

Variables used in the code of the model

The model is composed mainly of global and patch variables. However, we added also one-type turtles (agents) with only one variable that is used for the HubNet functionality of the model which allows live interactive simulation of the model through connecting remote clients representing actors in role-playing games or with real actors in the system.

Global variables

| Variables | Definition |
|--|---|
| Yield; Yield-A; Yield-C; EC; EC-A; EC-C; CS; Water; Water-A; Water-C; Biodiversity | The imported GIS shape files of the demand for the five ecosystem services (ESS) by actors A, B and C (i.e., The whole vector geodata file with all attributes; EC = erosion control; CS = carbon sequestration; water = water availability). N.B. Actor B has demand for CS and biodiversity, actor A and C have demand for the other three ESS. |
| LS | Agent-set for patches within the boundaries of the case study areas. |
| ESS-type-list | A list variable ¹ containing a sequential item numbers [0 1 2 3 4] corresponding to the five ESS [yield, EC, CS, water availability, biodiversity], respectively, used for calling items in other lists. |
| actors | A list variable containing a sequential item numbers [0 1 2] corresponding to the three dummy actors [A B C], respectively, used for calling them in other lists. |
| D-1; D-2; D-3 | Three list variables each contains the demands for the five ESS at the three potential demand areas (site 1, 2 and 3), respectively by the selected actor. It is used for displaying the values of the demand on the information board after selecting the actor, the ESS and then pressing show-demand button. It is used also for showing the supply-demand match patches and applying potential demands. |
| CSA | A variable to which the Corine Land Cover (CLC) GIS vector dataset of the three CSAs is imported. |
| output_file | A variable to which the map display is exported and stored as a raster geodata file in the assigned destination in the procedure. The exported geodata are: the demand, the supply, the supply-demand gap and the risk of conflict. |
| duration | A variable used for identifying the temporal scale until which the model runs. |
| month-num | A numerical value corresponding to the month number that is used to calculate until which month the model runs. |

Turtles variables

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|---------|---|
| user-id | A variable reports the ID of the connected clients while operating the HubNet function. |
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Patch variables

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|---------------------------|---|
| r; b; g | Three variables to which the RGB (red, blue, green) attribute values is imported from the CLC GIS vector dataset file so that it displays the standard CLC color. |
| label-1; label-2; label-3 | Three variables to which the three levels of labelling the CLC is imported so that the land use type can be displayed on the information board. |

¹ List variable is a variable that includes a list of values for different parameters. In this model, we developed list variables mainly for the five ESS and for the three actors.

| | |
|--|--|
| city-ID | A variable to which the objectID attribute of CLC shape files is imported. It is used to delineate the CSA and in creating the agent-set LS. |
| S-yield; S-ec; S-cs; S-w; S-bio | These are five variables to which the supply raster GIS data of the five ESS are imported. |
| S-ESS | A list variable made of five items listing the values of the supply level of the five ESS in a similar order to the ESS-type-list global variable. |
| D-yield; D-yield-A; D-yield-C; D-ec; D-ec-A; D-ec-C; D-cs; D-cs-B; D-w; D-w-A; D-w-C; D-bio; D-bio-B | These are single variables to which the demand value attribute in the imported demand GIS vector dataset is given. |
| D-A; D-B; D-C; D-N; D-all | List variables corresponding to each actor made of five items listing the values of the demand level for the five ESS. D-N is the demand of a new actor. D-all lists the demands for the five ESS by all actors in that patch, however, it contains only the value of the overlaying demand layer in case two or more actors have a demand in the same patch. They are created from the previous single variables to facilitate further procedures. |
| D-yield-A-ID; D-yield-C-ID; D-ec-A-ID; D-ec-C-ID; D-cs-B-ID; D-w-A-ID; D-w-C-ID; D-bio-B-ID | These are single variables to which the location ID attribute of the imported demand GIS vector dataset is given. |
| D-A-ID; D-B-ID; D-C-ID | List variables corresponding to each actor made of five items listing the values of location ID for the five ESS. They are created from the previous single variables and used to show the values of the demand of each drawn polygon separately in the information board. |
| G-ESS | A list variable made of five items listing the values of supply-demand gap of the five ESS. It reports a ratio of the supply/demand such that when supply equals to demand, it shows a value of 1; if the supply is more than the demand, it gives a value > 1 to a maximum <10 (i.e. supply = 100 and demand = 10); if the supply is less than the demand, it gives a value < 1 to a minimum > 0.01 (i.e. supply = 1 and demand = 100). All values => 10 or =< 0.01 are assigned zero values. |
| G-A; G-B; G-C | These variables filter the list variables D-A, D-B and D-C to values showing demands. The aim of these variables is to display on the view the patches with intersecting demands by the actors which functions using show-intersect button after selecting the intersecting actors. |
| Conf | A variable reports the value of the calculated risk of conflicts. |
| L | It reports the maximum supply potential. In our example we set a constant value of 100 since the supply values are in percent. |
| g2 | It reports the natural restoration rate of the ESS without human intervention. |
| n | It reports the rate of depletion of the supply of ESS due to natural external factors. |
| f | The fraction of the capital which the actor specifies his/her maximum efforts to be applied on the management options. When less than 1, it guarantees that the actor keep some reserves of his/her capital to survive in the system. This is used only under the competitive-gradient decision rule scenario. |
| K-1; K-2; K-3; K-4; K-5; K-6; K-7; K-8; K-9; K-10; K-11; K- | List variables of three items showing the initial capitals of the three actors in terms of 15 parameters representing five types of capitals (three parameters per each capital). |

12; K-13; K-14; K-15

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|---|---|
| d_x; d_y; d_z; d_l; d_m | List variables of three items showing the demands for the five ESS by the three actors (x, y, z, l and m corresponds to yield, EC, CS, water and biodiversity, respectively). They reflect the natural capital of the actors. |
| wt-1; wt-2; wt-3; wt-4; wt-5; wt-6; wt-7; wt-8; wt-9; wt-10; wt-11; wt-12; wt-13; wt-14; wt-15 | List variables of three items containing the weights (preferences) of the 15 parameters by the three actors. |
| r_x; r_y; r_z; r_l; r_m | List variables of three items including the preferences to the five ESS by the three actors. |
| MO-data-effort | A list of three list variables each is made of 15 items and contains the initial efforts taken from the 15 parameters of the capitals by applying one management option to increase the supply of ESS (i.e. the costs of the ESS). The three lists corresponds to the three management options under investigation. |
| MO-data-utility | A list of three list variables each is made of 15 items and contains the initial unit utility to be added to the 15 parameters of the capitals by applying one management option to increase the supply of ESS (i.e. the prices of the ESS). The three lists corresponds to the three management options under investigation. |
| MO-data-utility-elasticity | A list of three list variables each is made of 15 items and contains the elasticity of the unit utility of the ESS in terms of the 15 parameters of the capitals and for each management option. |
| efficiency | A list of three list variables each is made of five items and contains the efficiency (i.e. impact) of the management options on the supply of the ESS. |
| norm_efficiency | Similar to the previous variable but contains normalized values. |
| maximum-parameters | A list variable of 15 items containing the maximum values of the 15 parameters and used to normalize the capitals, the efforts and the unit utilities. |
| parameter-list | A list variable of 15 sequential item numbers that is used for calling items in similar size list variables in some procedures. |
| q | A conditional list variable of one of the three efficiency list variables according to the selected management option. |
| norm_q | A conditional list variable of one of the three norm_efficiency list variables according to the selected management option. |
| efforts | A conditional list variable of one of the three MO-data-effort list variables according to the selected management option. |
| values | A conditional list variable of one of the three MO-data-utility list variables according to the selected management option. |
| elasticity | A conditional list variable of one of the three MO-data-utility-elasticity list variables according to the selected management option. |
| norm-C | A list variables of 15 items containing the normalized values of efforts |
| norm-a | A list variables of 15 items containing the normalized values of "values" variable |
| norm-a-tot | The sum of items in norm-a variable |
| norm-C-tot | The sum of items in norm-C variable |
| a-share | A list variable containing the share of each parameter of the 15 in the values. |
| C-share | A list variable containing the share of each parameter of the 15 in the efforts. |

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| q_x; q_y; q_z; q_l; q_m | List variables of three items containing similar values of the efficiency of the five ESS for the three actors (inverse matrix of q). Although this is dependent on the management option, however, it is built here per actor to facilitate the calculations in other procedures. |
| C-1; C-2; C-3; C-4; C-5; C-6; C-7; C-8; C-9; C-10; C-11; C-12; C-13; C-14; C-15 | List variables of three items containing similar values of the normalized efforts per each parameter for the three actors created to facilitate further procedures and to assess the impact on each individual parameter. |
| a-1; a-2; a-3; a-4; a-5; a-6; a-7; a-8; a-9; a-10; a-11; a-12; a-13; a-14; a-15 | List variables of five items containing the contribution of each ESS to the normalized initial unit utility gained over the 15 parameters. This is used to assess the impact on each individual parameter. |
| b2-1; b2-2; b2-3; b2-4; b2-5; b2-6; b2-7; b2-8; b2-9; b2-10; b2-11; b2-12; b2-13; b2-14; b2-15 | List variables of five items containing the contribution of each ESS to the elasticity of the initial unit utility gained over the 15 parameters. In other words, it represents the change in the unit utility of the 15 parameters with the change in each ESS. |
| a | A list variable of five items containing the summation of the normalized initial unit utility of the 15 parameters (sum a-1 – a-15) over the five ESS. |
| b2 | A list variable of five items containing the summation of the elasticity of the initial unit utility of the 15 parameters (sum b2-1 – b2-15) over the five ESS. |
| K | A list variable of three items containing the summation of the normalized initial capitals in terms of the 15 parameters for the three actors. (sum K-1 – K-15). |
| C | A list variable of three items containing the summation of the normalized efforts in terms of the 15 parameters for the three actors. (sum C-1 – C-15). |
| C-x; C-y; C-z; C-l; C-m | List variables of three items containing the allocation of efforts towards the five ESS (x, y, z, l and m) by the three actors based on their preferences (r). |
| K-0 | A copy list variable of K but this remains as the initial total capital whereas K changes while running the model. It is used to calculate the share of each parameter in the total capital. |
| C-fin; C-soc; C-phy; C-hum; C-cul | List variables of three items containing the share of efforts in each capital type for the three actors. |
| K-fin; K-soc; K-phy; K-hum; K-cul | List variables of three items containing the share of capitals in each capital type for the three actors. |
| K0-1; K0-2; K0-3; K0-4; K0-5; K0-6; K0-7; K0-8; K0-9; K0-10; K0-11; K0-12; K0-13; K0-14; K0-15 | List variables of three items containing the share of each parameter in the total capital for the three actors. |
| K-plot | A temporary list variable of three items used to plot the capitals of the three actors. The default items is the total capital but it plots any capital type if selected from the drop-down button “Capital” or any parameter if selected from the drop-down button “Indicator”. |
| C-plot | The same as the previous one but for the efforts instead. |
| x_per_x; x_per_y; x_per_z; x_per_l; x_per_m | List variables of three items containing the perceived supply of the five ESS by the three actors. |

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| c_x; c_y; c_z; c_l; c_m | List variables of three items containing the inverse of unit efforts that are applied to make a unit change in the supply of the five ESS by the three actors. |
| harv_x; harv_y; harv_z; harv_l; harv_m | List variables of three items containing the added supply of the five ESS by the three actors. |
| u_x; u_y; u_z; u_l; u_m | List variables of three items containing the self-benefits per each ESS for the three actors. It is used for the calculation of the first part of the marginal value and for the calculation of the utility. |
| u | List variables of three items containing a summation of the self-benefits of the five ESS from the previous variable. This is used for the calculation of the utility (first component) and the change of efforts (last component). |
| f_x; f_y; f_z; f_l; f_m | List variables of three items containing the effective effort per each ESS for each actor which is applied in the cooperative scenario. |
| w1_x; w2_x; w3_x; w1_y; w2_y; w3_y; w1_z; w2_z; w3_z; w1_l; w2_l; w3_l; w1_m; w2_m; w3_m | List variables of three items containing the mutual-benefits for each actor from each ESS. This is used for the calculation of the marginal value of the five ESS for actor 1, 2 and 3 the sum of which represents the middle part of calculating the utility. |
| w_x; w_y; w_z; w_l; w_m | List variables of three items replicating one item of the previous variables representing the benefits from self-efforts. It is used for calculating the marginal value. |
| sum_w_c_x; sum_w_c_y; sum_w_c_z; sum_w_c_l; sum_w_c_m | List variables of three items that sums up the items in the list variables containing the mutual benefits (e.g. sum_w_c_x = [a, b, c]; a = [sum items in w1_x], b = [sum items in w2_x], c = [sum items in w3_y]). It represents the middle part in calculating the marginal value. |
| w1; w2; w3 | List variables of three items containing the summation of the mutual benefits from the five ESS weighted by the preferences of the actors 1, 2 and 3. |
| w | List variables of three items containing the summation of the benefits of self efforts from the five ESS weighted by the preferences of the actors. |
| sum_w_c | List variables of three items that sums up the items in w1, w2 and w3. It represents the middle part in calculating the change in investments and the last part in calculating the utility. |
| V | A list variable of three items containing the utility gained by the three actors. |
| V-fin; V-soc; V- phy; V-hum; V-cul | List variables of three items containing the share of the utility in each capital type for the three actors. |
| V-1; V-2; V-3; V-4; V-5; V-6; V-7; V-8; V-9; V-10; V-11; V-12; V-13; V-14; V-15 | List variables of three items containing the share of the utility in each parameter for the three actors. |
| V-plot | A temporary list variable of three items used to plot the utility of the three actors. The default item is the total utility but it plots for any capital type if selected from the drop-down button "Capital" or for any parameter if selected from the drop-down button "Indicator". |
| C_max | A list variable of three items containing the maximum efforts set by each actor based on the fraction f. |
| v_x; v_y; v_z; v_l; v_m | List variables of three items containing the marginal values of the five ESS for the three actors. |

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| growth | A list variable of five items containing the natural change in the supply of the ESS without applying management options. |
| tot_harv | A list variable of five items containing the added supply of the ESS by all actors summed over the actors. |
| Price | A list variable of five items containing the unit utility of each ESS. |
| P-fin; P-soc; P-phy; P-hum; P-cul | List variables of five items containing the share of the unit utility in each capital type. |
| P-1; P-2; P-3; P-4; P-5; P-6; P-7; P-8; P-9; P-10; P-11; P-12; P-13; P-14; P-15 | List variables of five items containing the share of the unit utility in each parameter. |
| Price-plot | A temporary list variable of five items used to plot the unit utility of the five ESS. The default items is the total unit utility over all parameters but it plots for any capital type if selected from the drop-down button “Capital” or for any parameter if selected from the drop-down button “Indicator”. |
| f_sum | A list variable of five items containing the joint effective efforts of all actors for changing the supply of the five ESS in the cooperative scenario. |
| f_targ | A list variable of five items containing the target joint effective effort for the five ESS. |
| C_targ | A list variable of three items containing the target efforts by the three actors in the competitive-optimizing scenario. |
| r_x_targ; r_y_targ; r_z_targ; r_l_targ; r_m_targ | List variables of three items containing the target preferences to the five ESS by the three actors in the competitive-optimizing scenario. |
| phi_x; phi_y; phi_z; phi_l; phi_m | List variables of three items containing the share of each actor in the joint effective effort to change the supply of the five ESS. |
| rv_x; rv_y; rv_z; rv_l; rv_m | List variables of three items containing the marginal values of the five ESS weighted by the preferences of the actors. |
| sum_rv | A list variable of three items containing the summation of the weighted marginal value of the five ESS for the three actors. |
| tmp | A temporary list variable of five items used for visualizing the demand, match, and potential-demand on the view. |
| tmp2 | A temporary single variable used for exporting the supply, demand, gap and conflict data visualized on the view to a raster GIS file. |

Initial state of the model

Description of the actors

| Capital | Variable | Unit | A (Farmer, organic) | | B (Nature protection) | | C (Farmer, conventional) | |
|--|---|---------------------------|------------------------|--------|--------------------------|--------|-----------------------------|--------|
| | | | Value | Weight | Value | Weight | Value | Weight |
| Natural capital (Demand for ESS at one demand area, however, there are different values per each actor in each demand area) | <i>Yield</i> | % | 90 | 0.33 | 0 | 0.09 | 90 | 0.35 |
| | <i>Erosion control</i> | % | 80 | 0.29 | 0 | 0.09 | 60 | 0.23 |
| | <i>Biodiversity</i> | % | 0 | 0.04 | 80 | 0.41 | 0 | 0.04 |
| | <i>Water availability</i> | % | 70 | 0.25 | 0 | 0.05 | 80 | 0.31 |
| | <i>Carbon sequestration</i> | % | 0 | 0.09 | 90 | 0.36 | 0 | 0.07 |
| Financial capital | <i>Income</i> | € | 100,000 | 0.06 | 36,000 | 0.01 | 300,000 | 0.01 |
| | <i>Expenditure</i> | € | 60,000 | 0.103 | 26,000 | 0.103 | 200,000 | 0.06 |
| | <i>Savings</i> | | 40,000 | 0.06 | 10,000 | 0.05 | 100,000 | 0.13 |
| Social capital | <i>Social insurance</i> | % | 100 | 0.06 | 100 | 0.103 | 100 | 0.103 |
| | <i>Health insurance</i> | % | 100 | 0.09 | 100 | 0.05 | 100 | 0.05 |
| | <i>Agricultural insurance</i> | % | 100 | 0.03 | 0 | 0.05 | 100 | 0.13 |
| Physical capital | <i>Equipment and tools (Inv.)</i> | € | 5,000 | 0.04 | 2,000 | 0.05 | 100 | 0.03 |
| | <i>Internet Network</i> | Mbits/sec | 100 | 0.06 | 10 | 0.06 | 10 | 0.04 |
| | <i>Vehicles/transportation means (Inv.)</i> | € | 50,000 | 0.15 | 5,000 | 0.09 | 2,000 | 0.04 |
| Human capital | <i>Health</i> | Likert (1-5) | 5 | 0.07 | 3 | 0.04 | 1 | 0.09 |
| | <i>Nutrition</i> | Likert (1-5) | 5 | 0.103 | 3 | 0.103 | 1 | 0.013 |
| | <i>Skills</i> | Likert (1-5) | 3 | 0.03 | 2 | 0.08 | 1 | 0.09 |
| Cultural capital | <i>Celebration</i> | Nr. of participation/year | 0 | 0.015 | 5 | 0.06 | 4 | 0.08 |
| | <i>Beliefs</i> | % of practice | 80 | 0.09 | 80 | 0.07 | 30 | 0.013 |
| | <i>Traditions</i> | % of follow | 10 | 0.04 | 80 | 0.06 | 90 | 0.12 |

Description of the management options

| | Unit | Effort | | | Utility | | |
|--------------------------------------|--------------|---------------|-----------|--------------|--|----------------------------|----------------------------|
| Variable | | Smart farming | Hedgerows | Agroforestry | Smart farming | Hedgerows | Agroforestry |
| Yield | % | - | -0.2% | - | 0.4% | | 0.2% |
| Erosion control | % | - | - | - | 0.8% | 0.5% | 0.4% |
| Carbon sequestration | % | - | - | - | 0.4% | 0.9% | 0.2% |
| Water availability | % | - | - | - | 0.6% | 0.2% | 0.1% |
| Biodiversity | % | - | - | - | 1.2% | 0.9% | 0.4% |
| Income | € | - | 30,000 | 50,000 | 200,000 | - | 10,000 |
| Expenditure | € | 10,000 | 20,000 | 40,000 | - | - | - |
| Savings | € | - | - | - | - | - | - |
| Social insurance | | - | - | - | -10%/yr | - | -5% per yr |
| Health insurance | % | - | - | - | - | - | -5% per yr |
| Agricultural insurance | % | - | - | - | - 10%/yr | -5% per yr | -5% per yr |
| Equipment and tools (Inv.) | % | - | - | - | 30,000 (sensors, robots, weather stations, computer) | 10,000 (Sensors/ computer) | 10,000 (Sensors/ computer) |
| Internet Network | € | - | - | - | 200 (Stations, cables) | 100 (Stations) | - |
| Vehicles/transportation means (Inv.) | Mbits /sec | - | - | - | 50000 (Computer-aided tractors) | - | - |
| Health | € | 0.1 | - | - | - | 0.25 | 0.35 |
| Nutrition | Likert (1-5) | - | - | - | 1 | 0.25 | 0.35 |
| Skills | Likert (1-5) | - | - | - | 1 | - | - |

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|-------------|--------------------------|---|---|-------------------------------|---|--------------------------------------|---|
| | | | | | IT | | |
| Celebration | Likert (1-5) | 1 | - | - | - | - | 0.25 |
| Beliefs | Nr. of participants/year | 10%/yr Analog ue/ conventional system, use of chemical fertilizers, pesticides | - | 5% chemical fertilizers | 10%/yr Digitalization, organic farming, food quality | 10%/yr Biodiversity importance | 5%/yr Environmental protection, organic farming and ESS |
| Traditions | % of practice | 20%/yr | - | - | - | - | 5% |

| Variable | Elasticity of unit utility | | | Maximum value For normalization |
|--------------------------------------|----------------------------|-----------|--------------|------------------------------------|
| | Smart farming | Hedgerows | Agroforestry | |
| Income | 0.1 | 0 | 0.1 | 1000000 |
| Expenditure | 0 | 0 | 0 | 500000 |
| Savings | 0 | 0 | 0 | 10000000 |
| Social insurance | 0.1 | 0 | 0.1 | 100 |
| Health insurance | 0 | 0 | 0.1 | 100 |
| Agricultural insurance | 0.1 | 0.1 | 0.1 | 100 |
| Equipment and tools (Inv.) | 0.1 | 0.1 | 0.1 | 100000 |
| Internet Network | 0.1 | 0.1 | 0 | 300 |
| Vehicles/transportation means (Inv.) | 0.1 | 0 | 0 | 200000 |
| Health | 0 | 0.1 | 0.1 | 5 |
| Nutrition | 0.1 | 0.1 | 0.1 | 5 |
| Skills | 0.1 | 0 | 0 | 5 |
| Celebration | 0 | 0 | 0.1 | 5 |
| Beliefs | 0.1 | 0.1 | 0.1 | 100 |
| Traditions | 0 | 0 | 0.1 | 100 |

Minimum values for normalization = 0

Potential supply = 100

Restoration rate = 0.002

Rate of depletion due to external factors = 0.0002

Fraction of capital for maximum effort calculation = 0.9

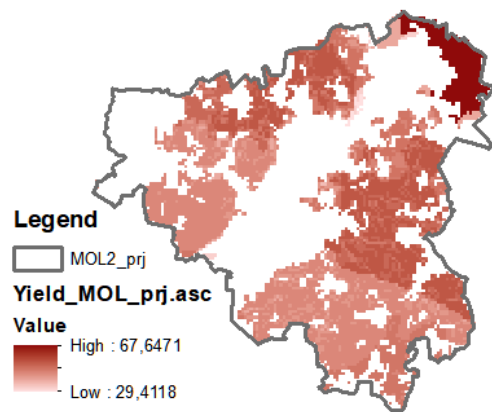
| Scenario | alpha | kappa | gama |
|------------------------|-------|-----------|------|
| Competitive-gradient | 0.005 | 0.000002 | N.A. |
| Competitive optimizing | 0.05 | 0.0000002 | N.A. |
| Cooperative-optimizing | N.A. | N.A. | 0.03 |

Supply geodata

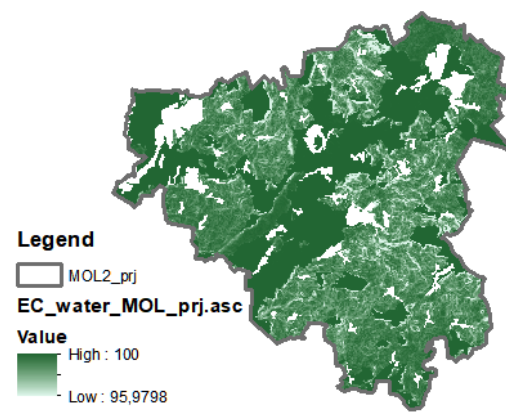
| ESS | Indicator | Unit | Max* | Min* | Data type | Resolution | Year | Source ** |
|----------------------|---|----------------|---------|----------|-----------|------------|------|-----------|
| Yield | Ackerbauliches Ertragspotential der Böden (Soil Quality Rating) | Ranking Points | 102 | 0 | Raster | 250 m | 2013 | BGR |
| Erosion control | Soil erosion by water | tons/ha/a | 325 | 2.96E-05 | Raster | 100 m | 2015 | JRC ESDAC |
| Carbon sequestration | Organic carbon content in the surface horizon of soils | % | 63 | 0 | Raster | 1 km | 2004 | JRC ESDAC |
| Water availability | Pflanzenverfügbares Wasser im Sommerhalbjahr (The plant available water in Summer in Germany) | mm | 1845.34 | 323.34 | Raster | 250 m | 2015 | BGR |
| Biodiversity | High nature value (HNV) farmland (Aggregated to 1km) | % | 100 | 0 | Raster | 1 km | 2012 | EEA |

* These are the minimum and maximum values in Germany which is used for the normalization of the values used in the CSA so that we have values between 0 and 100. We used Equation 6 for the normalization.

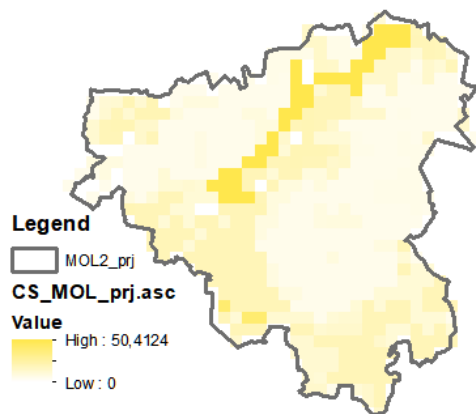
**BGR = Die Bundesanstalt für Geowissenschaften und Rohstoffe; JRC ESDAC = Joint Research Centre European Soil Data Centre; EEA = The European Environment Agency



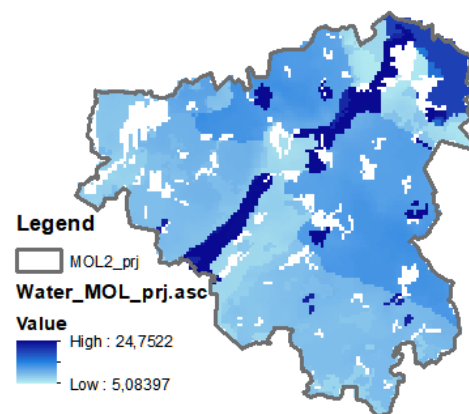
Yield



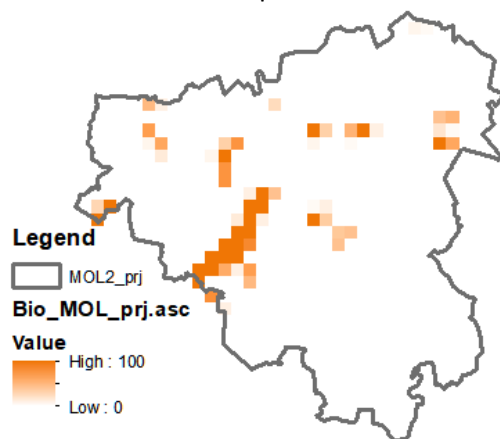
Erosion control
 (=100 – normalized erosion by water)



Carbon sequestration

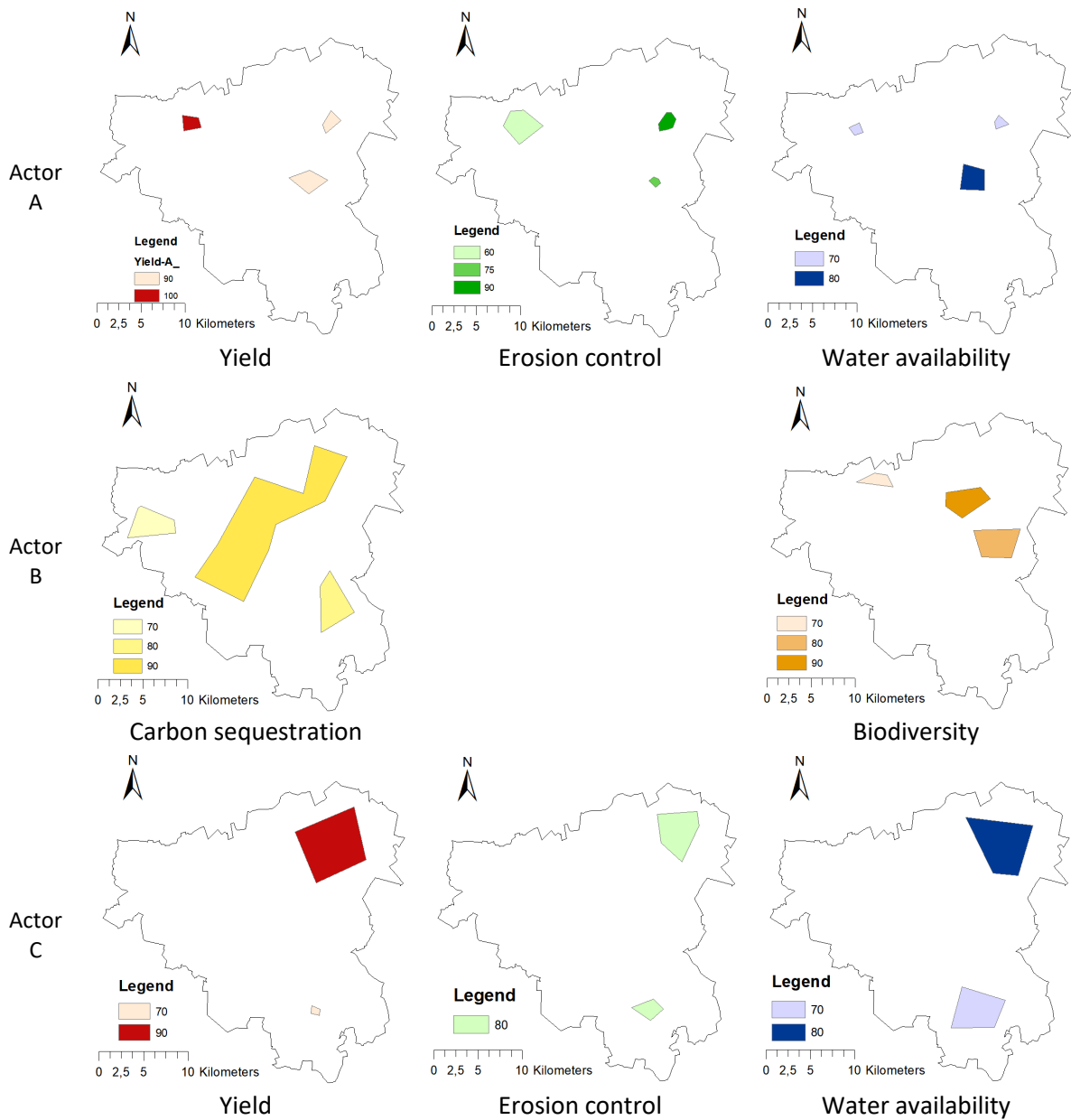


Water availability



Biodiversity

Demand maps



Corine Land Cover (CLC)

