Regional integrated assessment of environmental and socio-economic impacts of biofuel production

Demonstrated for Mozambique

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Biomass for Energy -
Lessons learned from the Bioenergy Boom

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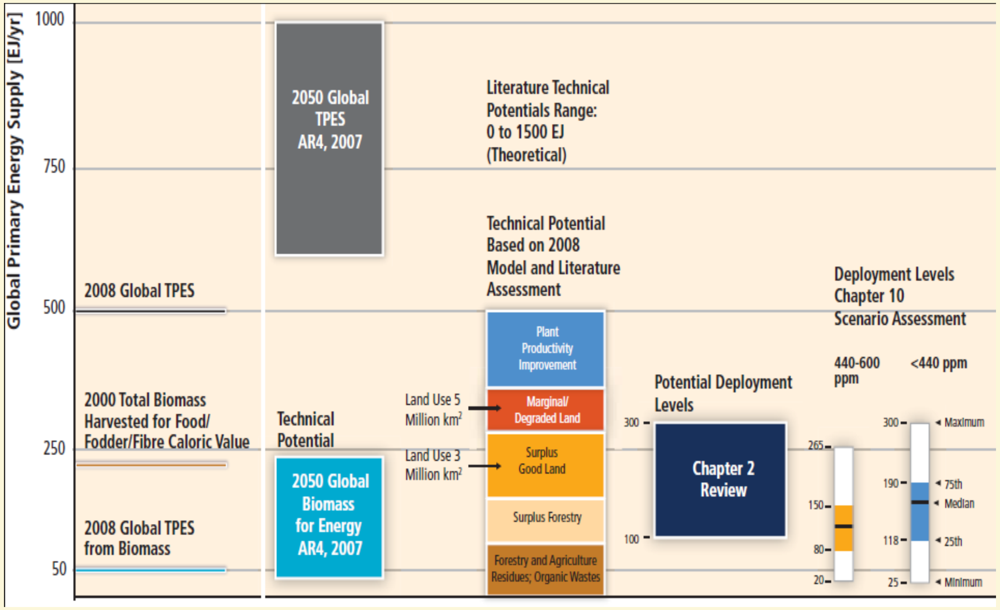
Universiteit Utrecht

Increasing demand for biomass

- Biomass is expected to play an important role in the global energy supply (100-300 EJ in 2050)
- The current use of biomass resources is about 50 EJ of which ± 10 EJ is used in modern bioenergy systems (electricity, heat, fuels, etc).



- The use of biomass for the production of biomaterials and biochemicals is expected to increase
- Therefore the supply of biomass for modern applications should increase by a factor of 10 to 40!

Sustainability concerns

- Large scale deployment of biomass could have implications:
  - GHG emissions
  - Competition with food (and other local applications)
  - Deforestation
  - Loss of biodiversity and other ecosystem functions
  - Water depletion
  - Impacts on soil quality
  - Impacts on local prosperity and social well being
  - Etc.

- At several levels sustainability criteria have been developed
- Key issues for policymakers and investors is: How to comply?

Rationale

- The majority of the impacts of bioenergy production is related to land use change
- The direction and the magnitude of the impacts depend on:
  - The characteristics of the supply chains
  - The biophysical and socio-economic conditions of the production region
- Therefore: impacts of bioenergy production should be assessed on a local level taking into account the impacts of land use change.
- As Indirect Land Use Change (ILUC) is to be avoided; the land availability for energy crops depend on the land use required for other land use functions.
- Therefore: we need to know where bioenergy crops could be cultivated in order to assess the potential impacts

Objective

Develop a methodological framework to make an ex-ante and integrated assessment of the sustainability of bioenergy production at a regional level.

Two methodological steps:

- Spatiotemporal scenario assessment of land availability for bioerrgy crops given developments in other land use functions
- Impact assessment of bioenergy supply chains given the biophysical and socio-economic characteristics of the location of production

Demonstrated for Mozambique

Step 1:

LAND AVAILABILITY FOR ENERGY CROPS

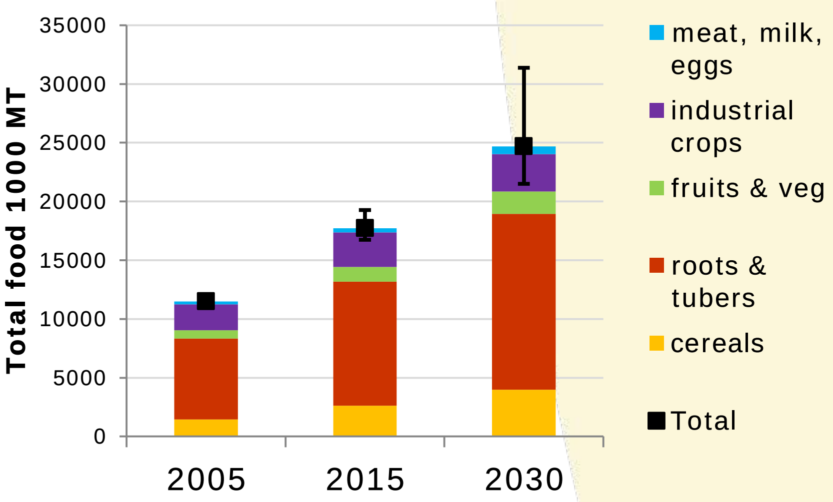
Land availability energy crops

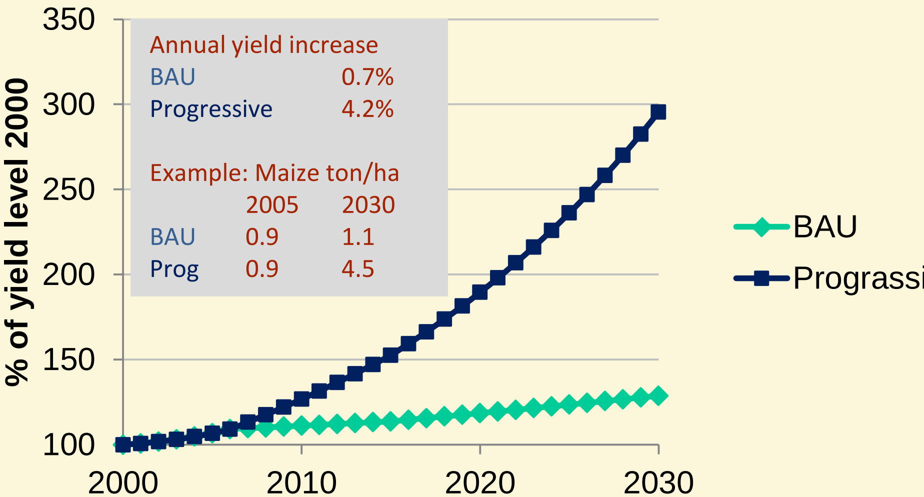
- Land for bioenergy crops should not compete with other land use functions. → need to prevent iLUC
- The amount of land available for bioenergy depends on the land required for:
  - Settlements
  - Food production
  - Livestock production
  - Nature conservation
  - Excluded areas (not suitable)

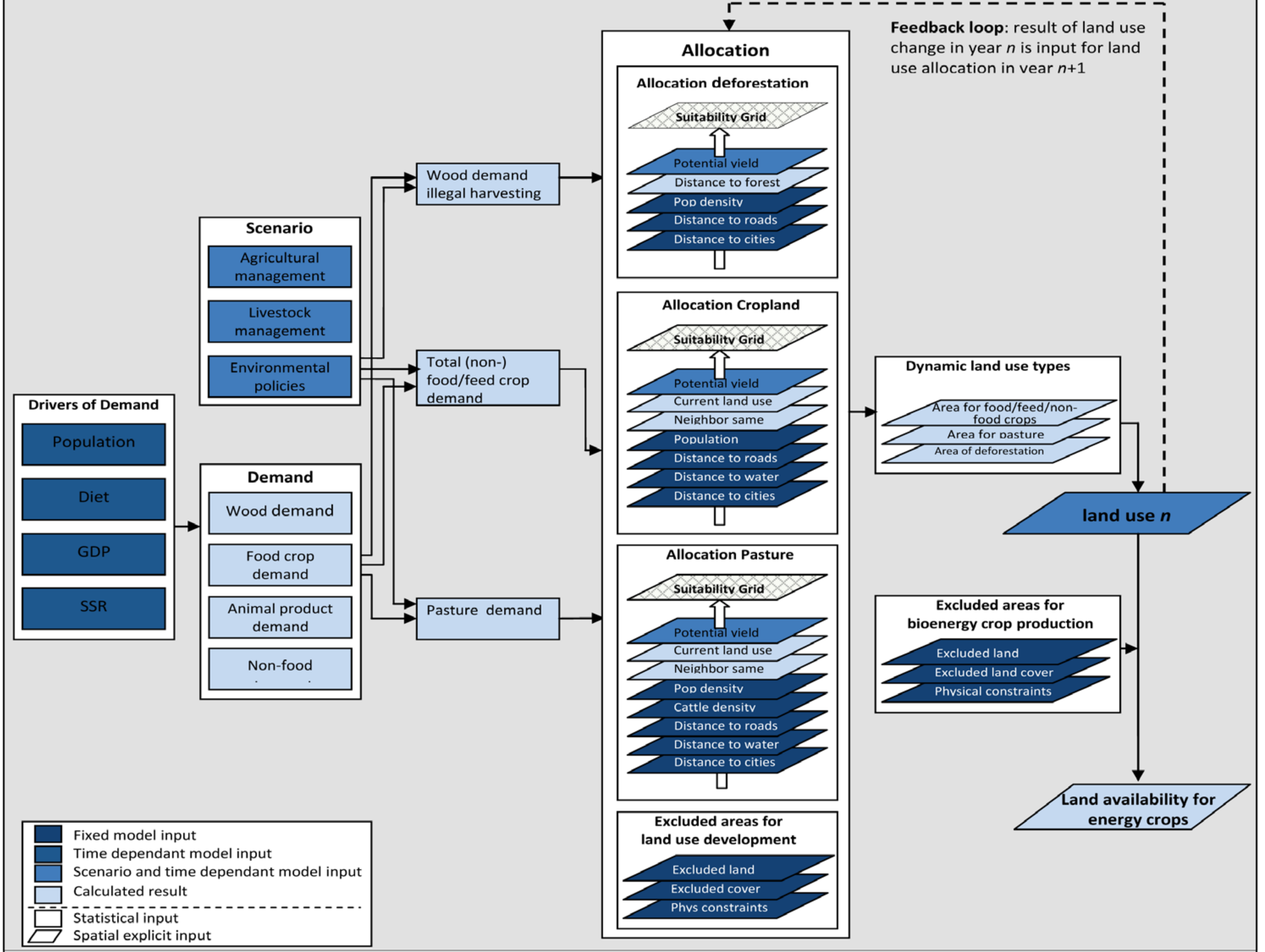
Land availability for energy crops

Demand for food is expected to increase
- Increased population
- Increased dietary intake (Kcal + nutritious)

Productivity in agricultural sector
- BAU continuous historic trends
- PROG steep increase in productivity






Feedback loop: result of land use change in year n is input for land use allocation in year n+1
Allocation
Allocation deforestation
Suitability Grid
Potential yield
Distance to forest
Pop density
Distance to roads
Distance to cities
Allocation Cropland
Suitability Grid
Potential yield
Current land use
Neighbor same
Population
Distance to roads
Distance to water
Distance to cities
Allocation Pasture
Suitability Grid
Potential yield
Current land use
Neighbor same
Pop density
Cattle density
Distance to roads
Distance to water
Distance to cities
Excluded areas for land use development
Excluded land
Excluded cover
Phys constraints
Wood demand illegal harvesting
Total (non-) food/feed crop demand
Pasture demand
Scenario
Agricultural management
Livestock management
Environmental policies
Drivers of Demand
Population
Diet
GDP
SSR
Demand
Wood demand
Food crop demand
Animal product demand
Non-food
Dynamic land use types
Area for food/feed/non-food crops
Area for pasture
Area of deforestation
land use n
Excluded areas for bioenergy crop production
Excluded land
Excluded land cover
Physical constraints
Land availability for energy crops
Fixed model input
Time dependant model input
Scenario and time dependant model input
Calculated result
Statistical input
Spatial explicit input

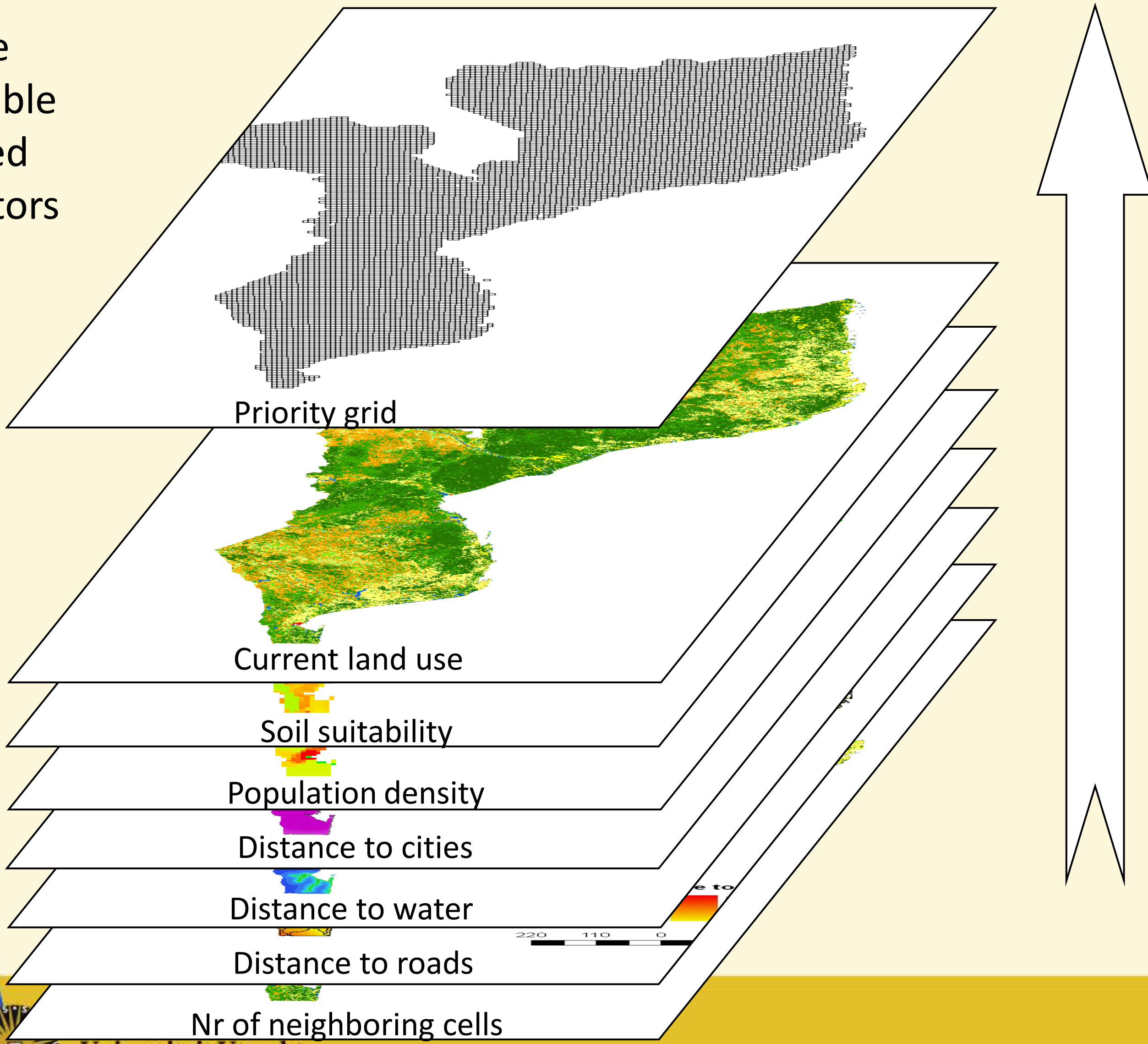
Land use allocation Model

- To allocate the additional land use requirements for food, feed and material production, a land use allocation model is developed.
- The land is allocated to a dynamic land use based on the suitability of the land for that specific land use → Priority grid based on suitability factors
- The model allocate the land use change for every subsequent year up to 2030
- Land availability for bioenergy crops can be spatially assessed by excluding all land required for other usages and all land that is not suitable

Land use allocation

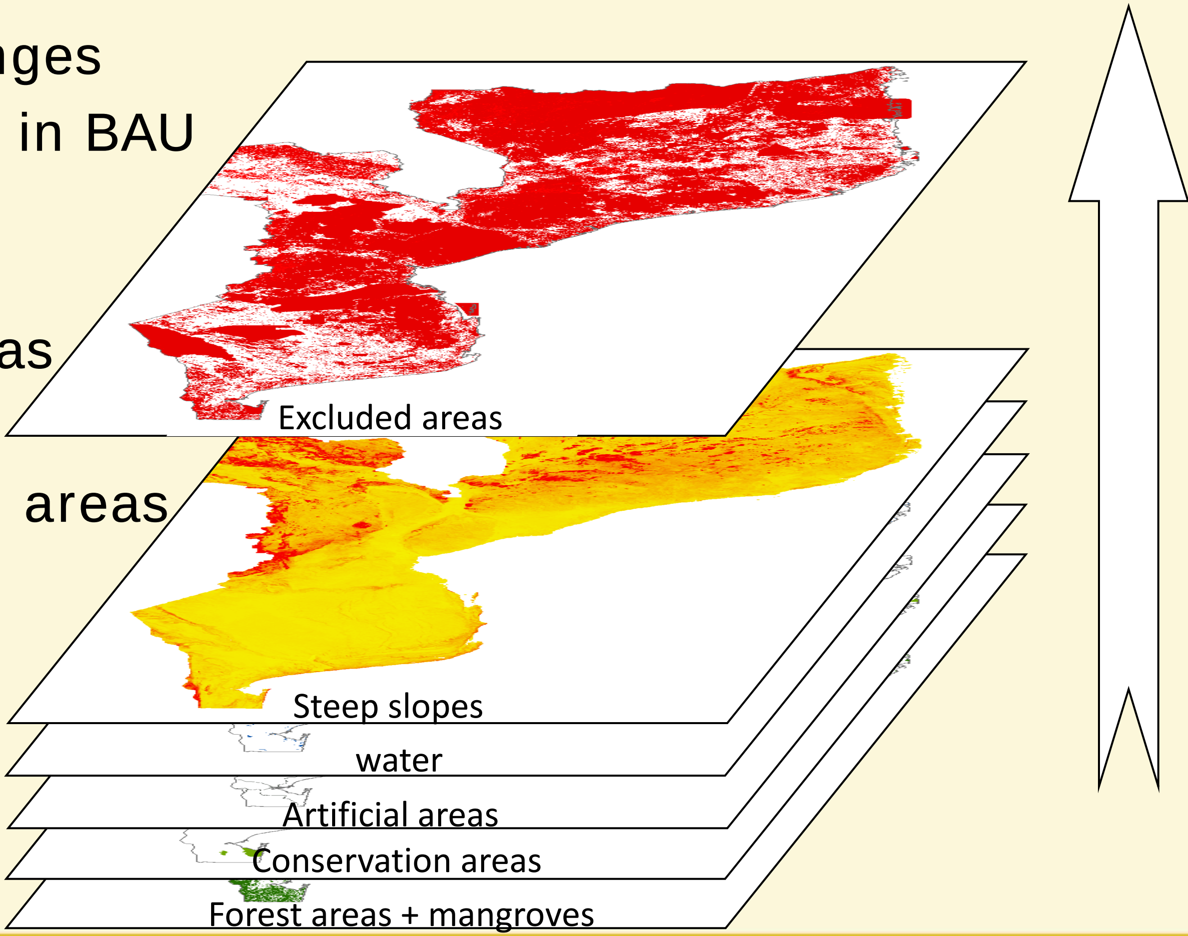
Land is allocated to a land use function when it is most suitable for that specific function based on several land suitability factors

Example:
suitability for cropland



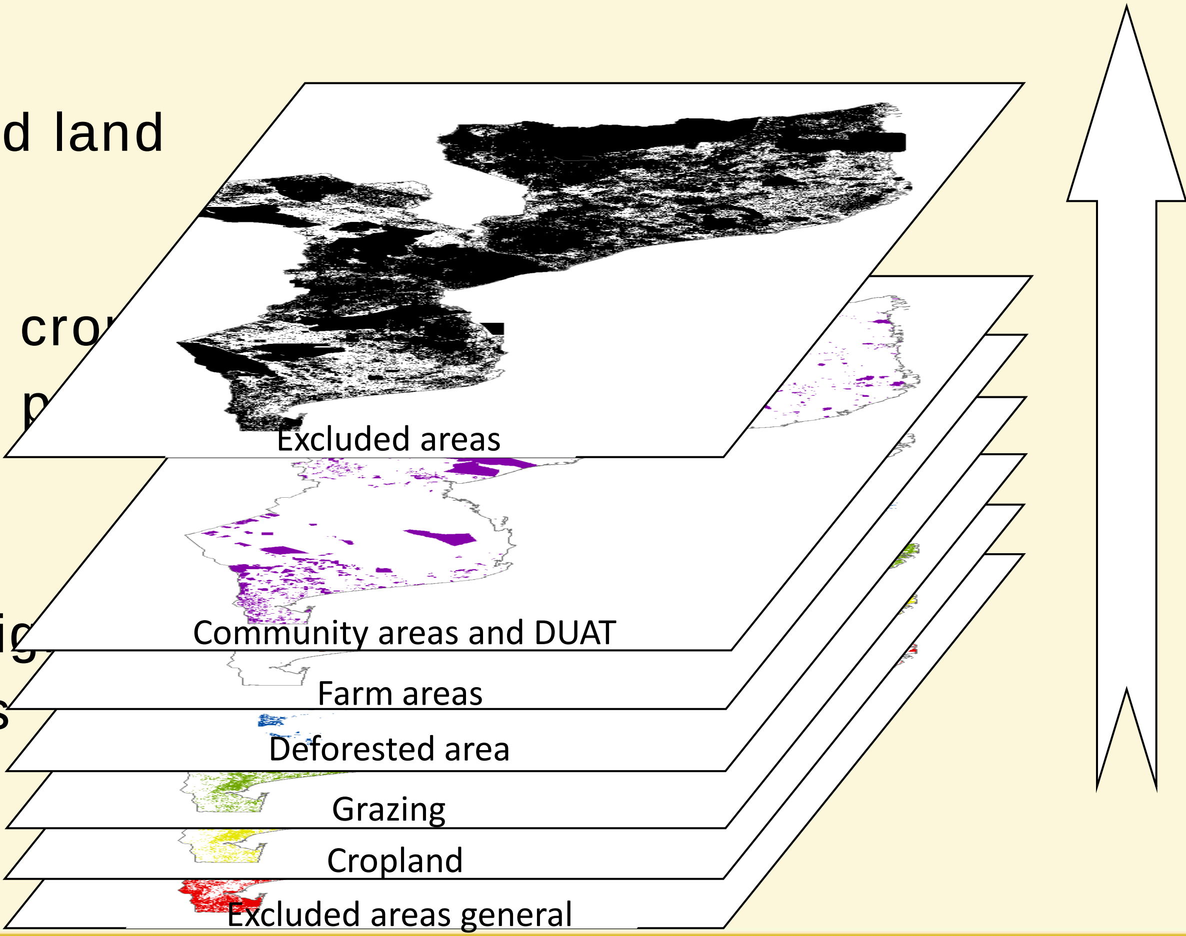
Excluded areas

- For all land use changes
  - Forest areas (not in BAU scenario)
  - Mangroves
  - Conservation areas
  - Bare areas
  - Regularly flooded areas
  - Steep slopes



Excluded areas

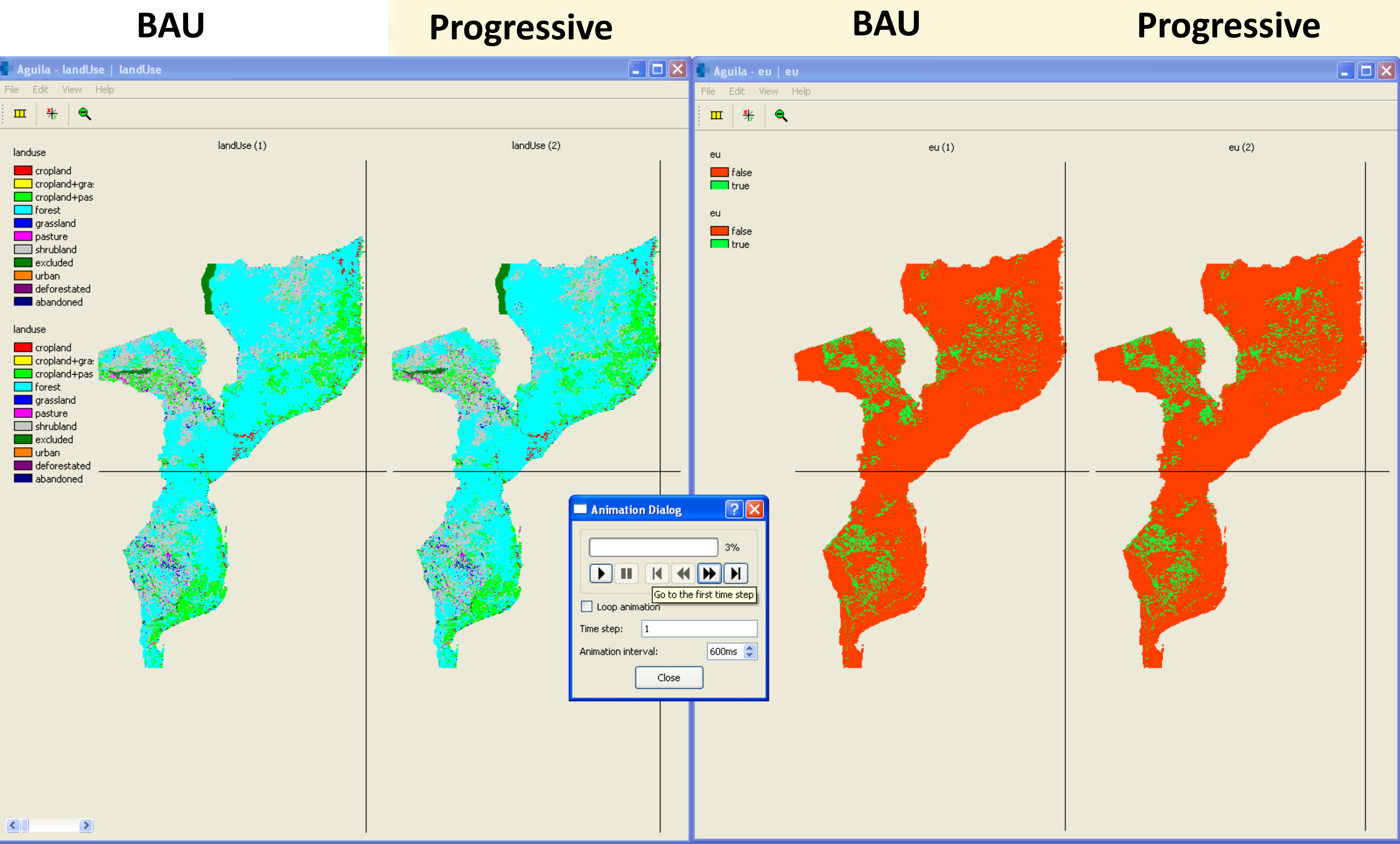
- For energy crops
  - All of the excluded land areas
    - Previous slide
  - Land required for cro
  - Land required for p
  - Deforested areas
  - Farm areas
  - DUAT (land use rig
  - Community areas



Results

- Land use change for every individual year up to 2030 for 2 scenarios
- Land availability for energy crops

2005



BAU
Progressive
BAU
Progressive
Aguila - landUse | landUse
File Edit View Help
landUse (1)
landUse (2)
landuse
cropland
cropland+gra:
cropland+pas
forest
grassland
pasture
shrubland
excluded
urban
deforestated
abandoned
landuse
cropland
cropland+gra:
cropland+pas
forest
grassland
pasture
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Animation Dialog
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Time step: 1
Animation interval: 600ms
Close
Aguila - eu | eu
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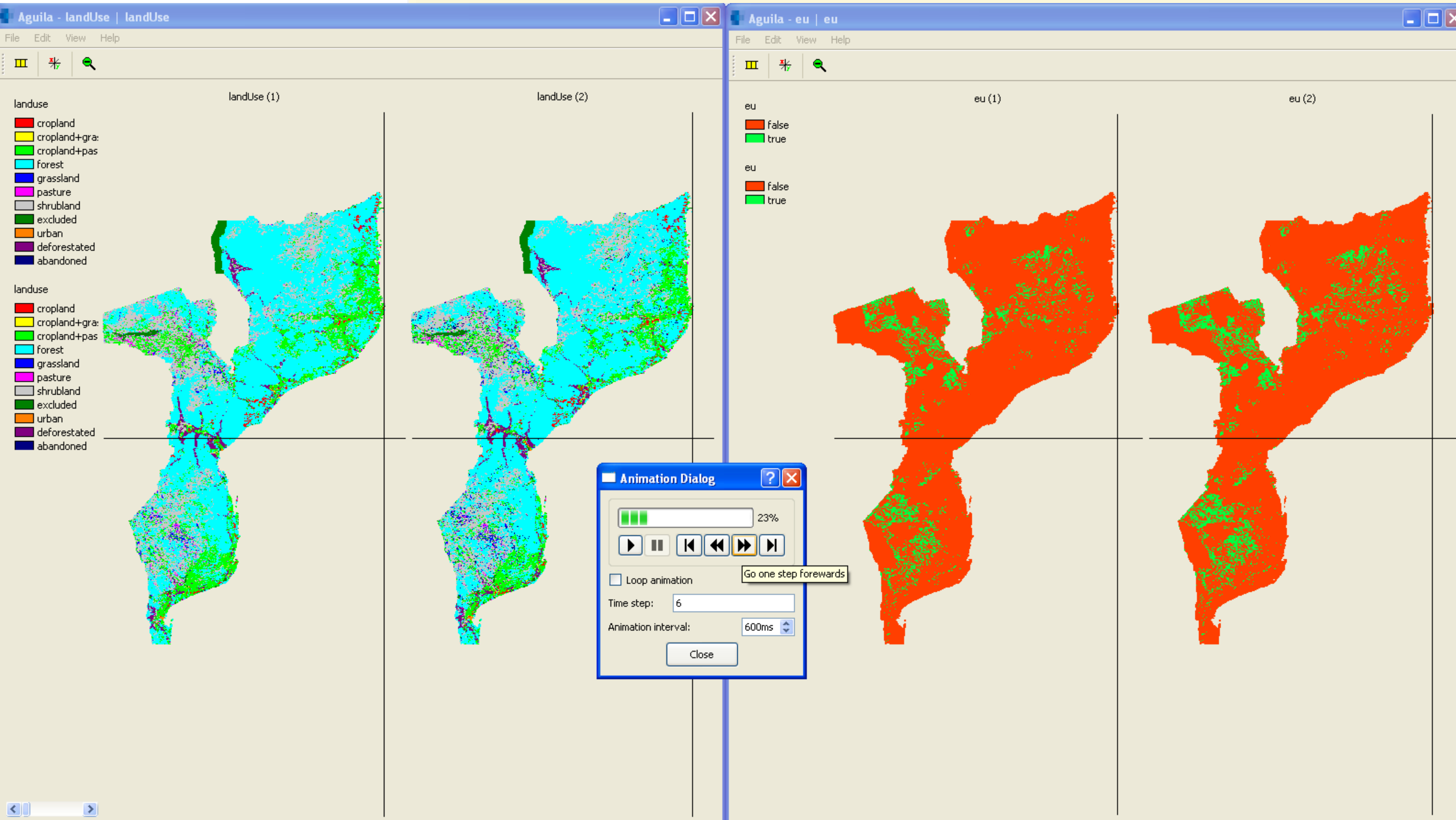
eu (1)
eu (2)
eu
false
true
eu
false
true

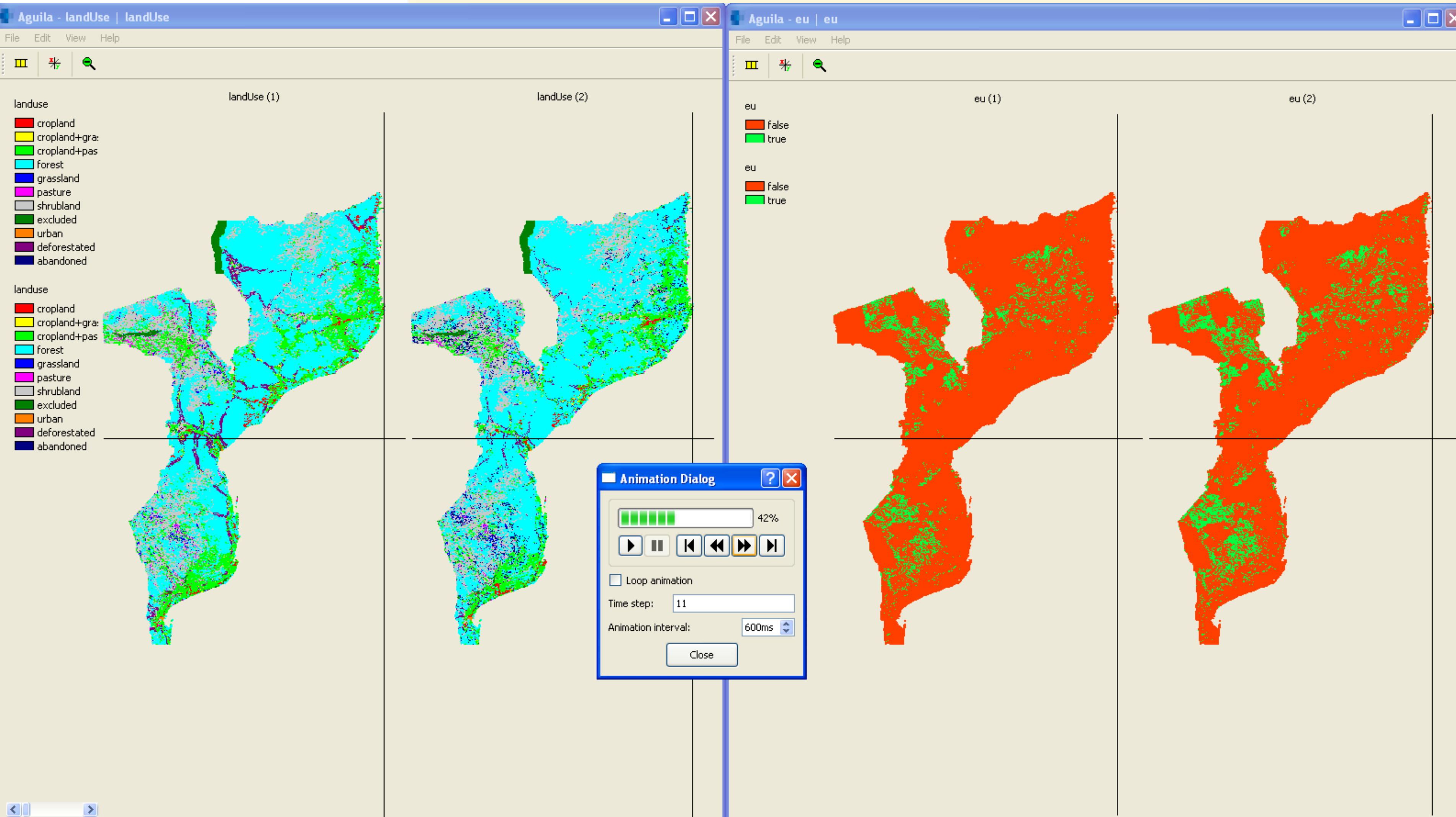
2010

BAU **Progressive** **BAU** **Progressive**



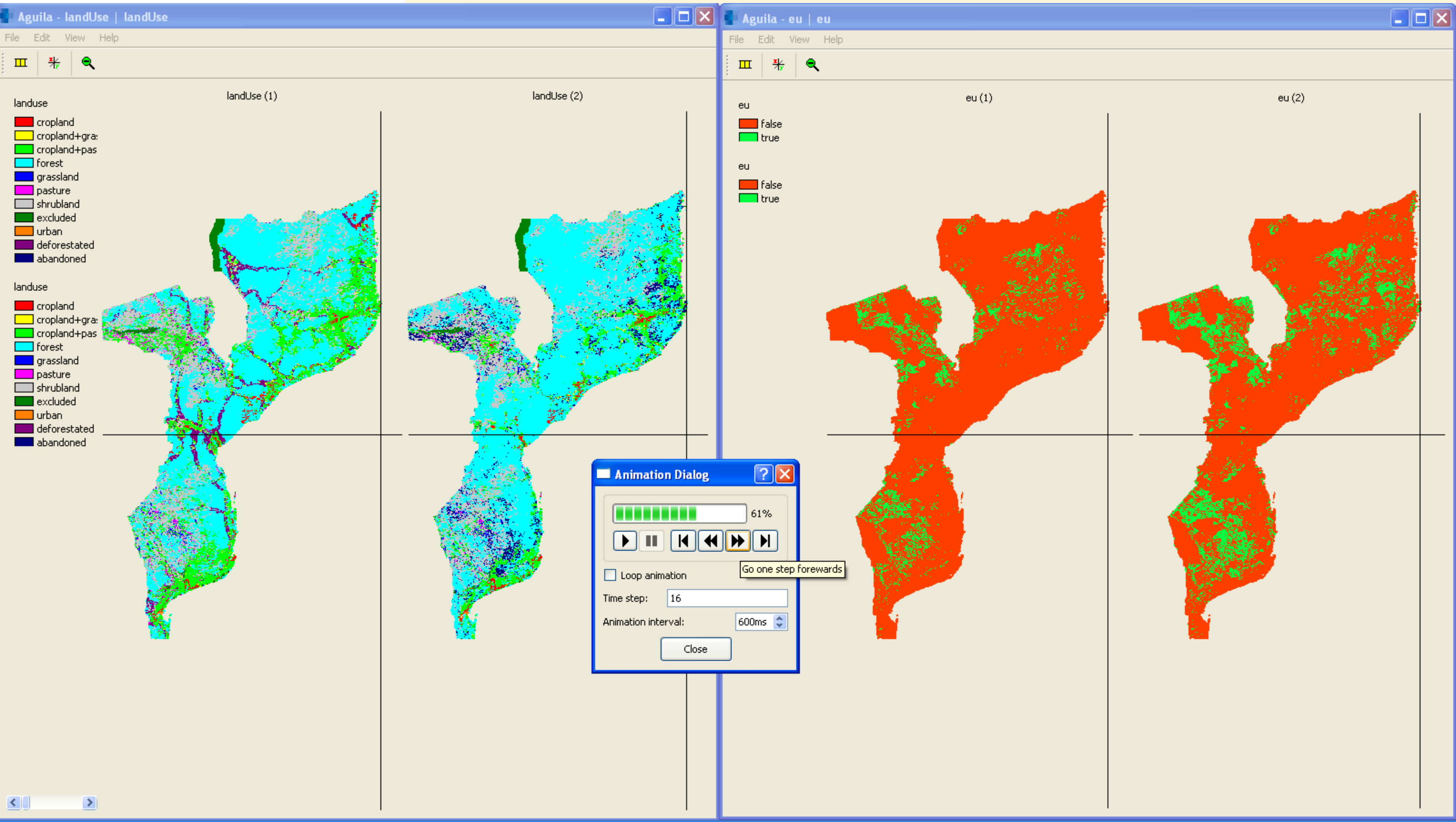
2015

BAU **Progressive** **BAU** **Progressive**



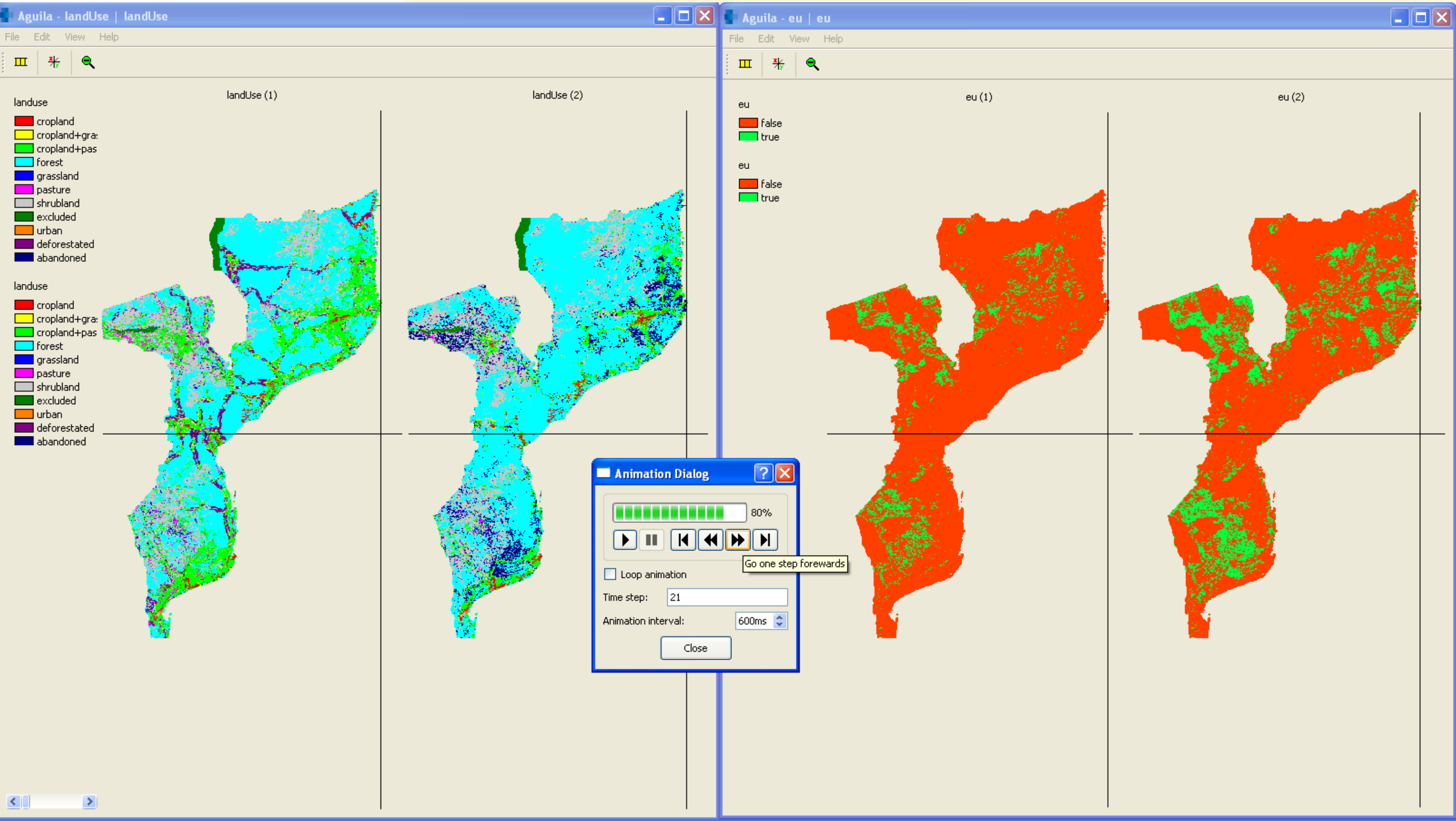
2020

BAU **Progressive** **BAU** **Progressive**



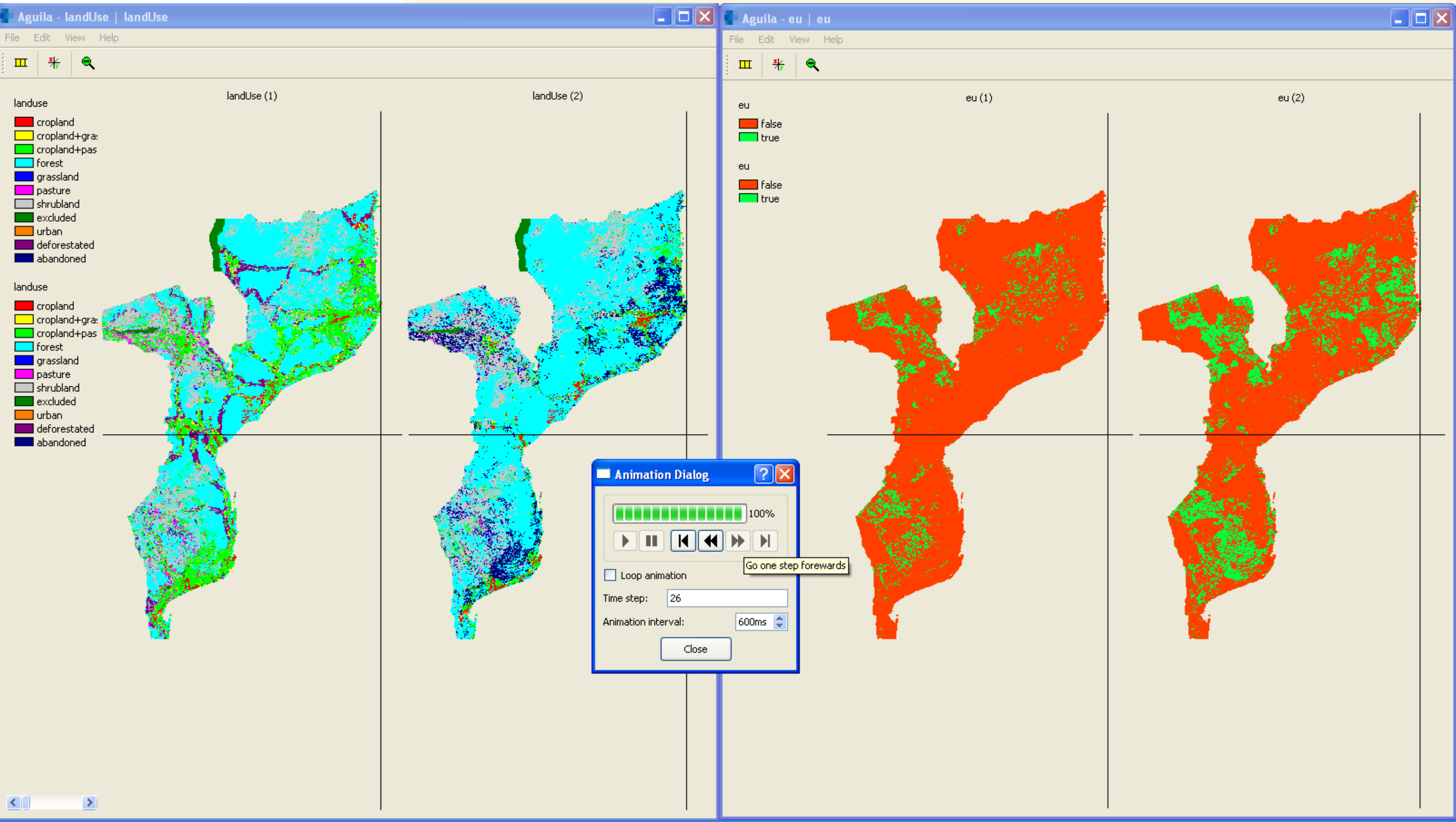
2025

BAU **Progressive** **BAU** **Progressive**



2030

BAU **Progressive** **BAU** **Progressive**



Next steps

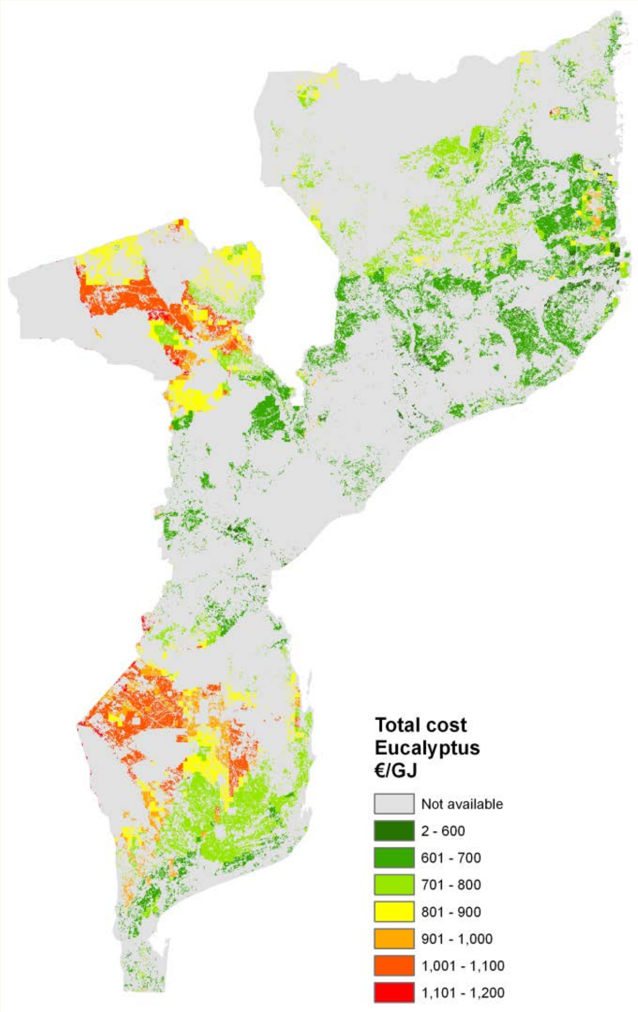
- This modeling assessments provides information on the amount, the location and the timeline of land availability for energy crops in Mozambique
- **Impact assessment** → given the location of land availability for biomass productions and the biophysical and socio-economic conditions in those regions, what are the environmental and socio-economic impacts.

Step 2:

ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACT ASSESSMENT

Setting selection

- The methodological framework is demonstrated for specific settings
- The settings are differentiated for
  - two selected regions
    - Gaza-Inhambane
    - Nampula
  - selected energy supply chains
    - Eucalyptus ethanol
    - Switchgrass ethanol
  - two scenarios
    - BAU
    - Progressive
- Year 2020
- EtOH plant size 1400MW input



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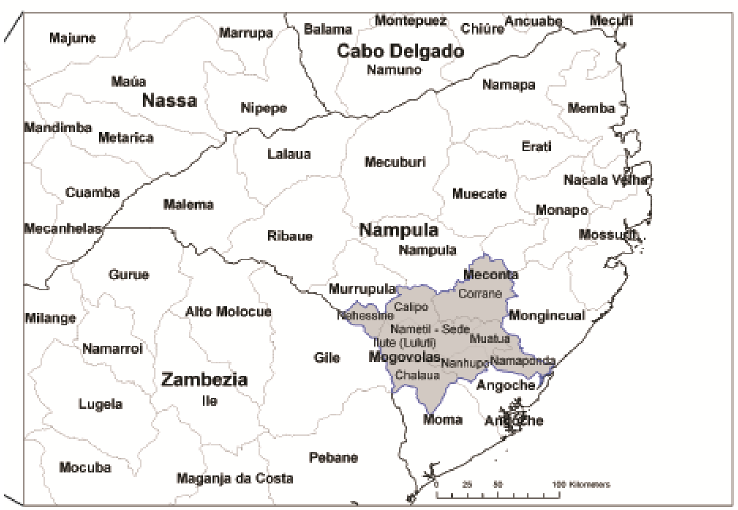
Setting selection



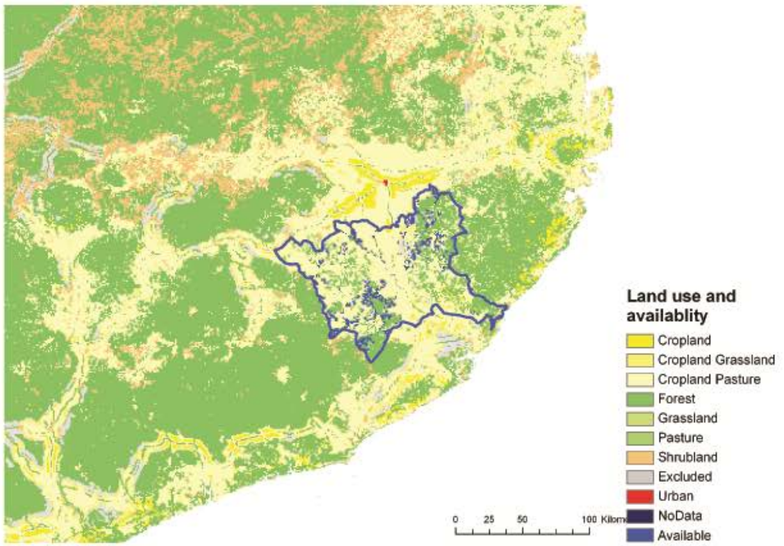
Nampula

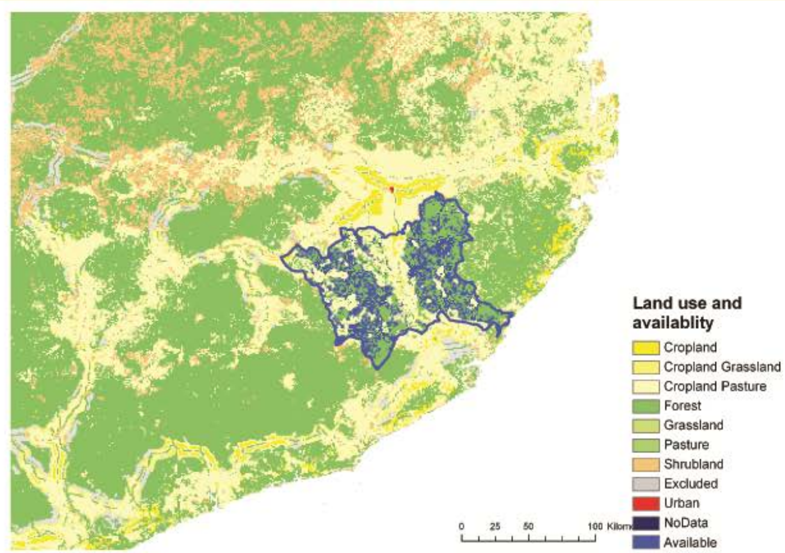
- Low land availability
- High population density
- High agro-ecological suitability
- Close to infrastructure

Gaza-Inhambane

- High land availability
- Low population density
- Low to moderately suitable
- Remote

Setting selection

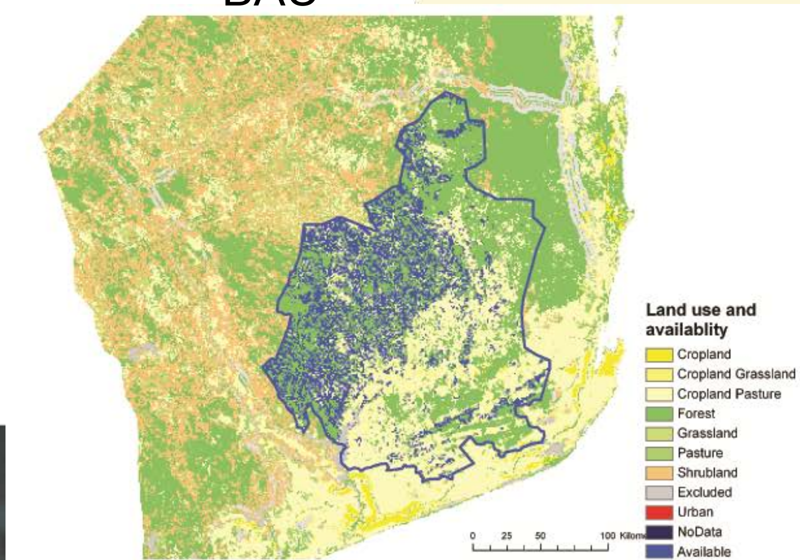


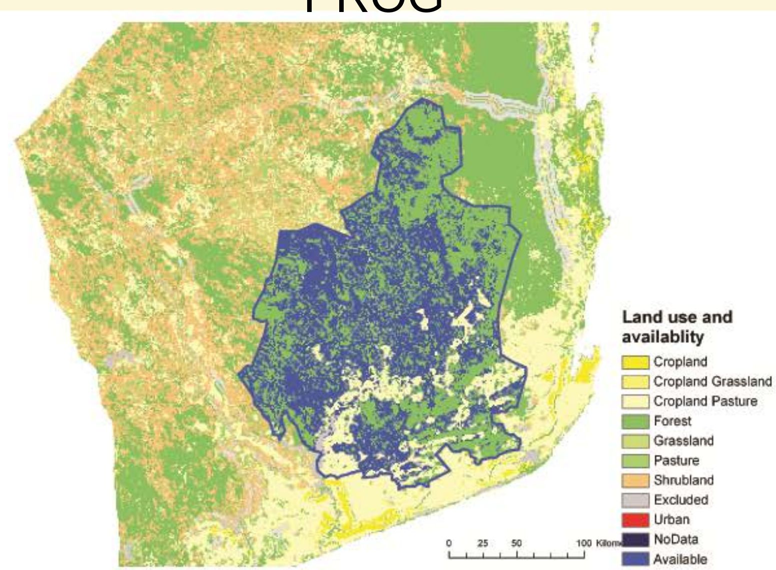


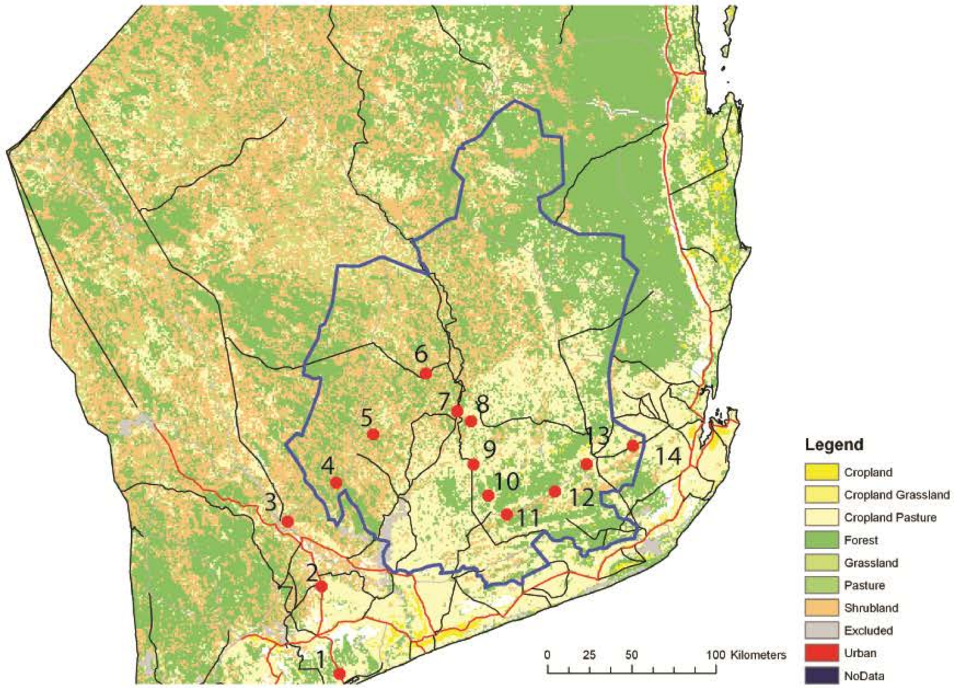
BAU

2020

PROG







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1a

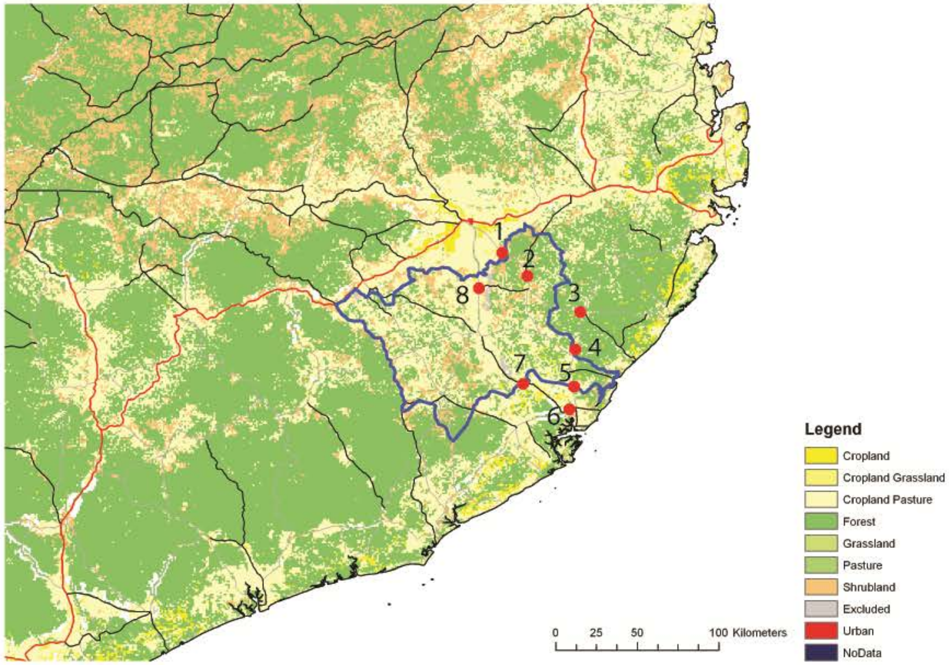

1b


2a


2b


8b


3a


1
2
8
3
4
7
5
6
Legend
Cropland
Cropland Grassland
Cropland Pasture
Forest
Grassland
Pasture
Shrubland
Excluded
Urban
NoData
0 25 50 100 Kilometers


8a


3b


7a


4a


6b


6a


5b


5a

Setting selection

Setting	Selected region	Scenario	Feedstock	Reference land use	Required area (km^2)	Average suitability	Potential Feedstock production
1	Gaza-Inhambane	BAU	Eucalyptus	Shrubland	2046	41%	100%
2	Gaza-Inhambane	BAU	Switchgrass	Shrubland	3013	39%	100%
3	Gaza-Inhambane	PROG	Eucalyptus	Agricultural land	1336	55%	100%
4	Gaza-Inhambane	PROG	Switchgrass	Agricultural land	1470	54%	100%
5	Nampula	BAU	Eucalyptus	Shrubland	826	63%	62%
6	Nampula	BAU	Switchgrass	Shrubland	826	63%	46%
7	Nampula	PROG	Eucalyptus	Agricultural land	1317	64%	100%
8	Nampula	PROG	Switchgrass	Agricultural land	1871	62%	100%

Sustainability criteria

	Issue	EU-RED	CSBP	GBEP	RSB	ISCC	NTA8080	RFTO	MOZ
Environmental impacts	GHG emissions	√	√	√	√	√	√	√	√
	Biodiversity	√	√	√	√	√	√	√	√
	Soil		√	√	√	√	√	√	√
	Water		√	√	√	√	√	√	√
Socio- economic impacts.	Legality				√		√		√
	Land right								√
	Food security	√		√			√		√
	Economic viability			√	√				√
	Local prosperity			√	√		√		√
	Social well being								
	Labour conditions		√	√	√	√	√	√	√
	Gender		√	√	√	√	√	√	√

GHG emissions - Method

- Lifecycle emissions
  - Emissions related to
    - Cultivation
    - Transport
    - Conversion
  - LCA approach (similar to GHG calculation tool)
  - But regional specific:
    - Fertilizer requirements
    - Yield levels
    - Transport distances

GHG emissions - Method

- Emissions related to LUC
  - Changes in carbon stock
    - Soil organic carbon (SOC)
    - Above ground biomass
    - Below ground biomass
- IPCC method is applied
- Setting specific:
  - Climate
  - Soil characteristics
  - Above and below ground biomass (before and after conversion)
  - Management applied (before and after conversion)
  - Fertilizer application

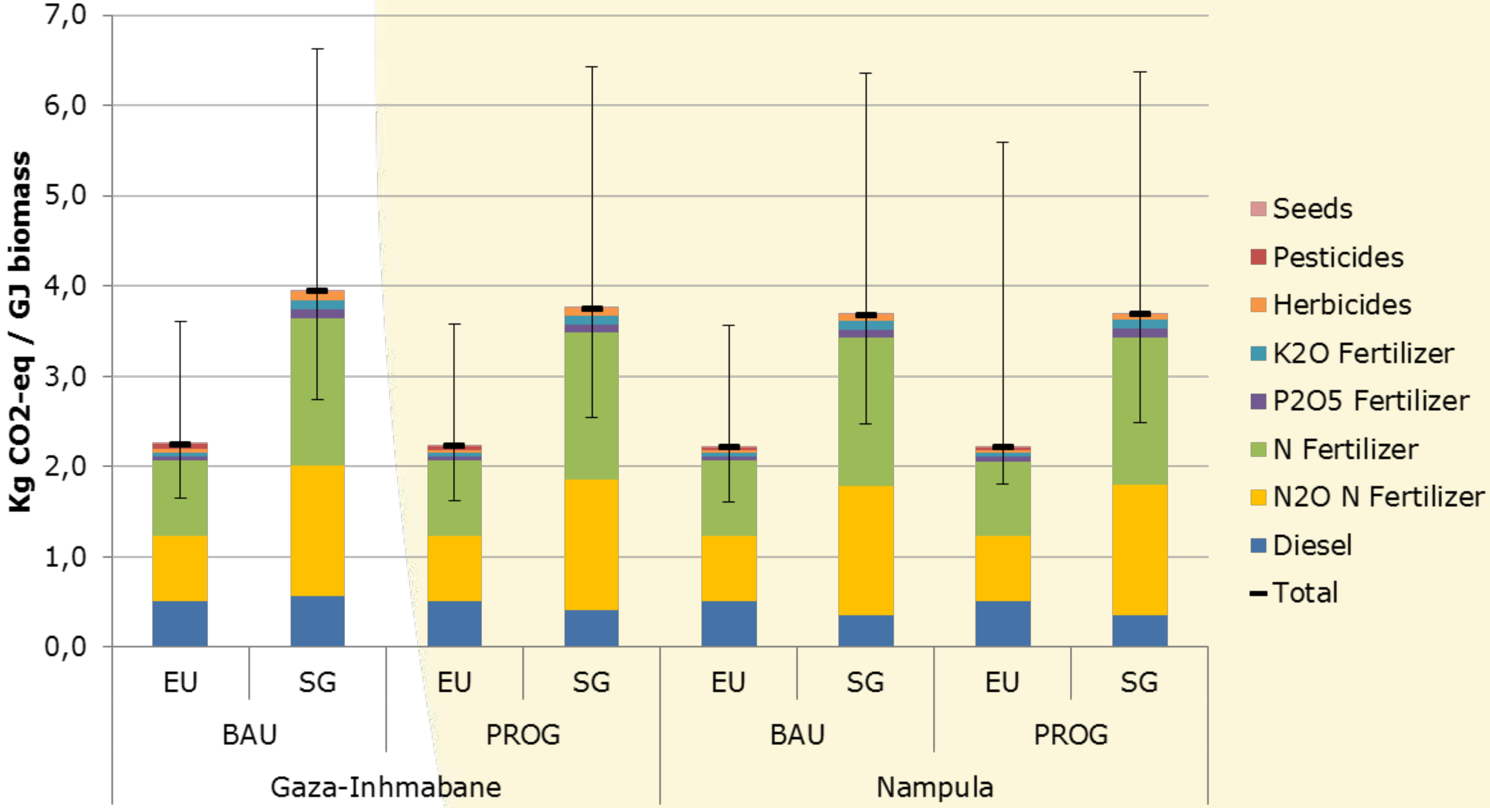
$$GHG = \left(\Delta C \cdot -\frac{44}{12} \cdot GWP_{CO2} \right) + \left(N \cdot \frac{44}{28} \cdot GWP_{N2O} \right)$$

$$\Delta C_{SOC} = \left(\frac{SOC_t - SOC_{t-1}}{D} \right)_{Mineral} + \Delta C_{Organic}$$

$$\Delta C_B = \Delta C_G + \Delta C_{Conversion} + \Delta C_L$$

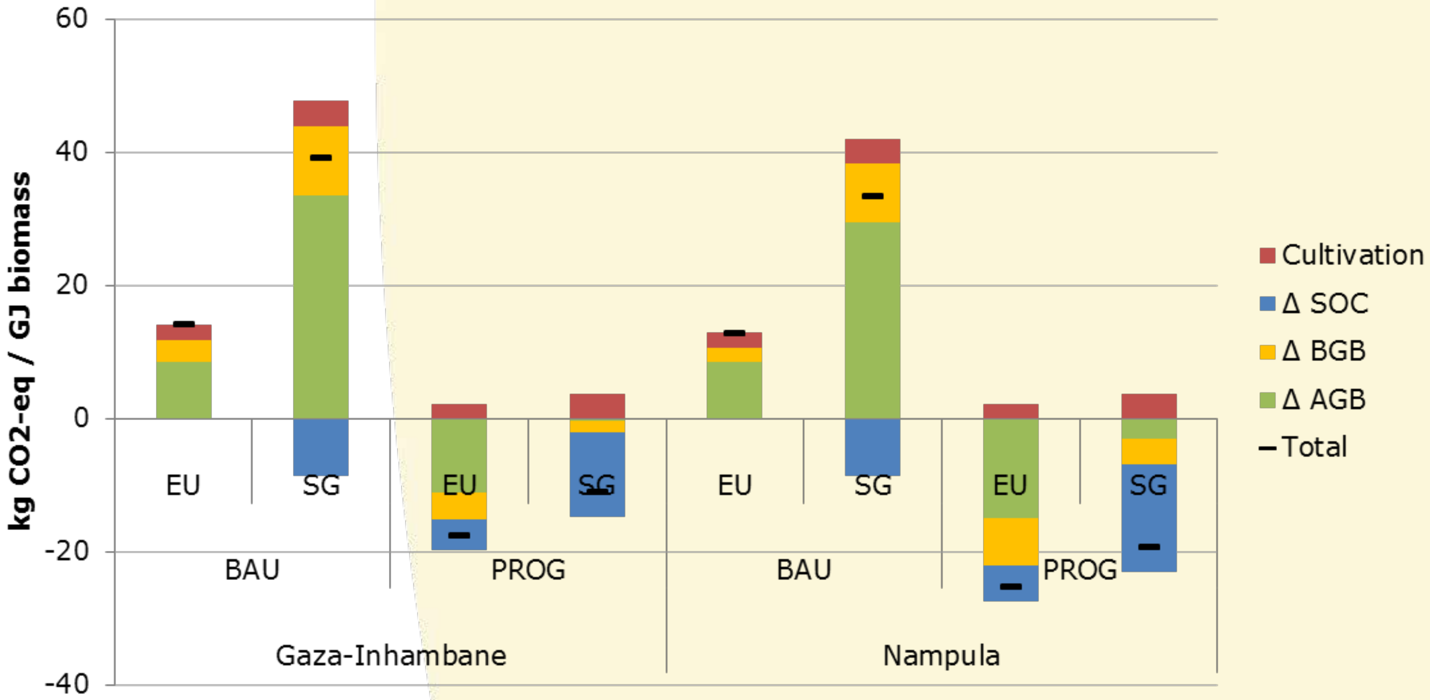
$$C_{Conversion} = \sum_i \left(B_{After_i} - B_{Before_i} \right) \cdot CF$$

GHG emissions – Results (cultivation)



GHG emission related to the cultivation of eucalyptus and switchgrass in the selected area in Gaza-Inhambane and in Nampula

Results – GHG emissions (incl LUC)



- In BAU shrubland is converted to cultivated land → carbon loss biomass carbon is dominant factor.
- In PROG, cultivated land is converted to energy crops → carbon sequestration (especially SOC when converted to switchgrass)

Soil - Method

- Soil quality: soil organic matter content
  - SOC as proxy indicator
    - water holding capacity
    - nutrient retention
    - soil structure
- Wind and water erosion
  - Loss of fertile topsoil → degradation
  - Damage to plants
  - Off site problems (contamination and soil displacement)
- Water erosion less relevant in selected regions

Method - Soil

- Wind erosion

$$E = \int (IKVCL)$$

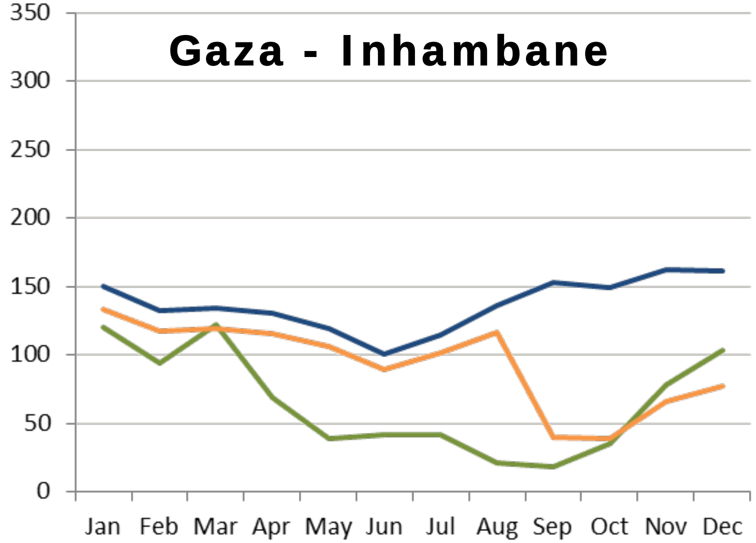
E	Erosion	Ton $ha^{-1\ yr}$
I	Soil erodibility index	ton ha−1 y
K	Soil surface roughness factor	dimensionless
C	Climate factor	dimensionless
L	Length of field	m
V	Vegetation factor	dimensionless

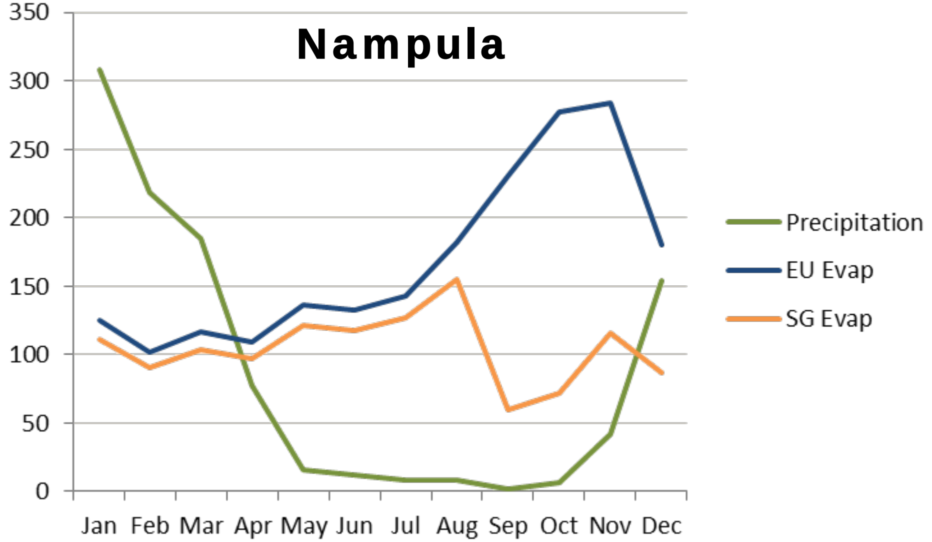
- Setting specific:
  - Vegetation factor is the important parameter which changes for different land covers
  - Highly depends on climatic changes during the year (precipitation, temperature, wind) in combination with the changes in vegetation cover (growth cycle)

Water - Method

- Water use
  - Water use efficiency (WUE)
    - Annual evapotranspiration
      - Precipitation
      - Temperature
      - Wind
      - Crop type
    - Annual biomass production
      - Agro-ecological suitability
  - Water depletion
    - Monthly evapotranspiration
      - Growth stage of crop
      - Access to water
    - Monthly precipitation

Water - Results





Actual water deficits and damage trough drought can only be assessed using a hydrological model including ground water and discharge levels.

Higher risk on water deficits in Gaza-Inhambane region because evapotranspiration exceed precipitation during the year, no replenishment.

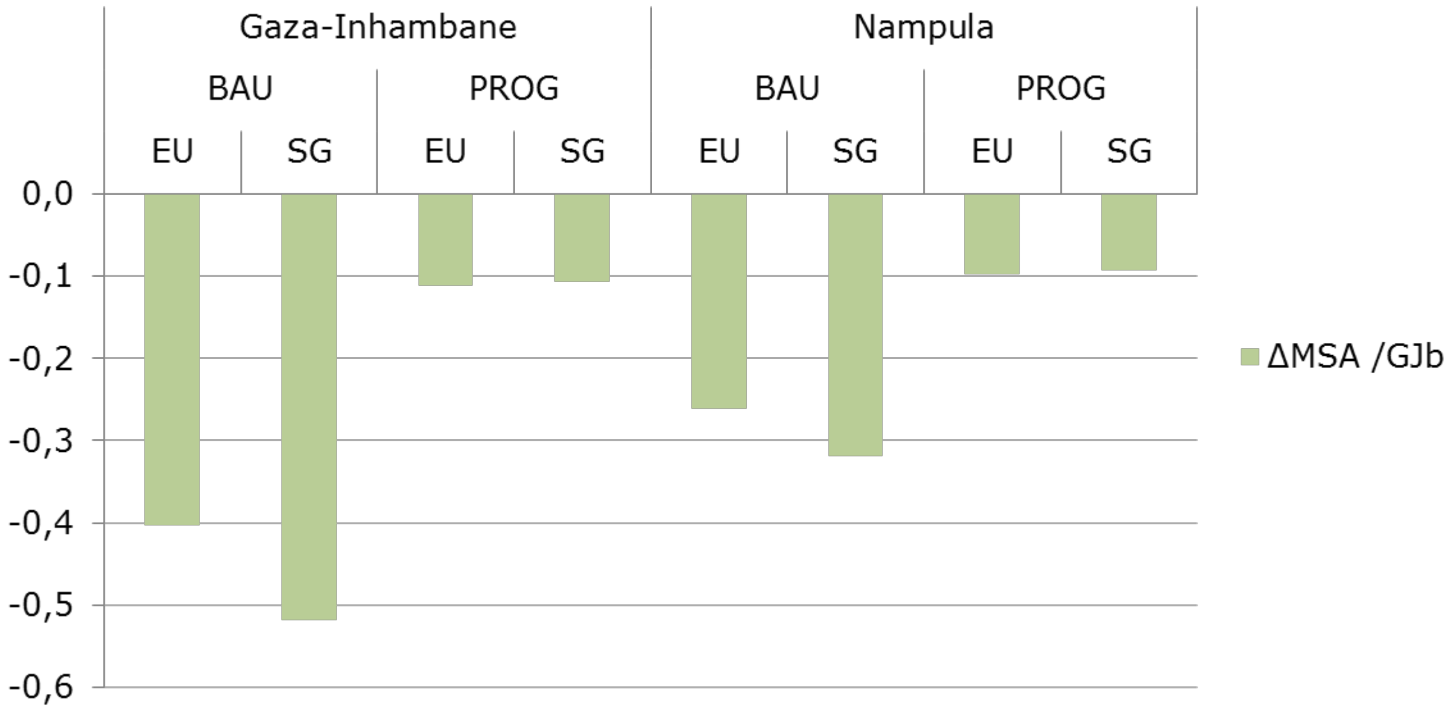
Eucalyptus causes higher risks on water depletion because of high evapotranspiration and deep rooting system.

Method - Biodiversity

- Modelling land availability
  - Excluded land
    - Conservation areas
    - Forest areas
    - Mangroves
- Biodiversity indicator Mean Species Abundance → compared to the species abundance of the original land use
  - ΔMSA per GJ biomass produced
  - Taking into account:
    - Regional agro-ecological suitability
    - Previous land use
    - New land use

$$\Delta MSA_{GJ_{EtOH}} = \sum \left(\frac{MSA_{new} - MSA_{currnet}}{Y_{c,ay} \cdot E_c \cdot Ef_{conversion}} \right)$$

Results - Biodiversity



ΔMSA per $GJ_{biomass}$ is negative. In BAU native vegetation is converted. In PROG extensive and mosaic agriculture is converted to plantations. MSA value for switchgrass is higher than euclayptus but due to lower yields similar effect on MSA. In BAU more area is required → effects MSA negatively

Socio-economic impacts

No.	Theme's	Qualitative	Quantitative
1	Legality	√	
2	Land rights	√	√
3	Food security	√	√
4	Economic viability		√
5	Local prosperity	√	√
6	Social well-being	√	√
7	Labour conditions	√	
8	Gender	√	

Some of the socio-economic impacts are directly related to the implementation and the management of the project. For those impacts no ex ante analysis can be made, but recommendations for best practice can be provided

Socio-economic impacts

- Many of the socio-economic impacts depend on the project design / management, but
- Are also heavily context related:
  - Legality → comply with national, regional and local law
  - Land rights → local situation on customary rights
  - Food security → subsistence farming, access to markets, poverty
  - **Economic viability** → agro-ecological suitability, accessibility, infrastructure
  - Local prosperity → main sources of income, employment level
  - Local well being → number of people affected
  - Labour conditions and gender issues → depends on implementation

Economic Viability - Method

The project should be able to sustain operation on the basis of current and projected revenues and expenditures. Project failure due to financial problems to could have detrimental socio-economic effects.

- Discounted cost for supply chain are calculated including
  - feedstock
  - transportation
  - conversion

$$C_{cr} = \sum_{Y=1}^{Y=x} \frac{\sum_{n=1}^{N}\left(I_{ny} \cdot C_{ny}\right) + \sum_{m=1}^{M}\left(J_{my} \cdot C_{my} \cdot Y_{y}\right)}{\left(1+a\right)^{y}} \Big/ \left(\sum_{x=1}^{y=x} \frac{Y_{y}}{\left(1+a\right)^{y}}\right)$$

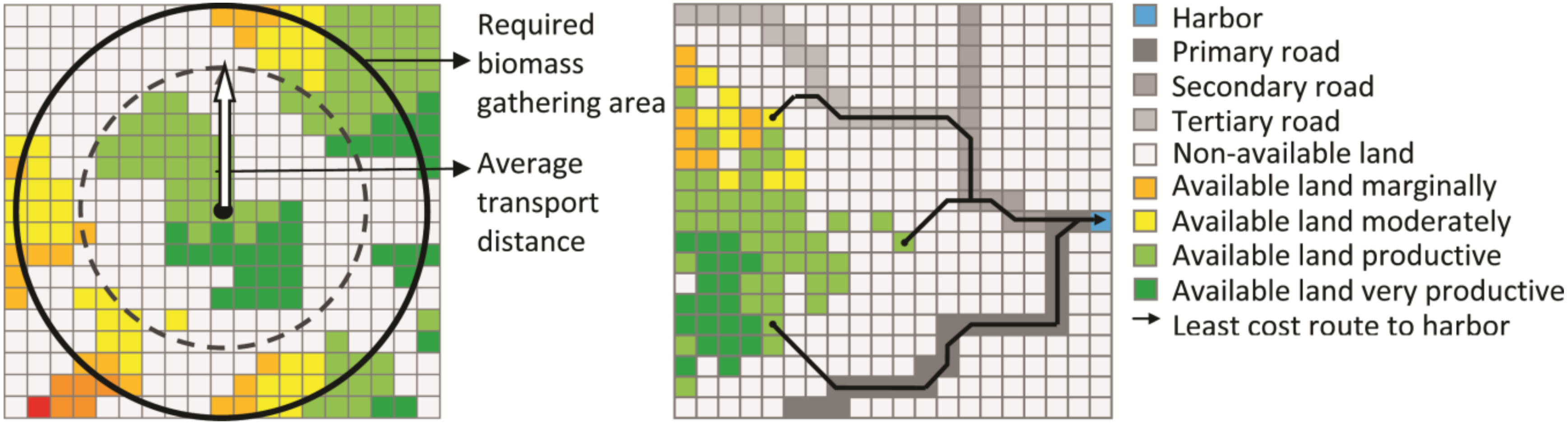
- Cost depend on suitability of available land
- Total cost of supply chain per GJ compared to cost of GJ gasoline

Economic viability - Method

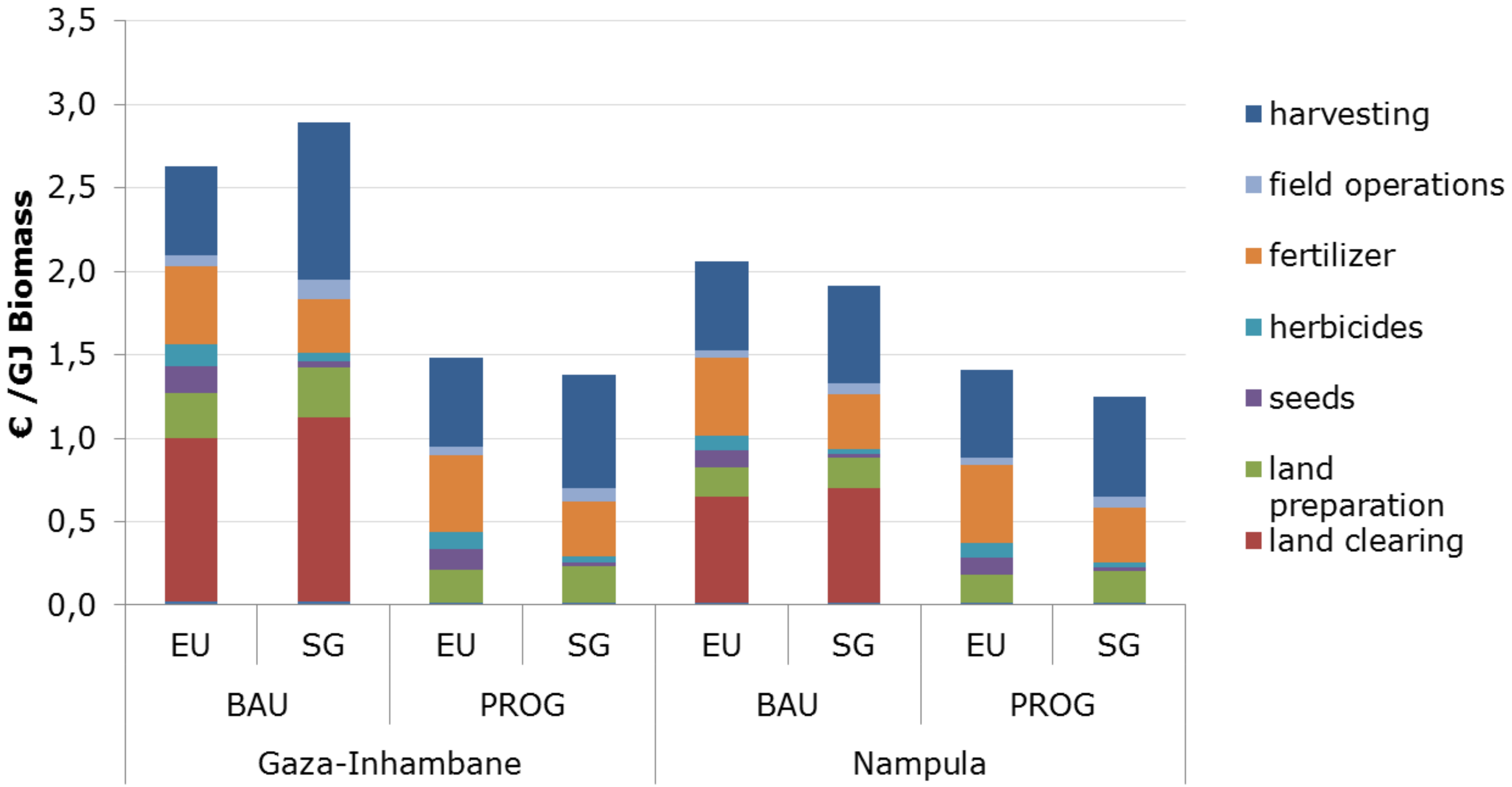
Cost of feedstock depend on suitability of available land

$$Y_{ay} = A_{ay} \cdot S_a \cdot M_y$$

Cost of transport depend o the availability and the suitability of land and therefore the radius to meet input requirements

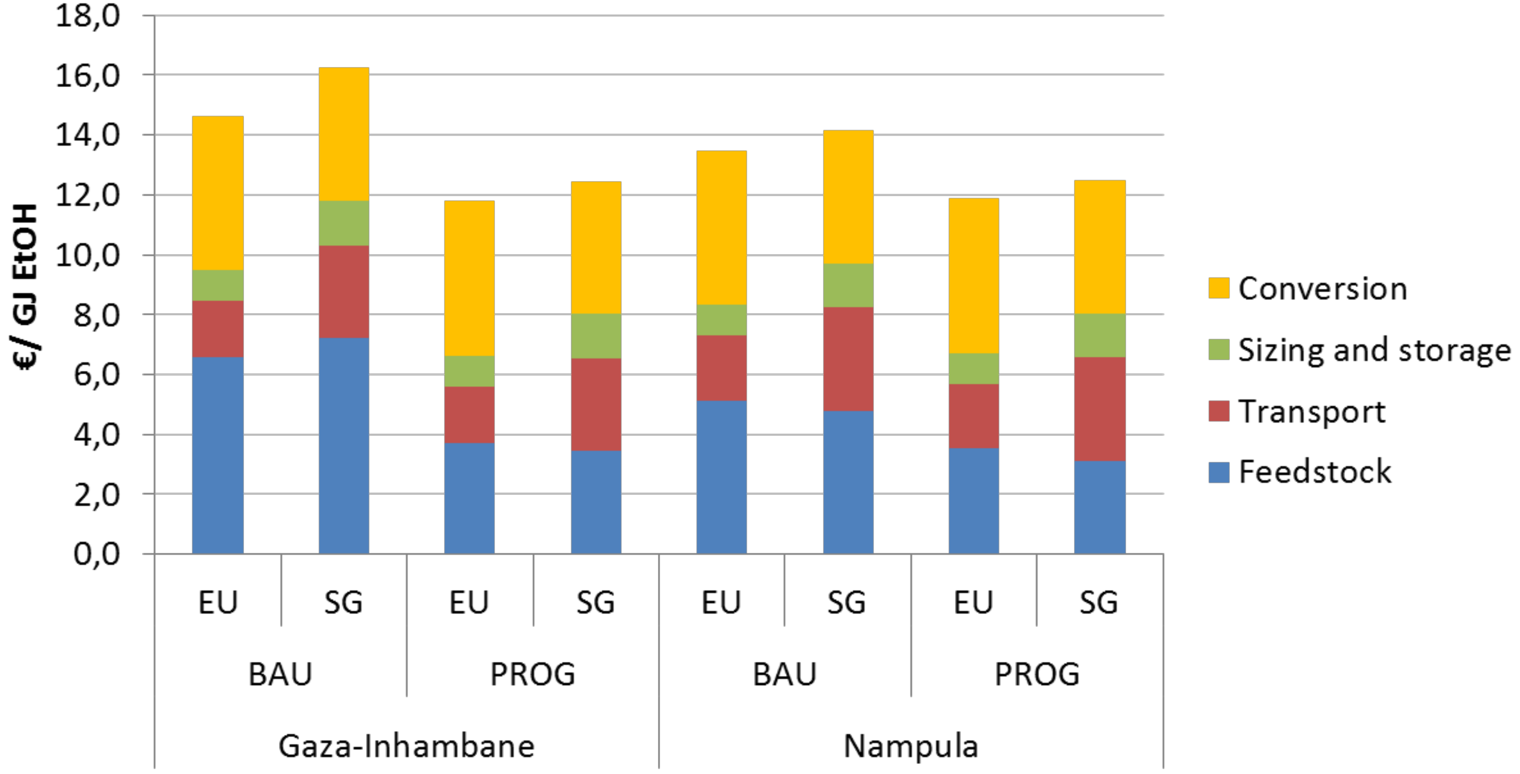


Economic Viability - Results



Feedstock cost are higher in BAU scenario because of cost for land clearing and preparation. Cost per GJ biomass are lower in Nampula because of higher yields

Economic Viability - Results



- The cost are higher in BAU scenario because of higher feedstock cost.
- The lower feedstock cost of Switchgrass is balanced by the higher transport cost.
- Cost are lower in Nampula because of higher yields.

Overall results – Environmental Impacts

	Impact	Unit	Gaza-Inhambane				Nampula			
			BAU		PROG		BAU		PROG	
			EU	SG	EU	SG	EU	SG	EU	SG
Environmental Impacts	**GHG Emission [b]**									
	Life cycle	Kg CO_2-eq /$GJ_{biomass}$	2.3	3.9	2.3	3.9	2.2	3.6	2.2	3.6
	LUC related emissions	Kg CO_2-eq /$GJ_{biomass}$	11.9	34.2	-20.4	-15.4	10.6	29.0	-27.3	-22.3
	Total emissions	Kg CO_2-eq /$GJ_{biomass}$	14.2	38.2	-18.2	-11.5	12.9	32.6	-25.1	-18.7
	Total avoided emissions	Kg CO_2-eq /GJ_{EtOH}	-36	24	-117	-100	-39	10	-134	-118
	Soil [c]									
	Soil Organic Carbon	Δ kg C /$GJ_{biomass}$	0.0	-2.1	-1.3	-3.3	0.0	-2.1	-1.5	-3.9
	Wind Erosion	Qualitative	-	0	+	++	-	0	+	++
	Water [d]									
	Water use efficiency	$Odt_{biomass}$/ l water	0.7	0.7	0.9	0.9	0.8	0.9	0.8	0.9
	Water depletion	mm/season	426	-96	426	-96	523	-237	523	-237
	Biodiversity [e]									
	MSA	ΔMSA x100 /$GJ_{biomass}$	-0.4	-0.5	-0.1	-0.1	-0.3	-0.3	-0.1	-0.1

Overall Results – Socio-economic Impacts

	Impact	Unit	Gaza-Inhambane				Nampula			
			BAU		PROG		BAU		PROG	
			EU	SG	EU	SG	EU	SG	EU	SG
Socio-economic Impacts	**Legality** [f]		*No ex-ante analysis possible, recommendations to comply with national law are provided see*							
	Land rights [g]									
	Land right risk	Qualitative	+	+	+	+	-	-	+	+
	Food security [i]									
	Food security	Qualitative	+/-	+/-	+	+	-	-	+	+
	Economic viability [j]									
	Feedstock	$\$/GJ_{biomass}$	2.44	3.05	1.29	1.54	1.84	2.01	1.03	1.31
	End product	$\$/GJ_{EtOH}$	14.18	16.62	11.32	12.86	12.96	14.38	10.93	12.63
	Local Prosperity [k]									
	Total jobs	X 1000 jobs	9.7	6.9	8.0	5.9	4.8	2.3	7.1	4.7
	Local labour	%	100	100	100	100	100	100	100	100
	Total investment	M$	260	297	208	230	157	127	201	226
	Total wages	M$	10.1	7.1	8.3	5.8	4.9	2.4	7.4	4.9
	Social well-being [l]									
	Total no of people affected	X 1000 people	49	34	40	28	24	12	36	24
	Labour conditions [m]		*No ex-ante analysis possible, recommendations to comply with (inter-) national law and best practice are provided, see*							

Discussion and Conclusion

- These assessments provide information on:
  - The amount, the location and the timeline of land availability for energy crops
  - The development in potential of biomass production (actual yield levels)
  - The most favorable areas for biomass production from economic point of view
  - The most favorable areas for bioenergy production from a sustainability point of view
  - The key sustainability issues for a specific supply chains in a specific region → flag areas of concern
  - Provide steering for tailor made best practices (are supply chain and region specific)

Discussion and conclusion

- This *ex ante* analysis of the land availability, and the environmental and socio-economic impacts contributes to the **identification of go and no- go areas** for bioenergy production.
- This is important information for:
  - **National Governments**: enables a sound planning of land use, sustainable investment in bioenergy production capacity, and infrastructure over time. It enables to define the preconditions for a sustainable sector
  - **Investors**: to make realistic estimations of the economic viability of a project and it provides the ability to define the preconditions to comply with sustainability criteria.
- This could help to prevent competition for land, reduce investment risks, avoid large scale project failures, **minimise negative environmental and socio-economic impacts and optimize positive** effects of large scale bioenergy production.

References

- Van der Hilst, F. and A. P. C. Faaij (2012). "Spatiotemporal cost-supply curves for bioenergy production in Mozambique." Biofuels, Bioproducts and Biorefining 6(4): 405-430.
- Van der Hilst, F., J. van Eijck, J. Verstegen, V. Diogo, B. Batidzirai and A. Faaij (2013). Global Assessments and Guidelines for Sustainable Liquid Biofuel Production in Developing Countries. Impacts of Scale up of biofuel production case studies: Mozambique, Argentina and Ukraine. Vienna, Commissioned by UNEP, GEF, FAO, UNIDO. Copernicus Institute, Utrecht University: 166.
- van der Hilst, F., J. A. Verstegen, D. Karssenberg and A. P. C. Faaij (2012). "Spatiotemporal land use modelling to assess land availability for energy crops – illustrated for Mozambique." GCB Bioenergy 4(6): 859-874.
- Verstegen, J. A., D. Karssenberg, F. van der Hilst and A. Faaij (2012). "Spatio-temporal uncertainty in Spatial Decision Support Systems: A case study of changing land availability for bioenergy crops in Mozambique." Computers, Environment and Urban Systems 36(1): 30-42.
- Batidzirai, B., F. van der Hilst, H. Meerman, M. H. Junginger and A. P. C. Faaij (2014). "Optimization potential of biomass supply chains with torrefaction technology." Biofuels, Bioproducts and Biorefining 8(2): 253-282.

Thank you for your attention

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