's spatial configuration. GLOBIO's land use allocation method can work with user-defined land-use classes and regional totals, or ‘claims,' represented in surface area per region per land-use class. Each land-use class's regional totals are spatially allocated based on an overall ‘suitability layer' for that class (Schipper et al., 2020). This layer is created using a collection of environmental factors that influence the probability of the land-use class of concern being present in that grid cell. Land cover, road proximity, elevation, and slope are examples of relevant environmental factors (Schipper et al., 2020).

The allocation algorithm prioritises potential grid cells based on their suitability values and allocates claims for each land use type in each region starting with the cells with the highest suitability and working its way down to the total claim (Schipper et al., 2020). GLOBIO allocates land in a predetermined order, with urban land coming first, followed by cropland, reflecting the fact that urbanisation is often prioritised over other land uses (including existing cropland; D'Amour et al., 2017), and cropland expansion often occurs in forest or grazing land (Piquer-Rodríguez et al., 2018). Following that, forestry and pasture are allocated, with forestry allocating within remaining forest areas and grazing occurring in regions that are not productive enough for crops (Hasegawa et al., 2017). If several cells in a particular region are equally suitable for a certain land use type, the land use claim is distributed among them at random. Claims or changes in claims from a previous scenario-year combination are assigned to each scenario-year combination. If the land claim allocated in one scenario-year is smaller than the claim allocated in the preceding scenario-year, cells are abandoned in reverse order of suitability and assigned to urban (Schipper et al., 2020).

Land use type

We defined six land use classes, urban, cropland, pasture, forestry, bare/sparse vegetation, and undefined. These land use classes can be configured in the module's configuration file.

Data

The input data set for the extended Land-use Allocation module includes raster region, raster with land-cover, raster with land-use, Raster with areas which cannot be allocated, Rasters with suitability for the land-use types to allocate, Land-use claims, and the Land-use claims lookup (Please refer to deliverable 3.7 for more details). Many of these datasets need to be pre-processed before being used as input. Pre-processing often involved resampling and resizing the original dataset, as well as converting them to a tif raster.

Input data preparation

Many of these datasets have been pre-processed before being used as input, as detailed below.

Land cover map

We have used the European Space Agency (ESA) WorldCover 10 m 2020 map (Zanaga et al., 2021) to establish a baseline land-use map for the present day.

The ESA WorldCover 10 m 2020 product provides a global land cover map for 2020 at 10 m resolution based on Sentinel-1 and Sentinel-2 data. The classification system of ESA WorldCover 10m is different from LUH2, with 12 land use classes in the LUH2 datasets and 11 land use classes in ESA WorldCover 10m. To make these two datasets comparable for land use simulations, we have merged them into six major classes (see Table 1). Because the change in the amount of water area is not projected in the LUH2 datasets, we assume that water areas do not change under different scenarios and are not simulated in the land use simulation model in this study. The resulting LULC map for Hasselt with merged categories is shown in Figure 2.

Table 1. Reclassification for land use simulation in this protocol.

LUH2 land classes	ESA WorldCover 10 m 2020 Classes	Our Defined classes in GLOBIO
Forested primary land Potentially forested secondary land	Tree cover Shrubland	Forestry
Managed pasture Rangeland	Grassland	Pasture
C3 annual crop C3 perennial crop C4 annual crop C4 perennial crop C3 nitrogen-fixing crop	Cropland	Cropland
Urban land	Built-up	Urban
Non-forested primary land Potentially non-forested secondary land	Bare / sparse vegetation	Bare / sparse vegetation
None	Snow and ice Permanent water bodies Herbaceous wetland Mangroves Moss and lichen	Undefined

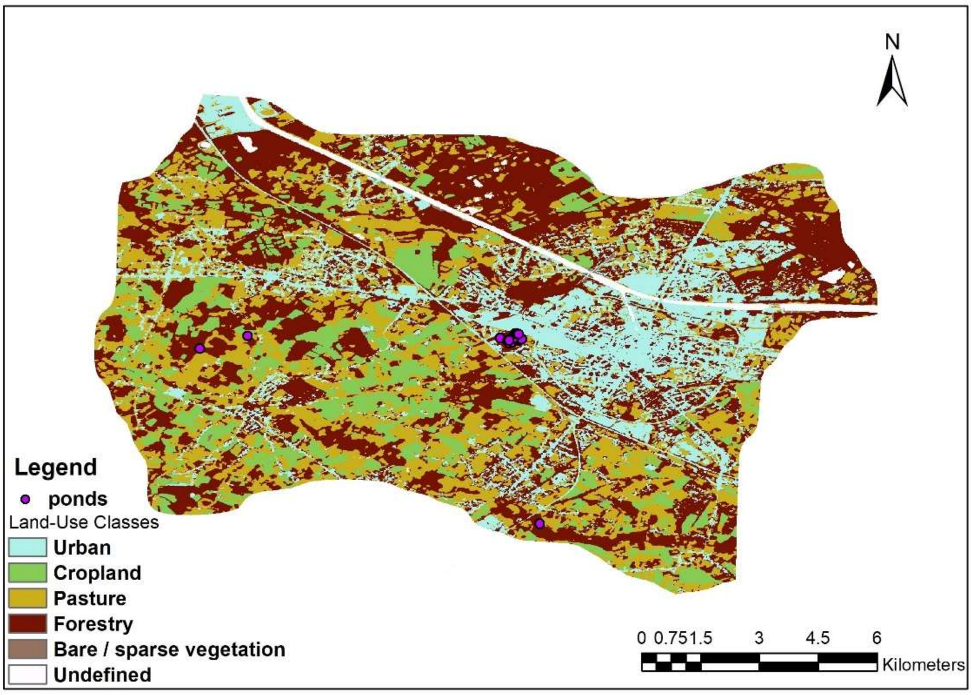

Figure 2. Merged landcover into six major land classes for the Hasselt region in Belgium.

Suitability layers

We created a suitability layer (see Figure 3) for four major land-use types, urban area, cropland, pasture, and forestry, based on the guidelines provided by Schipper et al (2020). Because spatial clustering and edge expansion have been identified as significant factors in the growth of urban areas and croplands, we retrieved the suitability layers for urban areas and croplands based on their proximity to existing urban areas and croplands (Ay et al., 2017, Huang et al., 2020, Richards, 2018). To that end, we used the ESA WorldCover 10 m 2020 product (after reclassification) to calculate the Euclidean distance to existing urban area or croplands, assign the highest suitability to existing cropland or urban area, and invert and normalise the distances to existing urban area or cropland. We also set the suitability of non-urban and non-cropland cells inside protected areas to zero, based on the assumption that urban and cropland areas within protected areas would not expand beyond what they were in 2020. The World Database of Protected Areas (WDPA) was used to identify the protected areas.

We created a pasture suitability layer based on the density of ruminant livestock species (goats, sheep, and cattle) from the FAO's gridded livestock of the world dataset (GLW; head per km^2, 30 arc-seconds) (Robinson et al., 2014). Modelled livestock densities are provided by the GLW, which are based on detailed subnational livestock statistics and a set of predictor variables linked to climate, vegetation, topography, and demography (Schipper et al., 2020). To account for variances in body mass among livestock species, we converted their densities to tropical livestock units (Petz et al., 2014).

We considered that access to wood is mostly determined by elevation, proximity to infrastructure, and the presence of protected areas when creating the forestry suitability layer (Schipper et al., 2020). The Euclidean distance to the nearest road was calculated. We used the GRIP database to get a road map (Meijer et al., 2018). To get at suitable values between 0 and 1, we inverted and normalised the distances and multiplied the resulting values with inverted and normalised elevation values (retrieved from the Copernicus Land Monitoring Service and resampled to 10 m). We also assumed that no forestry activities would take place in protected areas, therefore we set the suitability values for forestry inside protected areas to zero. Finally, we clipped the forestry suitability layer to land cover with trees, using the European Space Agency (ESA) WorldCover 10 m 2020 product, and set the suitability of other cells to zero.

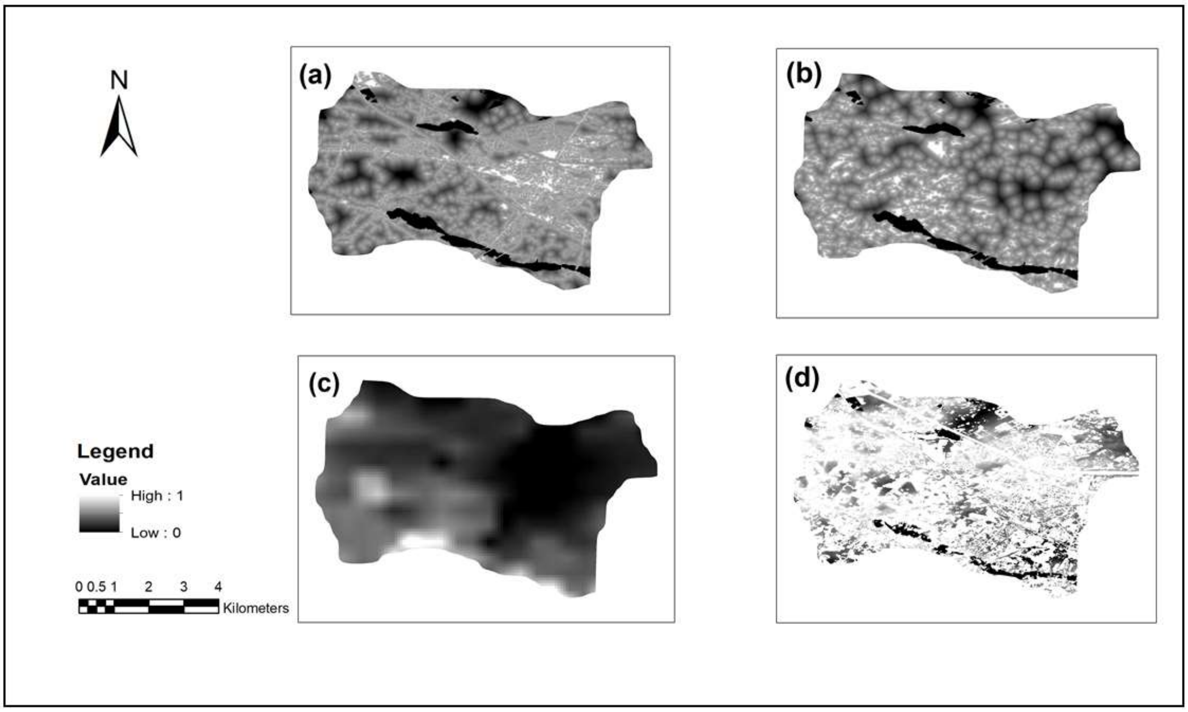

Figure 3. Suitability layers for: (a) urban, (b) cropland, (c) pasture, and (d) forestry for the Hasselt region in Belgium.

Claims

Claims can be obtained from national or regional statistics or from models, such as Integrated Assessment Models, that estimate land demand based on socioeconomic development (Schipper et al., 2020). All claims must be expressed in terms of area (km^2). Original LUH2 dataset has a coarse spatial resolution (0.25°), which is more informative at a global scale, but is likely to have high uncertainty at local scales. Therefore, to calculate the claims that are likely to be more accurate for local scale, we chose to use the downscaled LUH2 dataset from Deliverable 3.7 which is available at 100 m resolution.

Not-allocatable areas

Not-allocatable areas were constructed by reclassifying the reclassified land cover map into two classes: allocated areas (urban, crop, pasture, forestry, and bare/sparse vegetation) and not allocated areas (undefined).

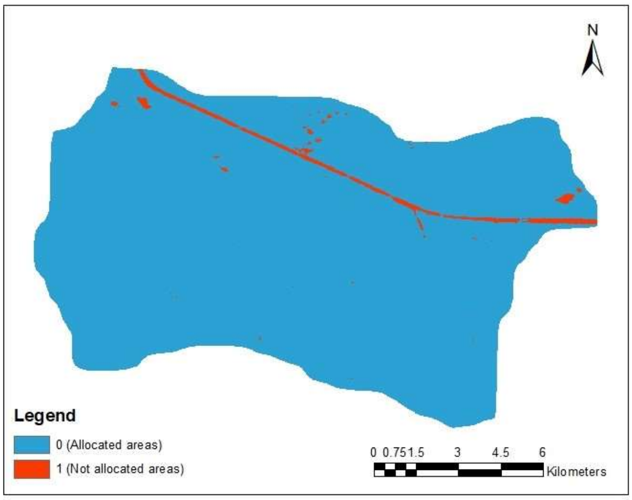

Figure 4. Not-allocatable area map

Module execution

After installing the GLOBIO 4 software (see the installation guide in the https://github.com/GLOBIO4/GlobioModelPublic/wiki), the Land-use Allocation module can be run like any other GLOBIO 4 module using the command globio4.

We have provided some detailed information on how to run the GLOBIO model in Deliverable 3.7.

4. Results

Present-day land-use map

We used the land-use allocation routine with the reclassified ESA WorldCover 10m land-cover map for 2020 as the 'background' map, the suitability layers as described above, and regional-level total areas (i.e., 'claims') of urban, cropland, pasture, and forestry land to create a land-use map for the reference year 2020 (Figure 5a). The most representative claims for 2020 were obtained using a similar approach to Schipper et al. (2020). Specifically, claims for urban areas and cropland were obtained from the 2020 ESA WorldCover 10m map, whereas the claims for pasture and forestry were obtained from the downscaled 100 m resolution present-day land-use map from Deliverable 3.7. The use of same source for both the suitability layers and the claims of urban and cropland regions meant that the 'claims' for urban and cropland areas were only assigned to cells identified as such in 2020, i.e., the allocated layers were like the ESA WorldCover 10m map for 2020. As a result, we adhered as near as possible to the claims and patterns identified in 2020.

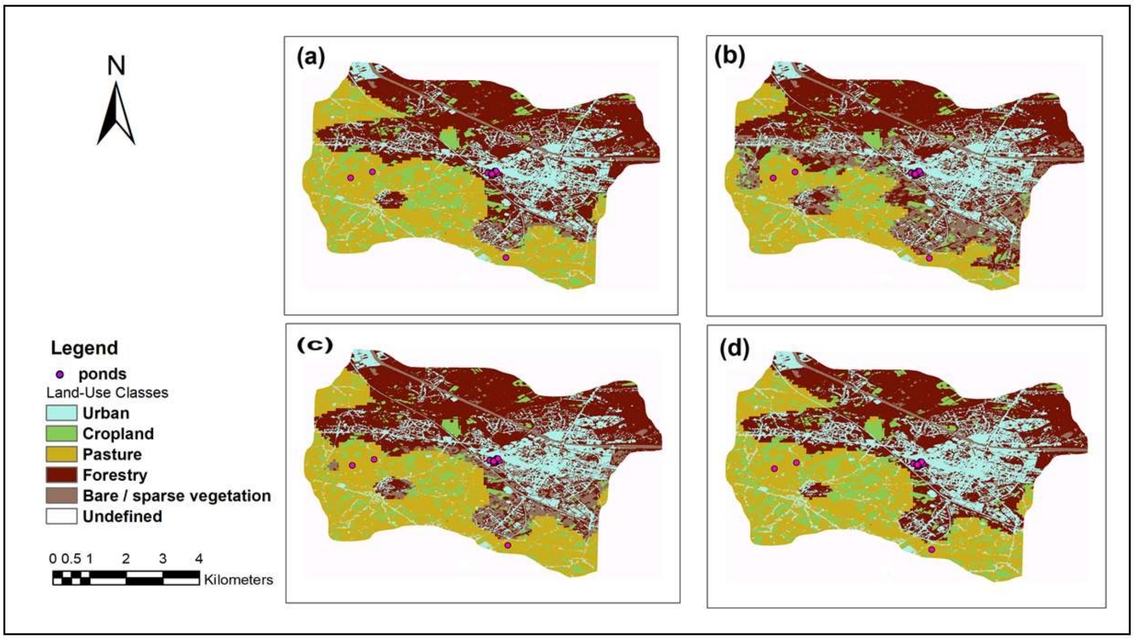

Figure 5. Land use distribution in (a) present day (2020), (b) SSP1 RCP2.6 scenario for 2050, (c) SSP3 RCP6.0 scenario for 2050, and (d) SSP5 RCP8.5 scenario for 2050.

Future land-use maps

To create the future land-use maps (Figure 5b, 5c, 5d), we used the downscaled LUH2 dataset from deliverable 3.7 to calculate regional total areas of the four land use types (urban, farmland, pasture, and forestry) for each scenario-year (i.e., 2020 and three times 2050, for each SSP scenario). For each future scenario year (downscaled future land-use maps at 100 m from deliverable 3.7), the difference in area of each land-use types relative to 2018 (downscaled present-day land-use map at 100 m from deliverable 3.7) was computed, and the difference was added to the claims defined for 2020 (as mentioned above), with the sum being the overall claim (Schipper et al., 2020). As a result, rather than defining the claims themselves, we used the LUH2 data to define the change in claims, reasoning that the Integrated Assessment Models underlying LUH2 are good at representing temporal trends in land use, but that remote sensing data and national statistics, which were included in our initial land-use map, are better at representing the current situation.

Table 2 outlines the changes in the areas of different land use types under various future scenarios in relation to the present-day land-use map of 2020. In the sustainability scenario (SSP1 (moderate land use pressure) x RCP2.6 (low level of climate change)) urban and forestry remain steady, but cropland and pasture have dropped. In the regional rivalry scenario (SSP3 (high land use pressure) x RCP6.0 (moderate level of climate change)), urban and forestry areas remain the same while cropland and pasture areas decrease. In the fossil-fuelled development scenario (SSP5 (moderate land use pressure) x RCP8.5 (high level of climate change)), there is a loss in forestry area, an increase in urban area, and essentially no change in cropland or pastureland.

Table 2. Total area (km^2) of different land use types per scenario and % changes in the area relative to 2020.

Land use type	2020	Sustainability scenario		Regional rivalry scenario		Fossil-fuelled development scenario	
	Area (km^2)	Area (km^2)	% Change	Area (km^2)	% Change	Area (km^2)	% Change
Urban	19.316	19.316	0	19.316	0	23.14	3.82

Cropland	12.923	9.775	-3.14	7.908	-5.01	12.923	0
Pasture	29.962	21.789	-8.17	29.484	-0.48	29.814	-0.15
Forestry	37.995	37.142	-0.85	37.898	-0.1	35.691	-2.3

4. Conclusions

Land use projections with a finer spatial resolution can be used in conjunction with environmental models to analyse the impacts of land use change on the Earth's system under various emission and socioeconomic scenarios. To simulate multiple land use transitions under uncertain future conditions, complex linkage and feedback mechanisms must be understood. This protocol extends and explains the land-use allocation method used by the GLOBIO4 model to simulate land use changes around the pond at the local level (10m) under several SSP-RCP scenarios. land use demands were extracted using the downscaled LUH2 data set at 100 m of deliverable 3.7 (the areas of urban, cropland, pasture, and forestry). Next, the totals per region were allocated to 10m cells with the GLOBIO4 land allocation routine, with specific suitability layers for urban, cropland, pasture, and forestry. The allocation algorithm then prioritizes candidate grid cells according to their suitability values and allocates the claims of each land-use type in each region starting from the cells with the highest suitability until the total claim is allocated. In the allocation a predefined order is followed, where urban land takes precedence over cropland (D'Amour et al., 2017) and cropland in turn takes precedence over pasture (Hasegawa et al., 2017). Forestry and pasture are allocated thereafter, such that forestry is allocated within remaining forest areas, and reflecting that grazing typically takes place in areas not productive enough for crops (Hasegawa et al., 2017). Claims relative to a preceding scenario- year are allocated per scenario-year combination. If for a given land-use type in each region there are multiple cells with the same suitability, the allocation is done randomly. If the land claim allocated in a given scenario-year is smaller than the claim allocated in the preceding scenario-year, cells are abandoned in reverse order of suitability and assigned to bare/sparse vegetation. This protocol successfully downscaled the LUH2 data set to 10 m at the local level for Hasselt, Belgium, using the GLOBIO4 land allocation routine. Our findings show the changes in the pond's surrounding land uses under different scenarios. We highlight the significant potential for including stakeholder scenarios into the model with shifting claims for various land use types based on stakeholder willingness in the recommended methodology (GLOBIO) for land use projection at the local level.

5. Further information

The output data from this model will be downloadable from the website of the Ponderful Models in the future.

The following data source were used for running the model.

a) https://land.copernicus.eu/pan-european/corine-land-cover

b) http://luh.umd.edu/data.shtml

c) https://www.iucn.org/theme/protected-areas/our-work/quality-and-effectiveness/world-database-protected-areas-wdpa

d) https://worldmap.harvard.edu/data/geonode:Digital_Chart_of_the_World

e) https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1

f) http://www.fao.org/faostat/en/#data/RL

g) http://www.fao.org/faostat/en/#data/RL

h) https://github.com/GLOBIO4/GlobioModelPublic/wiki

i) https://esa-worldcover.org/en

All the codes are provided in a GitHub repository.

https://github.com/GLOBIO4/GlobioModelPublic

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