An LCA-GIS INTEGRATED APPROACH for sustainable allocation of energy crops

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Research targets on energy crops

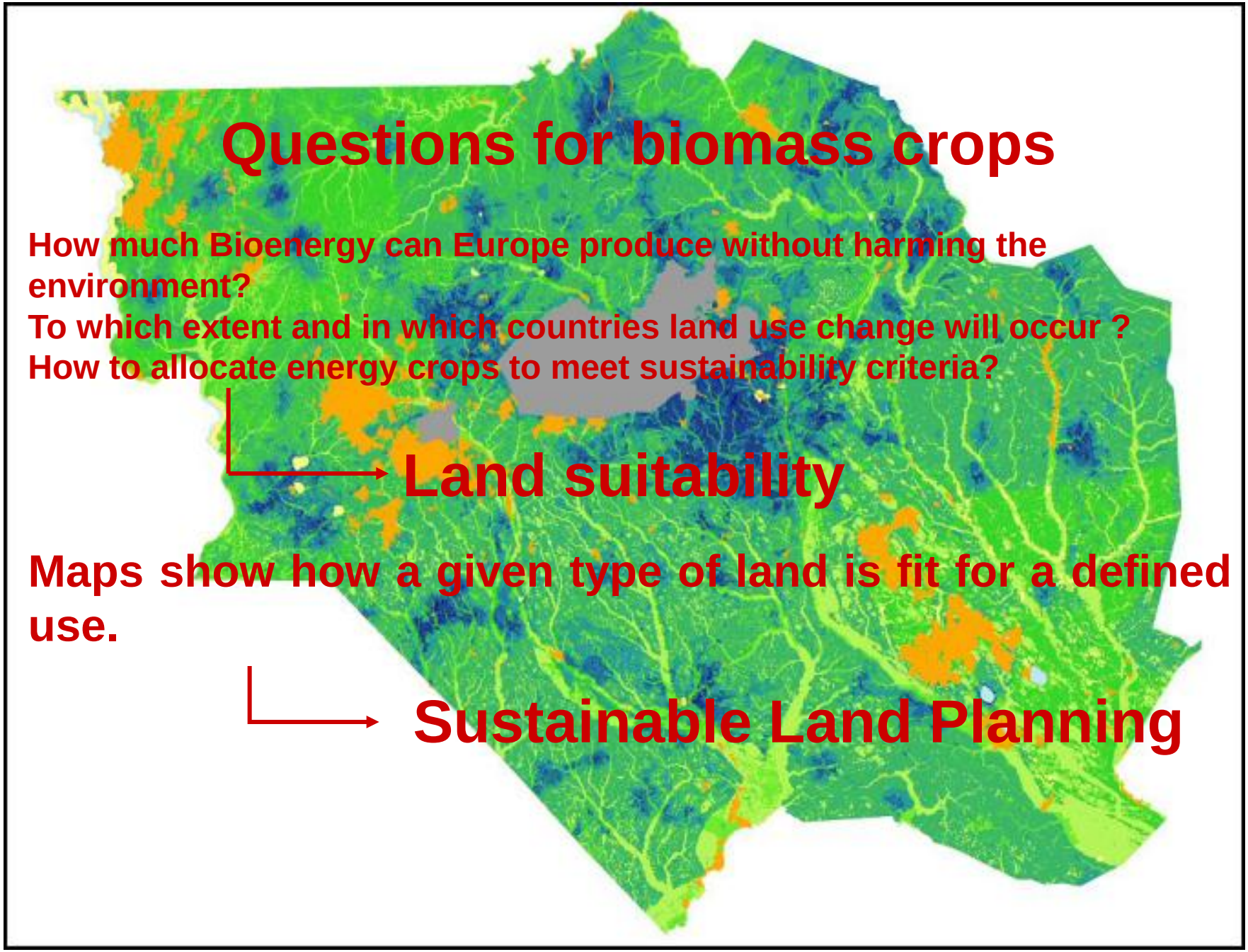
Agricultural sector

Genotypes matching the local environment. Agro-technique (low inputs, high yield: quality and quantity). *Best management techniques to combine yield maximisation and environmental sustainability. Impacts - Land use, land use change & land suitability.*

Economic sustainability of the production chain.

Industrial sector

- Adaptability of the products to the transformation plant.
- Adaptability of the transformation plant, conversion efficiency.
- Investigation on emissions and waste disposal.



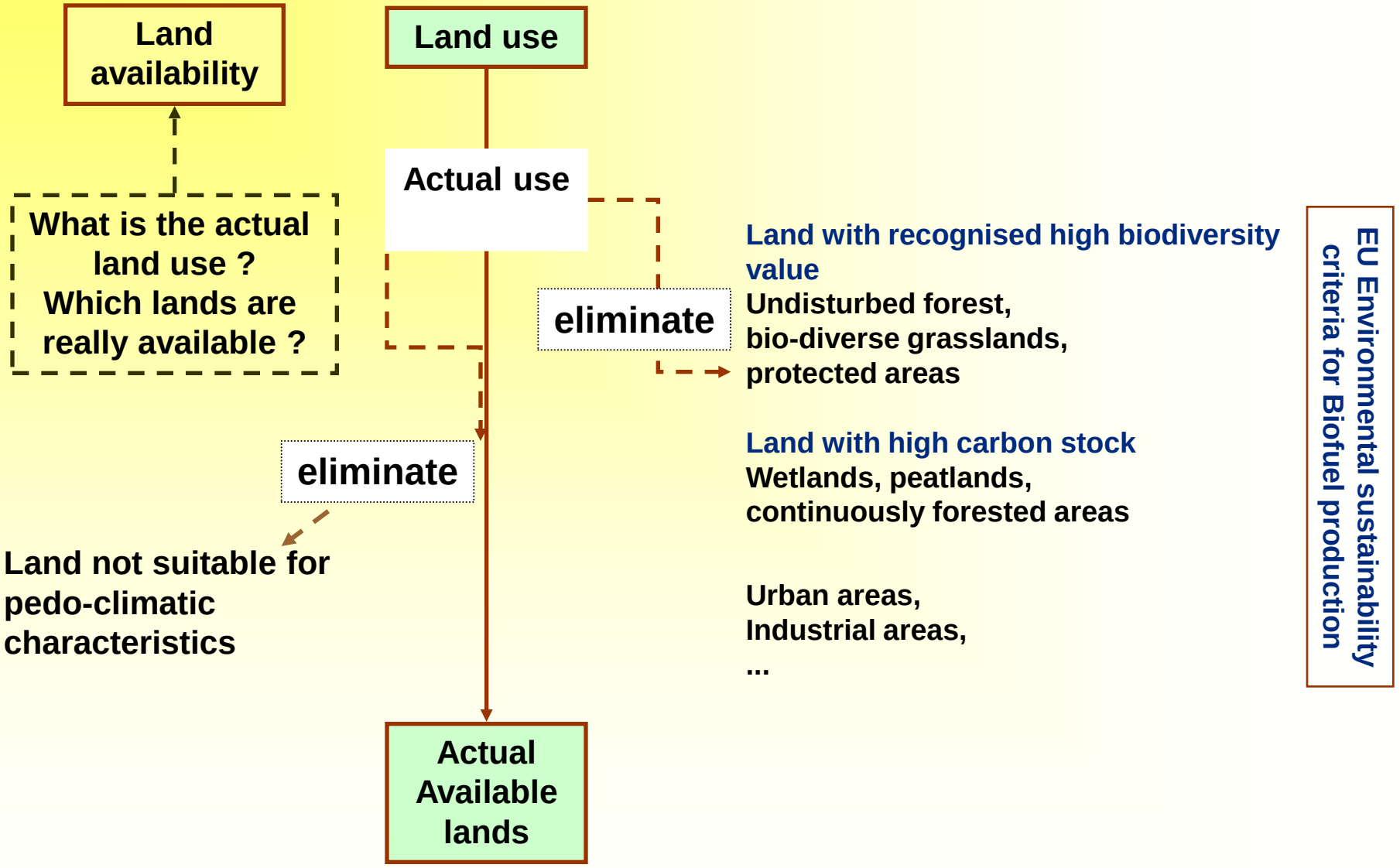
Questions for biomass crops

How much Bioenergy can Europe produce without harming the environment?
To which extent and in which countries land use change will occur ?
How to allocate energy crops to meet sustainability criteria?

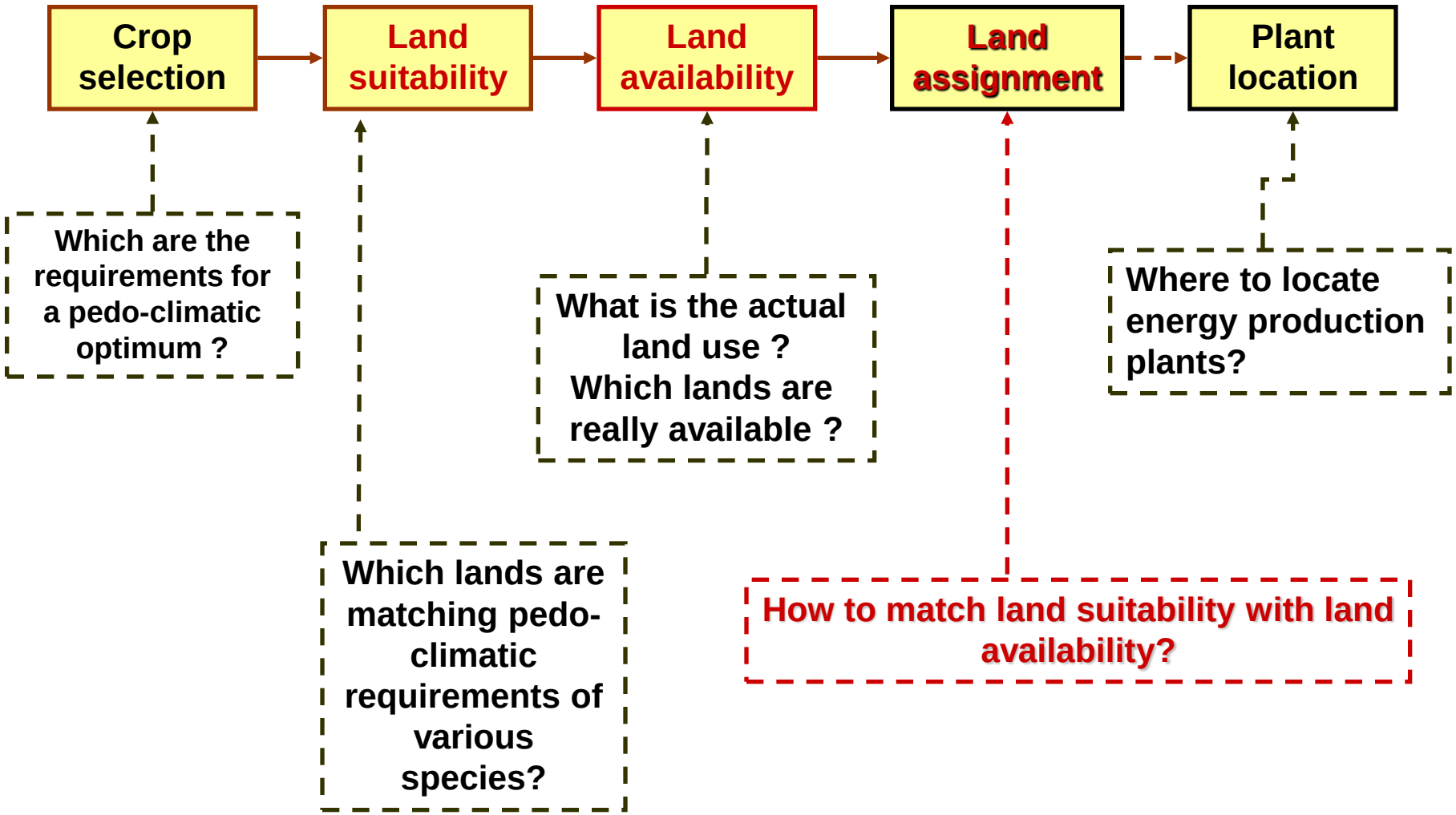
→ **Land suitability**

Maps show how a given type of land is fit for a defined use.

→ **Sustainable Land Planning**


Land availability
Land use
Actual use
What is the actual land use ? Which lands are really available ?
eliminate
Land with recognised high biodiversity value
Undisturbed forest, bio-diverse grasslands, protected areas
eliminate
Land with high carbon stock
Wetlands, peatlands, continuously forested areas
Land not suitable for pedo-climatic characteristics
Urban areas, Industrial areas, ...
Actual Available lands
EU Environmental sustainability criteria for Biofuel production

From biomass crop selection to energy plants location: a chain of decisions to mitigate risks and increase benefits



"Environment to Crop" oriented approach to land suitability

environmental aptitude to meet crop requirement

Environment

Land climate weather soil and terrain features

Crop issues
Crop production chain
Agro-technique, logistics
…

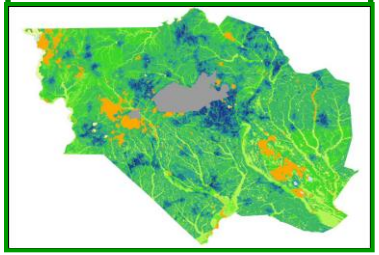
morphology
(slope, altitude)

soil features
(texture and depth, stability, drainage, pH, limestone, organic carbon, N, C/N ratio, P, Ca)

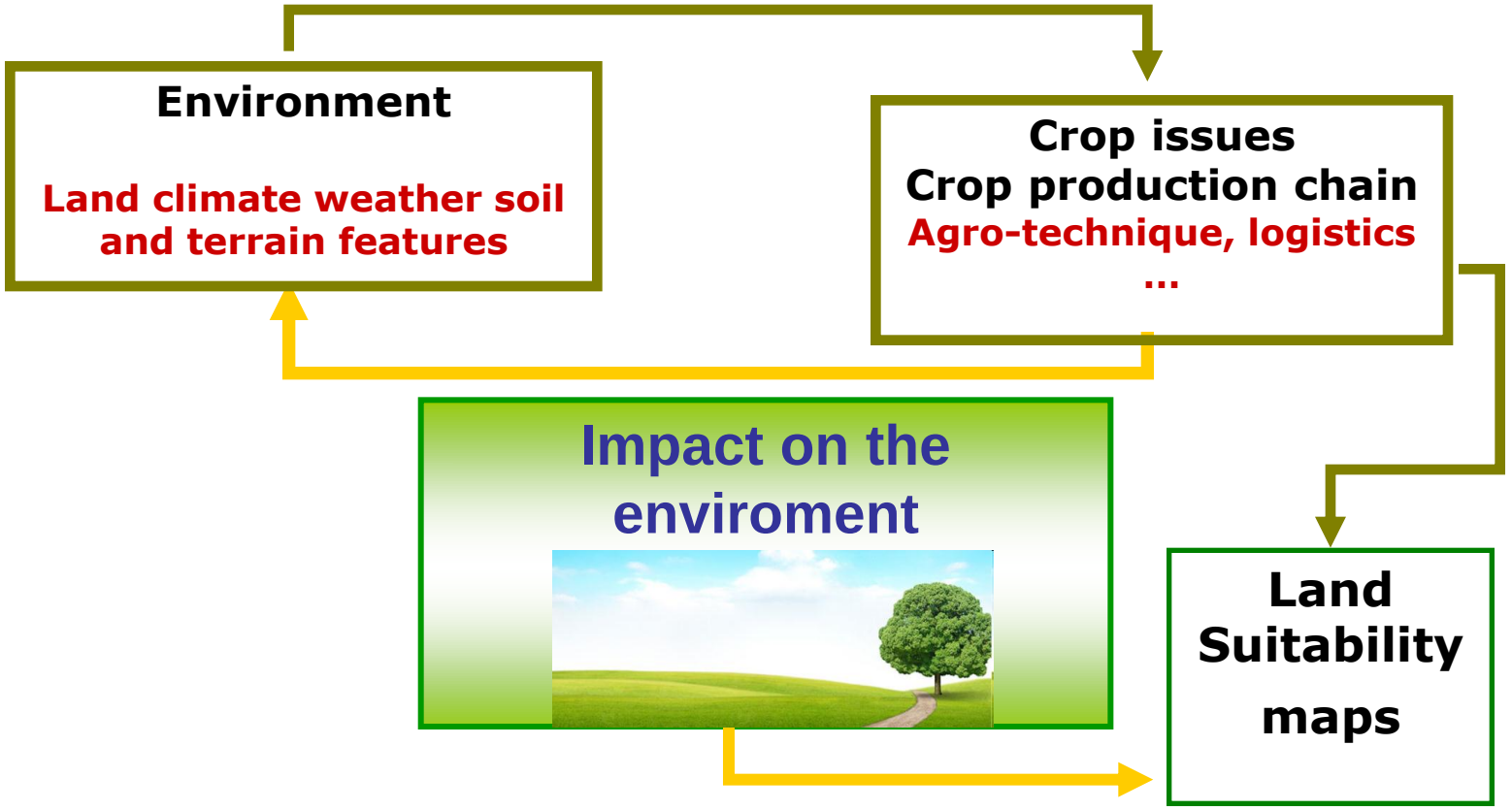
climate
(temperatures and precipitation regimes, accumulation of growing degree days)

Crop needs
Species, physiology, cv, farming

Land Suitability Maps



From the "Environment to Crop"
"Crop to environment" oriented approach



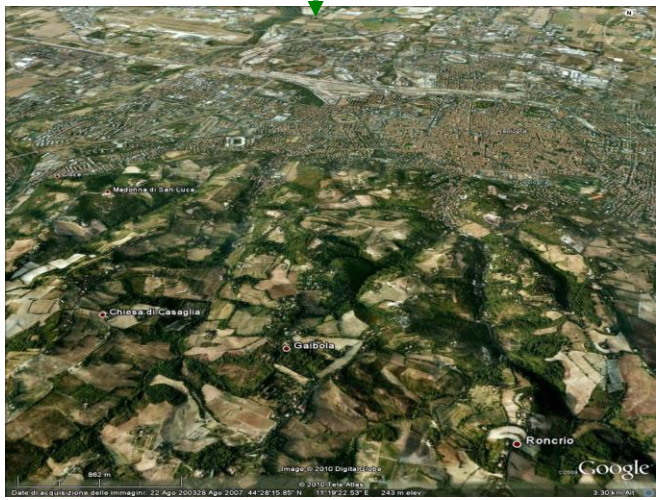
… the inclusion of the environmental impact of different biomass crops into land suitability is crucial, since the main stimulus to their spreading is based on environmental protection concepts.

LCA-GIS integrated decision support tool

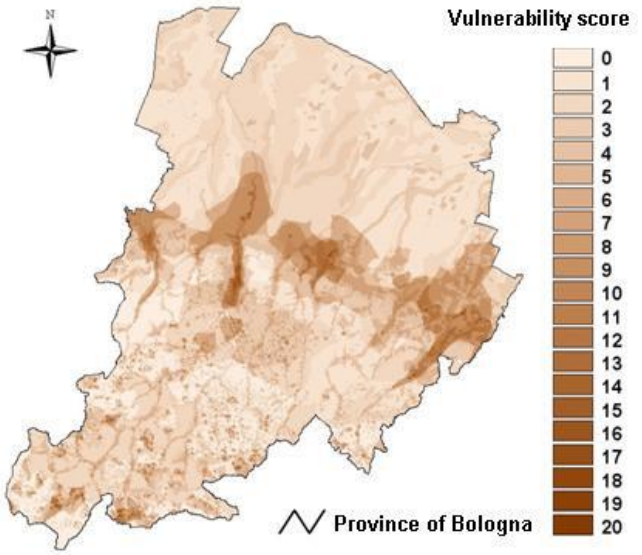
Biomass crops

Life Cycle Assessment (ecobalance, assembling impacts on categories (resource depletion, greenhouse effect, Ozone layer reduction, …)

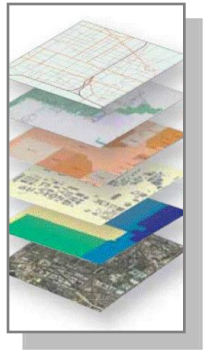
Impact indexes



Map of Land Vulnerability



GIS Geographic Information System framework



The output is the link between LCA impacts and landscape features, and defines site-specific land vulnerability to specific crop impact categories.

Case study

- **Annual crops**

Rapeseed **Sunflower** **Fibre sorghum**



⇩ Oil crops ⇩ Ligno-cellulosic crops

- **Perennial crops**

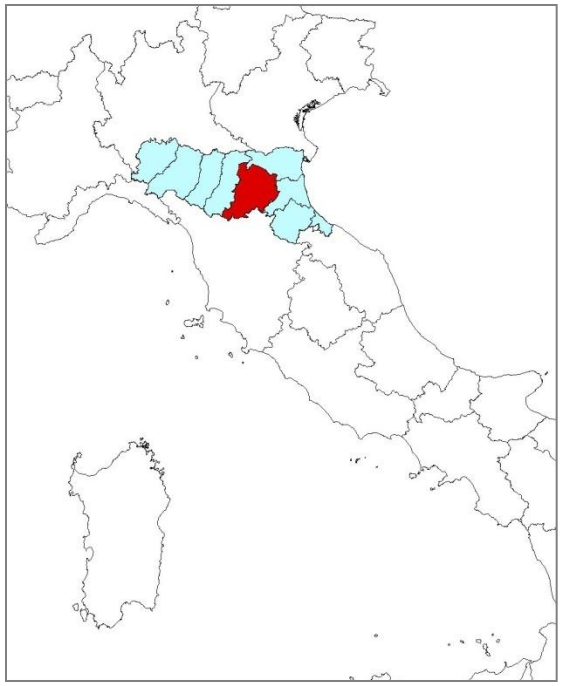
Switchgrass **Cardoon** **Arundo** **Miscanthus**




⇩ Ligno-cellulosic crops

- **Food crops** **Maize** **Wheat**

Province of Bologna
Emilia Romagna



LCA > **Eutrophication** and **Human Toxicity**

SimaPro 7.0 (PRè Consultants, Amersfoort, NL)

Impact indexes of Eutrophication and Human Toxicity.

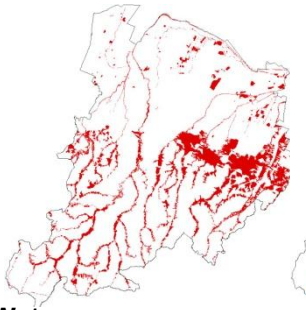
Eutrophication as kg ha^{-1} of phosphate ion equivalents (PO_4^{3-} eq.) and as % of the highest impacting crop (maize).
COMPOUNDS (PO4- NO, NO2- Nitrates, Ammonia)

Human toxicity as Kg ha^{-1} of 1,4-diclorobenzene equivalents (1,4-DC eq.) and as % of the highest impacting crop (maize).

Crop	PO_4^{3-} eq. (kg ha^{-1})	%	1,4-DC eq. (kg ha^{-1})	%	Total impact index	%
maize	**5,56**	**100,0**	**1810**	**100,00**	**7,37**	**100,00**
rapeseed	4,61	82,9	1150	63,54	5,76	78,15
f. sorghum	4,38	78,8	1360	75,14	5,74	77,88
sunflower	4,46	80,2	1150	63,54	5,61	76,12
wheat	4,37	78,6	1180	65,19	5,55	75,31
cardoon	1,85	33,3	738	40,77	2,59	35,12
miscanthus	1,67	30,0	709	39,17	2,38	32,28
arundo	1,64	29,5	661	36,52	2,30	31,22
switchgrass	1,37	24,6	474	26,19	1,84	25,02

No	Compound
1	PAH, polycyclic aromatic hydrocarbons
2	Chromium VI
3	Arsenic
4	PAH, polycyclic aromatic hydrocarbons
5	Hydrogen fluoride
6	PAH, polycyclic aromatic hydrocarbons
7	Hydrogen fluoride
8	Barite
9	Nickel
10	Nickel
11	Arsenic, ion

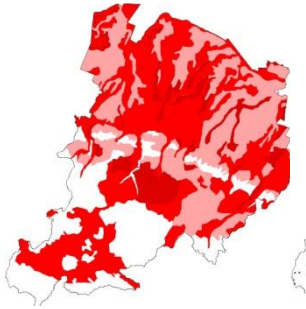
Thematic maps. Vulnerability to eutrophication



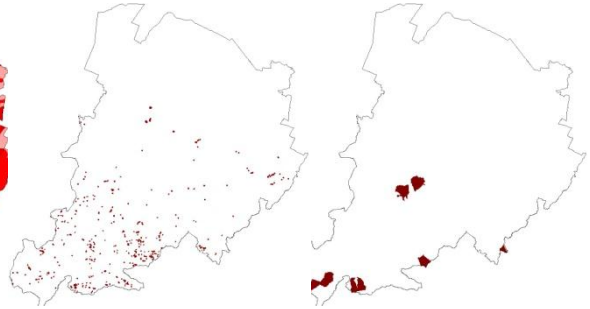
Wet areas

Fluvial terraces

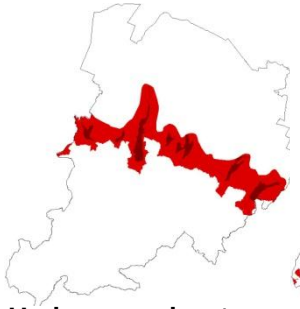
Nitrogen vulnerable lands



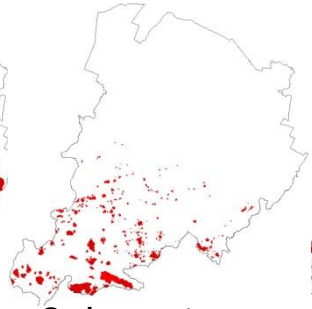
Soil map



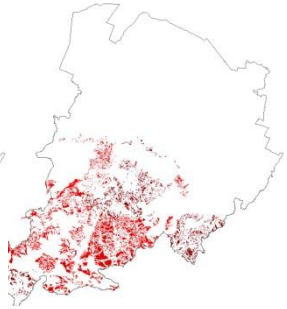
Springs buffer areas



Underground water buffer areas



Springs water basins



Water Recharge areas

Land Use Map 2003 and Water Protection Plan of the Emilia Romagna Region

Vulnerability score of land map attributes

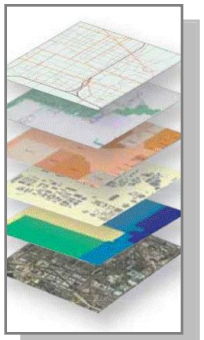
regular spatial grid (elementary pixel size 50 m)

Land map	Map attribute	**Vuln. score**
N vulnerable lands	Vulnerability to Nitrogen	**4**
Wet areas. Low lands generally flooded during winter or covered by water during all seasons. Riverbeds with vegetation. River valleys and wet areas (from the Land use Map 2003 of the Emilia Romagna Region)	Wet areas	**3**
Fluvial terraces and alluvial fans with high vulnerability of water	Fluvian terraces	**3**
Soil map 1:250000 from the Emilia Romagna Region Information service	fine texture medium texture	**1** **3**
Spring buffer zone	buffer areas for water springs	**4**
Water uptake areas	buffer areas for drinking water uptake	**4**
Undergroud water buffer zones. Fluvial terraces and alluvial fans with high vulnerability of water recharging	indirect direct	**3** **4**
Spring water basins	known uncertain	**4** **2**

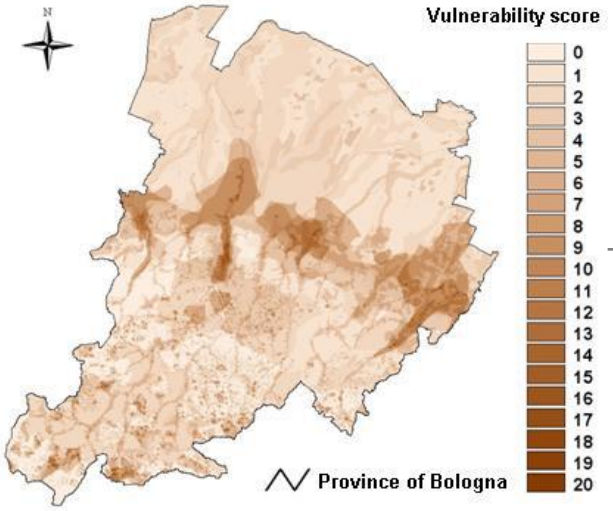
Map of Land Vulnerability to Eutrophication

Topological overlay

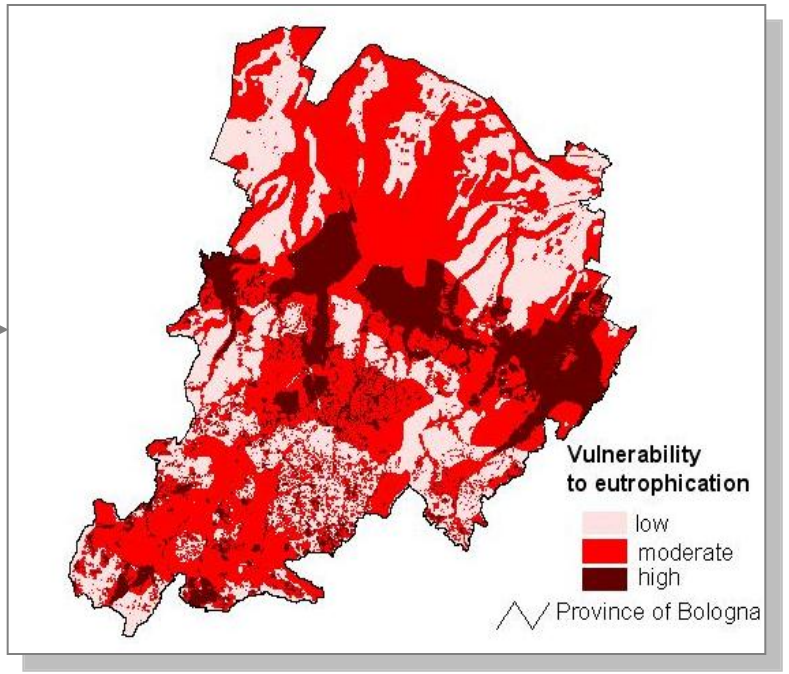
GIS framework



Map calculator tool
(vulnerability scores of each map are summed: each pixel is the sum of the scores associated to each single variable)



Vulnerability score from 0 to 20 refers to from low to high land vulnerability to eutrophication.



Classes: Low 0-1 , Medium 2-5, High 6-20

Higher vulnerable areas are located in the centre (coexistence of vulnerability to N and underground water recharge areas)

Northern part > flat areas

Southern part > spring water basins, river valleys, spring buffer zones

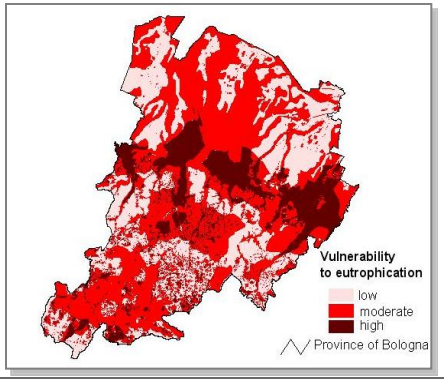
31 % > low; 51 % moderate; 17 % high

Integration between LCA and land vulnerability

Crop	PO_4^{---} equivalent ($kg\ ha^{-1}$)	character. (%)
maize	**5.56**	**100.0**
rapeseed	4.61	82.9
sunflower	4.46	80.2
sorghum	4.38	78.8
wheat	4.37	78.6
cardoon	1.85	33.3
miscanthus	1.67	30.0
arundo	1.64	29.5
switchgrass	1.37	24.6

LCA

Land vulnerability



Eutrophication effect of crops

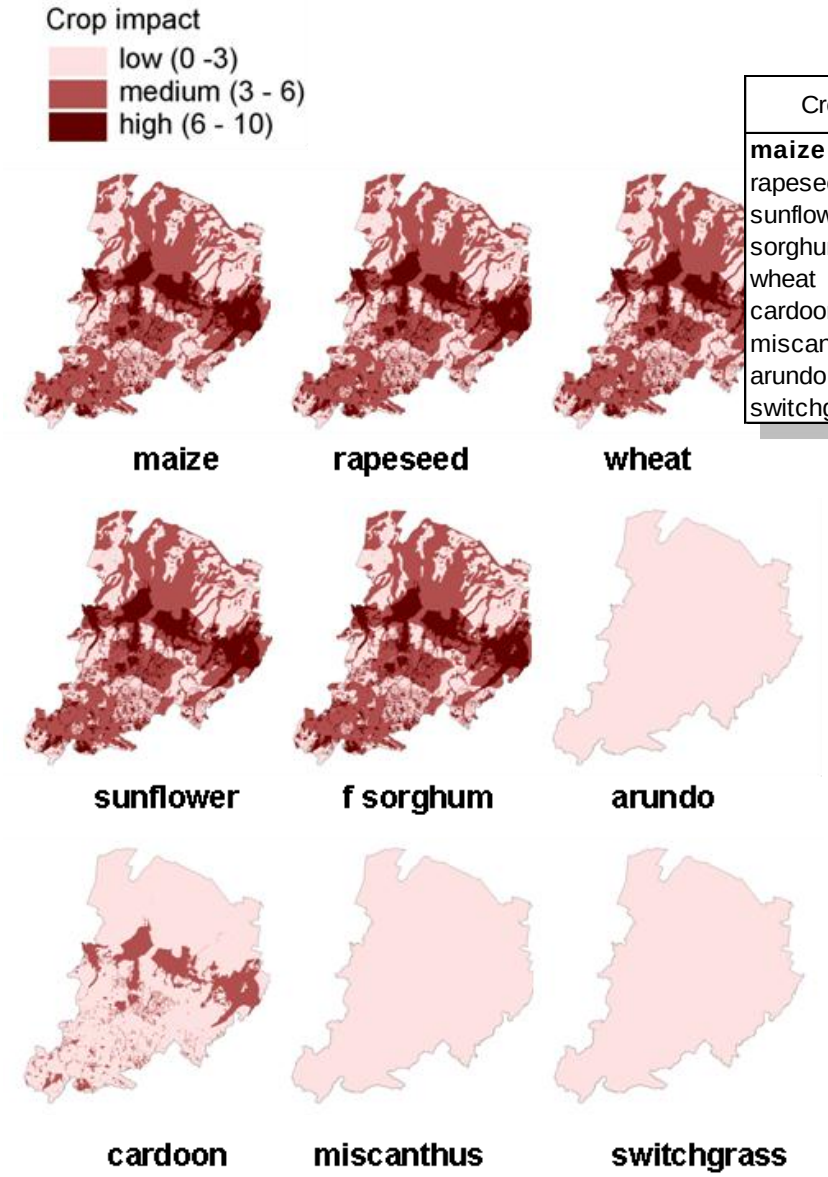
Crop - environment allocation risk scenarios

Crop	low	moderate	high
maize	**3,0**	**6,0**	**10,0**
rapeseed	2,5	5,0	8,3
sunflower	2,4	4,8	8,0
sorghum	2,4	4,7	7,9
wheat	2,4	4,7	7,9
cardoon	1,0	2,0	3,3
miscanthus	0,9	1,8	3,0
arundo	0,9	1,8	2,9
switchgrass	0,7	1,5	2,5

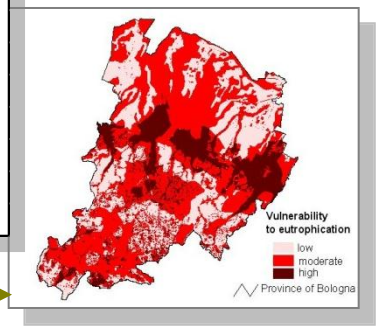
The eutrophication effect is combined with the land vulnerability and weighted on the worst scenario (maize in the high vulnerability land = 10).

> Rapeseed in high vuln. land:
82.9/100 x 10 = 8.3
> Rapeseed in moderate vuln. land:
82.9/100 X 6 = 5

The eutrophication risk with respect to crop



Crop	low	moderate	high
maize	**3,00**	**6,00**	**10,00**
rapeseed	2,76	5,53	8,29
sunflower	2,67	5,35	8,02
sorghum	2,63	5,25	7,88
wheat	2,62	5,24	7,86
cardoon	1,11	2,22	3,33
miscanthus	1,00	2,00	3,00
arundo	0,98	1,97	2,95
switchgrass	0,82	1,64	2,46



Land vulnerability map (GIS)

Eutrophication values (LCA)

Maize induces important eutrophication risks in all lands

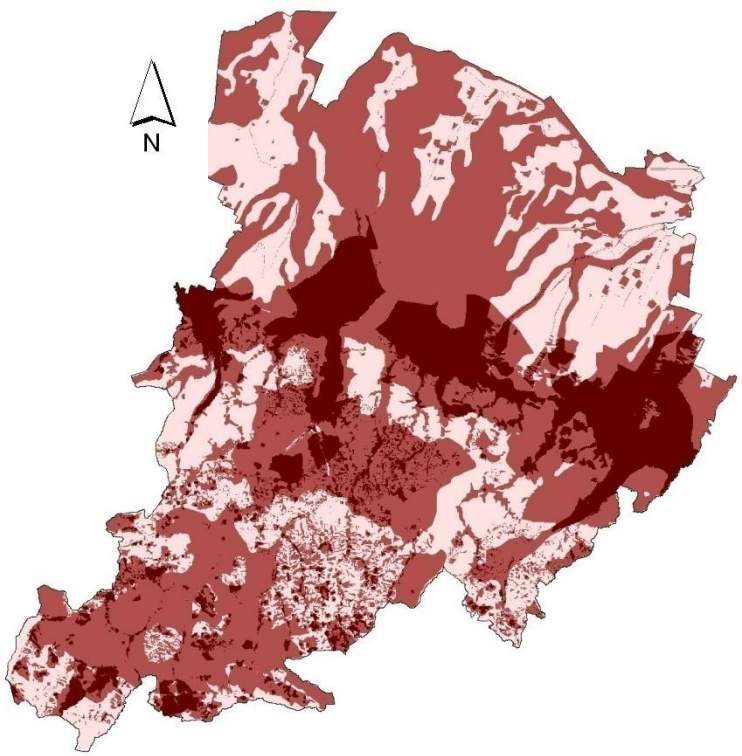
Similar risk levels are also observed for rapeseed, wheat, sunflower and fibre sorghum

Arundo, miscanthus and switchgrass revealed much lower impacts than maize at each vulnerability class

Cardoon showed a moderate impact only in the high vulnerability lands

Crop land allocation map

(minimizing the eutrophication risks)



low: all crops

moderate: arundo, miscanthus, switchgrass and cardoon

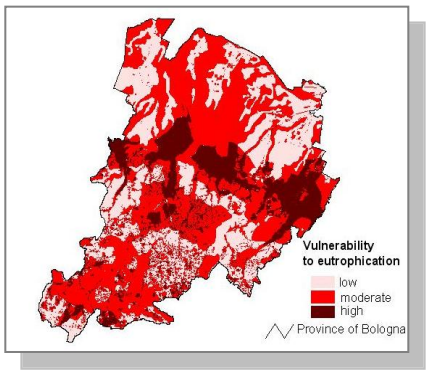
high: arundo, miscanthus and switchgrass only

Province of Bologna

If eutrophication is a major concern, maize should be grown only in less vulnerable areas

In the hypothesis of a district completely dedicated to energy crops the lowest risk scenario to eutrophication would include only arundo, switchgrass and miscanthus.

Use of Multiple Impact categories for crop allocation



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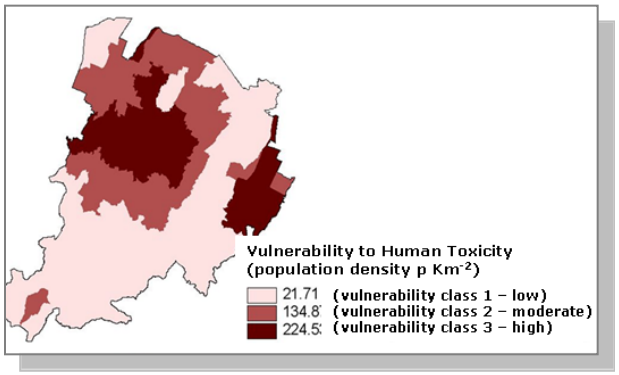


Topological overlay (GIS)

overlay multiple data layers in a vertical order
Raster based data > arithmetic overlay operations,
- Same resolution
- Comparability of variables

Overall vulnerability maps

Simple additive method

For each pixel, sum of Vulnerability value from the Vulnerability map to **Eutr** and the Vulnerability map to **HUM Tox**

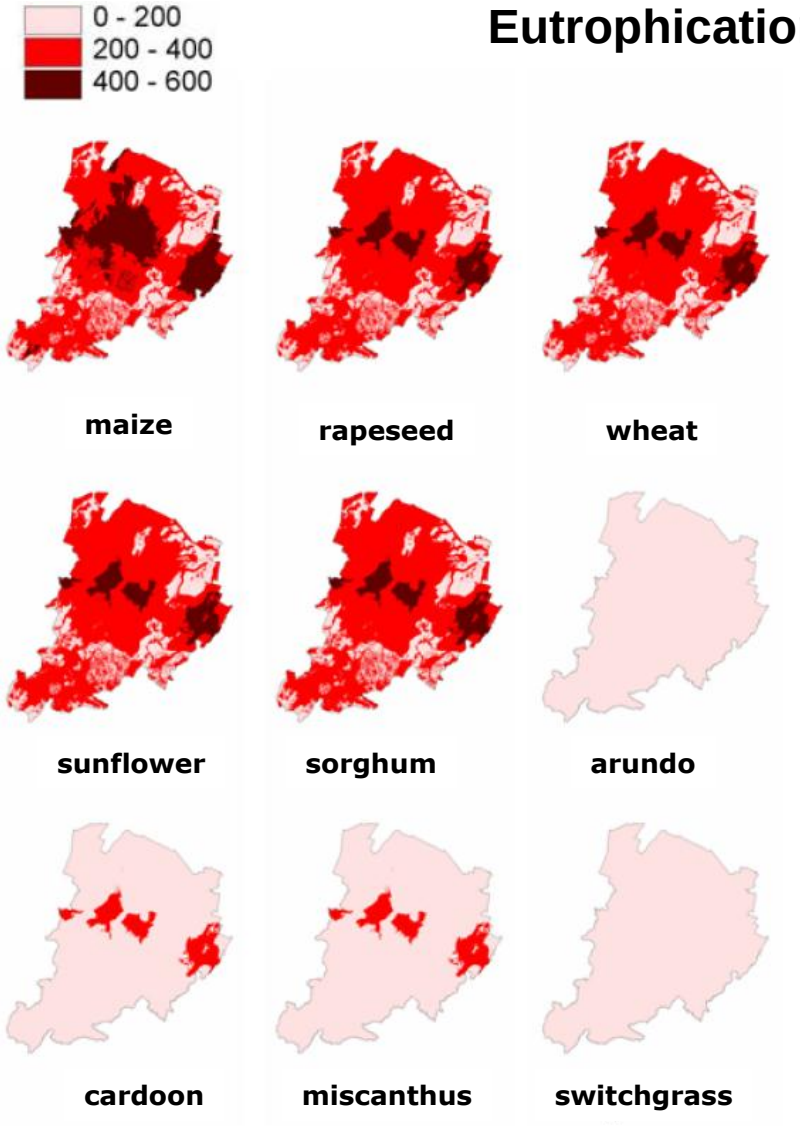
Additive method of classified maps

For each pixel, sum of Vulnerability value (as class) from the Vulnerability map to **Eutr** and the Vulnerability map to **HUM Tox** classified in the same number of classes

Composed multiplicative method

Total site-specific impact is defined

Eutrophication and Human Toxicity.



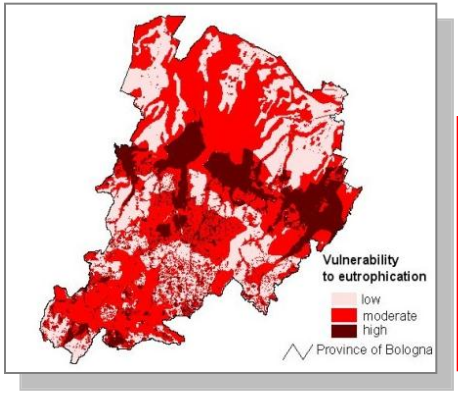
0-200 low risk
200-400 moderate risk
400-600 high risk

Rapeseed, wheat, sunflower and sorghum > same risk with respect to maize

Arundo and switchgrass > low risk for the whole area

Cardoon and miscanthus> moderate risk in central part of the map

Integration of environmental impact within land suitability procedures



species selection from energy crops catalogue

land characterization

land assignment matching agronomic needs and land features

along with pedo-climatic variables

complete vulnerability map (that may include all specific impact categories appraisable using LCA)

Re-asses the crop land allocation basing on the lowest environmental impact scenario. Optimize land assignment considering additional info on how each crop impacts the environment.

Environmental certification systems: effective schemes could be effective in ensuring that biomasses are sourced from lands where responsible practices are employed.

… thanks !!!