Integrated assessment of the sustainability of biomass supply chains

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- Previous work on sustainable biomass supply chains:
  - Land use change modeling
  - Dynamic Cost supply chains
  - Environmental and socio-economic impacts
- The Be Basic project:
  - Objectives
  - Case studies
  - Current work
  - Future work and potential collaboration

Rationale

- The total demand for biomass for energy and materials is expected to ranges between 100 – 405 EJ in 2050.
- Therefore a strong increase in the deployment of biomass is required.
- For large scale biomass production dedicated energy crop are required
- 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
  - Contribution to rural development, GDP and employment
  - Impacts on local well being
  - Etc.

Rationale

- The potentials, costs and impacts of biomass supply chains are highly dependent on the location of production.

- Therefore, spatio-temporal assessment is required to assess the sustainability of biomass supply chains.

Demonstration for Mozambique

1. **Land use change model** → potential land availability for biomass production
2. **Dynamic cost supply curve** → given the location and characteristics of the available land, what are the cost of the biomass supply chains
3. **Impact assessment** → given the location of available land for biomass production and the biophysical and socio-economic conditions in those regions, what are the environmental and socio-economic impacts.

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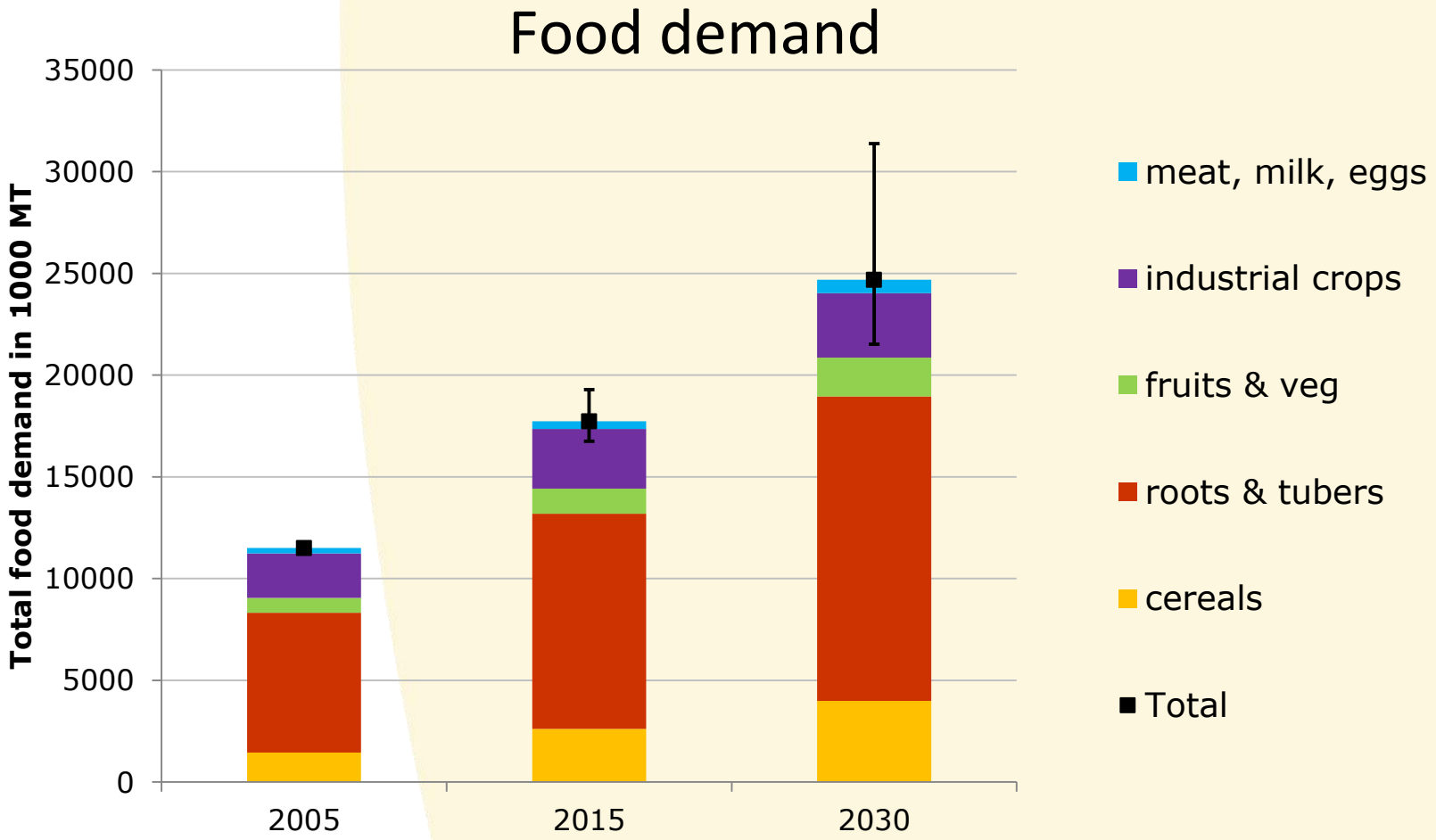
Land use change modeling

- Land for bioenergy crops should not compete with other land use functions.
- The amount of land available for bioenergy depends on the land required for:
  - Settlements
  - Food production
  - Livestock production
  - Material production (including fuel wood production)
  - Nature conservation
  - Excluded areas (not suitable)
- Land requirements for land use functions change over time.

Land use change modeling: scenarios Mozambique

	Business as Usual scenario	Progressive scenario
Farm	Mainly **subsistence** farming	Shift towards **commercial** farming
Technology	**Low adoption** of improved seeds, fertilizers pesticides and mechanisation. **Low yield increase**.	**Strong increase** in use of improved seeds, fertilizers, pesticides and mechanisation. **High yield increase**
Livestock	Cattle and goats mainly in **pastoral systems**	Shift towards **mixed systems** (higher efficiency)
Wood	**Deforestation** due to illegal logging and high demands for fuel wood	**Decrease in deforestation**. Due to regulated logging and decreased fuel wood demand related to higher implementation of improved stoves. Wood demand met by wood plantations.
Policy	**Current** policy framework	Highly **effective policies** on efficient and sustainable production

Land use change modeling: Drivers of land use change

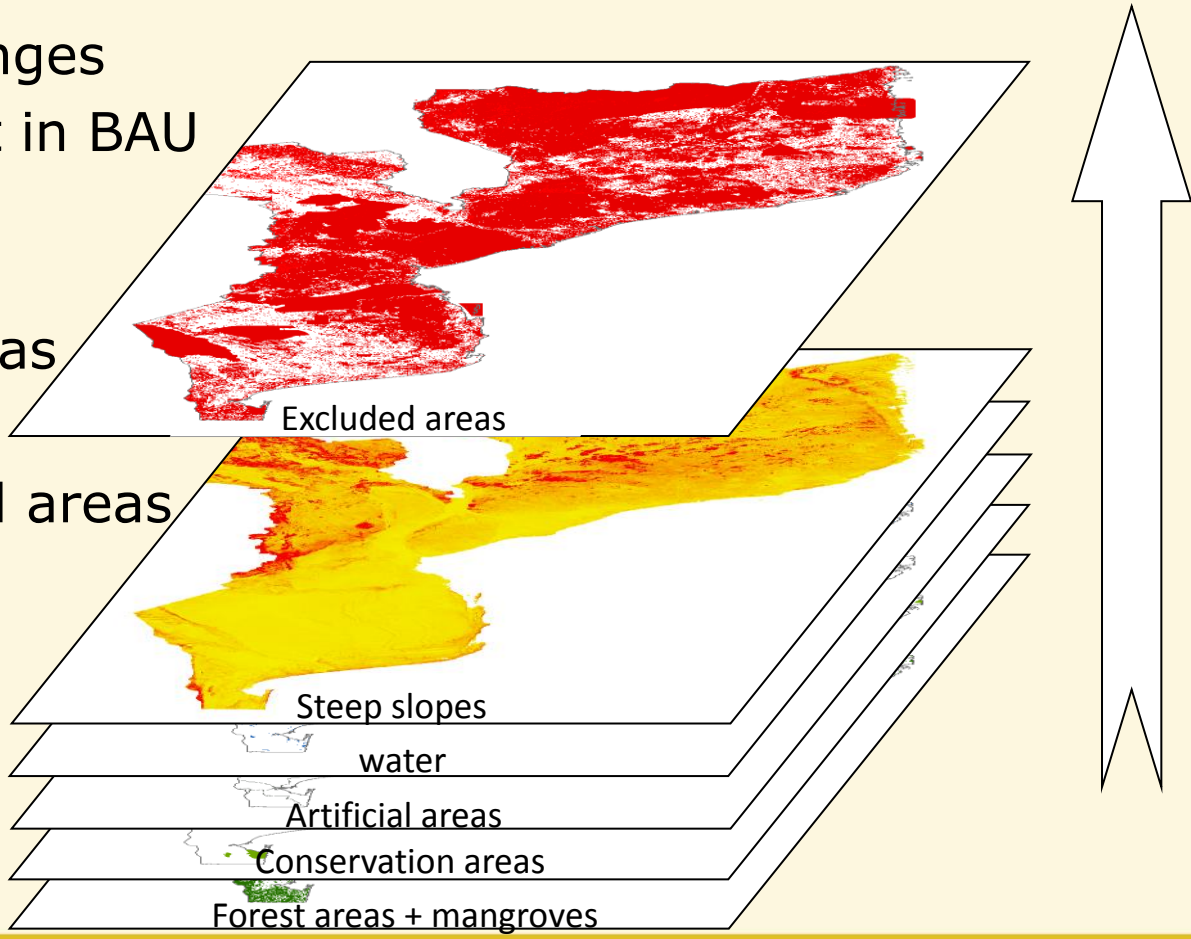


Land use change modeling: Approach

- A land use allocation model is developed. To allocate the additional land use requirements for food, feed and material production.
- Land that can not or may not be used for bioenergy production is excluded
- The land is allocated to a dynamic land use based on the suitability of the land for that specific land use → based on several 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

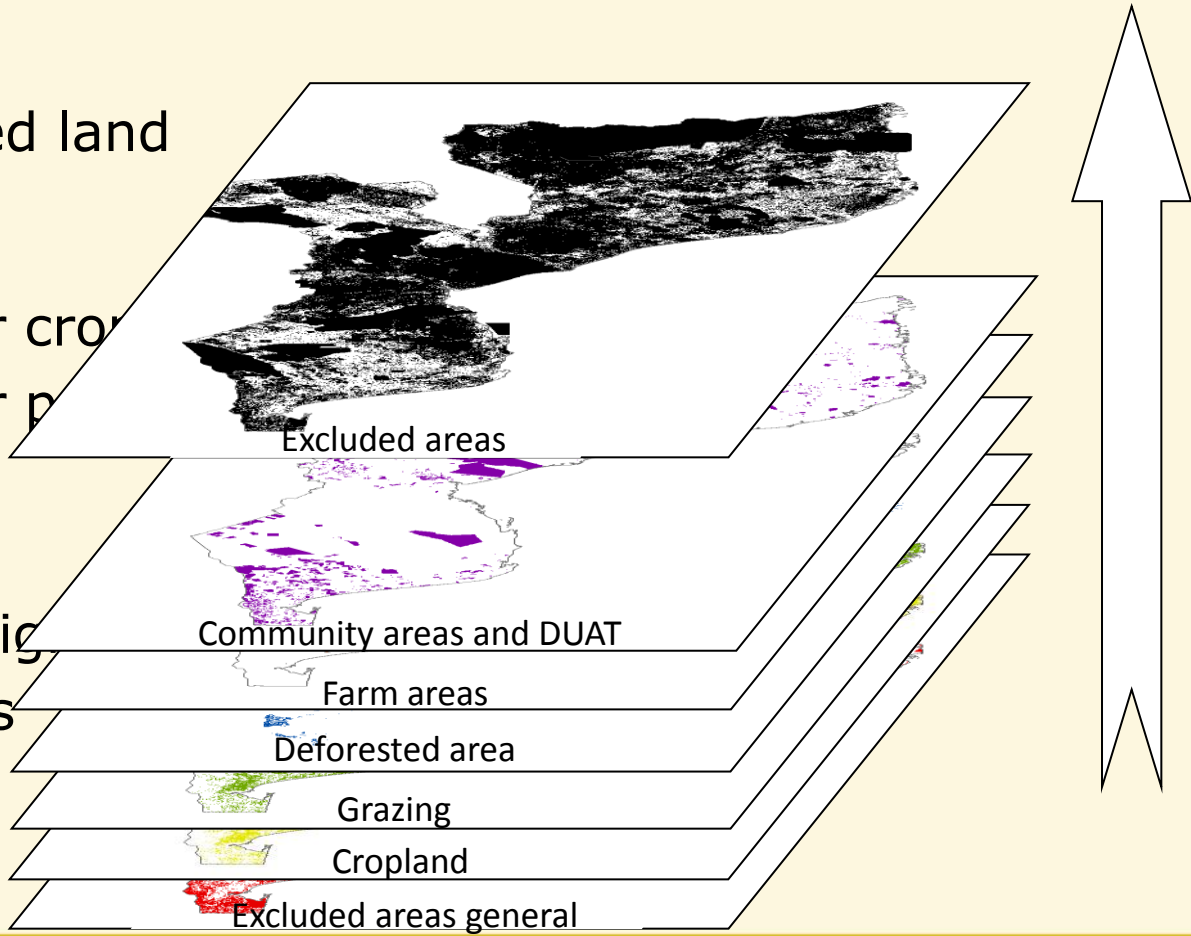
Land use change modeling: Excluded areas

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



Land use change modeling: 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

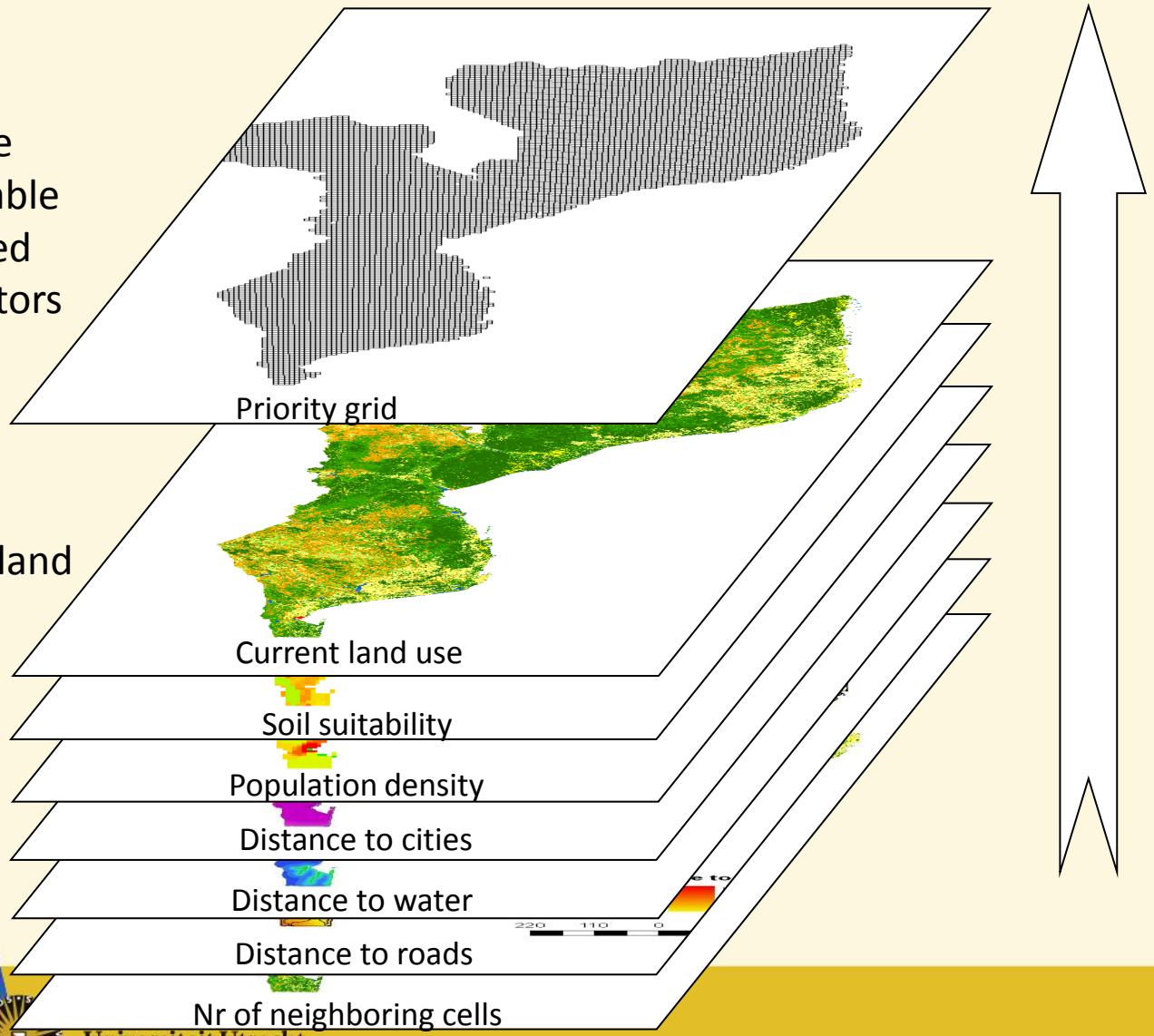


Land use change modeling: Allocation

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

Also done for other dynamic land use classes



2005

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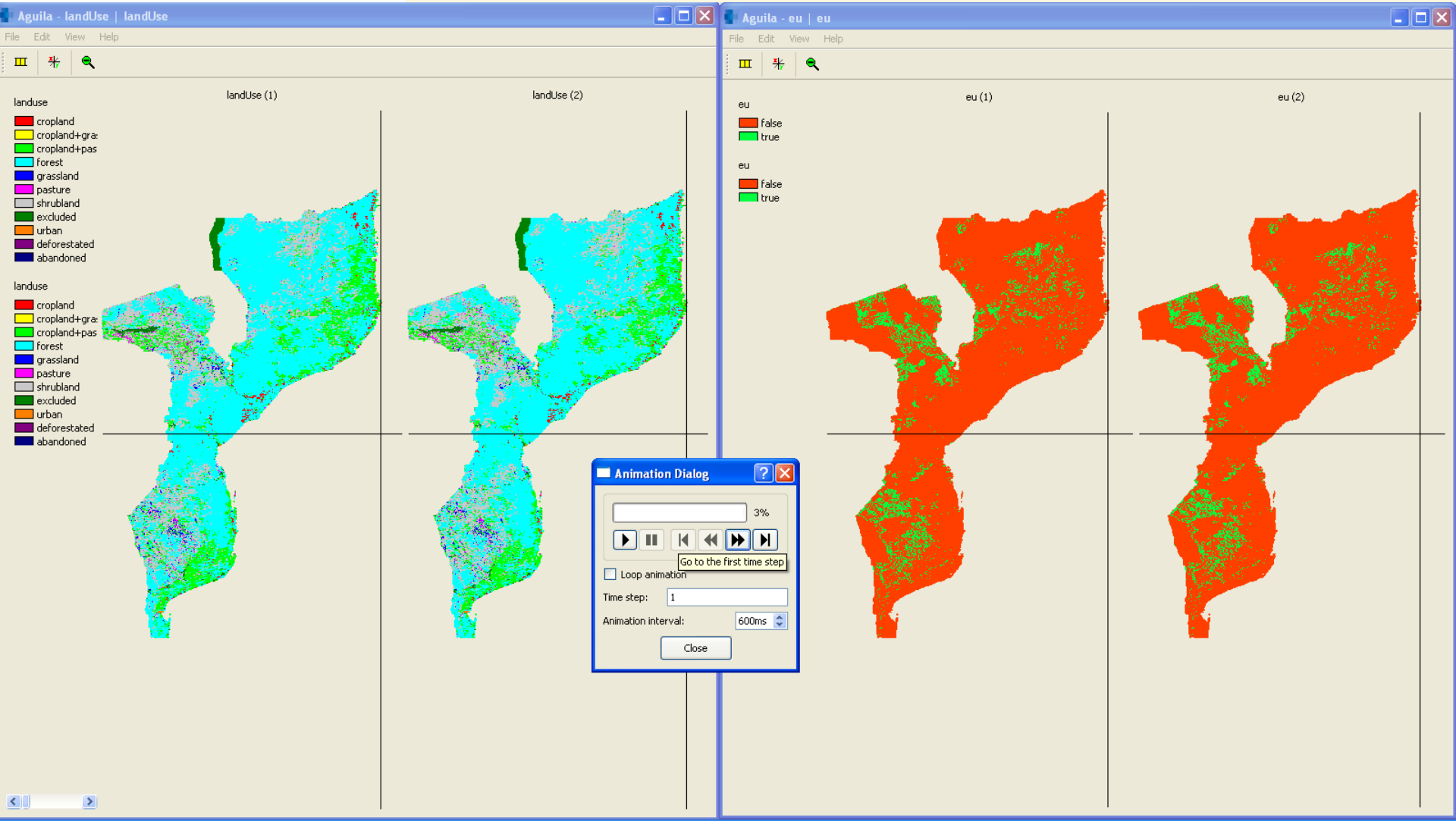

2006

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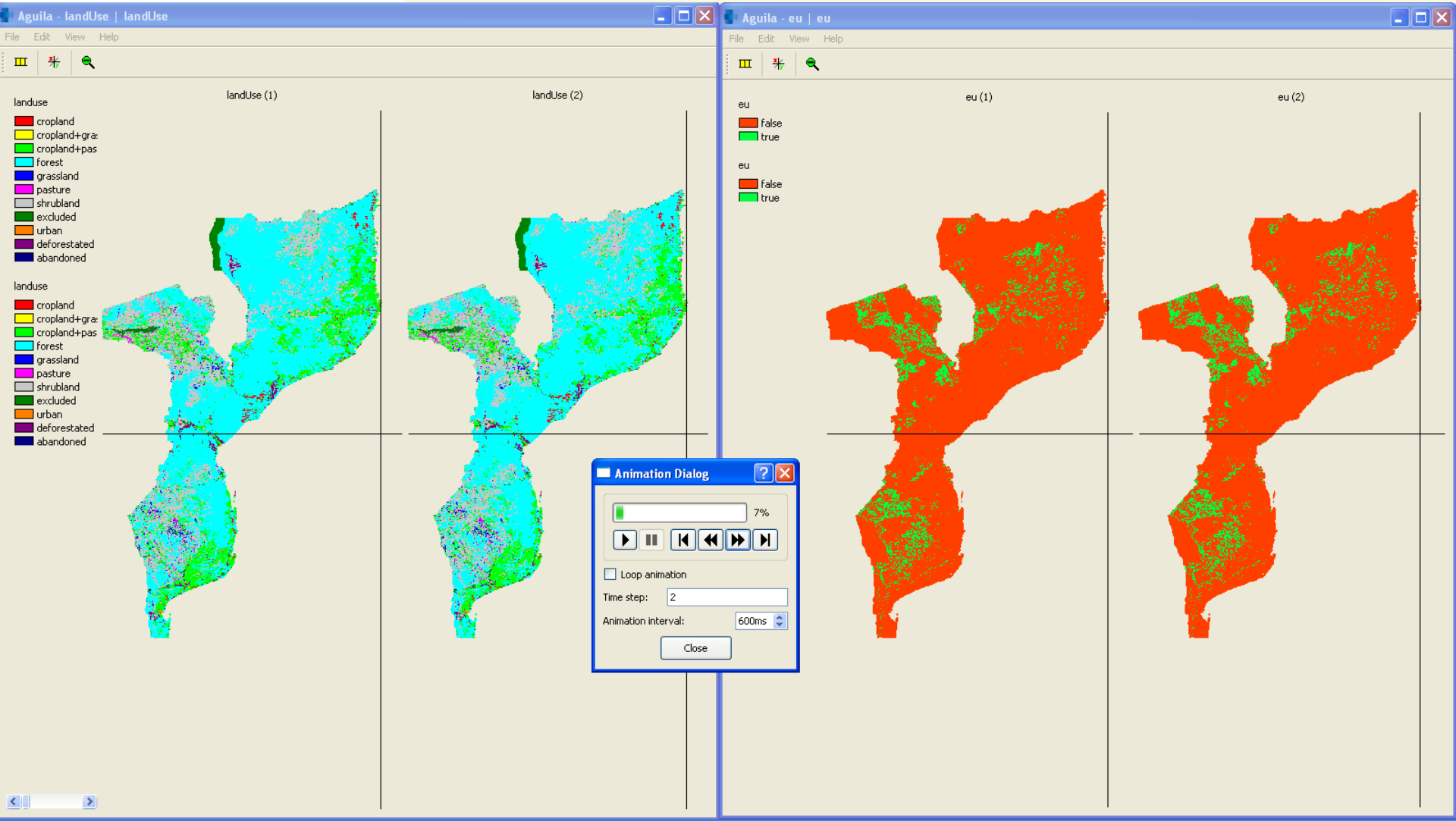

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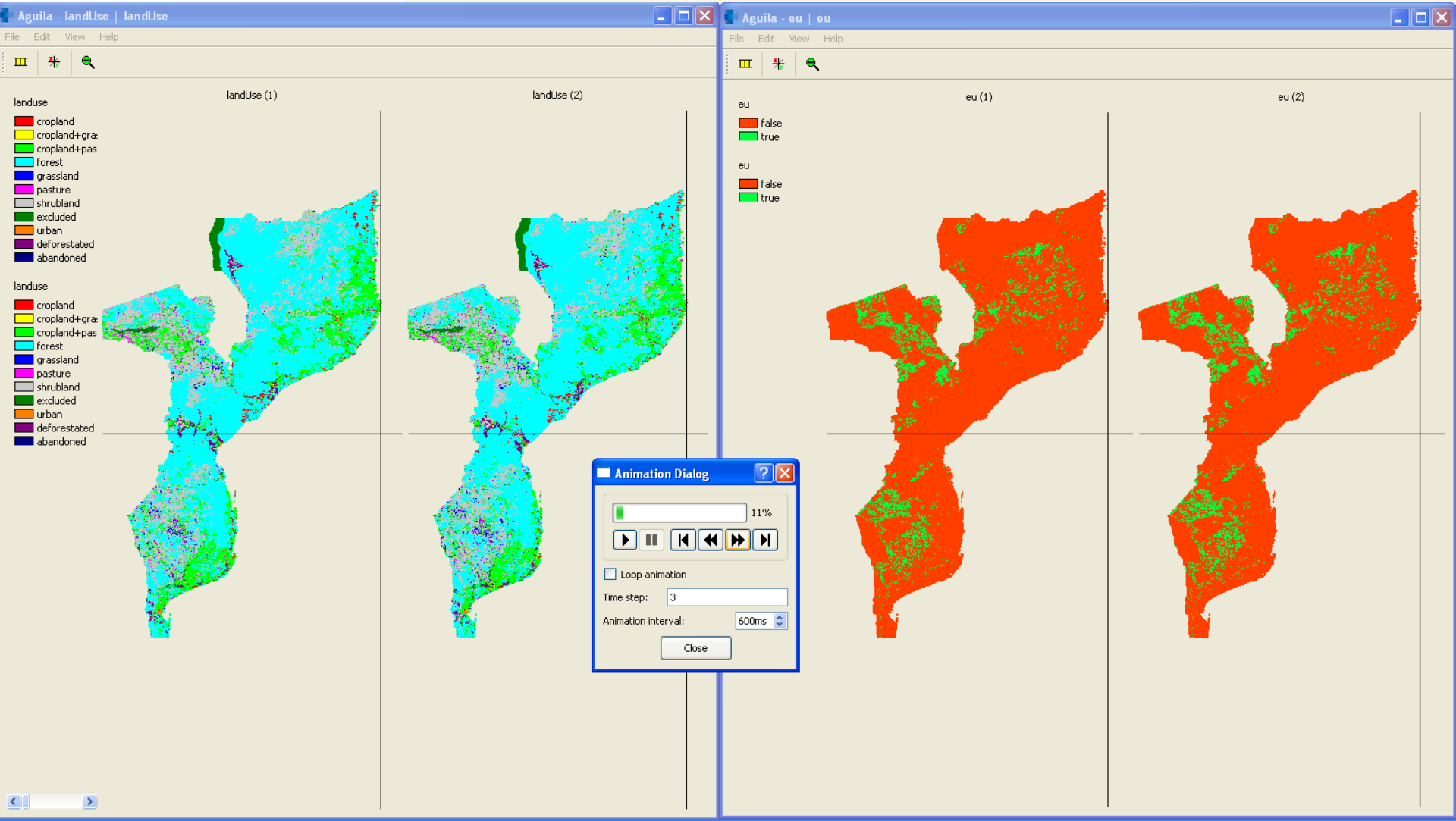

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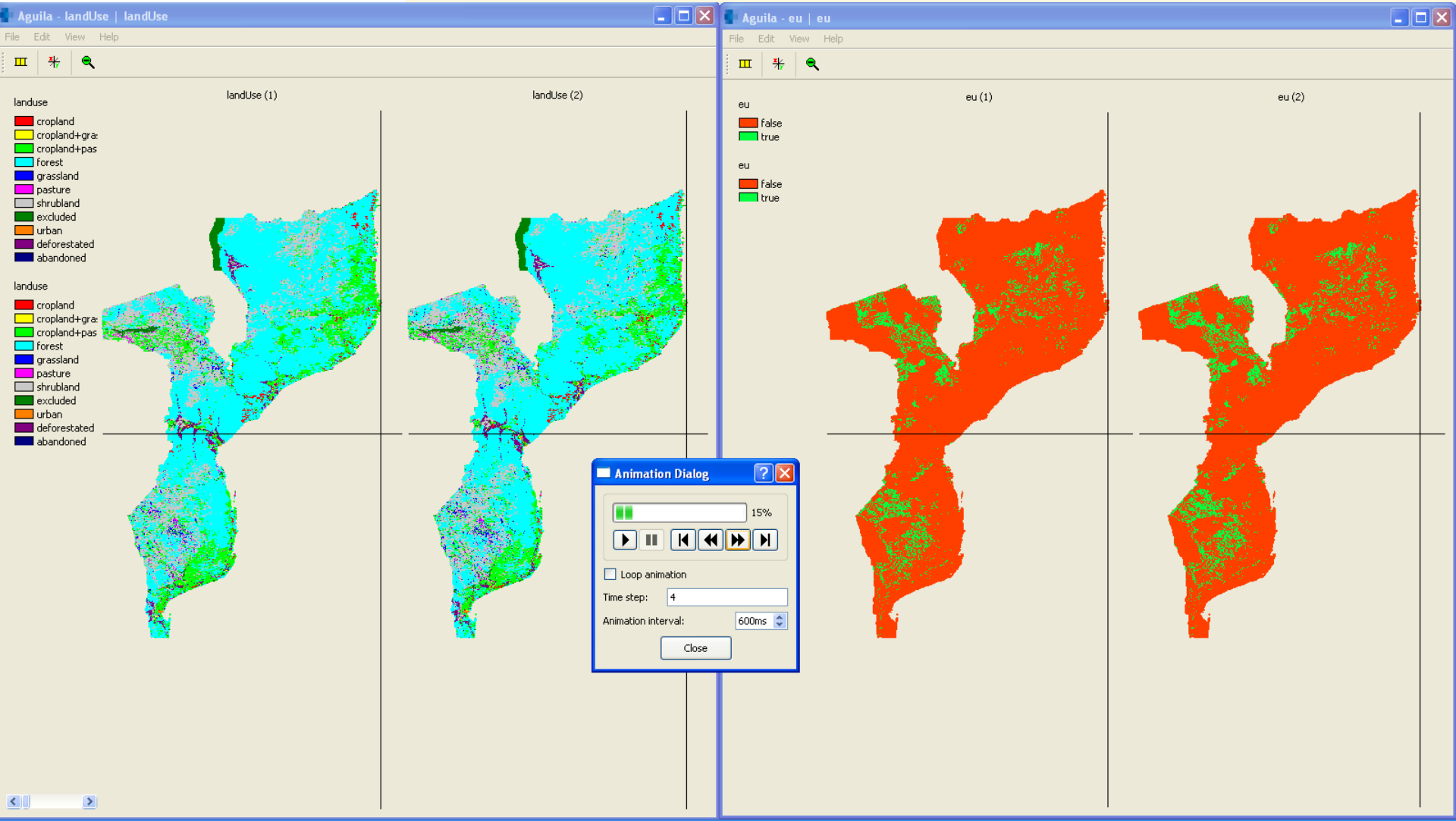

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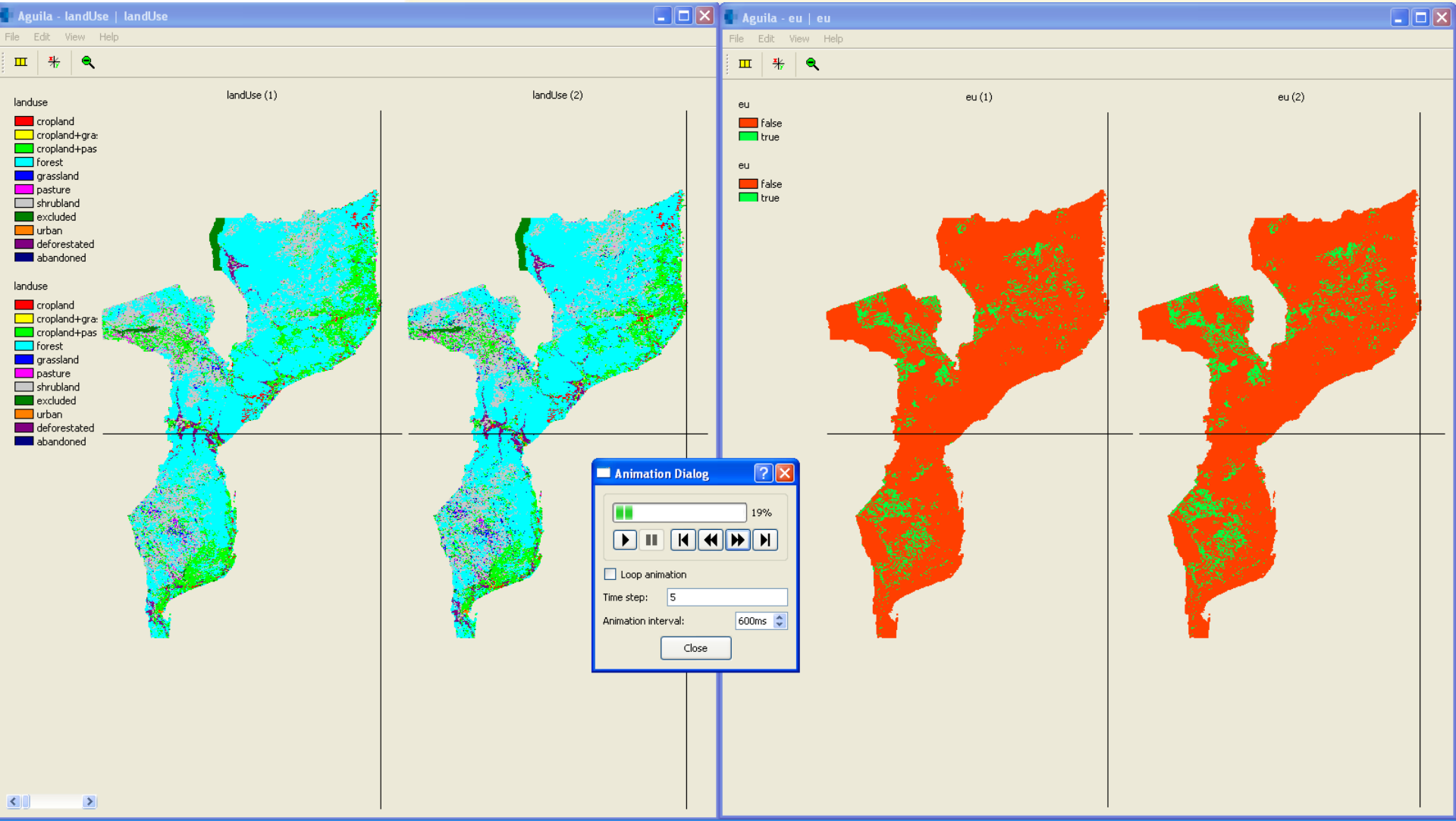

2010

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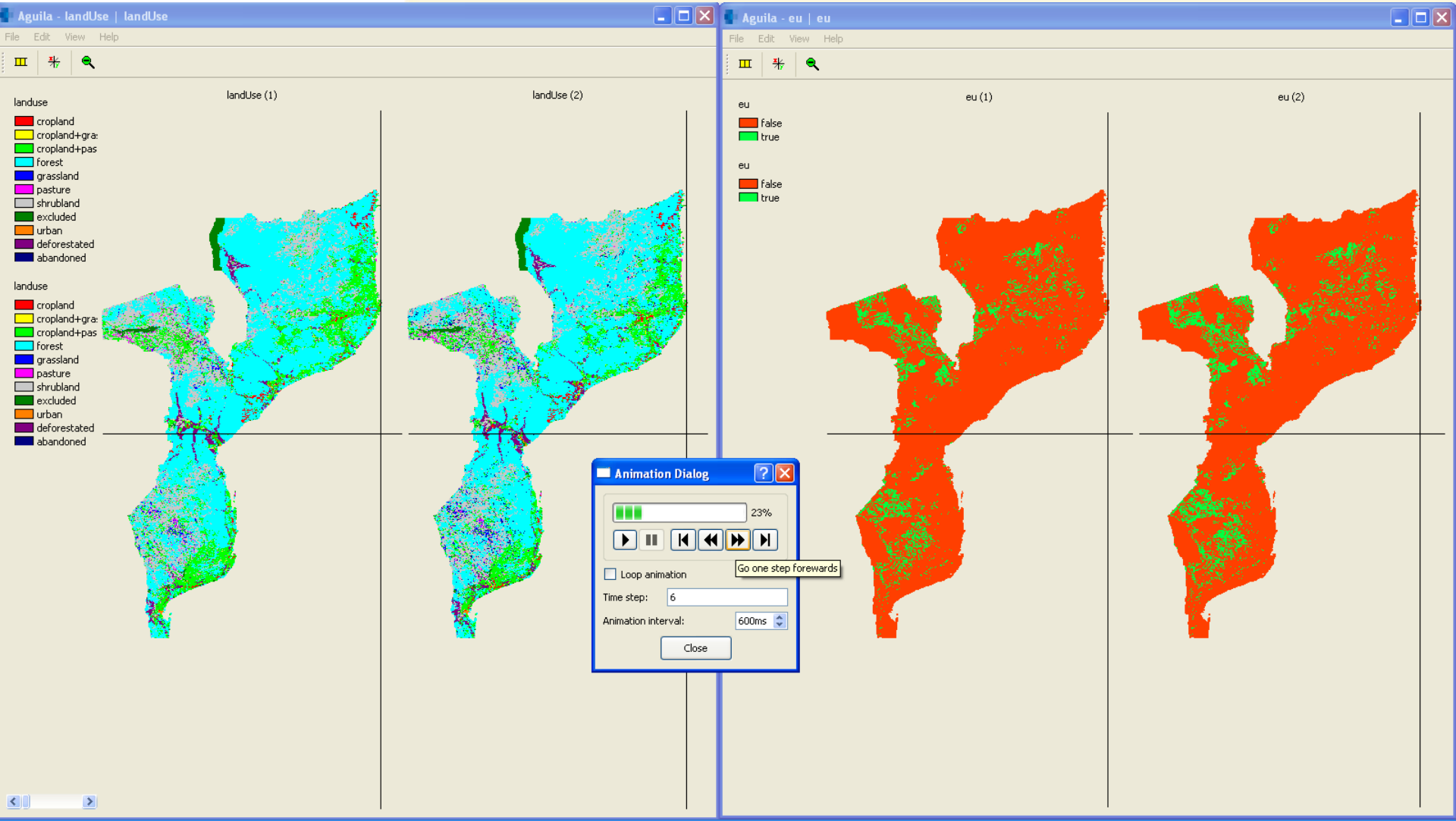

2011

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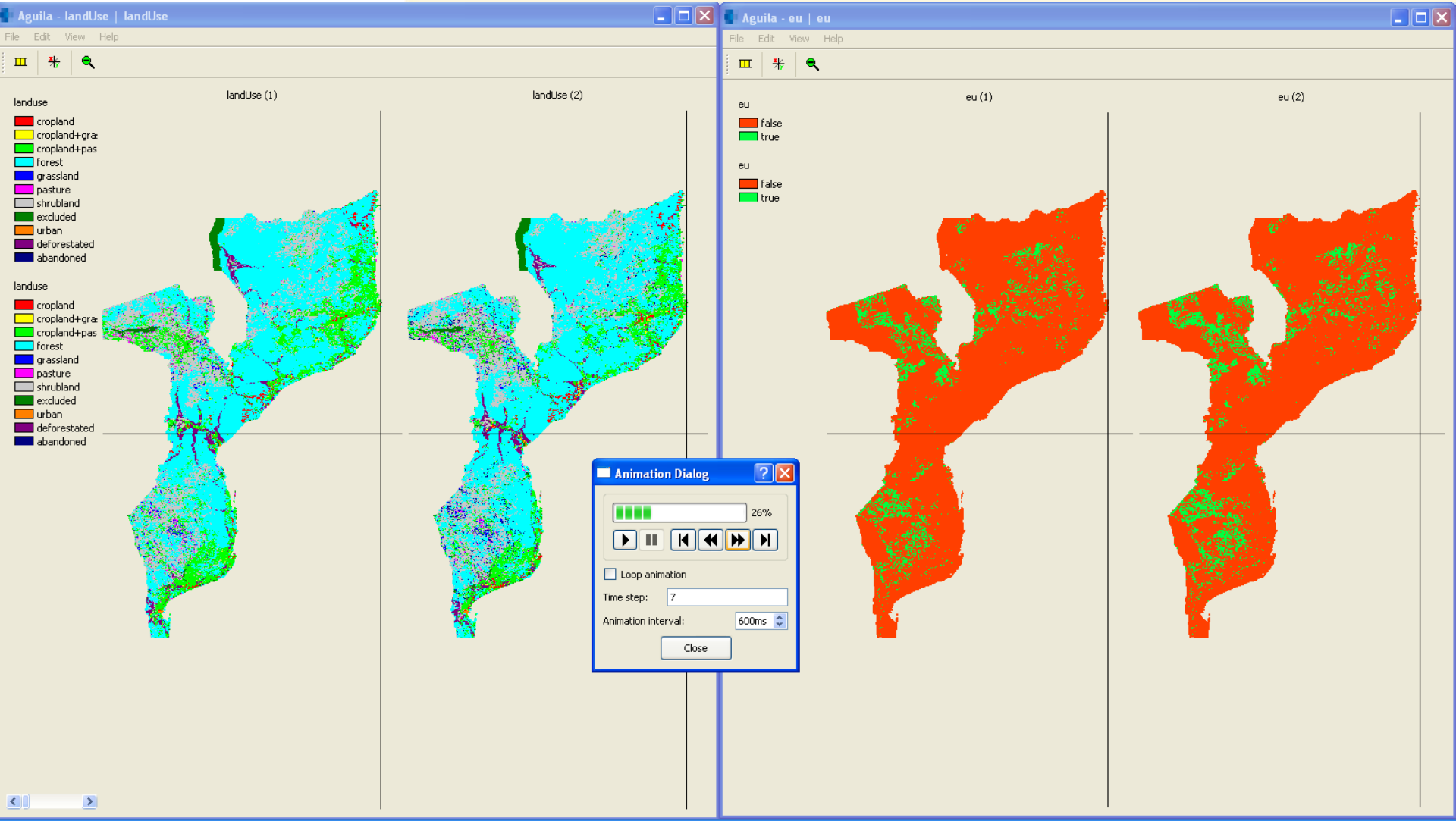

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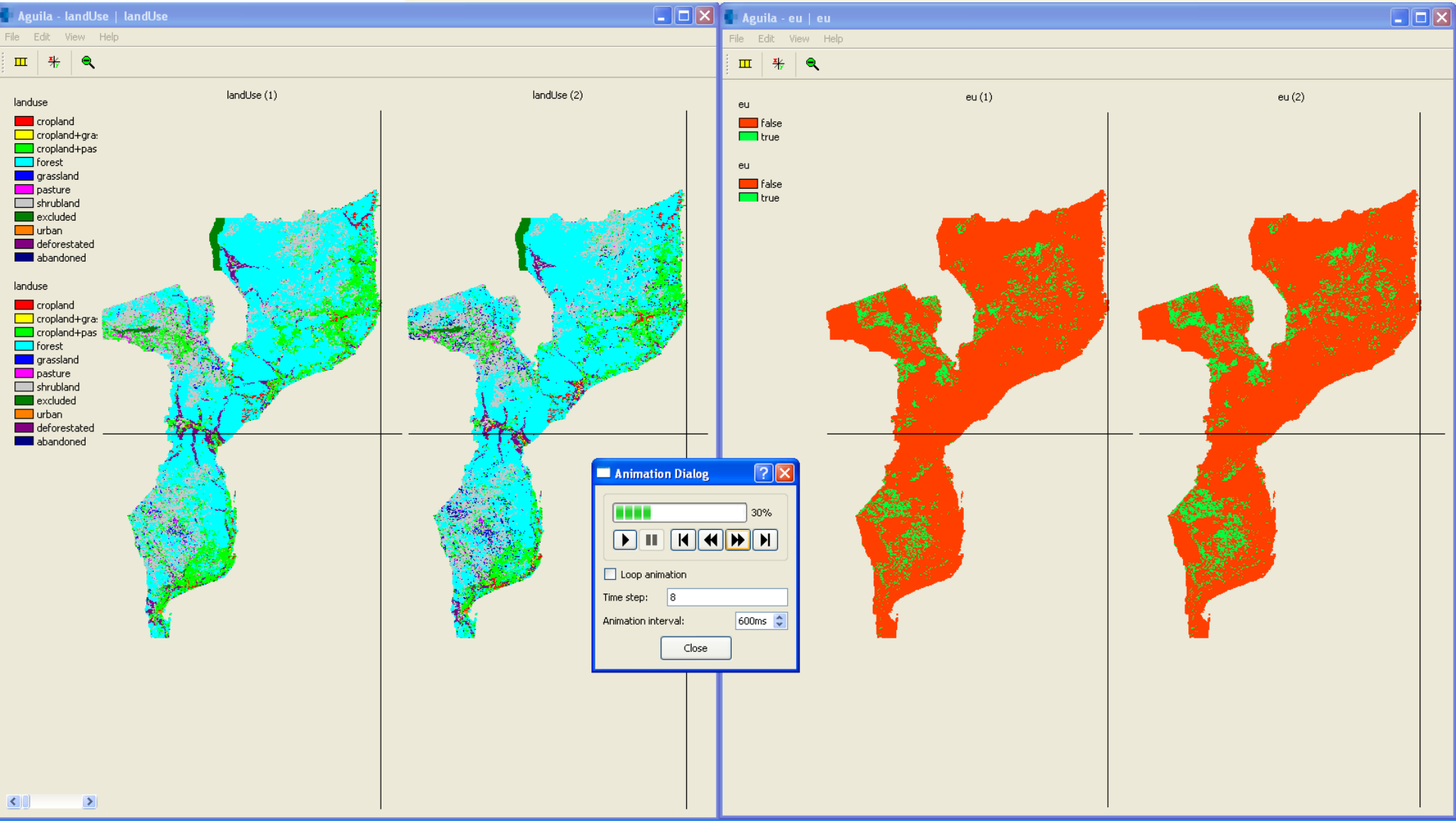

2013

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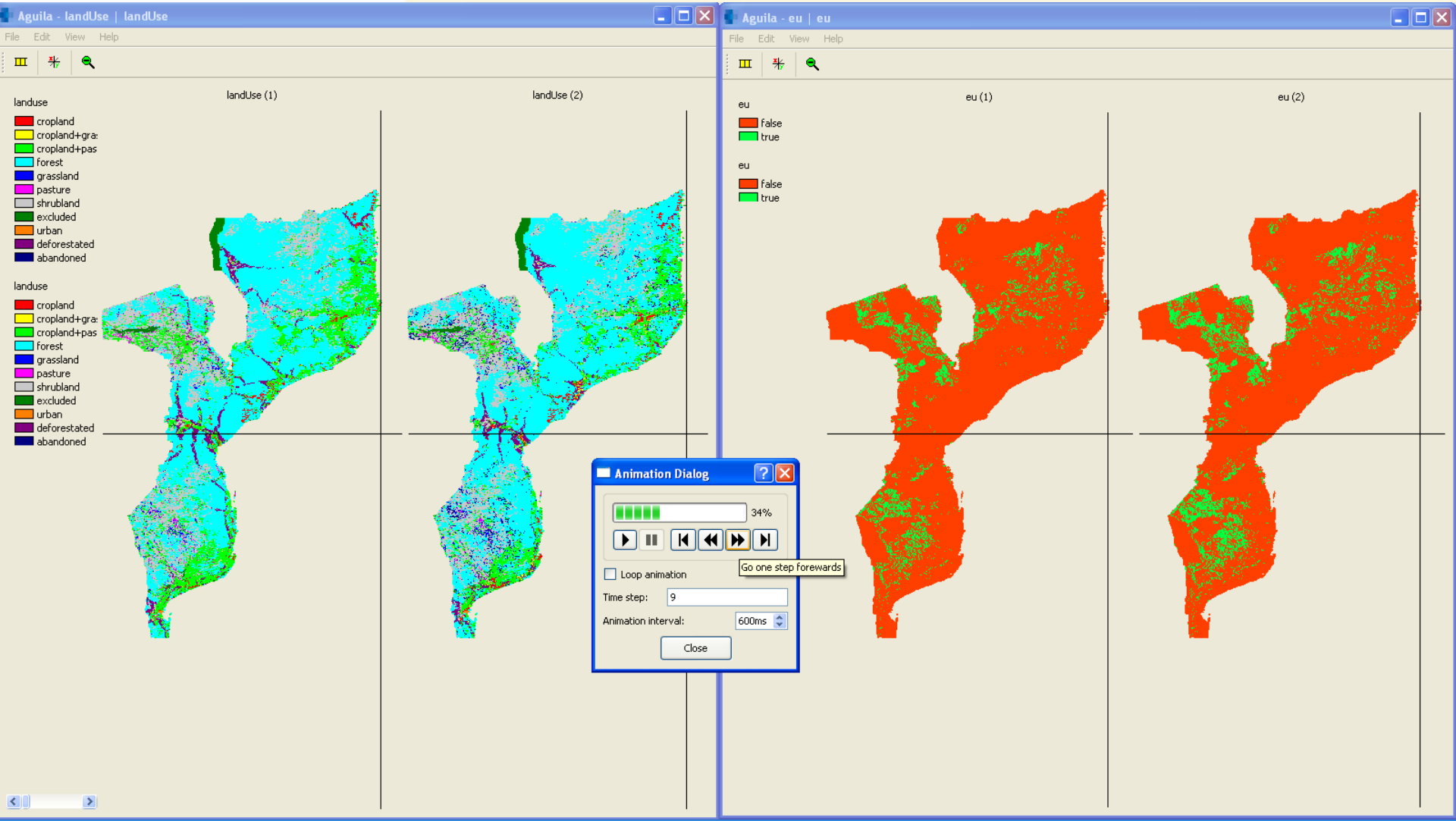

2014

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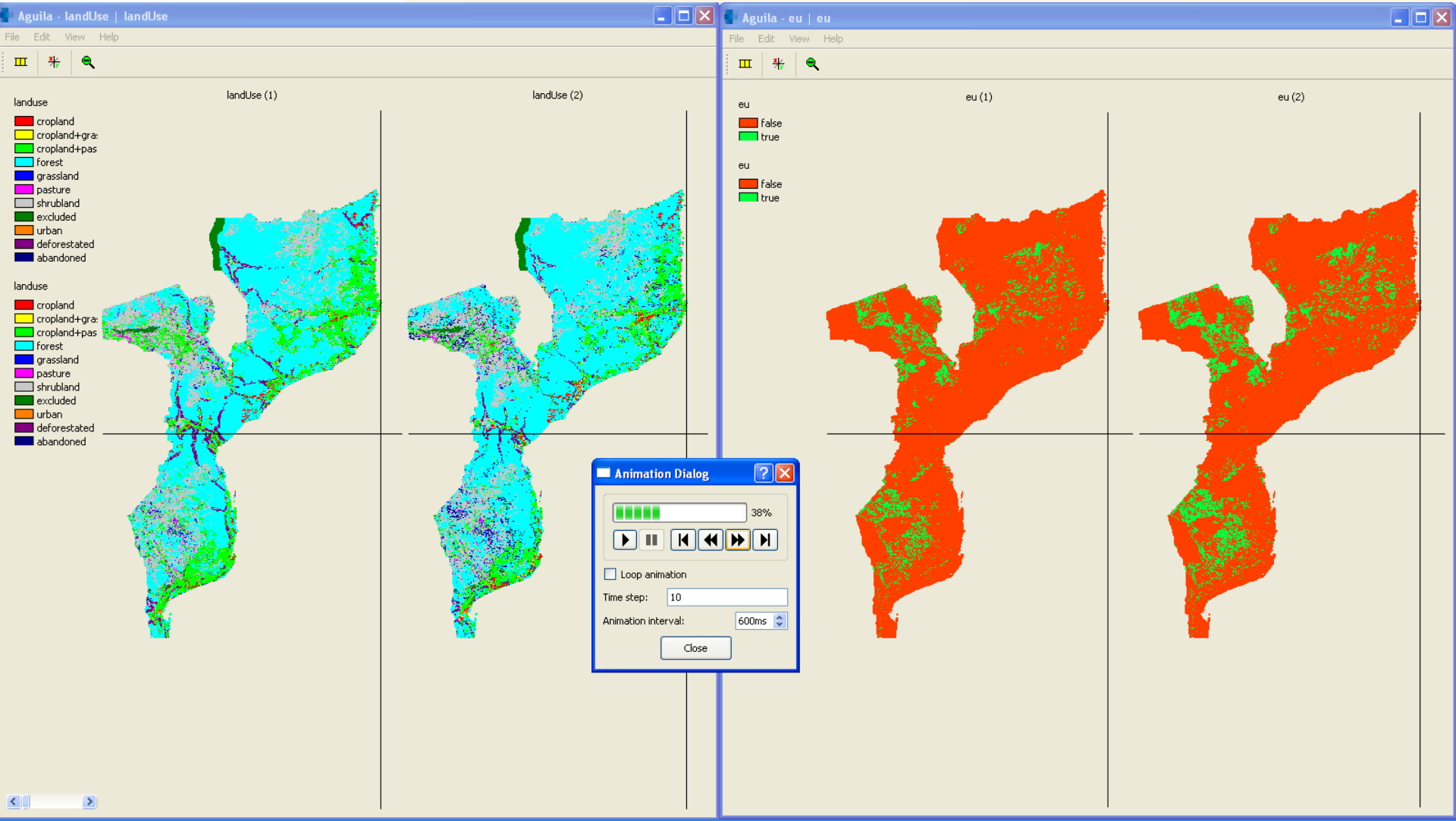

2015

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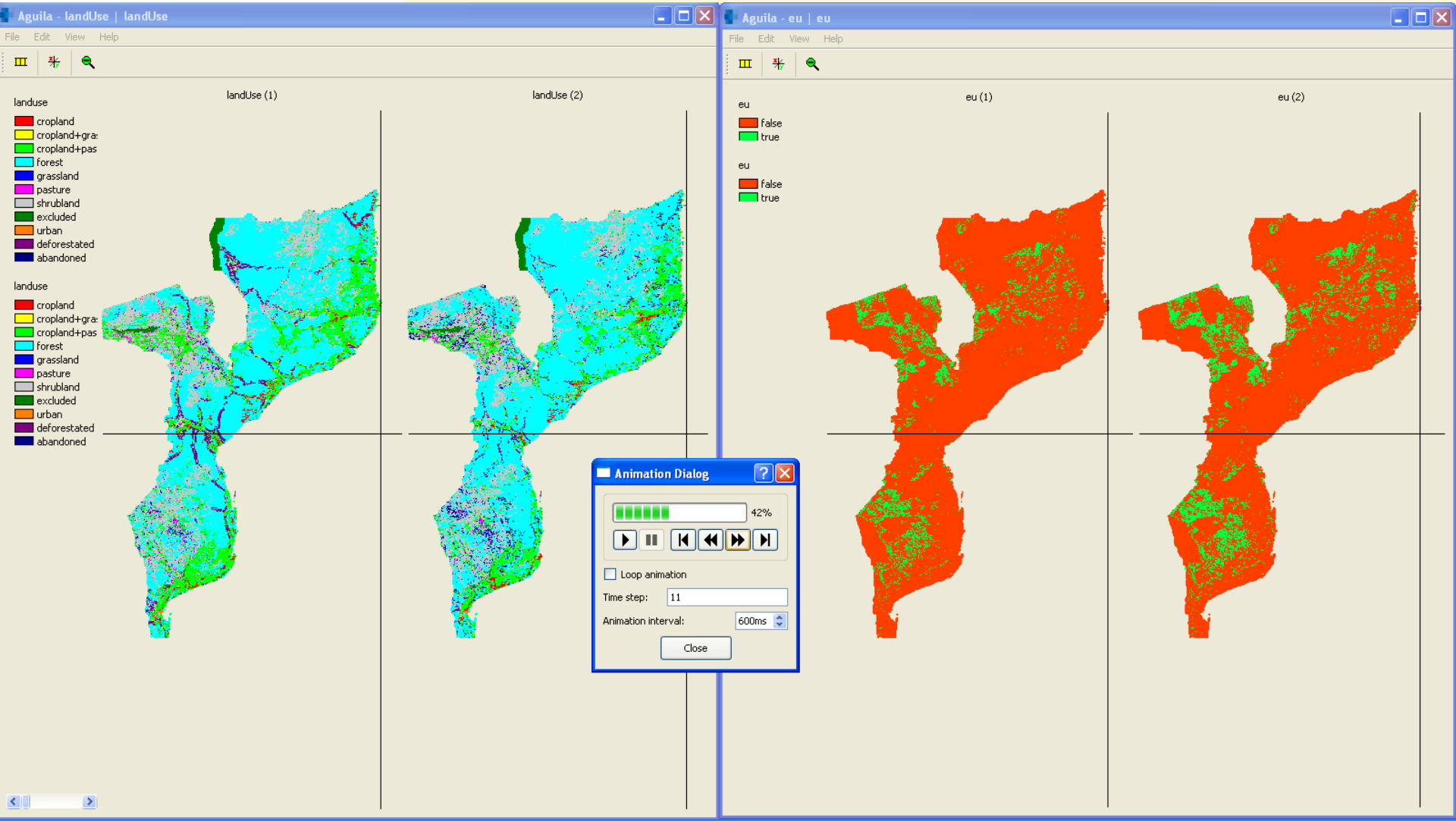

2016

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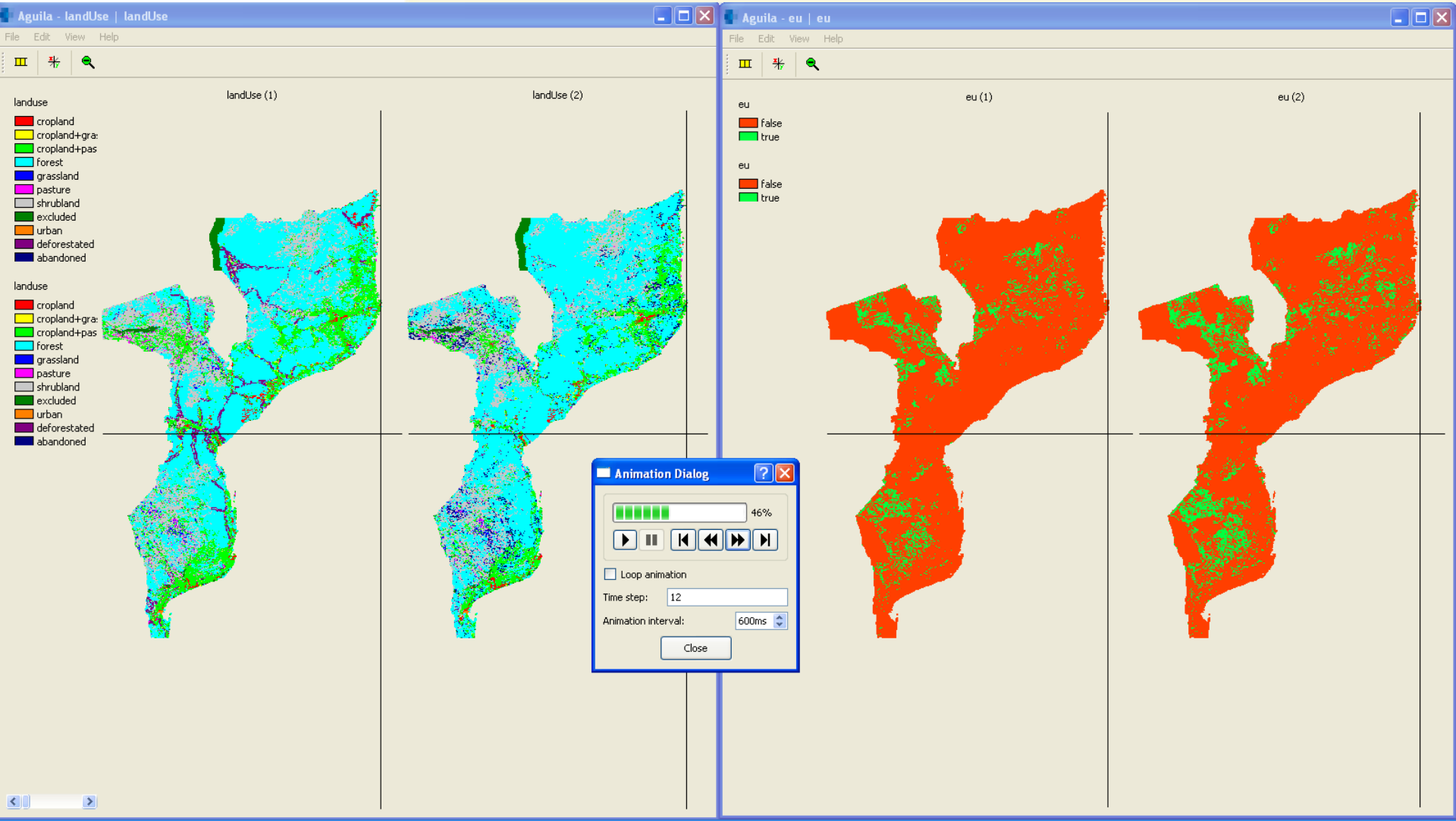

2017

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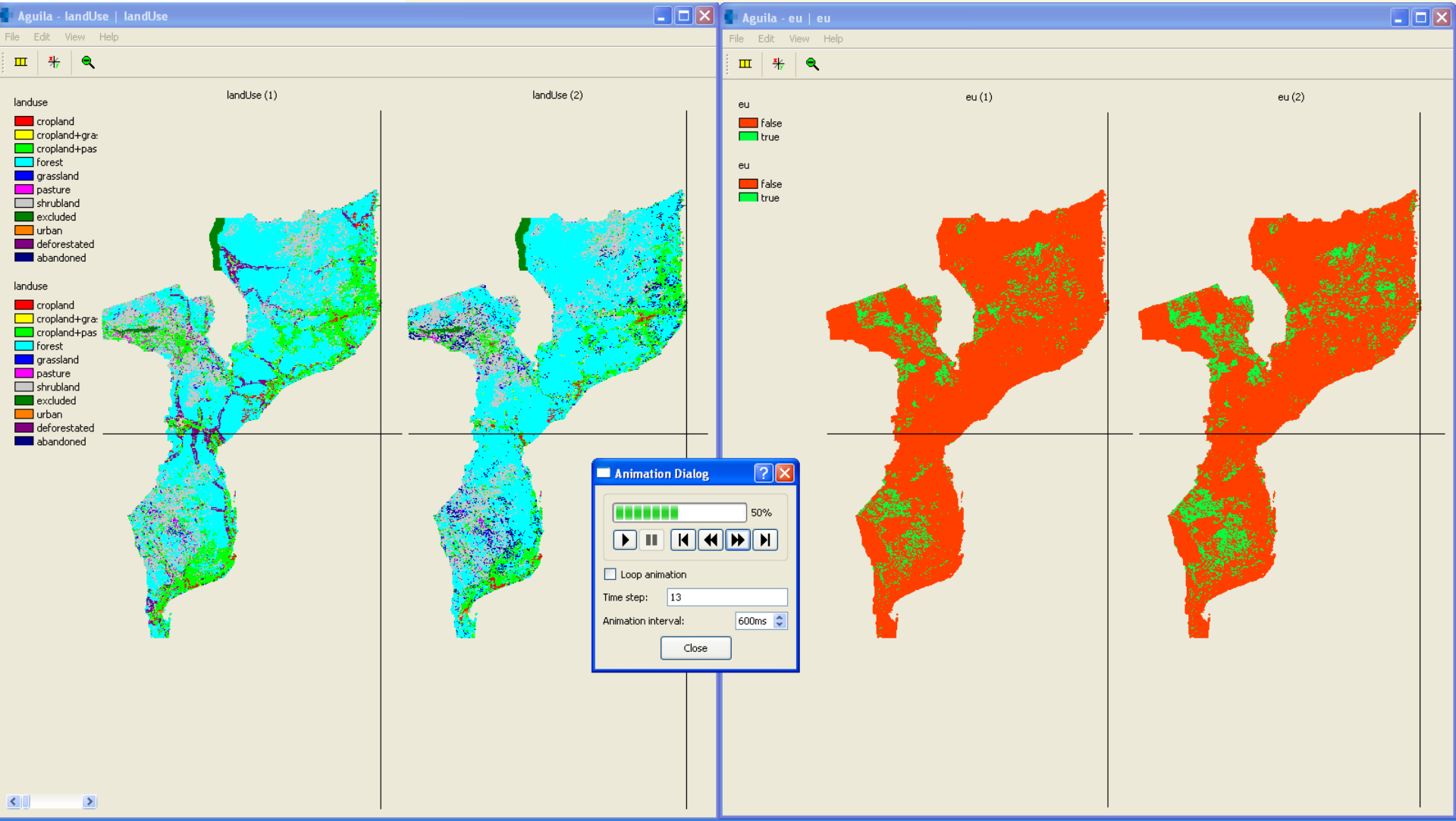

2018

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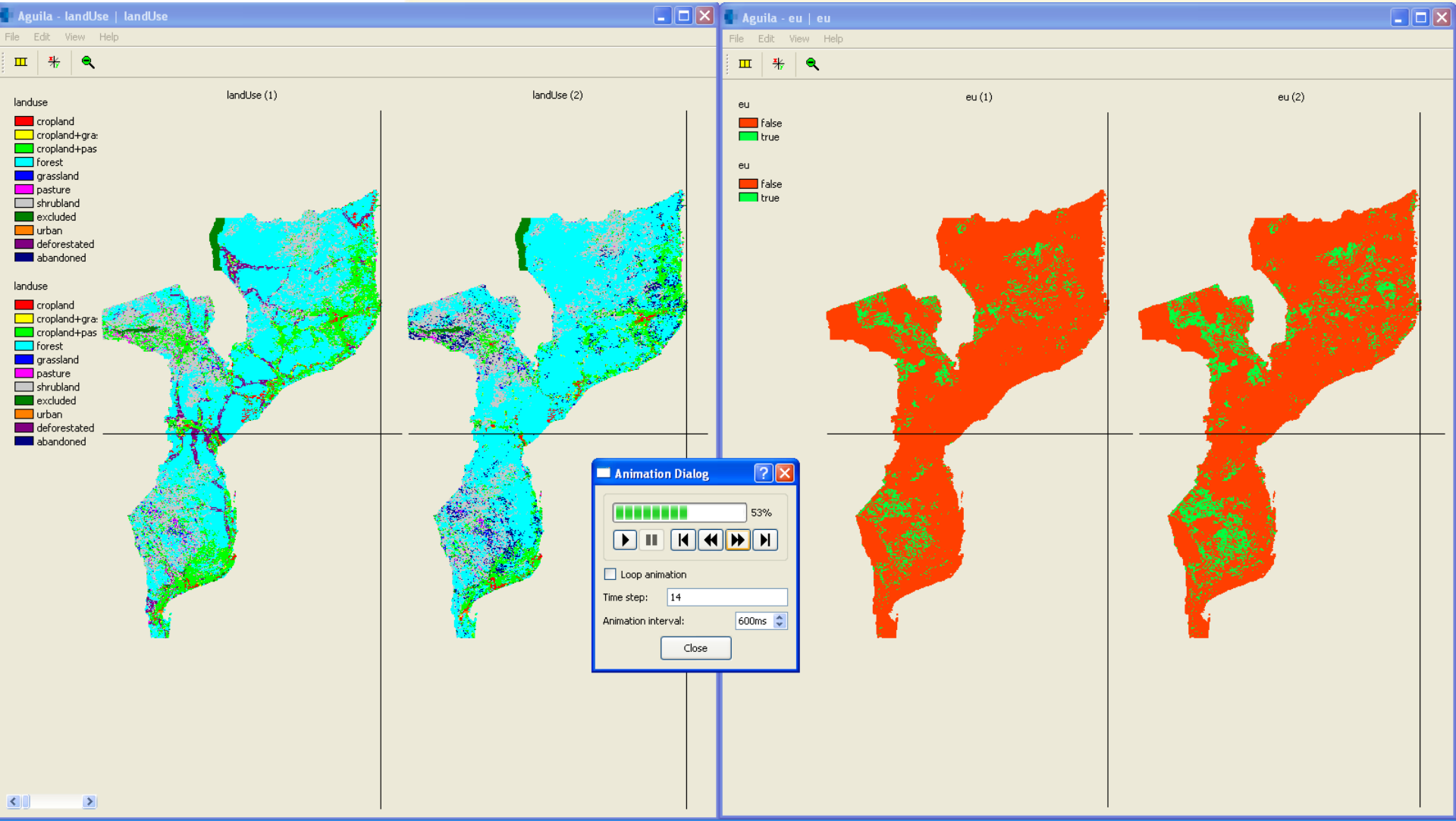

2019

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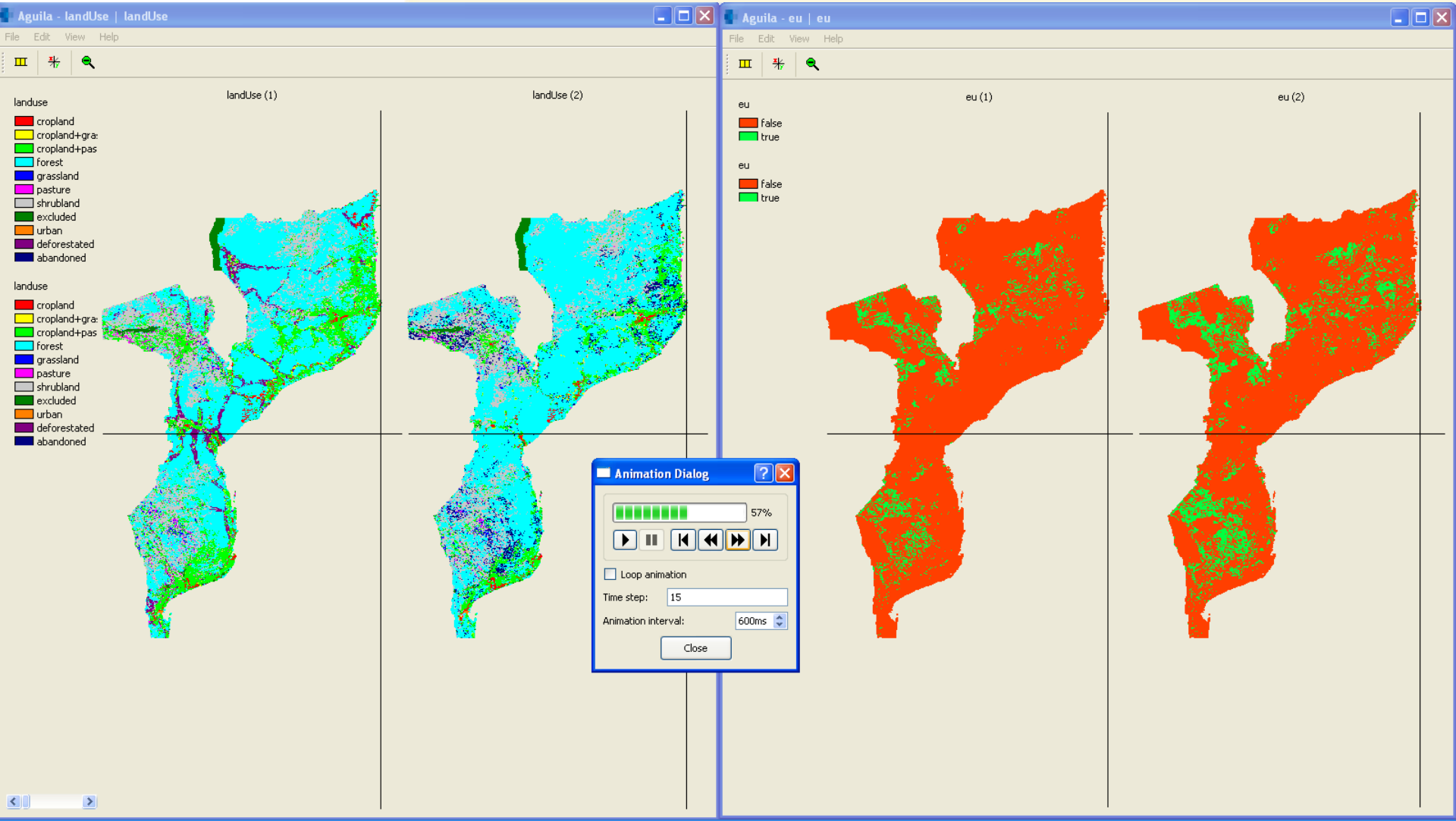

2020

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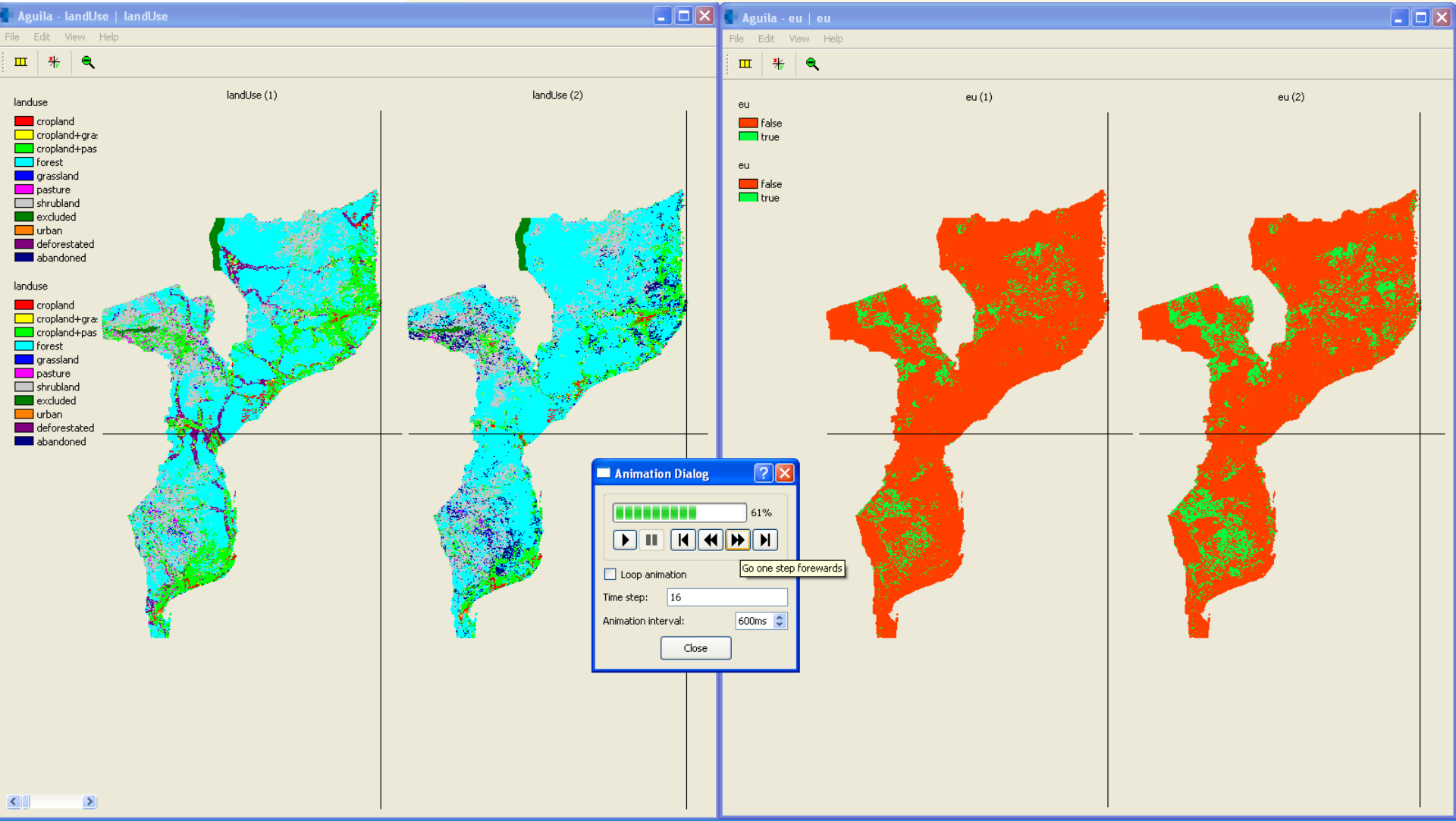

2021

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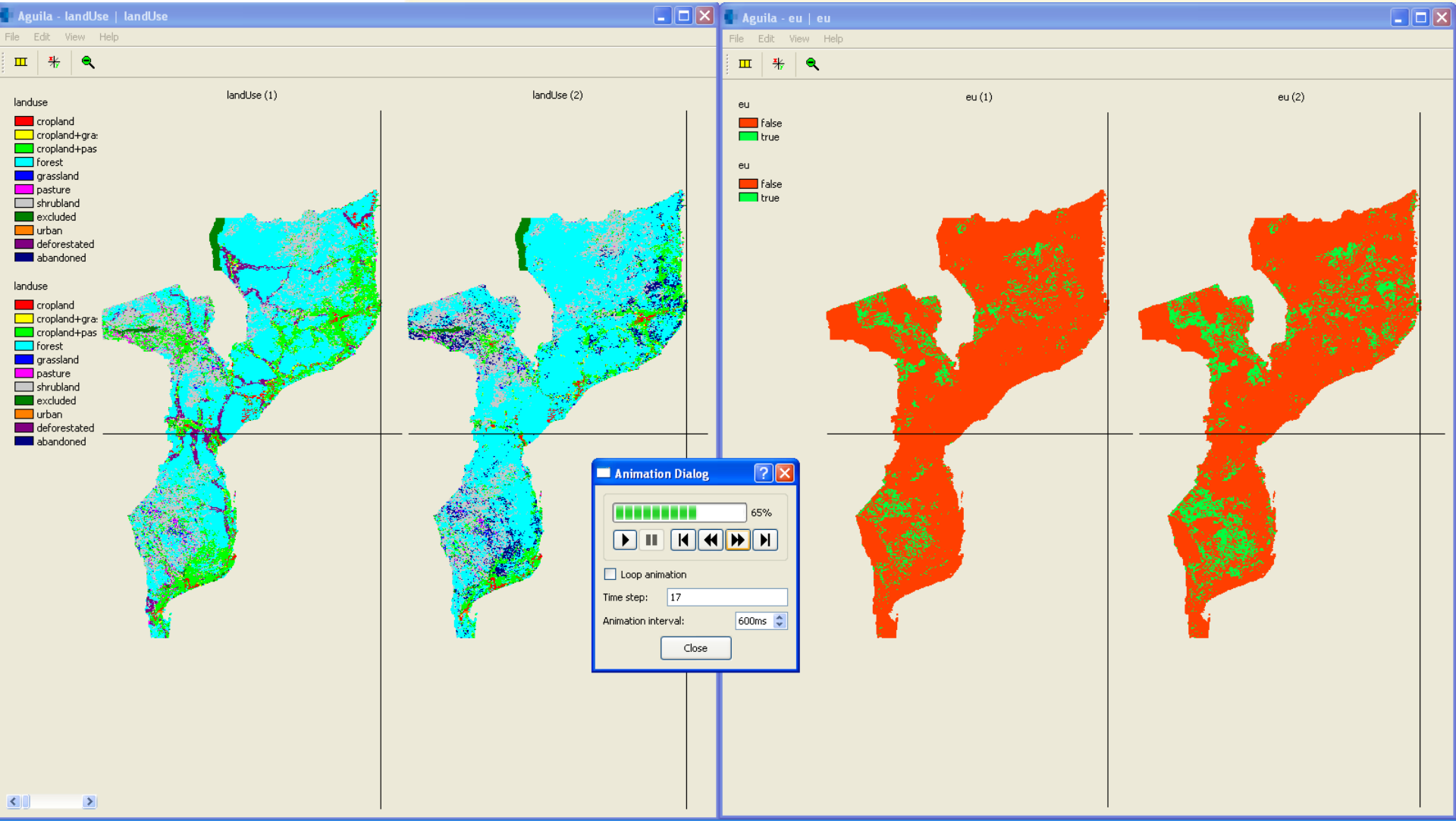

2022

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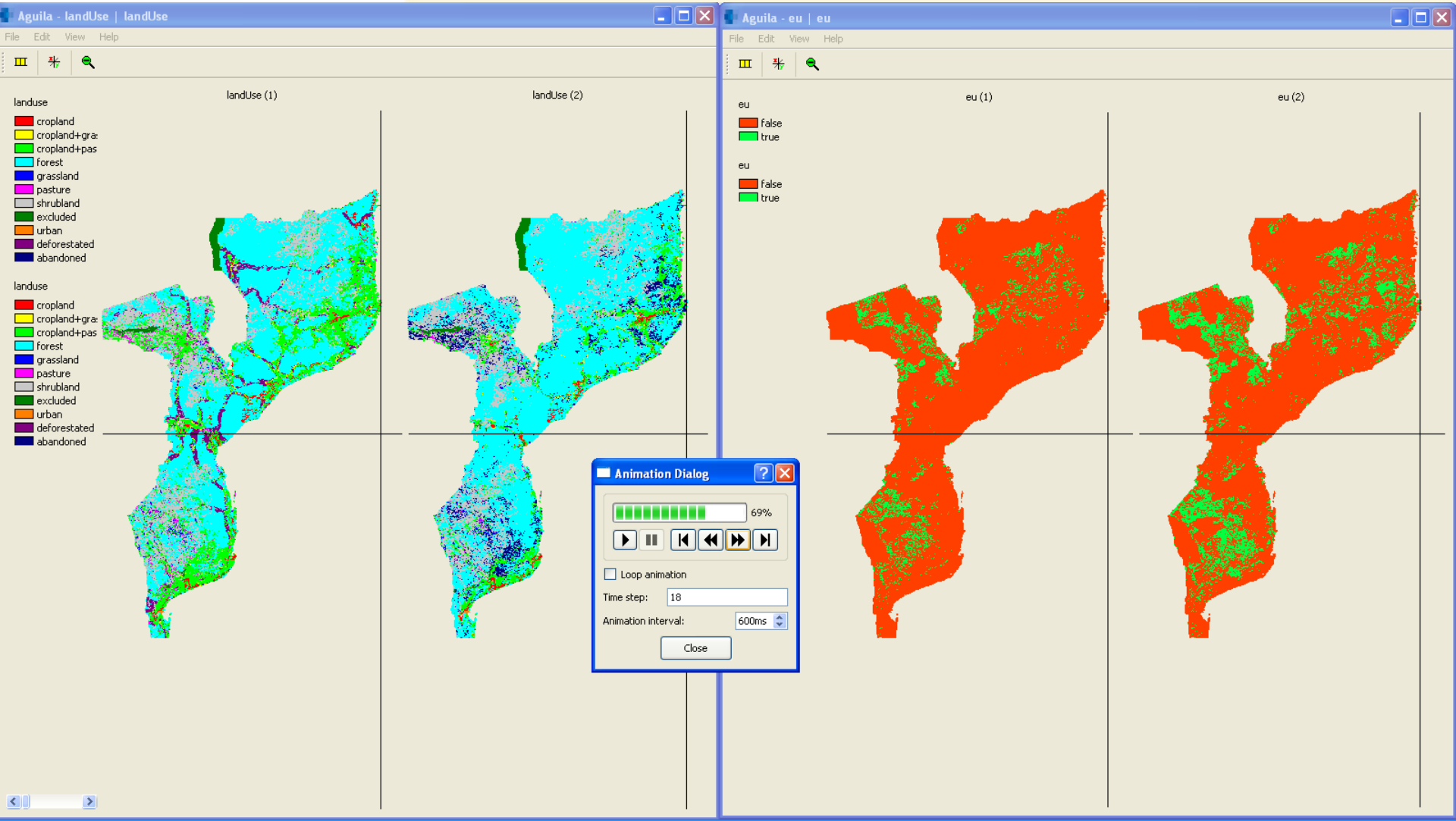

2023

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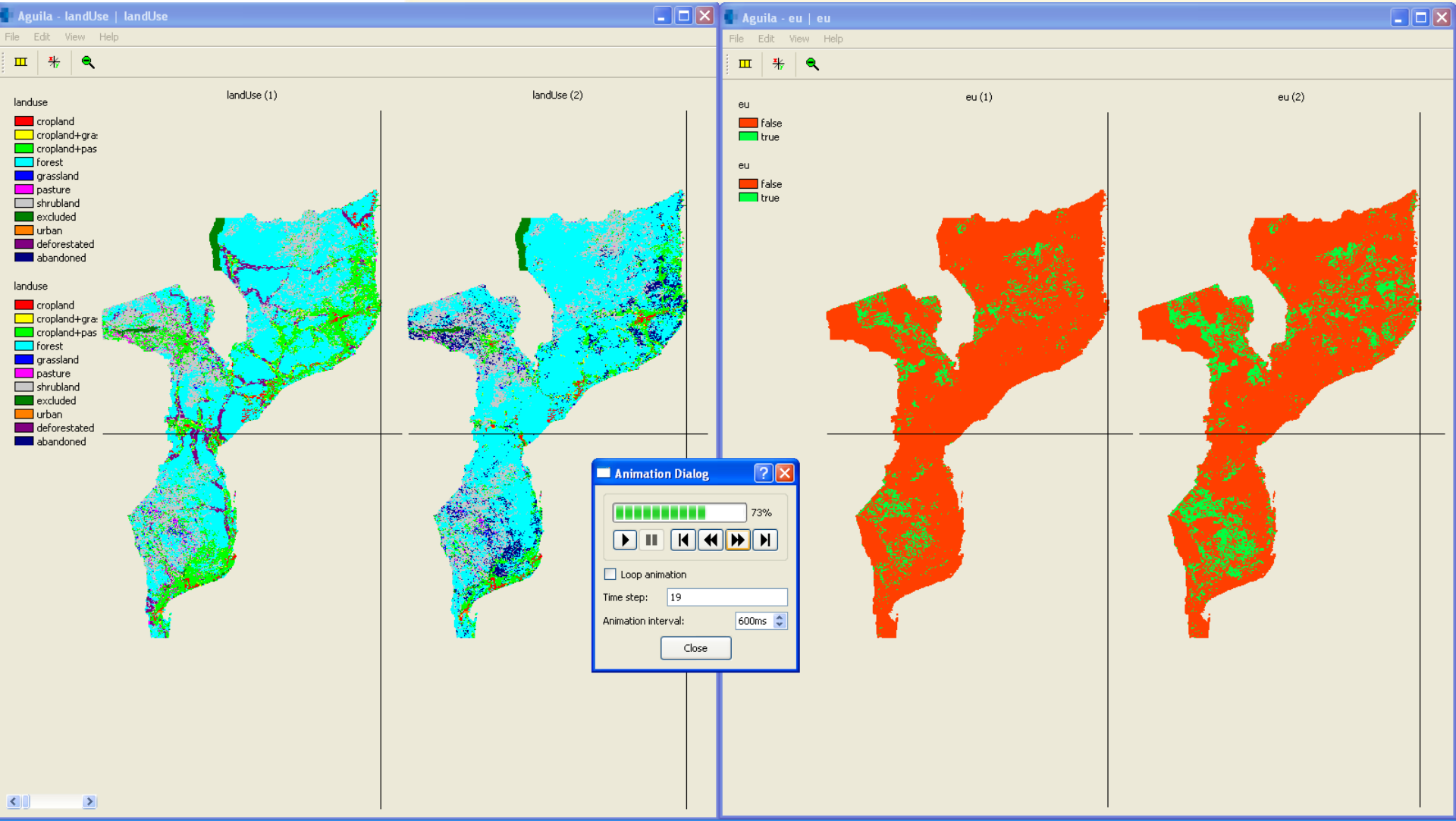

2024

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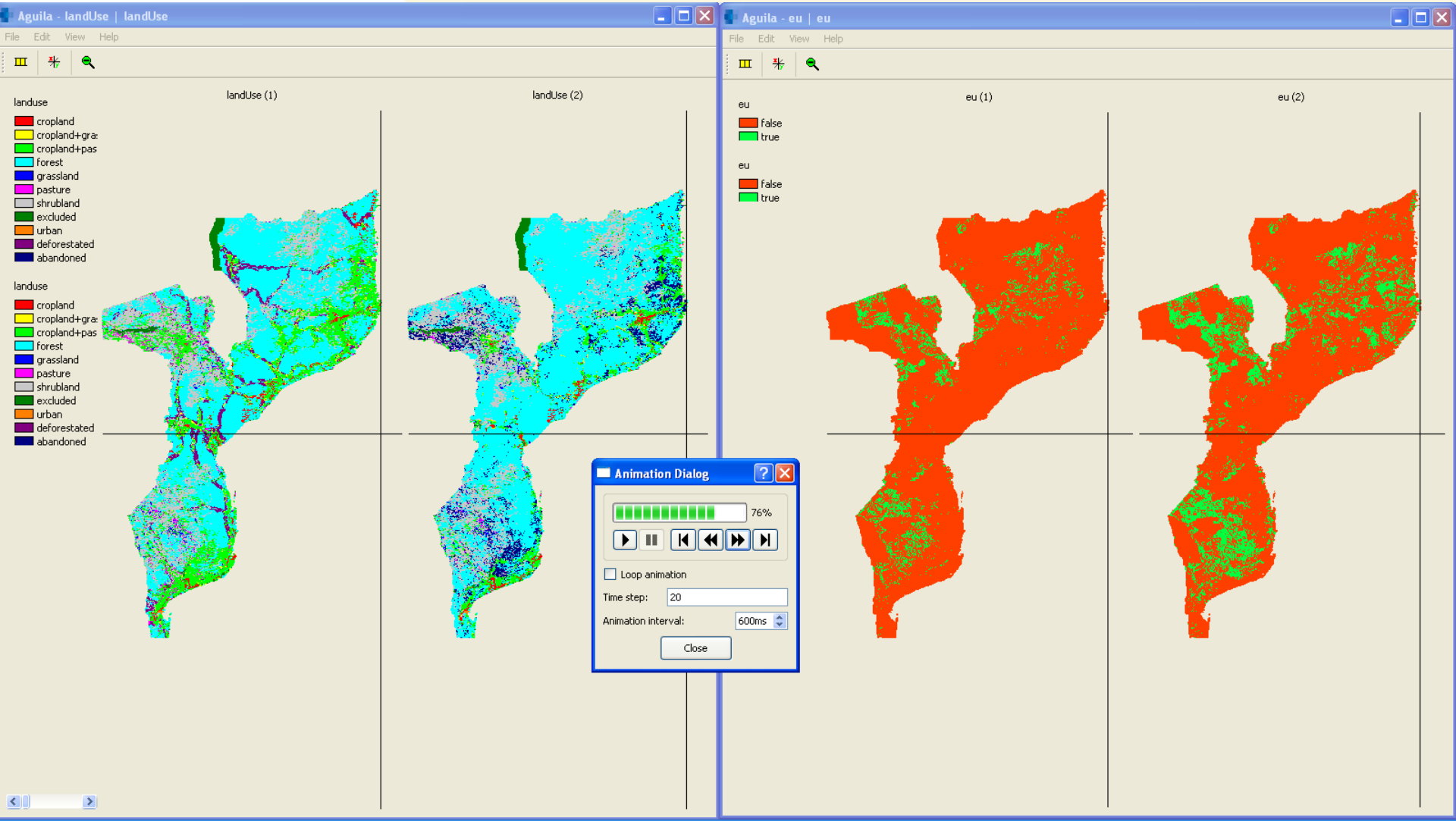

2025

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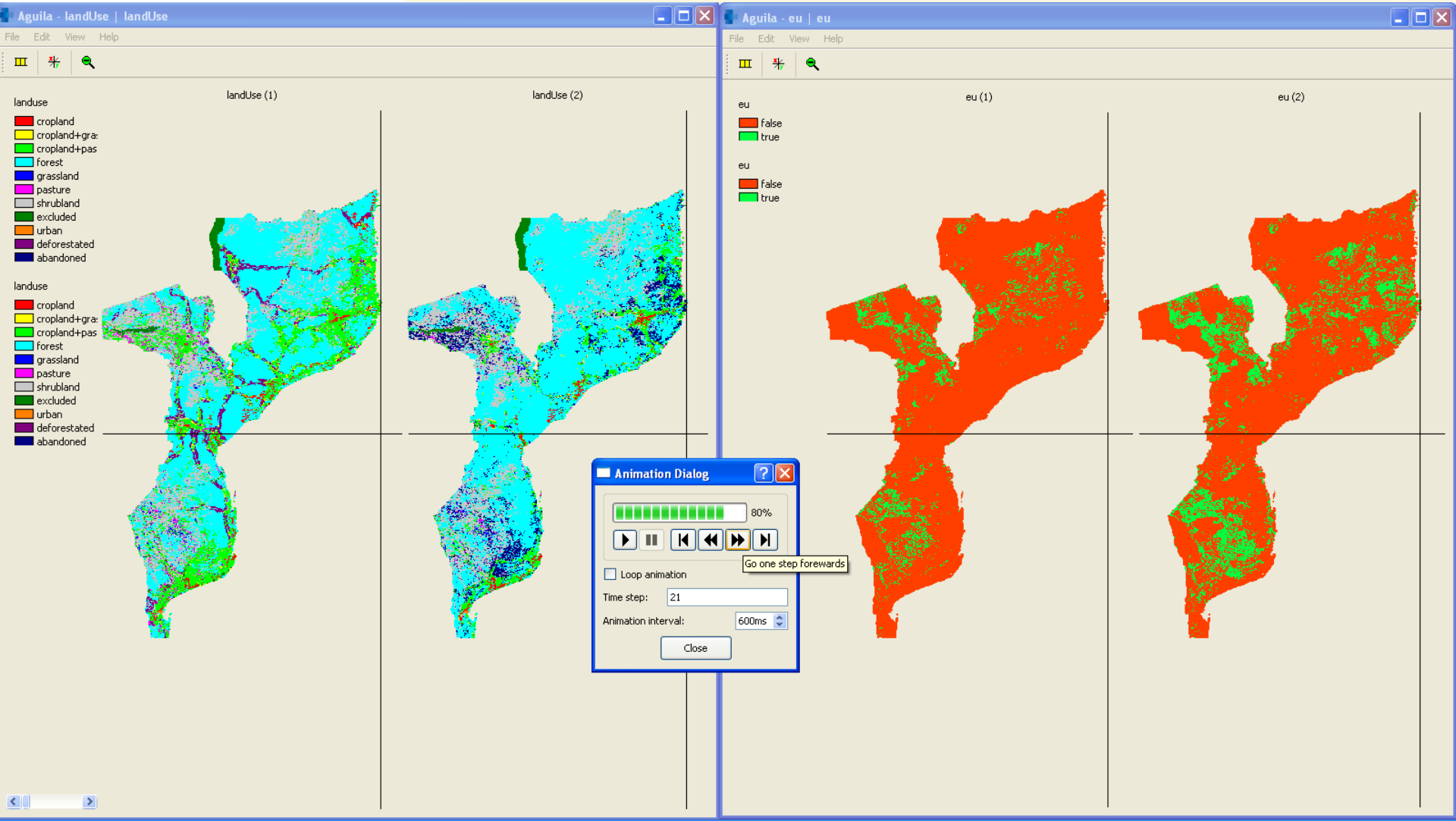

2026

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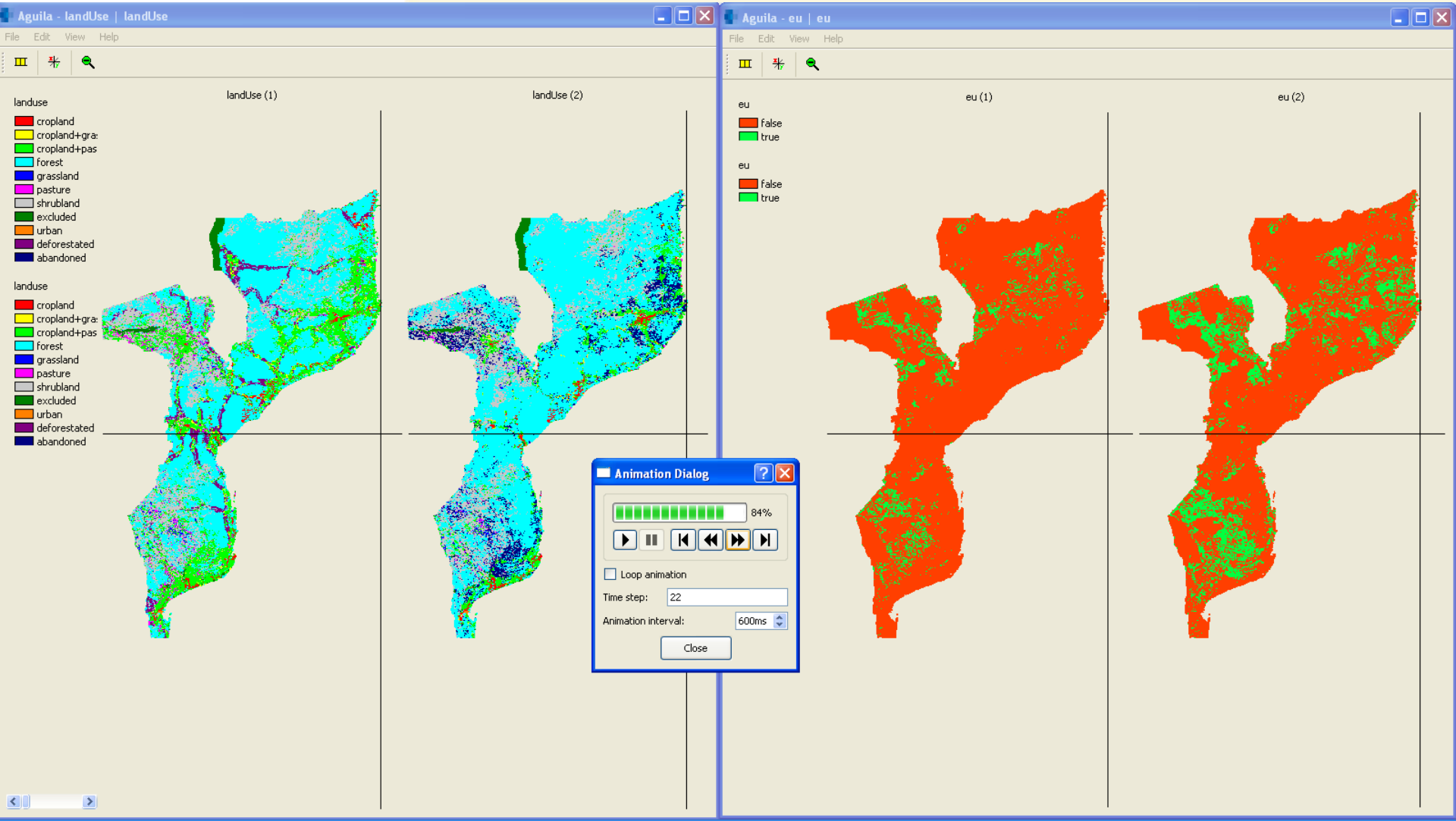

2027

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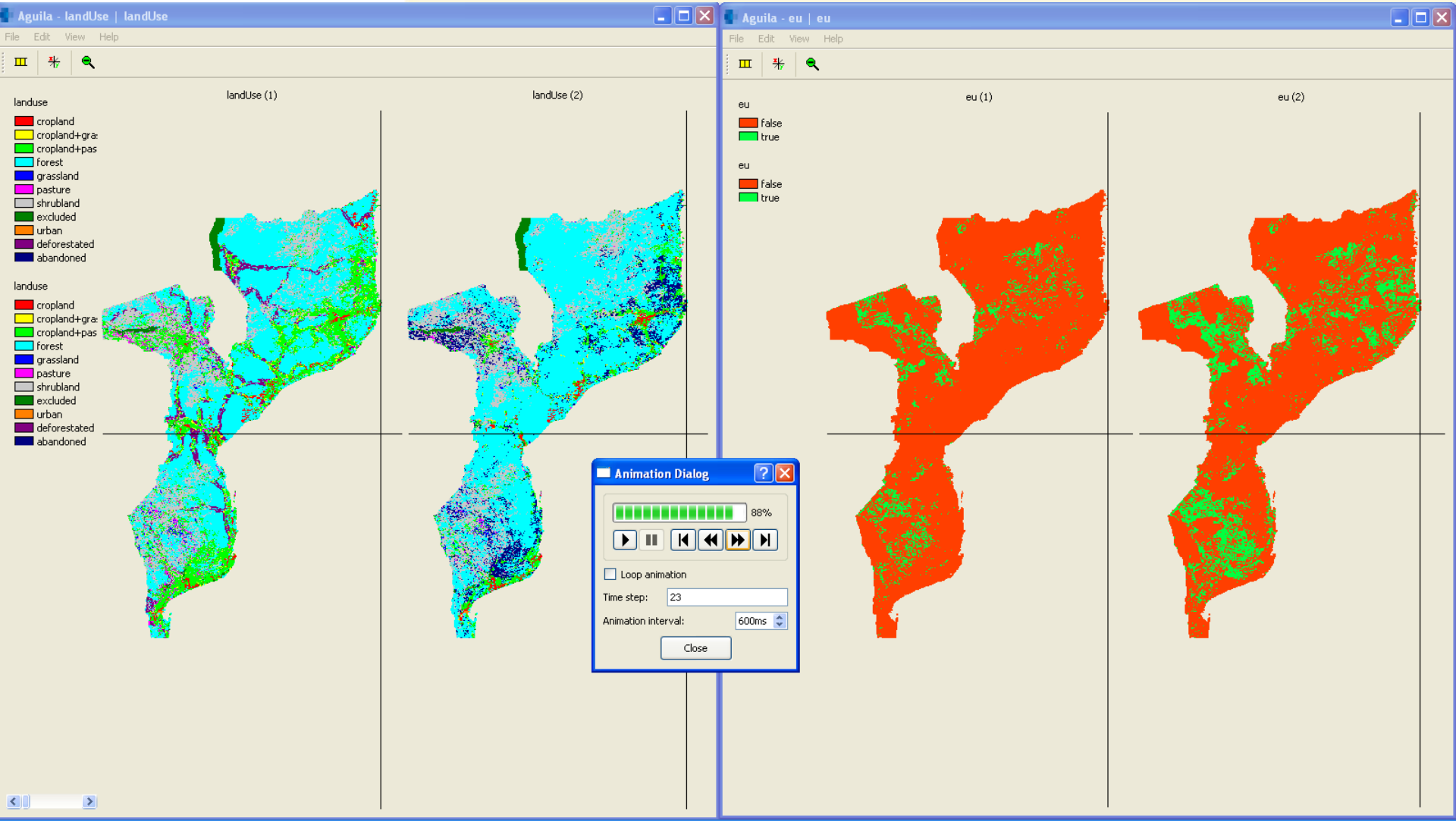

2028

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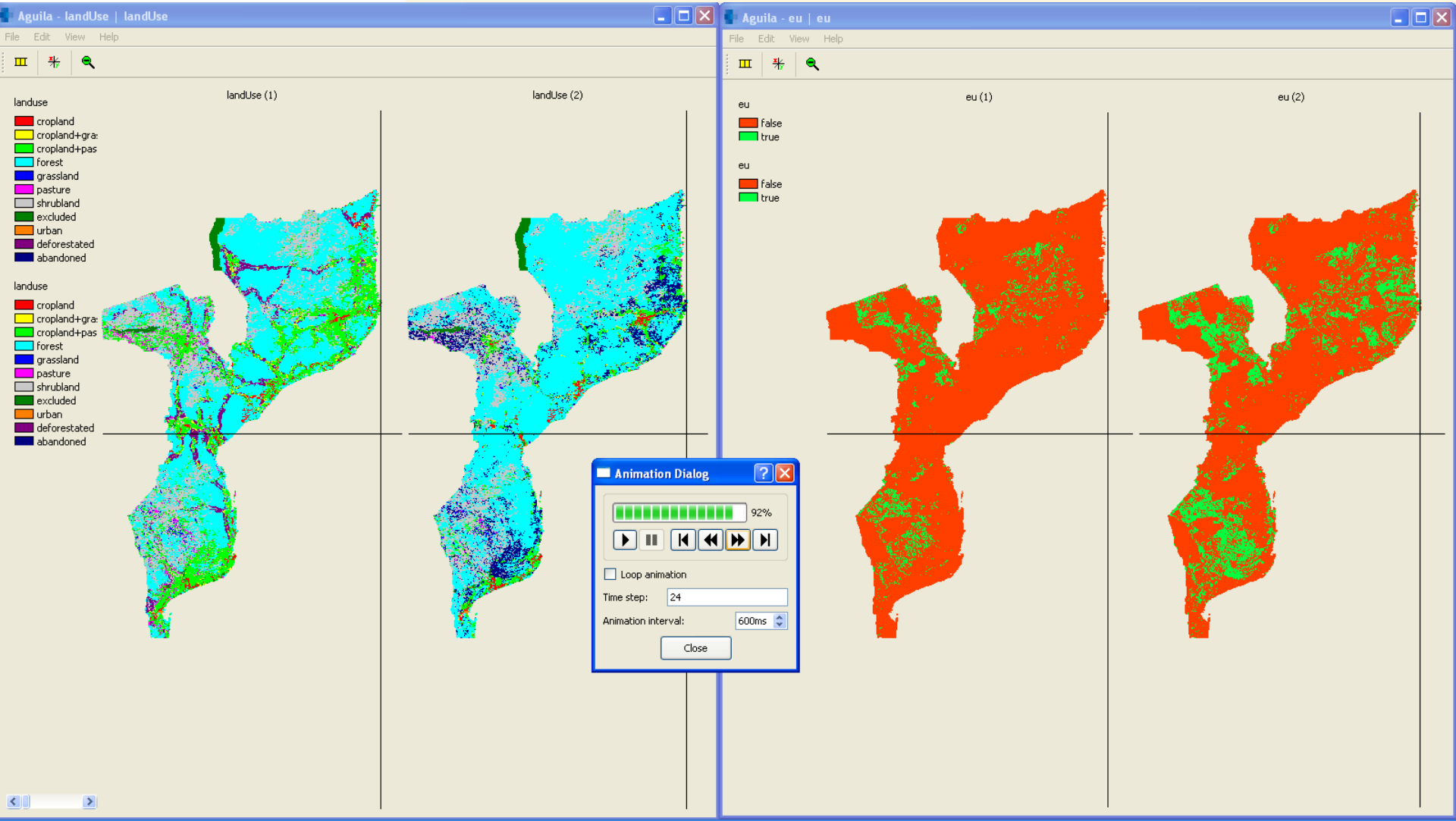
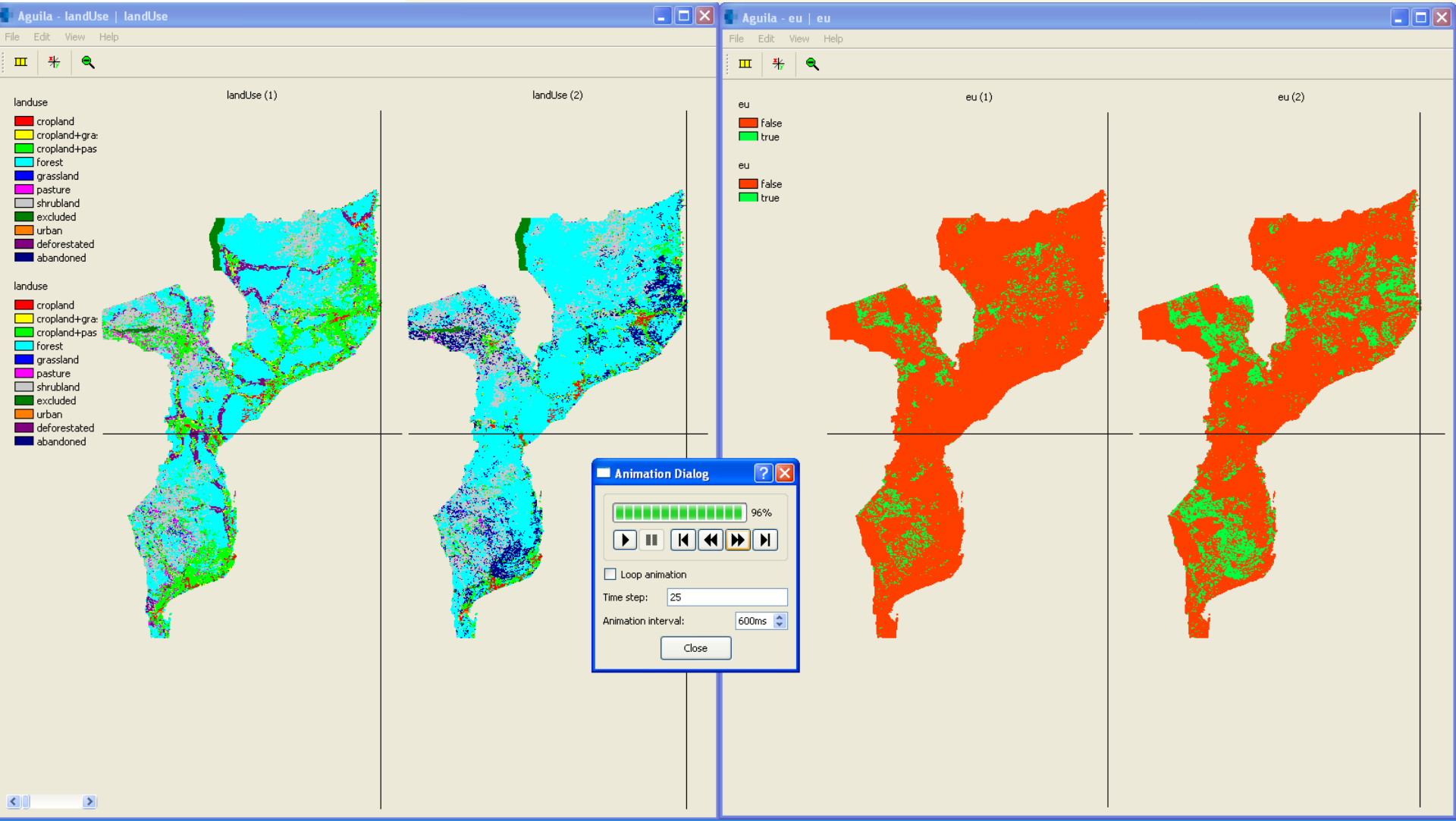


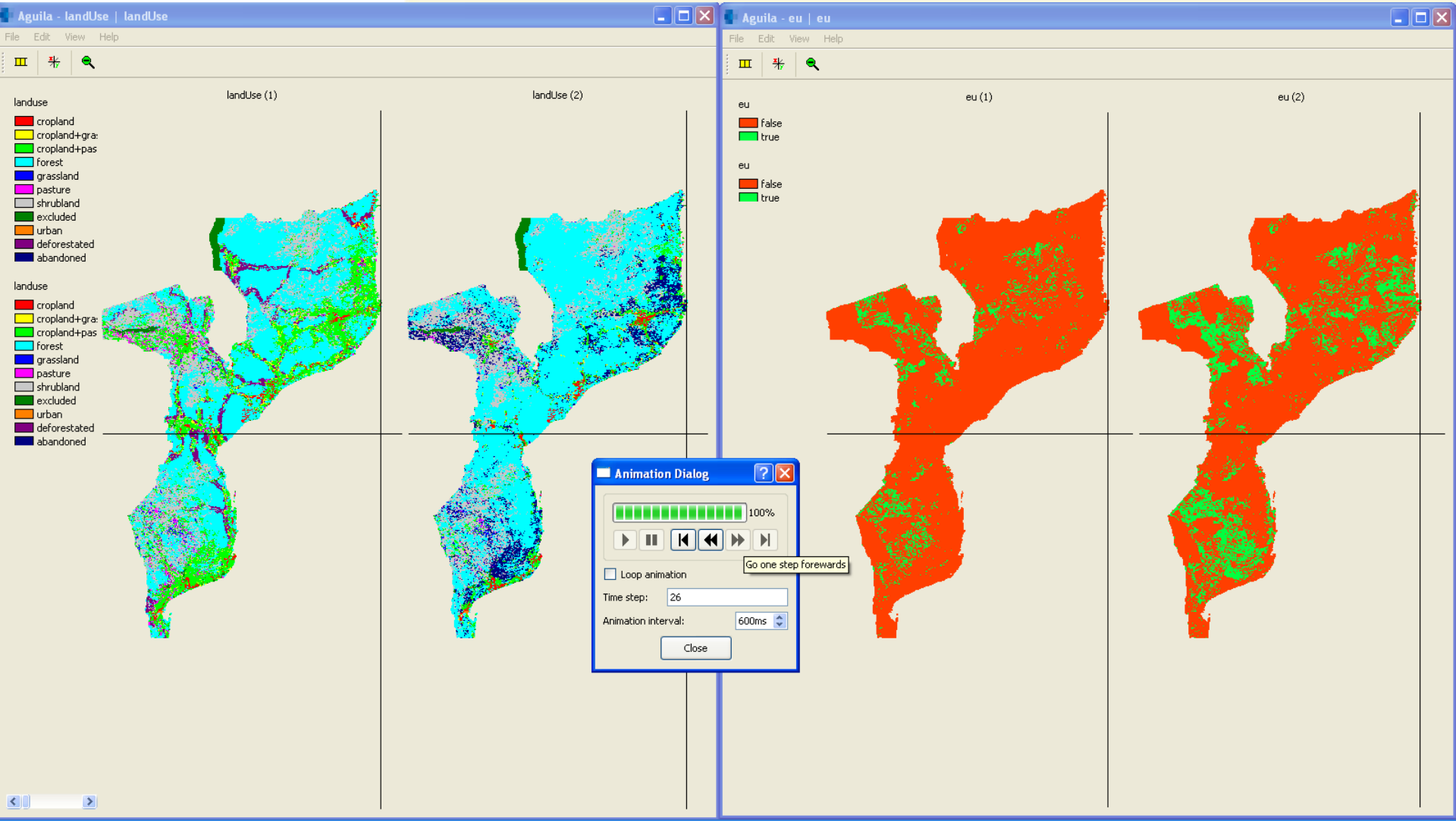
2029

BAU | Progressive | BAU | Progressive

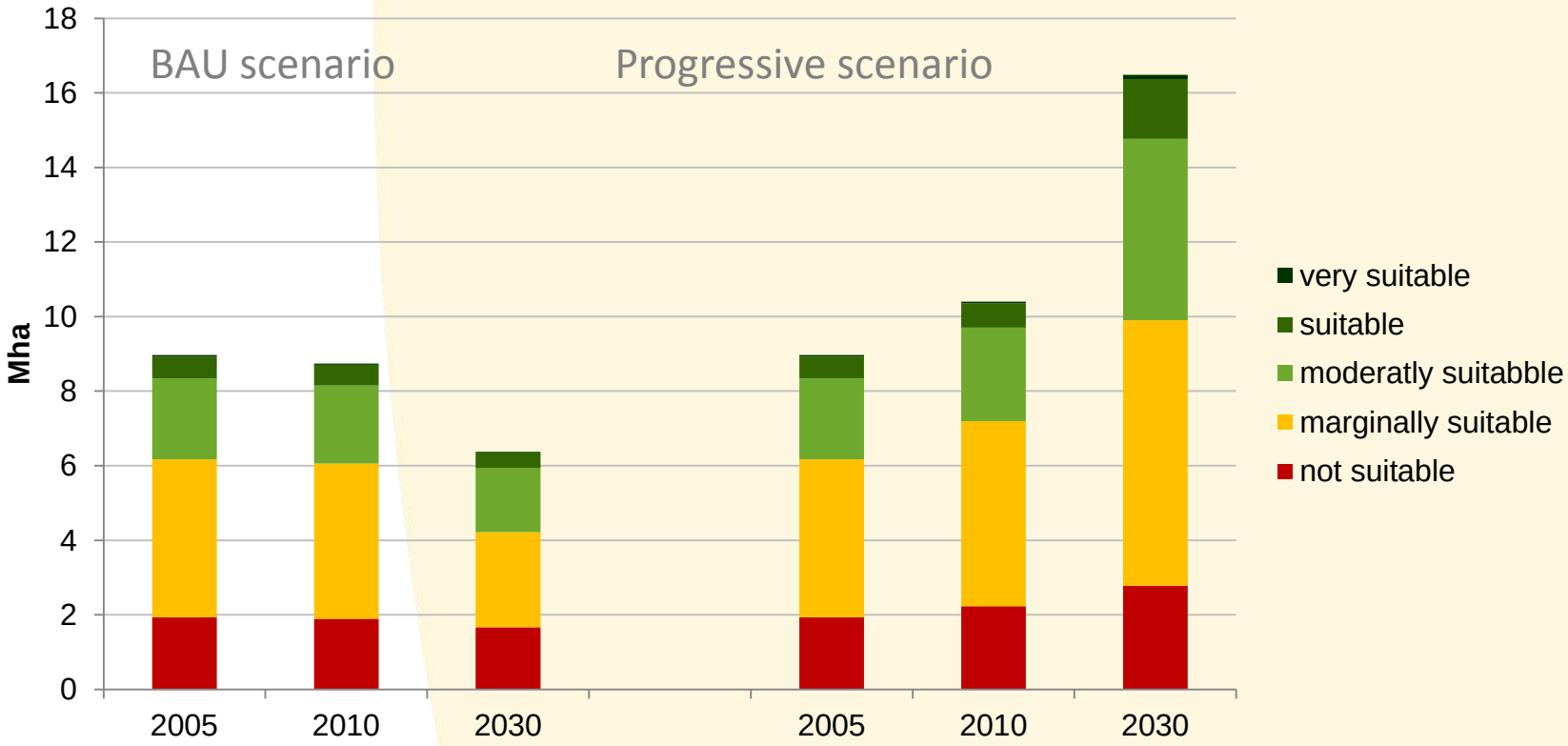


2030

BAU | Progressive | BAU | Progressive



Land use change modeling: Availability



Development of land availability over time differentiated for suitability classes for the BAU scenario (left) and the Progressive scenario (right).

Land use change modeling: PLUC model

- PLUC = **P**cRaster **L**and **U**se **C**hange Model
- Programmed in Python scripted with building blocks of PcRaster
- Advantage: Can run in Monte Carlo, deal with stochastic inputs and therefore provide information on uncertainty
- Can deal with different types of inputs (land demand in hectraes or in tons of product).
- Has been demonstrated for:
  - Mozambique
  - Argentina
  - Ukraine
  - Brazil (currently)
  - Indonesia (currently)
- Makes use of particle filter for simultaneous model parameter identification and calibration

Next steps

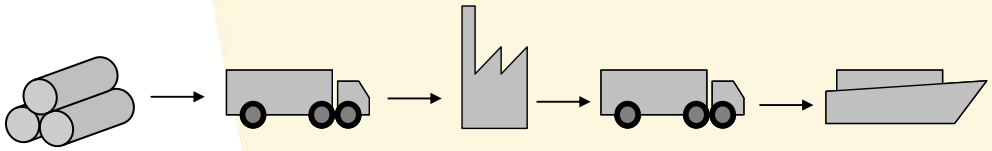
- This modeling assessments provides information on the amount, the location and the timeline of land availability for energy crops in Mozambique
- We want to know:
  - How much bioenergy can be produced?
  - What are the most favorable areas for bioenergy production?
- The next step:
  - Assess the developments in potentials and economic viability of biomass supply chains.
  - Assess the environmental and socio-economic impacts of biomass supply chains.

Demonstration for Mozambique

1. **Land use change model** → potential land availability for biomass production
2. **Dynamic cost supply curve** → given the location and characteristics of the available land, what are the cost of the biomass supply chains
3. **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.

Cost of Biomass supply chains

- Example:
  - Sugar cane ethanol
  - Eucalyptus torrefied pellets
- Total costs include:
  - Feedstock production costs
  - Primary transport costs
  - Conversion costs
  - Secondary transport costs
  - Shipping costs

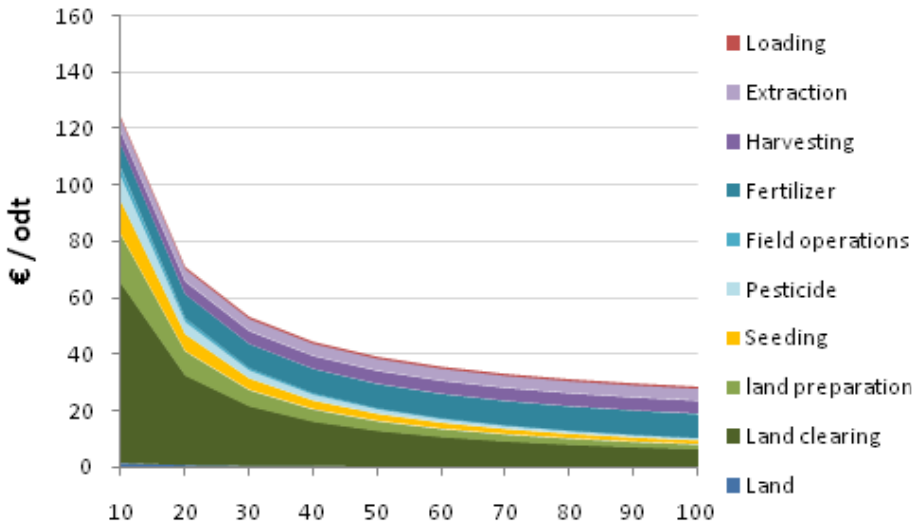


Cost of Biomass supply chains: Feedstock production costs

- All cultivation costs are calculated and discounted considering management (evolves over time) and suitability (depends on location)
- Costs included are:
  - Land lease
  - Field preparation
  - Seeding
  - Crop maintenance
  - Irrigation
  - Fertilizers
  - Pesticides
  - Harvesting and forwarding

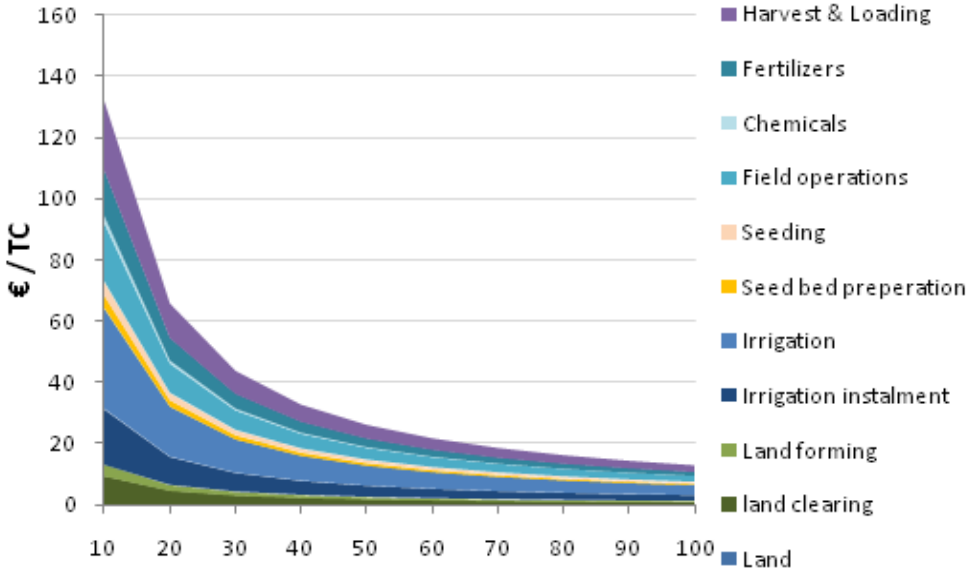
Cost of Biomass supply chains: Feedstock production costs

Eucalyptus



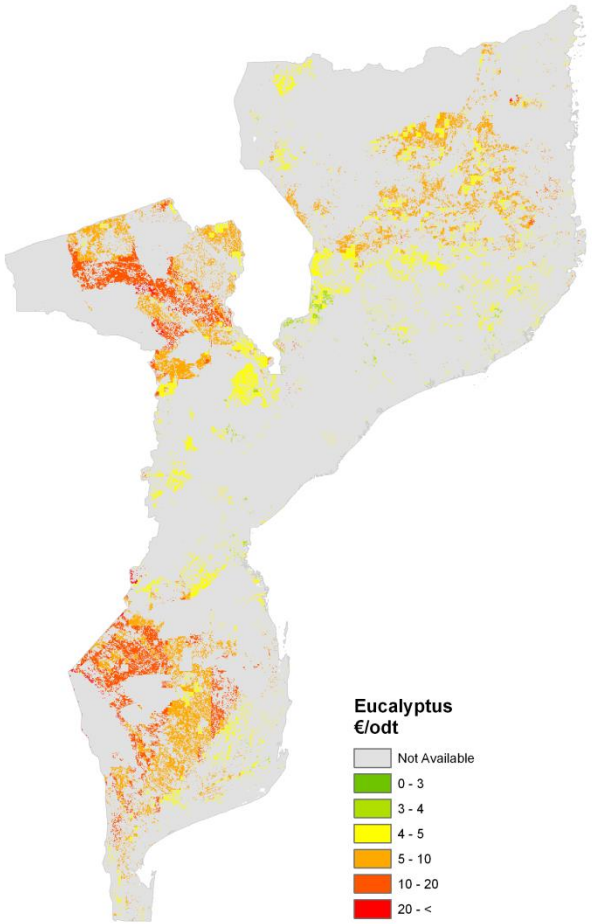
Suitability →

Sugar cane

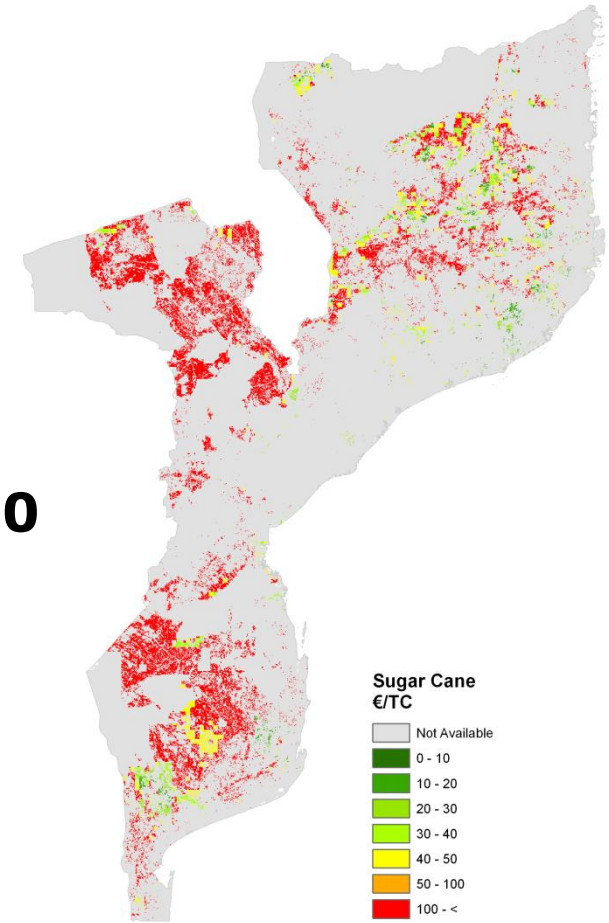


Suitability →

Cost of Biomass supply chains: Feedstock

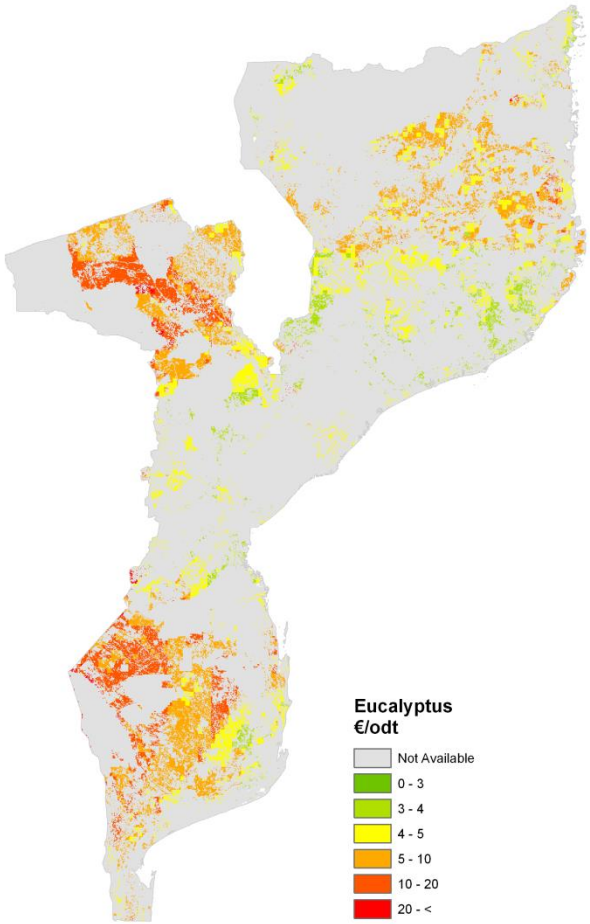


2010



Eucalyptus **Sugarcane**

Cost of Biomass supply chains: Feedstock



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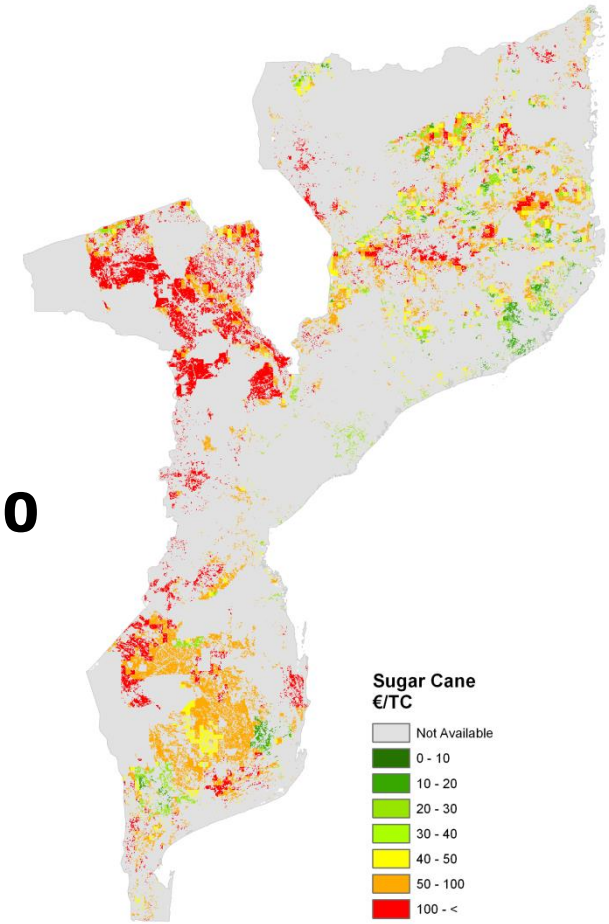
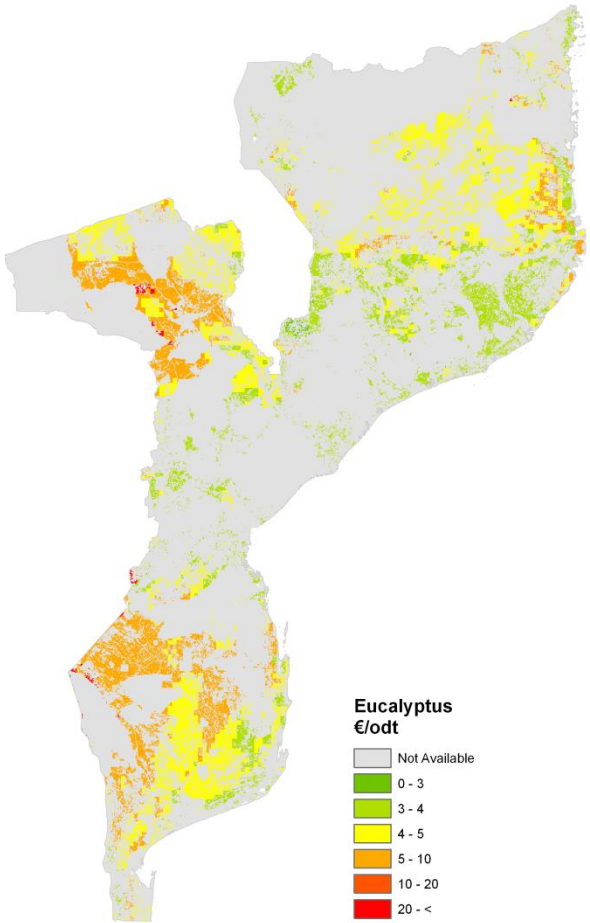
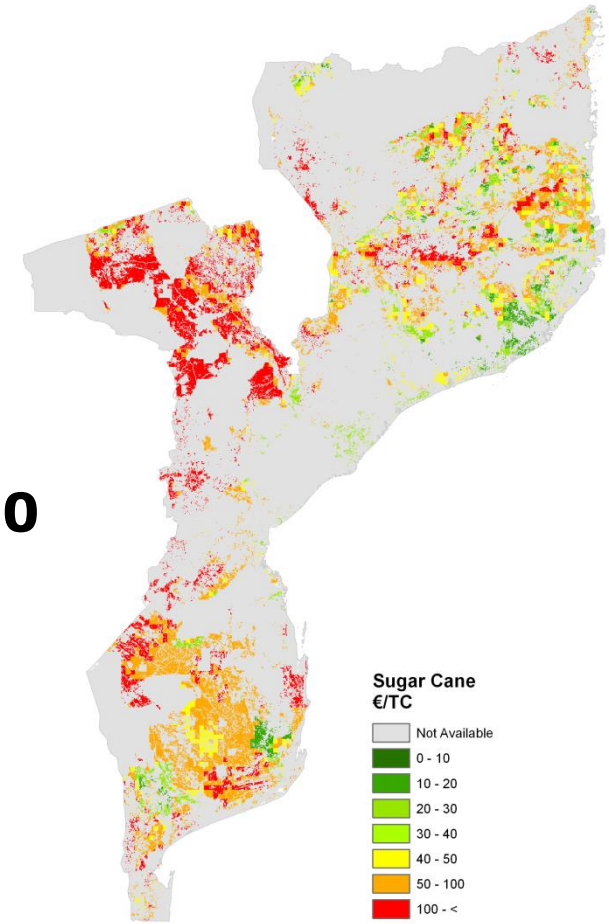


Eucalyptus **Sugarcane**

Cost of Biomass supply chains: Feedstock

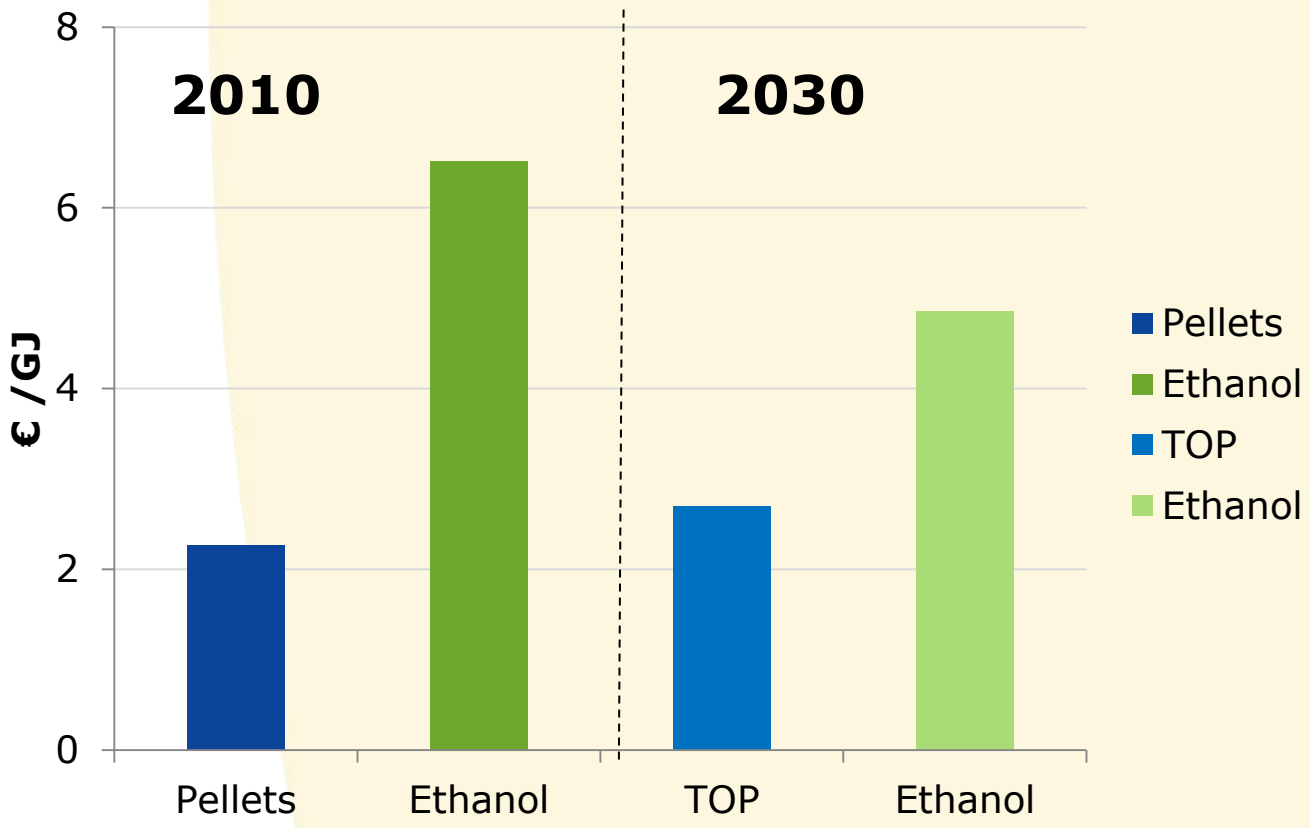


2030



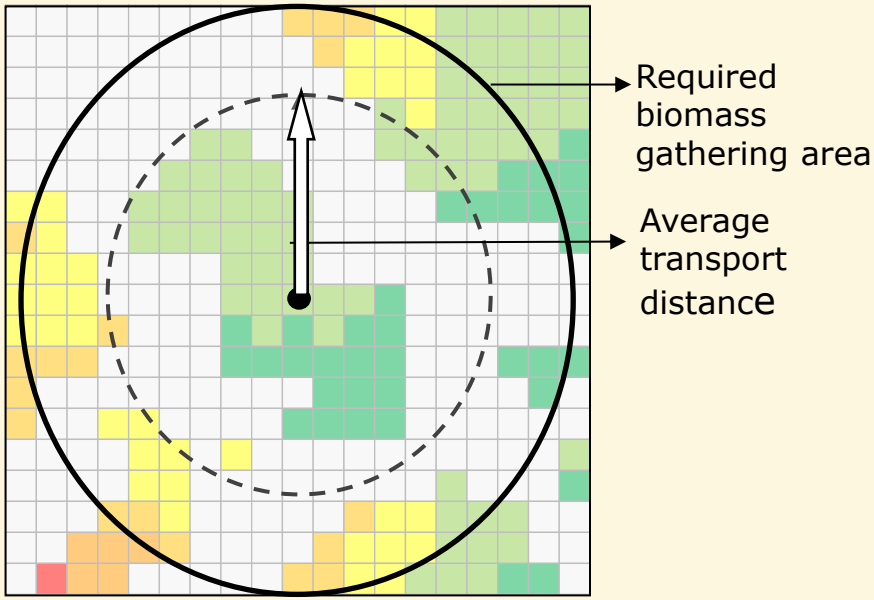
Eucalyptus **Sugarcane**

Cost of Biomass supply chains: Conversion

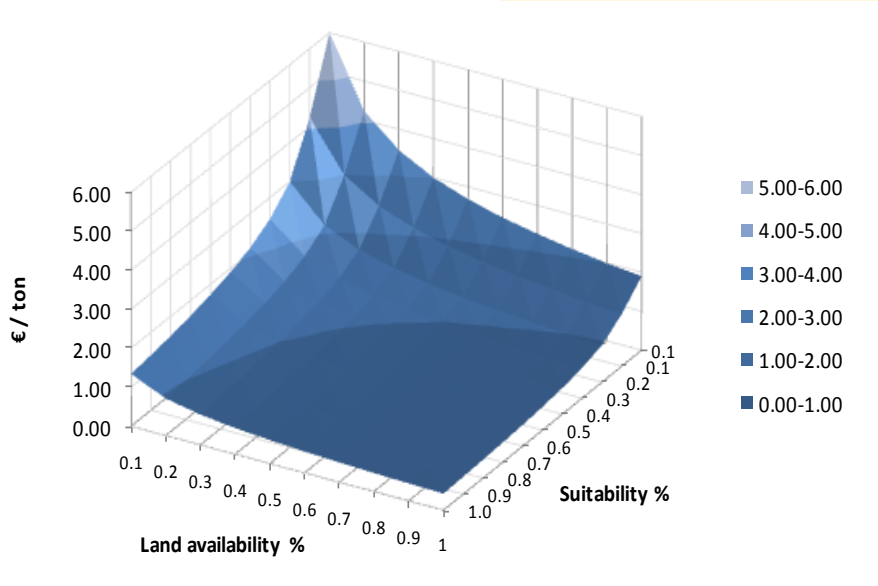


Cost of Biomass supply chains: Primary transport

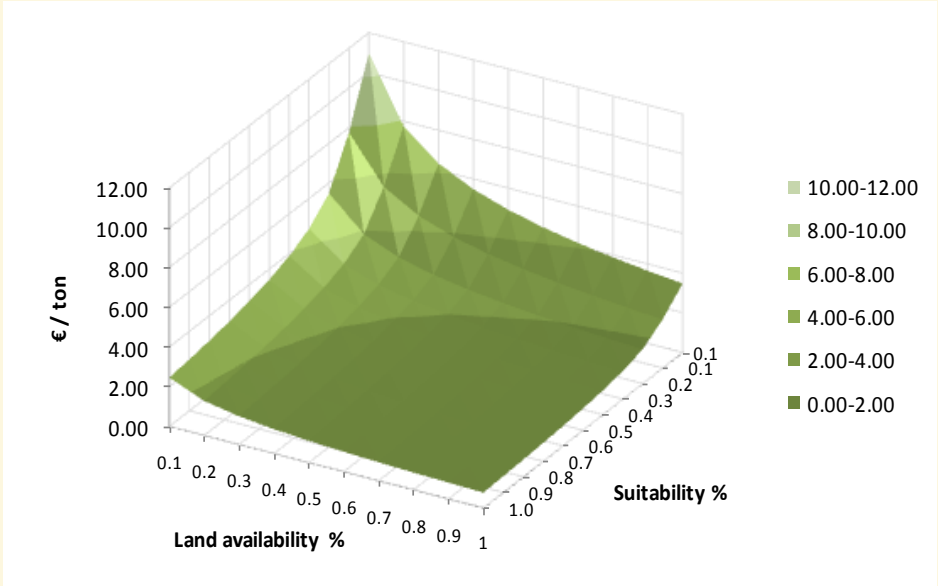
- The cost for primary transport (field to plant) in year *y* at location *a* depend on:
  - The **input requirements** of the plant (I)
  - The spatial distribution of the **land availability** at location *a* in year *y*
  - The **productivity** of the available land at location *a* at time *y*



Cost of Biomass supply chains: Primary transport

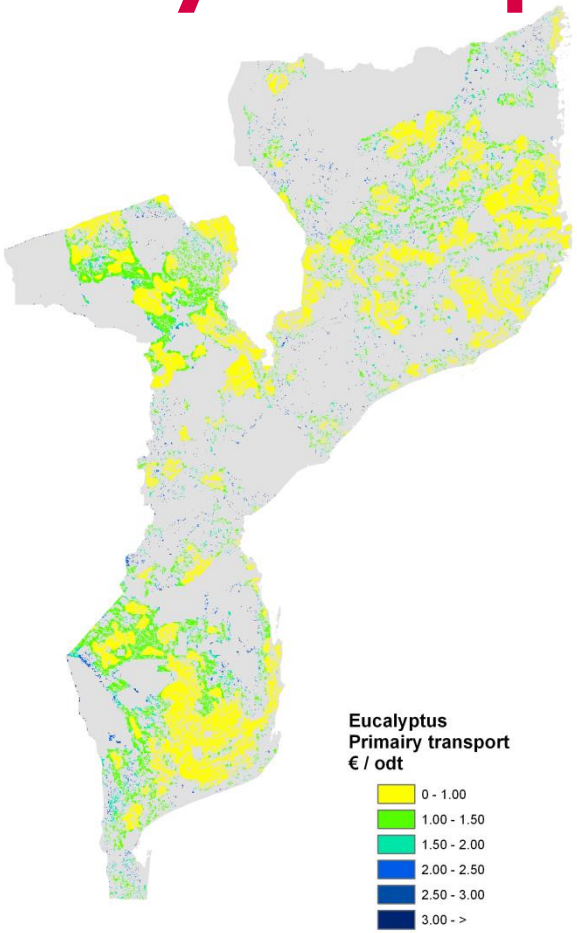


Eucalyptus

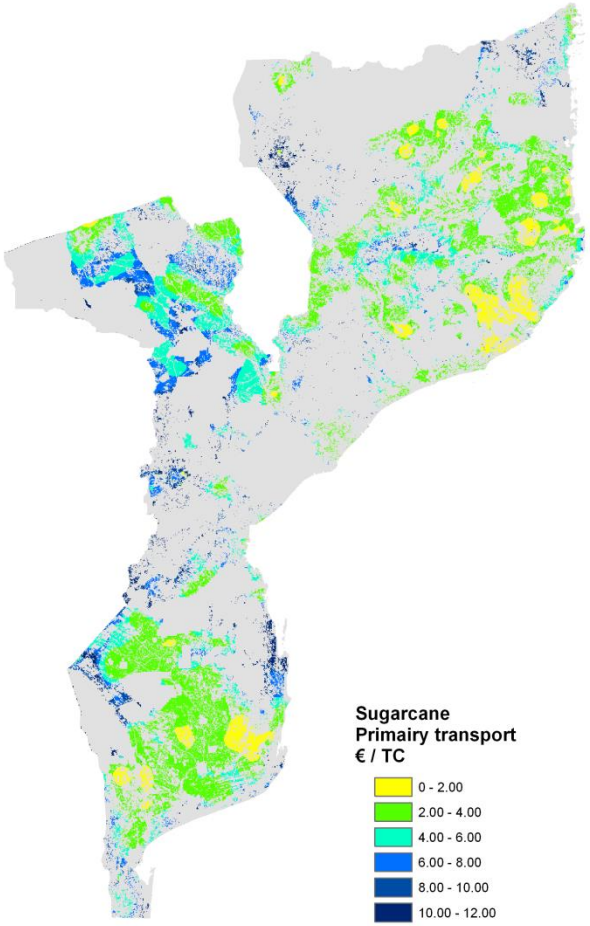


Sugar cane

Cost of Biomass supply chains: Primary transport



2030

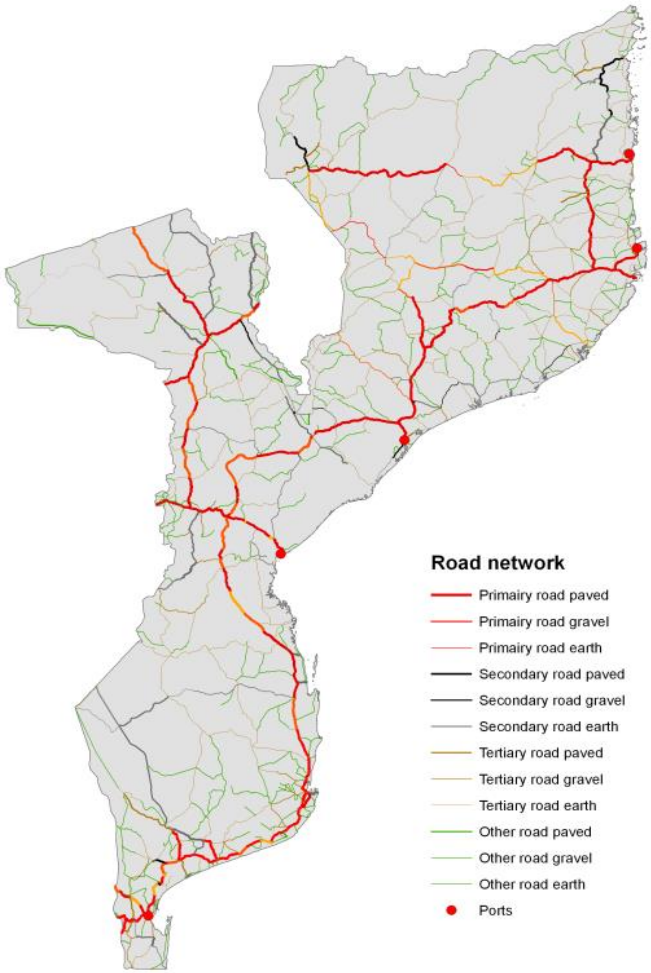


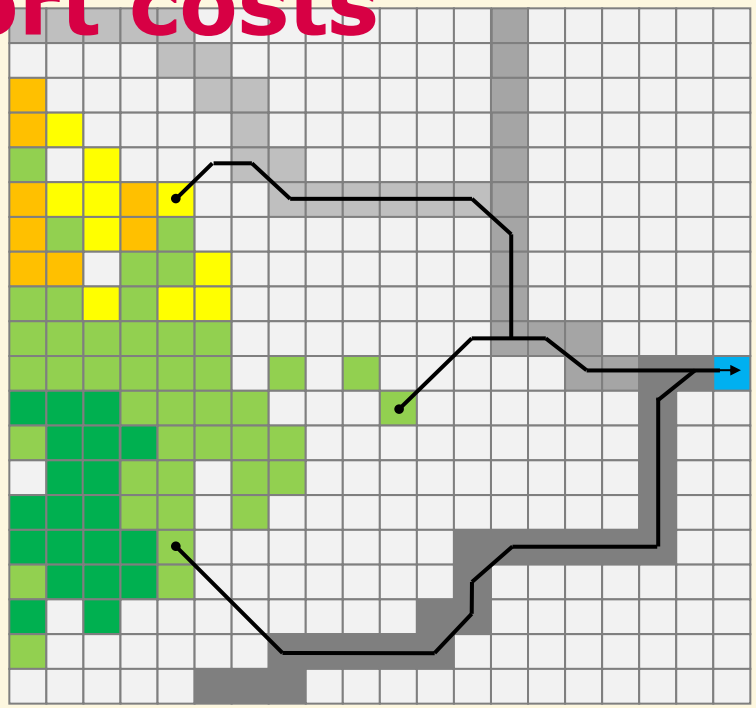
Eucalyptus **Sugarcane**

Cost of Biomass supply chains: Secondary Transport

- The cost of secondary transport (plant to harbor) depend on:
  - The spatial distribution of biomass production
  - The availability and condition of infrastructure
  - The location of the harbors

Cost of Biomass supply chains: Secondary transport costs

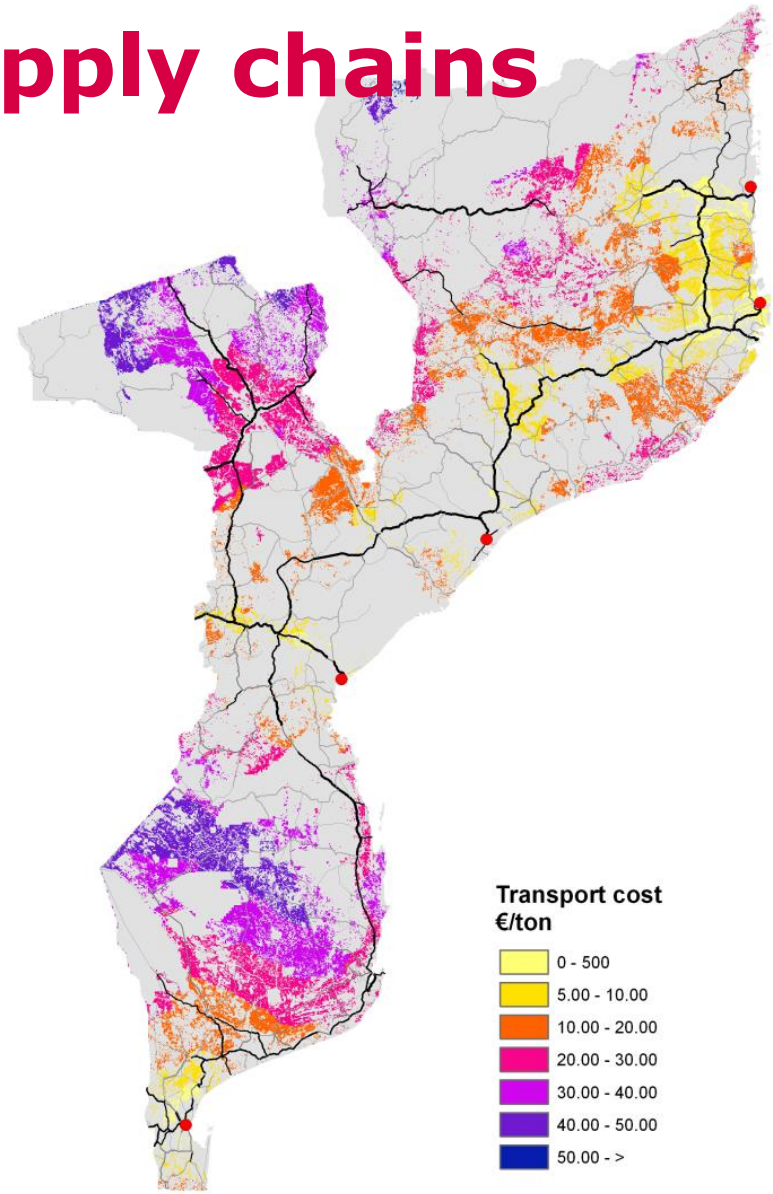




- Harbor
- Primary road
- Secondary road
- Tertiary road
- Non-available land
- Available land marginally productive
- Available land moderately productive
- Available land productive
- Available land very productive
- → Least cost route to harbor

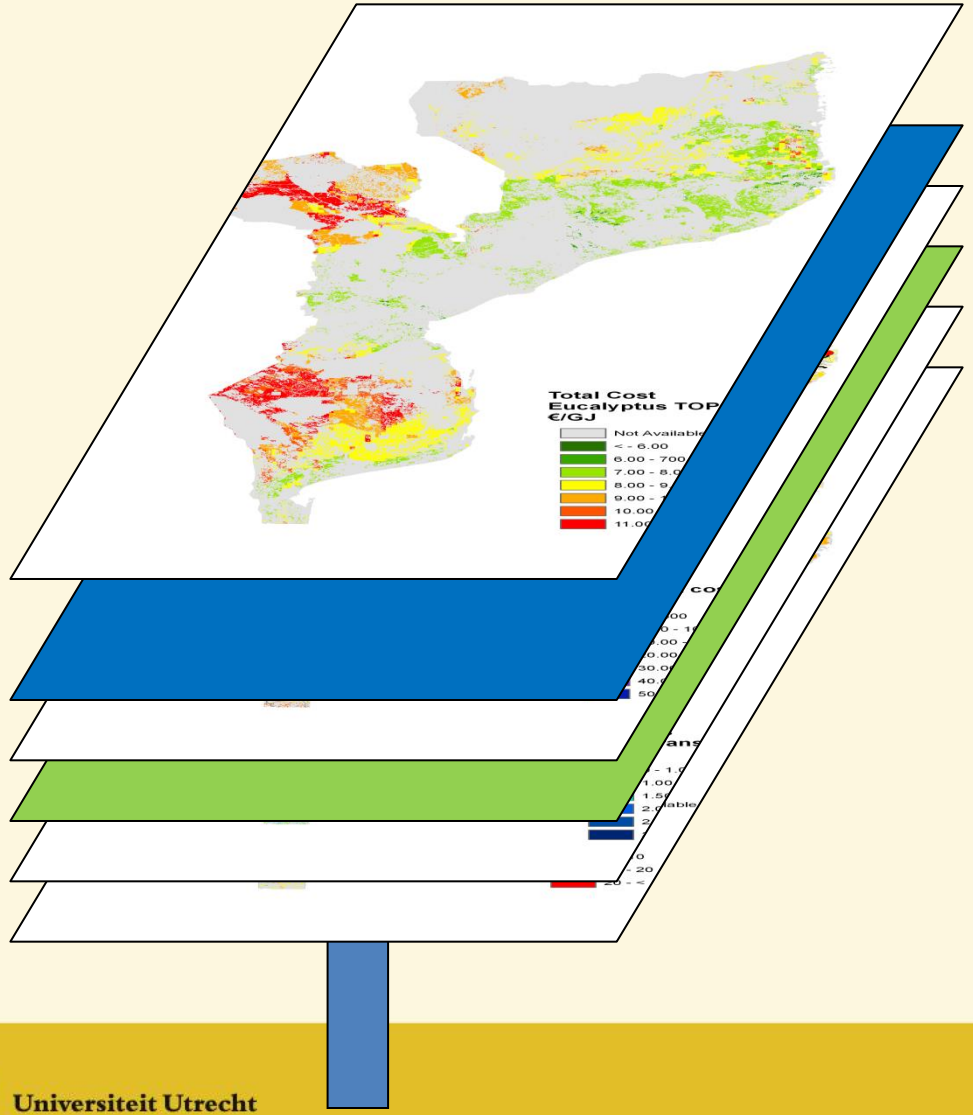
Cost of Biomass supply chains

2030



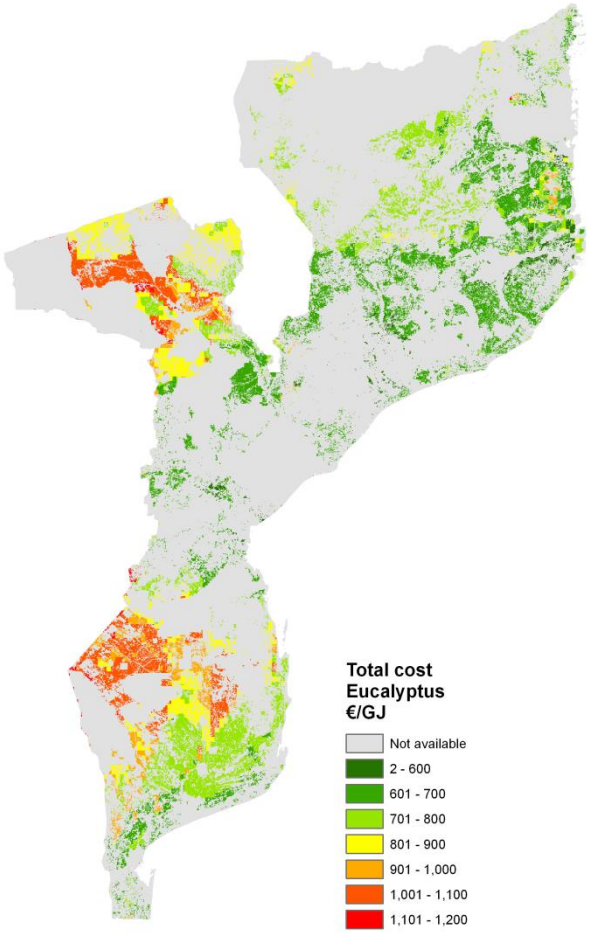
Total production costs

Total costs

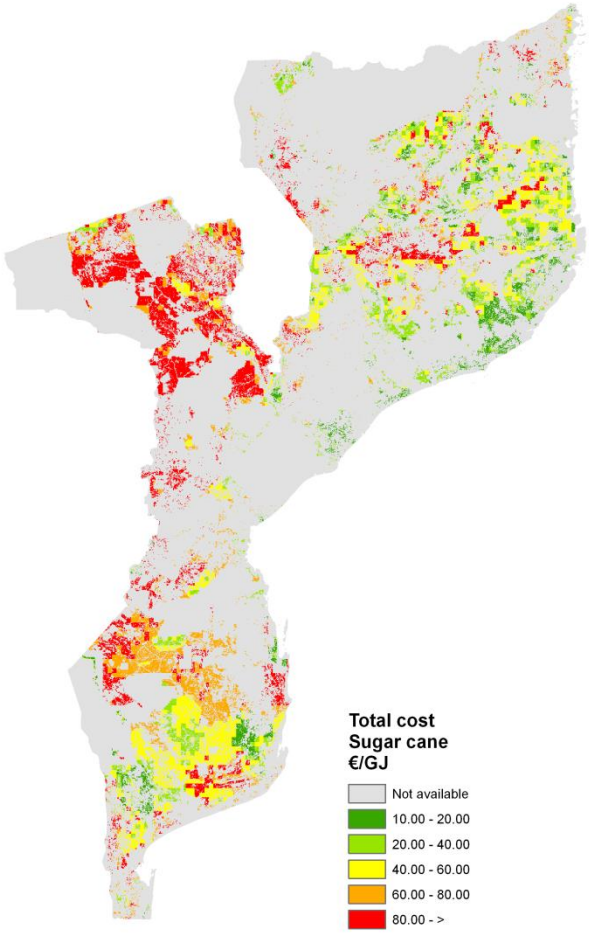


Shipping
Secondary transport
Conversion
Primary transport
Feedstock

Total production costs



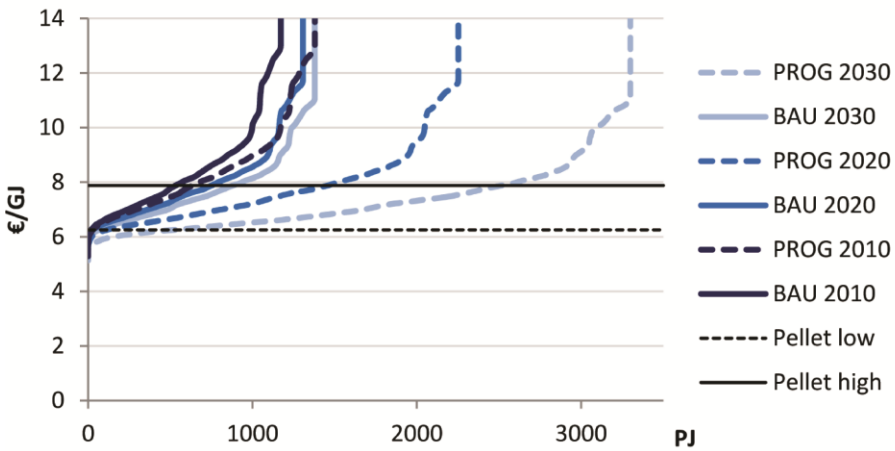
2030



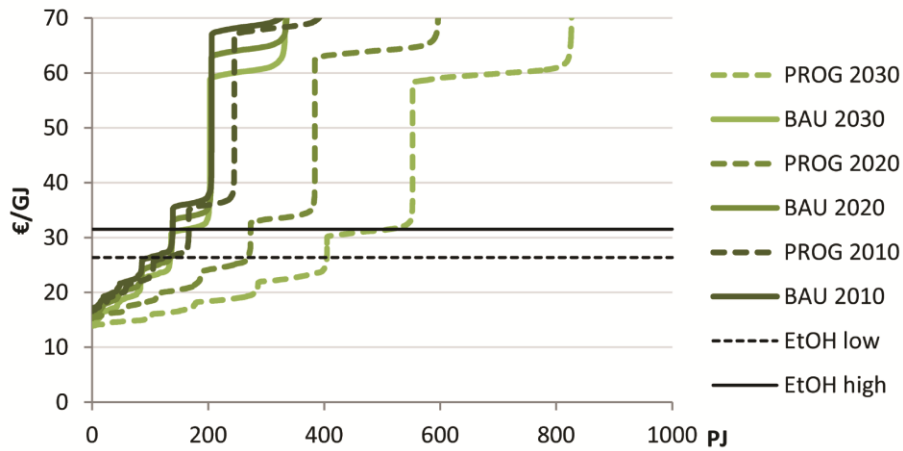
Eucalyptus pellets **Sugarcane ethanol**

Total production costs

Eucalyptus pellets



Sugar cane ethanol



Cost supply curves for eucalyptus pellets and sugar cane ethanol in timeframe 2010-2030 for 2 scenarios

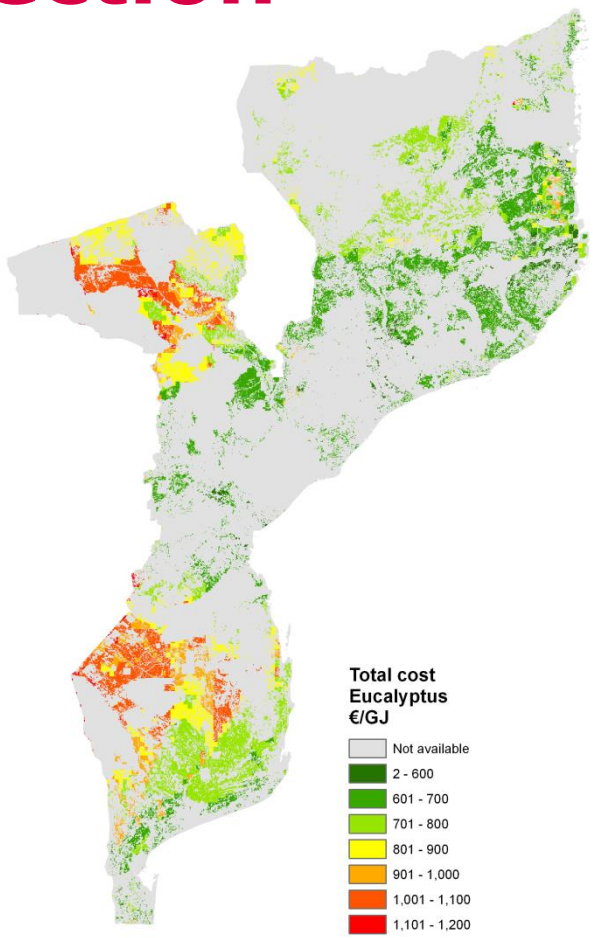
Next steps

- Now we have information on:
  - The amount, the location and the timeline of land availability for energy crops in Mozambique
  - The development in potentail of biomass production (actual yield levels)
  - The development in economic viability of biomass supply chains
  - The most favorable areas for biomass production from economic point of view
- We want to know:
  - What are the most favorable areas for bioenergy production from a sustainability point of view?

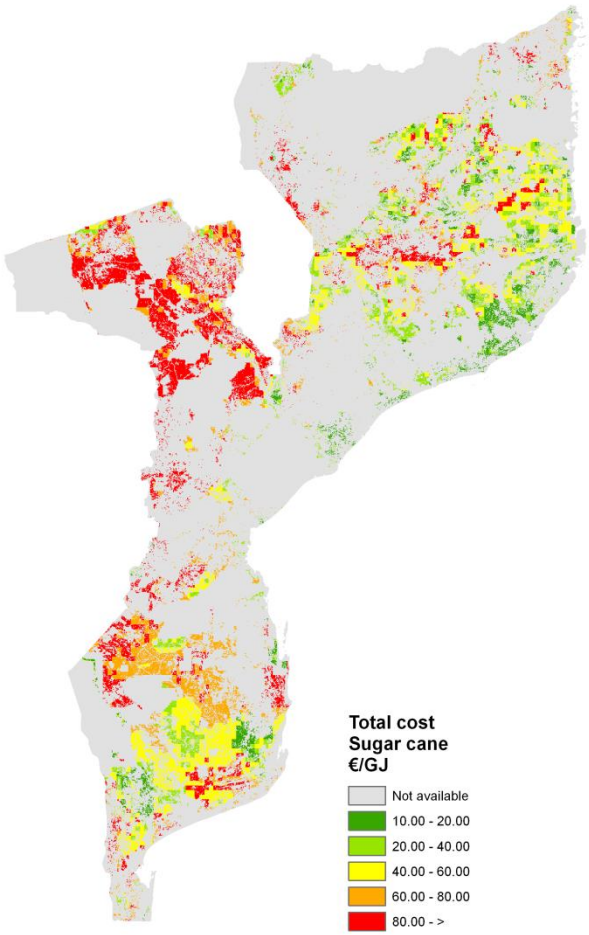
Demonstration for Mozambique

1. **Land use change model** → potential land availability for biomass production
2. **Dynamic cost supply curve** → given the location and characteristics of the available land, what are the cost of the biomass supply chains
3. **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.

Impact assessment: region selection



2030

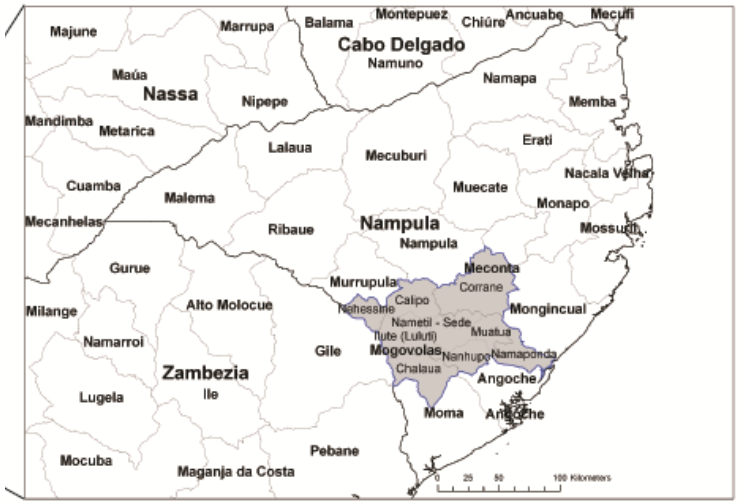


Eucalyptus pellets **Sugarcane ethanol**

Impact assessment: Region 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

7

8

9

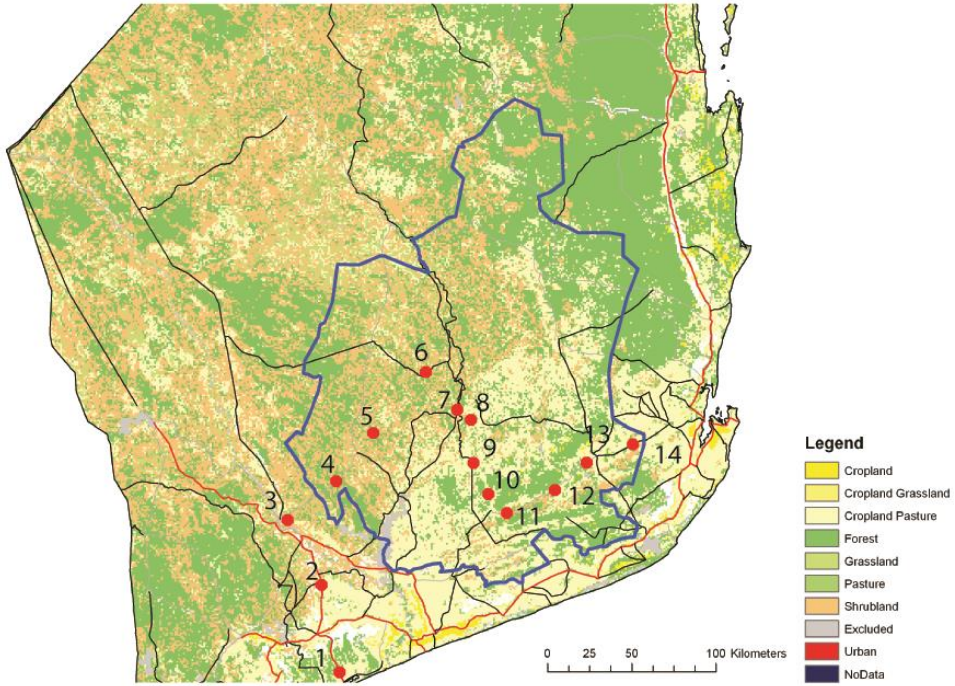
10

6

11

5

12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11
12
13
14
Legend
Cropland
Cropland Grassland
Cropland Pasture
Forest
Grassland
Pasture
Shrubland
Excluded
Urban
NoData
0 25 50 100 Kilometers

4

13

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2

1

14

1a

1b

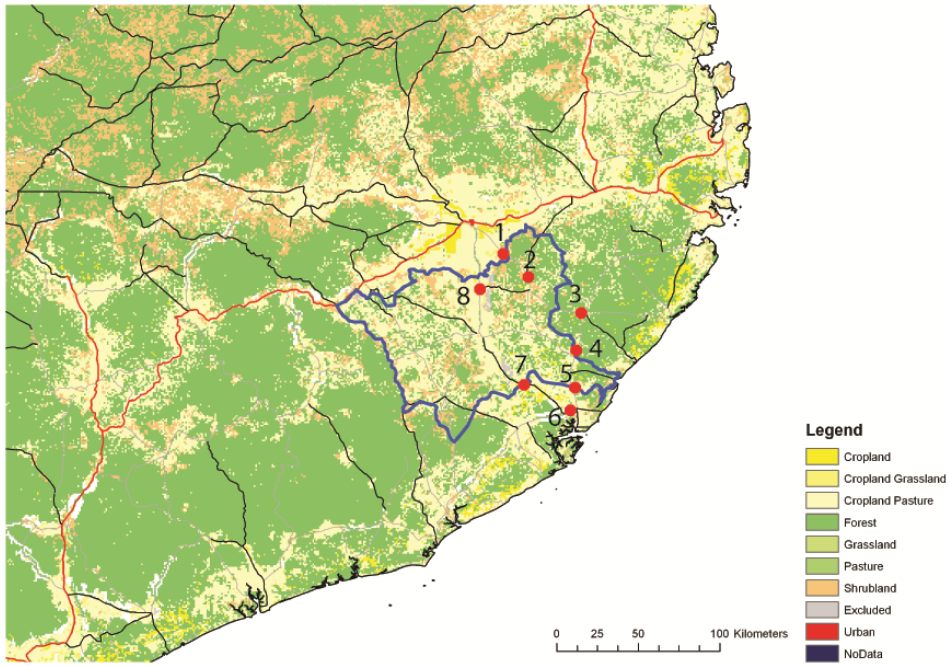
2a

2b

8b

3a

8a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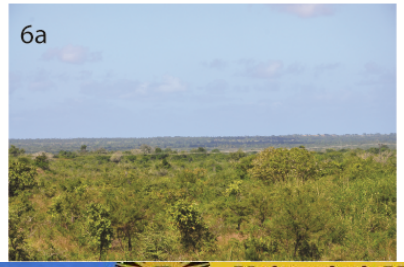
Cropland
Cropland Grassland
Cropland Pasture
Forest
Grassland
Pasture
Shrubland
Excluded
Urban
NoData
0 25 50 100 Kilometers

3b

7a

4a

6b


6a

5b

5a

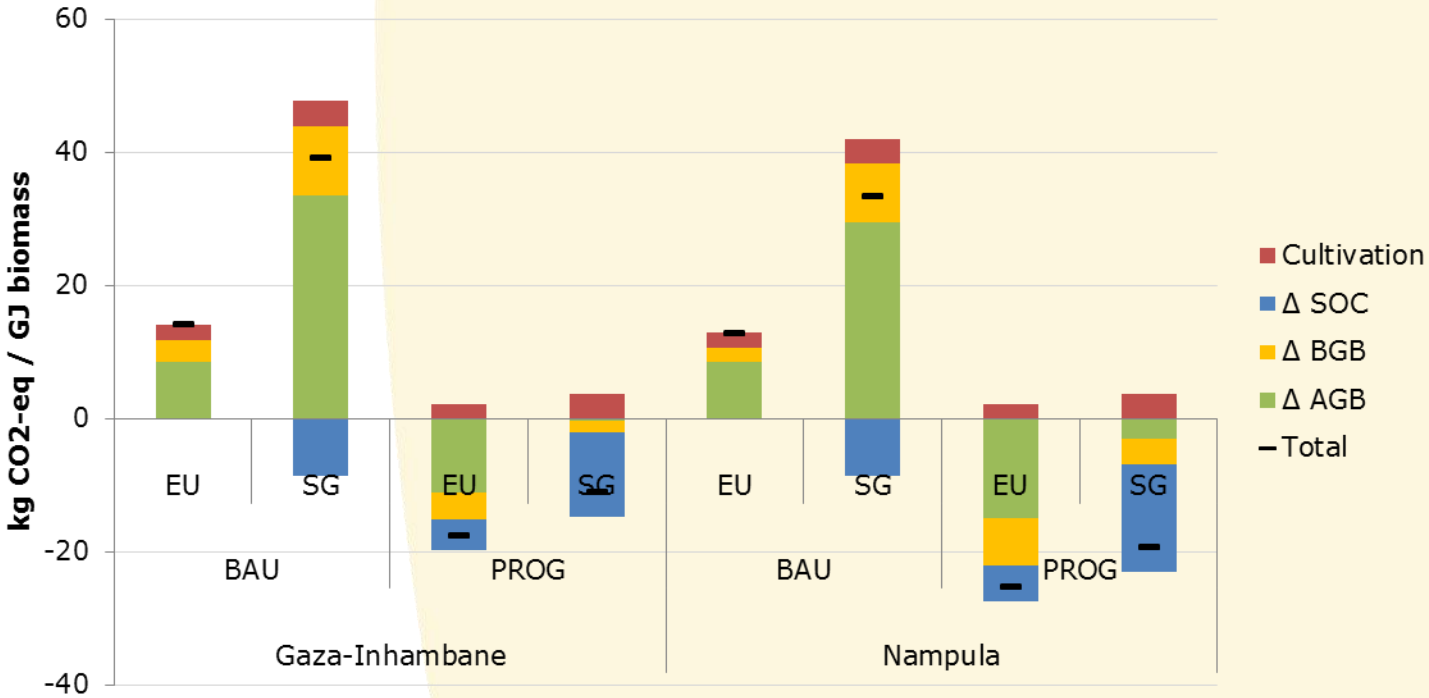
Impact Assessment: settings

- 2 regions in Mozambique
  - Gaza – Inhambane
  - Nampula
- 2 scenarios
  - BAU → low land availability
  - PROG → high land availability
- 2 biomass supply chains
  - Switchgrass ethanol
  - Eucaluptus ethanol

Impact assessment

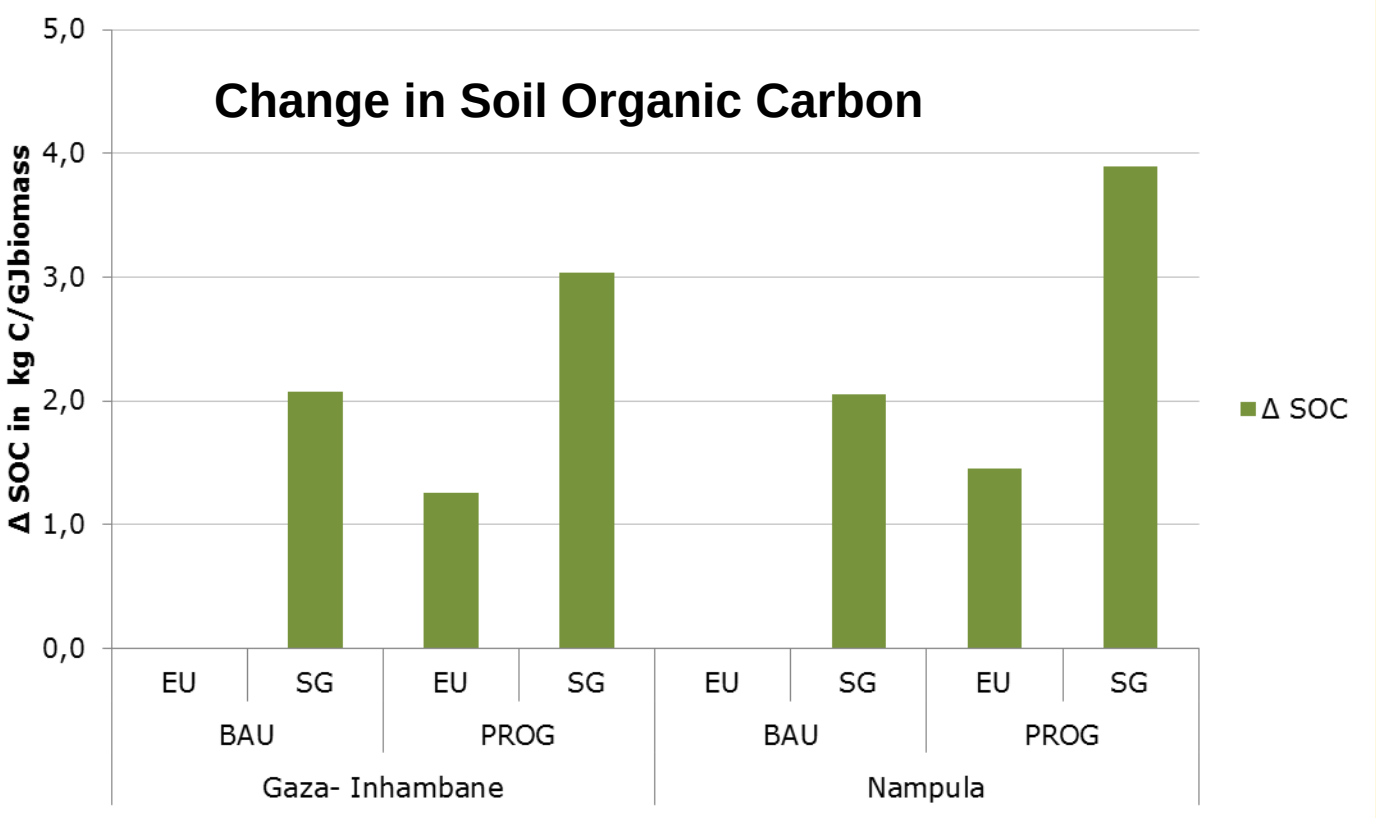
	Issue	EU-RED	CSBP	GBEP	RSB	ISCC	NTA8080	RFTO	MOZ
Environmental impacts	GHG emissions	√	√	√	√	√	√	√	√
	Biodiversity	√	√	√	√	√	√	√	√
	Soil		√	√	√	√	√	√	√
	Water		√	√	√	√	√	√	√
Socio- economic impacts.	Legality				√		√		√
	Land right								√
	Food security	√		√			√		√
	Economic viability			√	√				√
	Local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

Results – GHG emissions



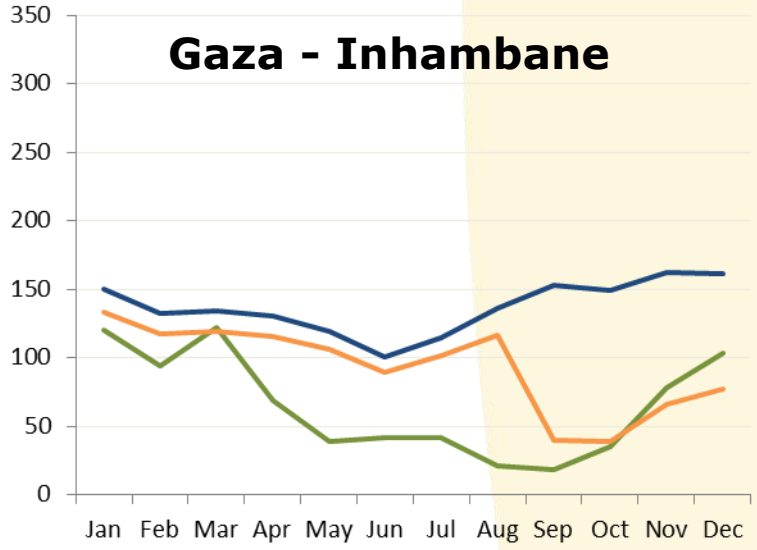
In BAU shrubland is converted to cultivated land → carbon loss
biomass carbon is dominant factor.
In PROG, cultivated land is converted to energy crops → carbon sequestration (especially SOC when converted to switchgrass)

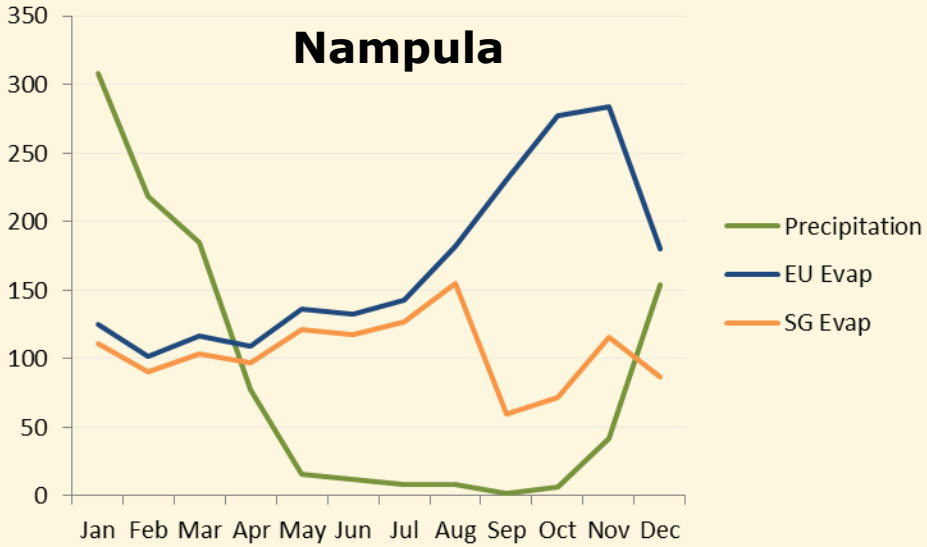
Soil - Results



Soil organic carbon (SOC) levels for different land use types. High uncertainty because dependent because of variations within soil type, climate region, vegetation, management.

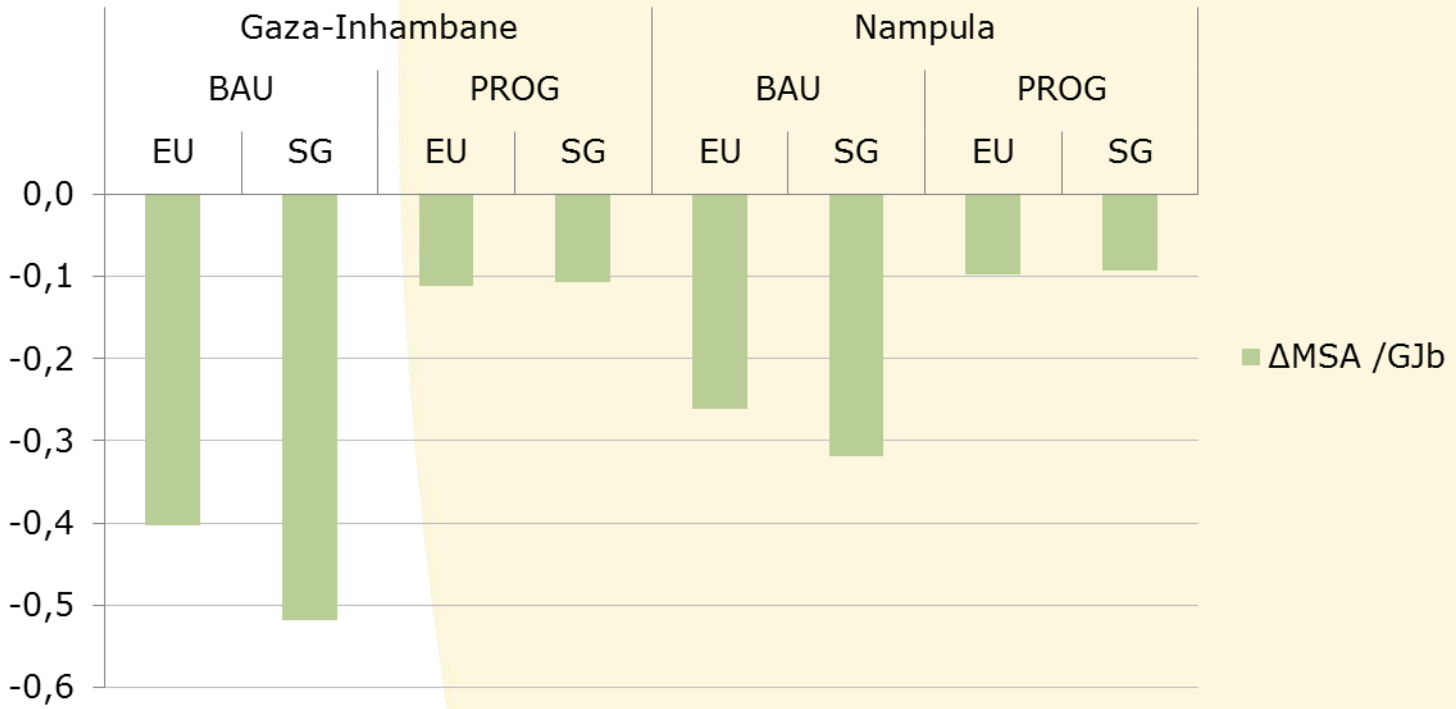
Water - Results





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.

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

Legality

- Legality refers to good agricultural practices and compliance with national laws and regulations.
- Relevant laws and polices:
  - Land Law and regulations
  - Investment Law and regulations
  - Specific environmental legislation
  - Labour law and regulations
  - Specific Biofuel policies

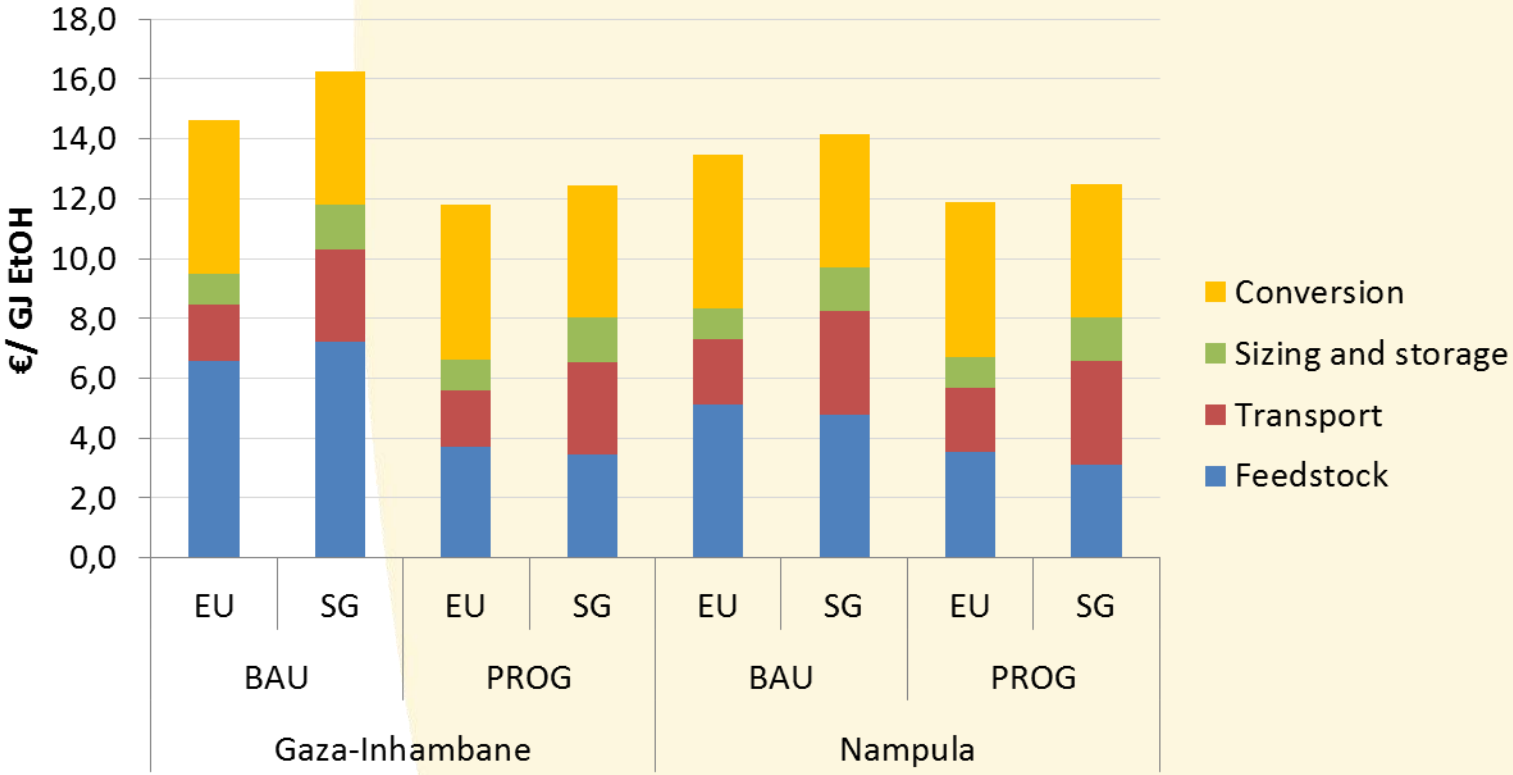
Land rights - Results

		Gaza-Inhambane				Nampula			
		BAU		PROG		BAU		PROG	
	Unit	EU	SG	EU	SG	EU	SG	EU	SG
Total land in selected region	Km^2	37324	37324	37324	37324	9974	9974	9974	9974
Total land availability	Km^2	8323	8323	16129	16129	837	837	3146	3146
Total land availability	% of region	22	22	43	43	8	8	32	32
Land requirements to meet input	Km^2	2039	2869	1567	2229	826	826	1313	1792
% of land required to meet scale	%	24	34	10	14	100	100	42	57

Food Security - Results

	Impact	Unit	Gaza-Inhambane				Nampula			
			BAU		PROG		BAU		PROG	
			EU	SG	EU	SG	EU	SG	EU	SG
	Food security [i]									
	Food security	Qualitative	+/-	+/-	+	+	-	-	+	+

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.

Local Prosperity - Results

Impact	Unit	Gaza-Inhambane				Nampula			
		BAU		PROG		BAU		PROG	
		EU	SG	EU	SG	EU	SG	EU	SG
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$ / yr	260	297	208	230	157	127	201	226
Total wages	M$ / yr	10.1	7.1	8.3	5.8	4.9	2.4	7.4	4.9

- The number of jobs and total wages is directly related to the amount of hectares required to meet the input requirements of a 1400 MW plant.
- The labour requirements are much lower compared to e.g. sugar cane or Jatropha.
- Switchgrass has low labour requirements because of relatively easy seeding and harvesting
- Large proportion of the investment will benefit others than Mozambique (fertilizers, machinery, equipment).
- Indirect effects, not calculated here, could potentially be large.

Social well being - Results

Impact	Unit	Gaza-Inhambane				Nampula			
		BAU		PROG		BAU		PROG	
		EU	SG	EU	SG	EU	SG	EU	SG
Social well-being [1]									
Total no of people affected	X 1000 people	49	34	40	28	24	12	36	24

The number of people affected is a result of the employment generated and the average size of households.
Both regions, the socio-economic conditions are relatively poor. This is especially true for the Gaza-Inhambane region. There is ample of opportunity to improve the current conditions

Overall Results – land availability

	Impact	Unit	Gaza-Inhambane				Nampula			
			BAU		PROG		BAU		PROG	
			EU	SG	EU	SG	EU	SG	EU	SG
	Scale up potential [a]									
	Total land in selected region	Km^2	37324	37324	37324	37324	9974	9974	9974	9974
	Total land availability	Km^2	8323	8323	16129	16129	837	837	3146	3146
	Total land availability	% of region	22	22	43	43	8	8	32	32
	Potential suitability of available land	% of max yield	31	31	34	34	63	63	62	62
	Land requirements to meet input	Km^2	2039	2869	1567	2229	826	826	1313	1792
	Suitability of best available land	% of max yield	41	39	53	50	63	63	64	62

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*									

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 development in economic viability of biomass supply chains
  - 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

Discussion and conclusion

- This *ex ante* analysis of the land availability, the economic viability 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.

More ambitions

- Make a more integrated assessment
  - trade offs between impacts
  - Model integration: e.g. Economic – land use – crop growth – impact models
- Improved assessments of socio-economic impacts
  - e.g. quantifying local impacts
- Improved assessments of environmental impacts
  - especially water and biodiversity
- More accurate data
- Better uncertainty analysis → e.g. error propagation
- Improved calibration of models
- More harmonized / uninform methodological framework to assess the sustainability of biomass supply chains, taken into account the high heterogeneity of supply chains and regions of origin.

Example Ukraine

- Integrated assessment of biomass potentials, agricultural intensification and GHG emissions
  - PLUC model + GHG emission module
  - Land use dynamics:
    - BAU → no agricultural intensification → low biomass potentials
    - PROG → high agricultural intensification → high biomass potentials
  - Emissions: Integrated assessment of effects of intensification and biofuel production
    - CO_2 , N_2O, CH_4
  - Demonstrated for Ukraine

BE-Basic

Programme 9.1

Identifying, Quantifying and Qualifying Sustainability for the Biobased Economy

BE-Basic

BE-Basic

- Public-Private Partnership in the Netherlands
  - Universities / Research institutes
  - Industry
- Aim: Building a sustainable biobased economy
- Flagship 9.1: Identifying, Quantifying and Qualifying Sustainability for the Biobased Economy
- UU coordination of Flagship 9.1
- 12 subprojects
- 5 sub-projects are performed by UU, 4 UU PhDs involved
- First case study: sustainability of the expansion of the ethanol sector in Brazil
- Next case study: pellet production SE USA

  (RWE Essent, EU Utility → co-firing coal fired power plant)

BE BASIC Context: Flagships

BE-BASIC

- **Flagship 1** Carbon Based Compounds
- **Flagship 2** Nitrogen Based Specialities
- **Flagship 3** Sustainable soil management and upstream processing
- **Flagship 4** Recycling of rare resources
- **Flagship 5** Bioprocess pilot facility
- **Flagship 6** Synthetic Biology
- **Flagship 7** High-throughput experimentation and (meta) genomic mining
- **Flagship 8** Environmental impact of chemical, bio-based molecules and processes
- **Flagship 9** Societal embedding of a biobased economy

Objective 9.1

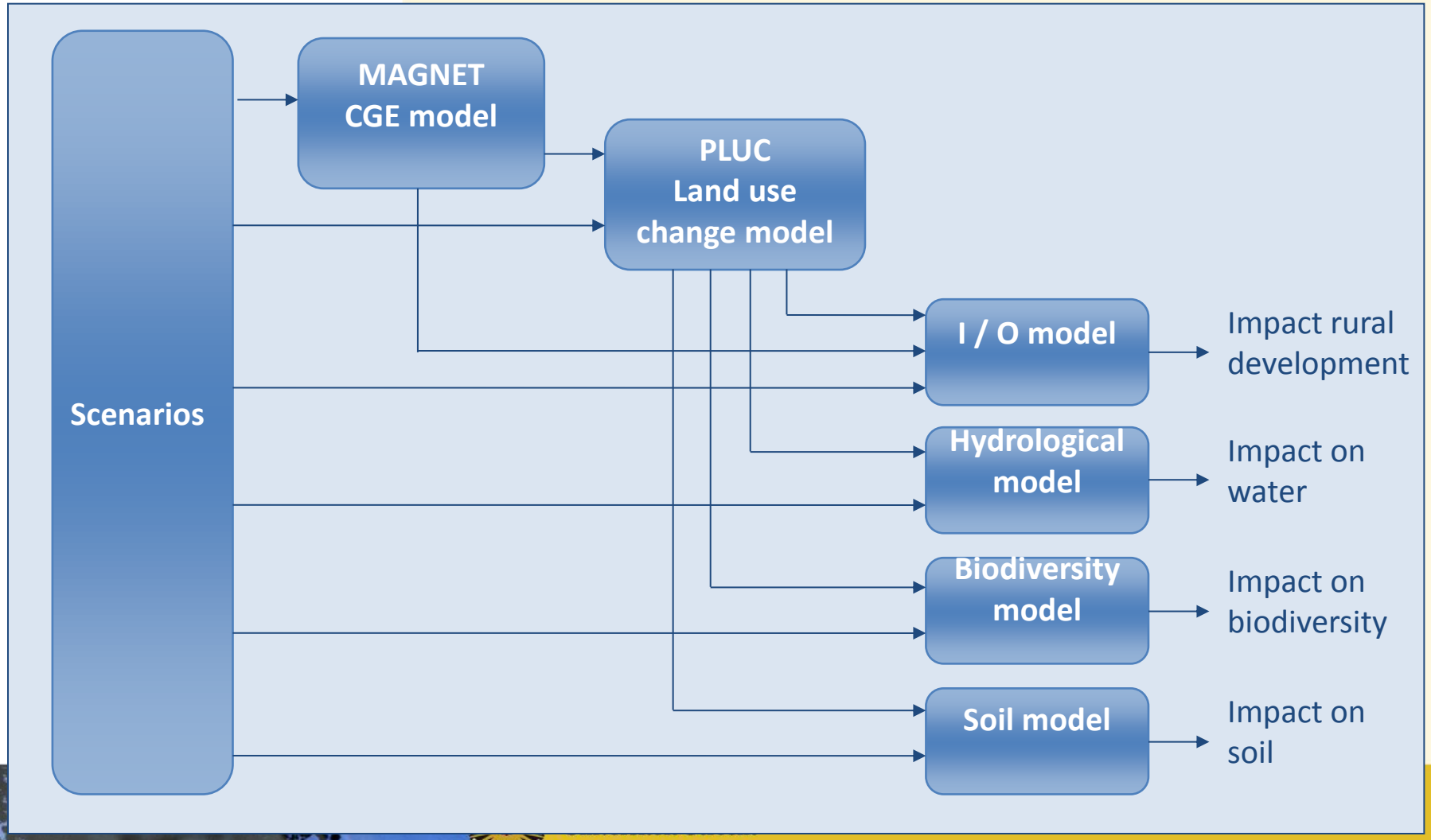
Develop an integrated methodological framework and deliver standardized procedures to evaluate the sustainability and performance of bio-based systems

Case study: Expansion of ethanol sector in Brazil

Methodological Approach

1. Economic outlook of Ethanol production in Brazil → Development in cost structure ethanol
2. Satellite and statistical data of current land use
3. Global Economic model → how much sugar cane and other agricultural commodities needs Brazil to produce
4. Land use change model → Where and how will agriculture expand
5. Interregional I/O model → Impact rural development (GDP, Employment)
6. Several environmental models → Environmental impacts

Methodological Framework



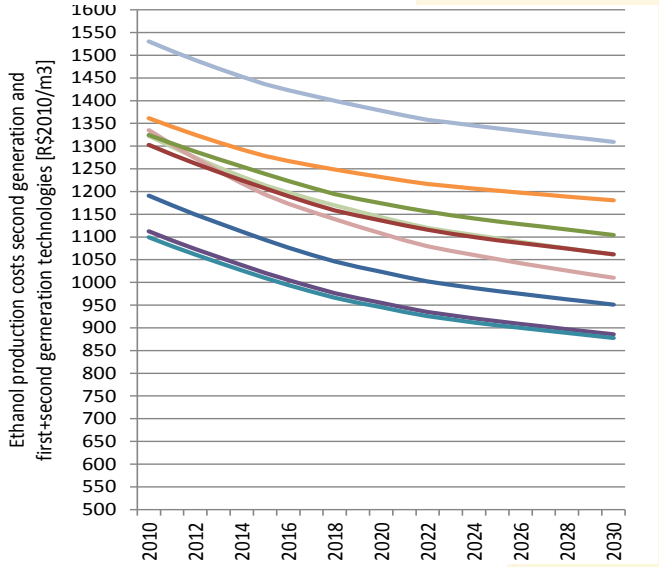
Methodological approach

Techno-economic outlook ethanol production

→ Development in ethanol production costs towards 2030

Global Economic model (CGE)

Commodity production per world region 2010-2030



Methodological approach

Global Economic model (CGE)

Commodity production per world region 2010-2030

CGE model

Commodity production per macro–region in Brazil 2010 – 2030

Methodological approach

Commodity production per macro –region in Brazil 2010-2030

PLUC Land Use Change Model

Location of commodity production every year 2010-2030

Satellite and statistical data on land use

Socio-economic impacts

PLUC Land Use Change Model

Location of commodity production every year 2010-2030

Inter-regional input output model

Impacts on employment and GDP on regional level

		Micro - region					State					Macro - region				Final demand			Total Output
		Sector 1	Sector 2													ro	e	cro	
Micro-region	Sector 1	10	25																Y
	Sector 2	10	25																Y
	Sector 3	56	34																Y
	...	45	15																Y
	Sector n	10	25																Y
State	Sector 1	10	25																Y
	Sector 2	10	25																Y
	Sector 3	10	25																Y
	...	56	34																Y
	Sector n	45	15																Y
Macro-region	Sector 1	10	25																Y
	Sector 2	10	25																Y
	Sector 3	56	34																Y
	Sector n	34	87																Y
Value added		l	l																L
Imports		m	m																M
Total Input		x	x																X=Y

Interregional I/O model

Effect on GDP, trade, employment and income for different regions and for different groups in society

Environmental Impacts

PLUC Land Use Change Model

Location of commodity production every year 2010-2030

Impact models

Environmental impacts of ethanol expansion

→ Hydrology

→ Biodiversity

→ GHG balance

→ Soil quality

Expected Results

- Able to quantify environmental and socio-economic impacts
- Identify causes of negative impacts and how to avoid these, and optimise positive impacts
- Important information for government: how to integrate biomass production in agricultural sector and sound land use planning, preconditions for sustainable biomass supply chains
- Important information for business: how to comply with sustainability criteria
- Important information for certification: how to measure sustainability?

Next steps

- Next case study: pellet production SE USA
- Potential next steps e.g.:
  - Integration CGE model land use change model
    - Competing markets for wood
    - Competing land uses
  - Integration land use change model and crop growth model
  - Dynamic linkages between land use change model and environmental impacts

  - Collaboration with excellent scientist in US
  - Better data availability → improvement of model accuracy

Thank you for your attention

Question? More information?
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Judith Verstegen
Land use change modeling

Michiel Nijsen
Impacts on water and Biodiversity

Gert Jan Jonker
Optimisation of biomass supply chains

Sanne Heijnen
Socio-economic impacts and food security

Future land use in Brazil under increasing demand for bioenergy

Judith Anne Verstegen (J.A.Verstegen@uu.nl)
Copernicus Institute for Sustainable Development and Innovation, Utrecht University, The Netherlands

Introduction

An important current debate is whether bioenergy from dedicated crops is still sustainable when land use change (direct and indirect) is taken into account, in view of, e.g., carbon emissions, rising food prices, and biodiversity. Impacts of a future increase in demand for bioenergy depend on the magnitude, location and pattern of energy cropland expansion. As processes herein act on global (e.g., economy) as well as local (e.g., potential yield) levels, we apply an integrated model.

We aim at:

1. projecting the magnitude and spatiotemporal pattern of sugar cane expansion and the effect on other land use types in Brazil towards 2030, and
2. assessing the uncertainty herein.

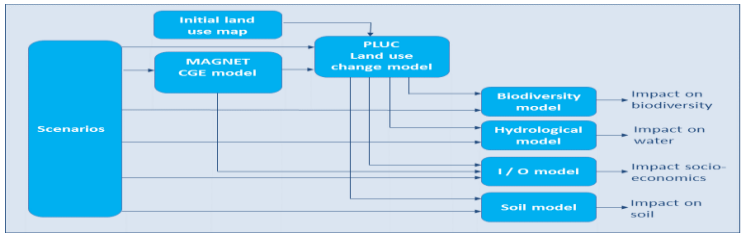


Figure 1: Model chain. The scenarios and Magnet (computable general equilibrium model)are global, while the rest of the analysis is specific for Brazil.

Methods

For the spatio-temporal projection, four model components are used (Figure 1):

1. an initial land use map that shows the initial amount and location of sugar cane and all other relevant land use types in Brazil,
2. a computable general equilibrium (CGE) model, Magnet, simulating the economy of the whole world to project the quantity of change of all land uses in Brazil,
3. a spatially explicit land use model, PLUC, is calibrated with agricultural statistics data (Figure 3) to finally determine the location of change of all land use types (Figure 4), and
4. several models evaluating the impacts of land use change on biodiversity, water, socio-economics, and soil, performed by the other three PhD students in project F09.001

Results

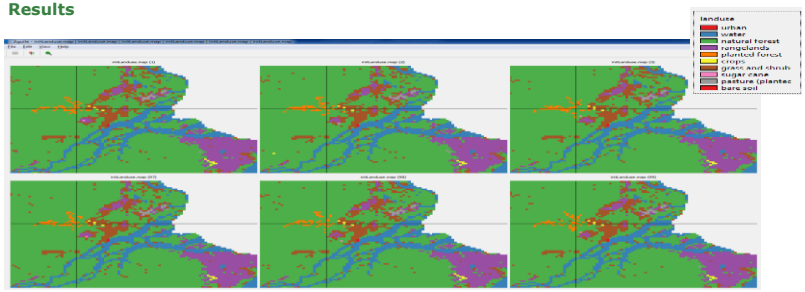


Figure 2: No recent accurate land use map is available for Brazil, so municipal census data and the global land cover map GlobCover are combined to create the initial land use map. The census data available per municipality are disaggregated stochastically using GlobCover as a probability surface, to obtain an ensemble of initial land use raster maps for 2006. Shown here in the visualization software the model is connected to, Aguila (pcraster.geo.uu.nl), is a detail of the initial land use map of Brazil, the mouth of the Amazon river, for six ensemble members. The total areas of the different land use types in the six ensemble members are similar, but the shapes of the patches differ. See for example the shape of the patch of planted forest (orange).

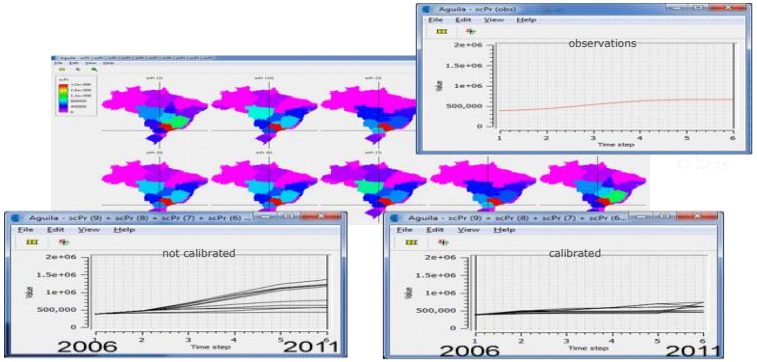


Figure 3: Using a Bayesian data assimilation technique and census data from 2007 to 2011 as observational data, PLUC is calibrated. The ensemble of maps shows the total area of sugar cane per state projected for 2011 by the calibrated ensemble of model runs. The variance in total area of sugar cane in the state Parana given by the ensemble of model runs for the not calibrated model (left hand graph) is more than twice as large as the spread given by the calibrated model (right hand graph). Also, the ensemble of the calibrated model predicts values closer to the observed values (upper graph).

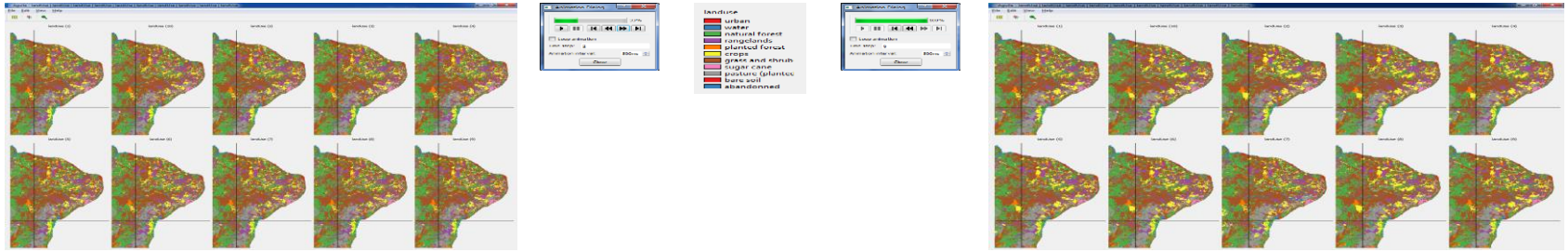


Figure 4: Land use in North-Eastern Brazil in 2007 (left) and 2011 (right) projected by the ensemble of model runs. The difference among the ten samples is larger in 2011 than in 2007, because of error propagation over time. For example the lower centre ensemble member in 2011 shows some abandoned cropland in the centre (blue) that is reallocated in the south (yellow), while the other members do not show that.

Copernicus Institute
Research Institute for Sustainable Development and Innovation

BE-Basic

This research is funded by BE-Basic

BE BASIC Context: Objective

- Public-private partnership
  - 14 industriële partners
  - 15 Universiteiten en kennisinstellingen
  - Coördinatie Delft University
- Budget 120 mln euro
- Missie:
  - To build a sustainable bio-based economy the chemical, energy and materials industry need to switch from fossil fuels to biomass. This requires new technologies and insight in the sustainability issues that come along with this transition.

BE–BASIC Context: Flagship 9

- This **programme 9.1** focuses on the sustainability dimension of (large scale) biomass production and addresses the following key problems:
  - **Full impact analyses** of biomass production, supply and utilisation systems on **regional level**, interlinked with higher scale-levels relevant for land-use and (macro-economic) impacts.
  - Development and demonstration of remote sensing techniques for **monitoring the spatio-temporal dynamics of land-use**, interlinked with full-impact analysis methods and frameworks.
  - Analyses of the **macro-economic and food security impact** of advanced biomass options.
  - Analysis of the **social impacts** and the social climate for biobased economy options and pathways.

BE–BASIC Context: Flagship 9

Flagship 9

Programme 9.1
Identifying, Quantifying and Qualifying Sustainability for the Biobased Economy

Programme 9.2
Development of effective and efficient education, communication and societal valorisation programmes

- **9.1.1** Regional biomass resource availability and dynamics
- **9.1.2** Optimising performance of biomass production and utilisation
- **9.1.3** Environmental impacts (II): water, soils and biodiversity
- **9.1.4** Socio-economic impacts
- **9.1.5** Tools for macro-economic impacts
- **9.1.6** Methodology, analysis and measurement of food security impacts
- **9.1.7** Integration into a coherent sustainability framework
- **9.1.8** Satellite-based retrieval algorithms
- **9.1.9** Satellite data assimilation
- **9.1.10** Integration: satellite based monitoring and inversion strategy
- **9.1.11** Qualitative and quantitative analysis of public opinions and values
- **9.1.12** Global normative frameworks for sustainable futures

Be Basic Context: Tasks Copernicus

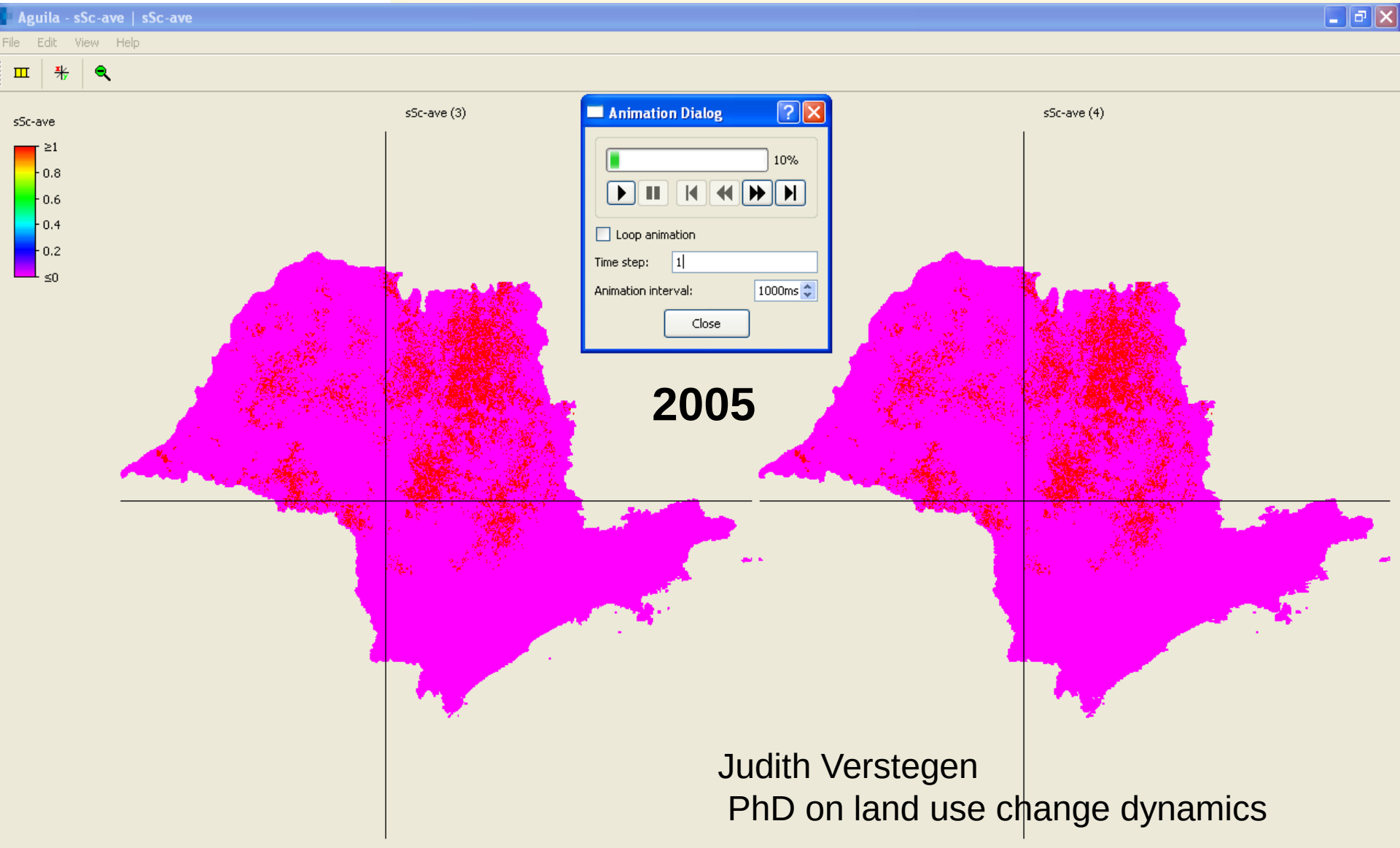
- Assessment of regional biomass resource availability making use of spatio-temporal **land use change modelling**.
- Assessment of **environmental impacts** of biomass production on water and biodiversity.
- **Optimisation** of technical, economical and environmental **performance of biomass supply** and utilisation chains.
- Analyses of the **macro-economic and social impact** of biobased economy options and pathways.
- Integrated analysis

Objective BE-Basic

Develop an integrated methodological framework and deliver standardized procedures to evaluate the sustainability and performance of bio-based systems

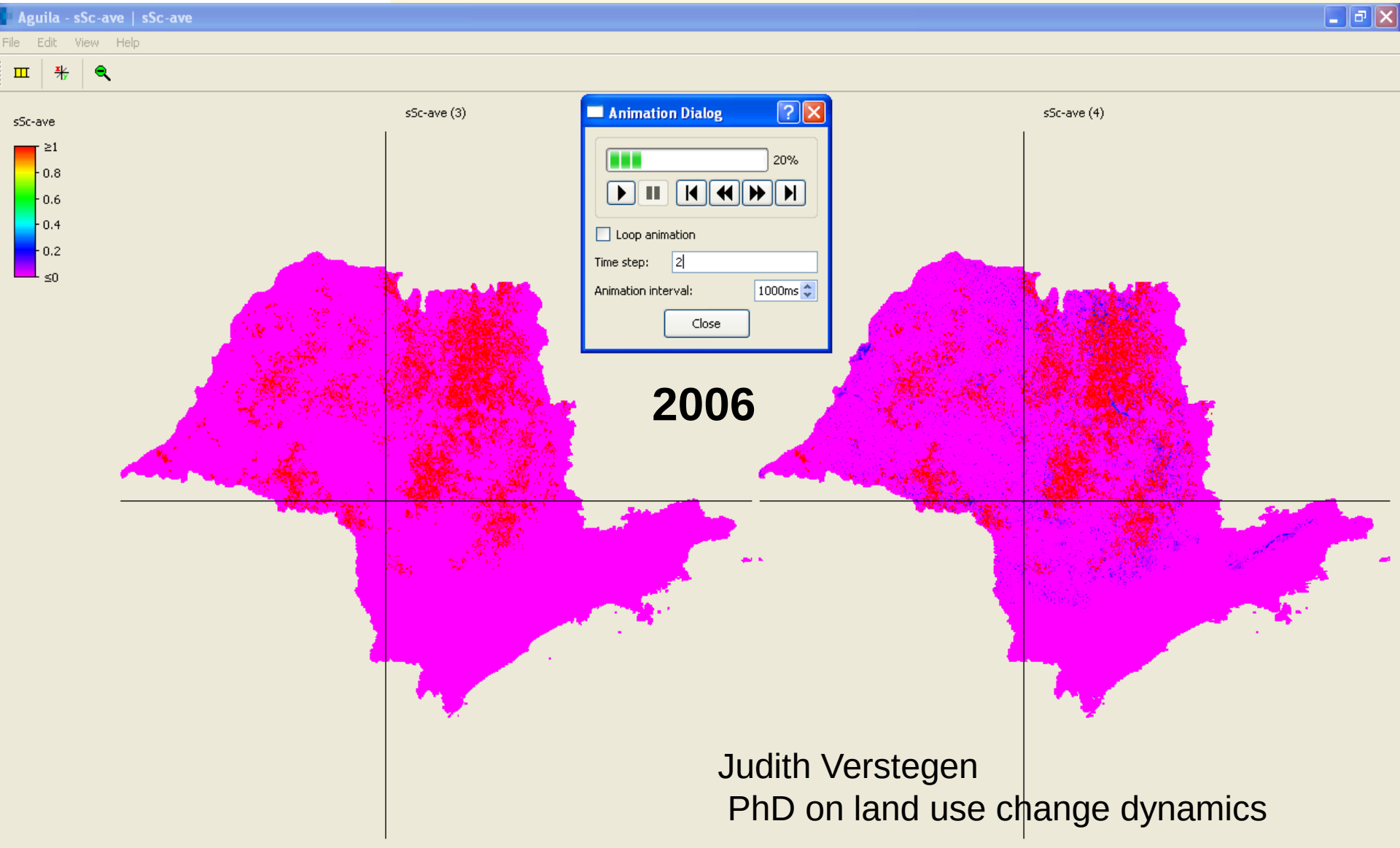
Previous work

PLUC – Illustration for SC in SP



Judith Verstegen
PhD on land use change dynamics

PLUC – Illustration for SC in SP



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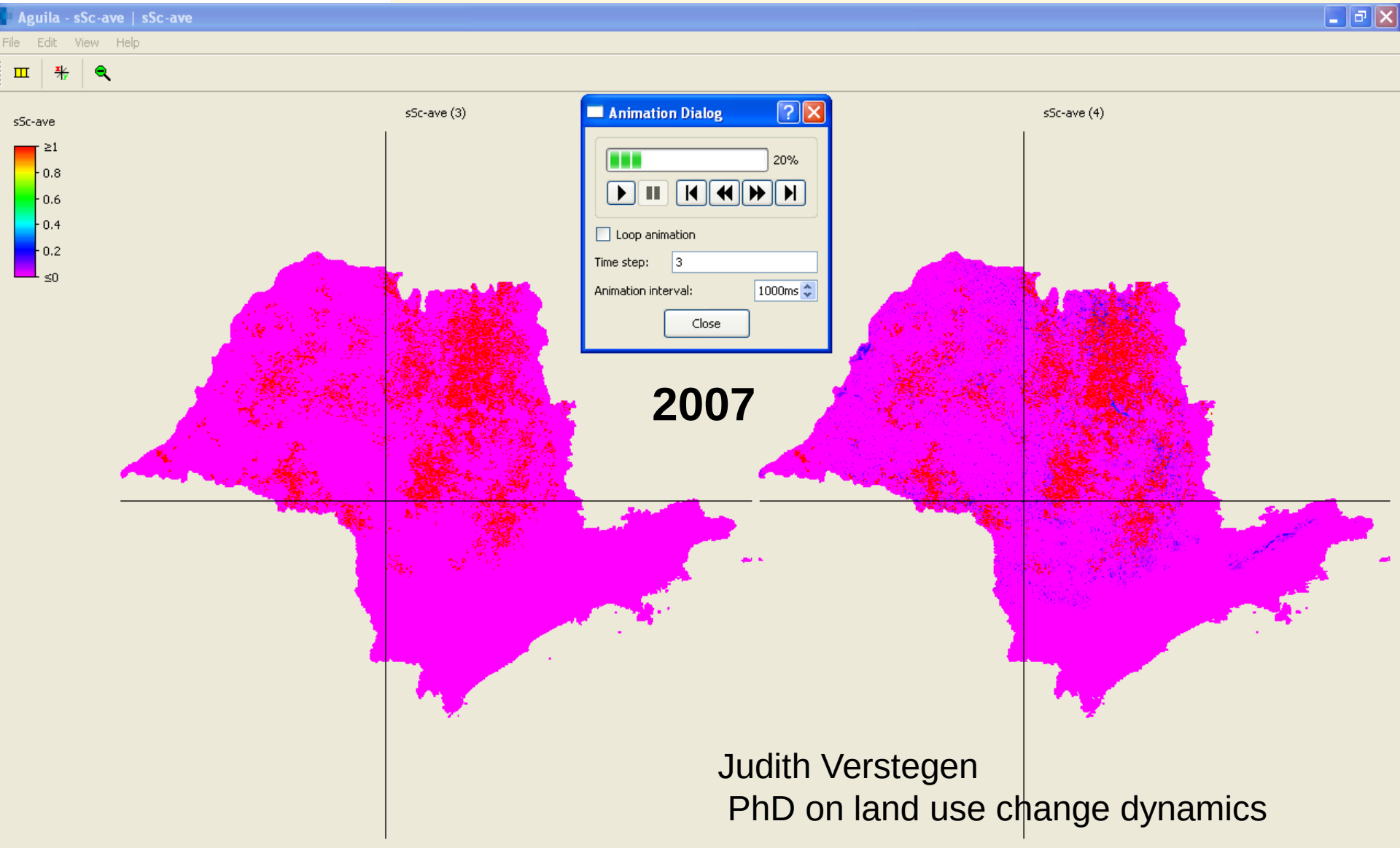

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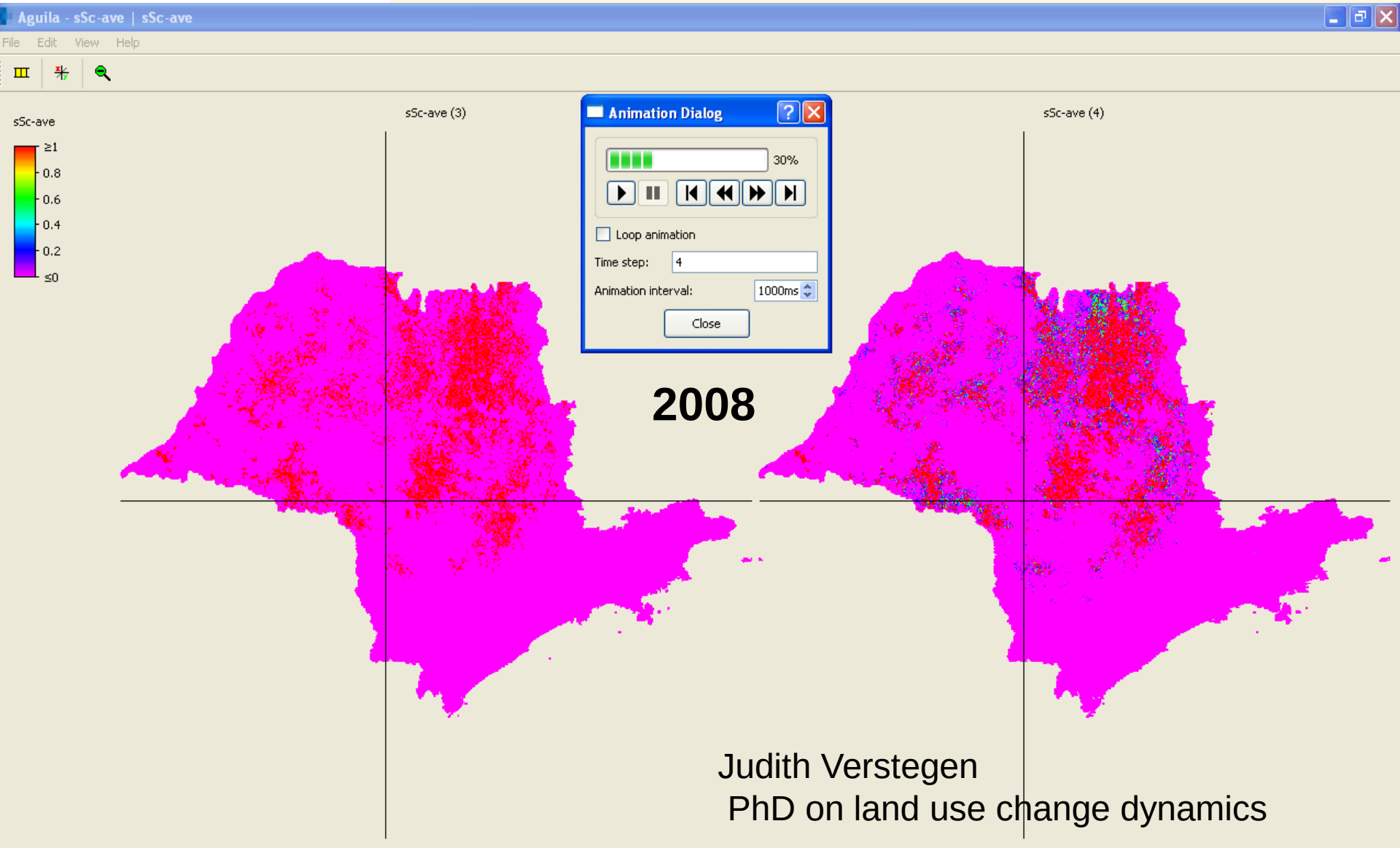

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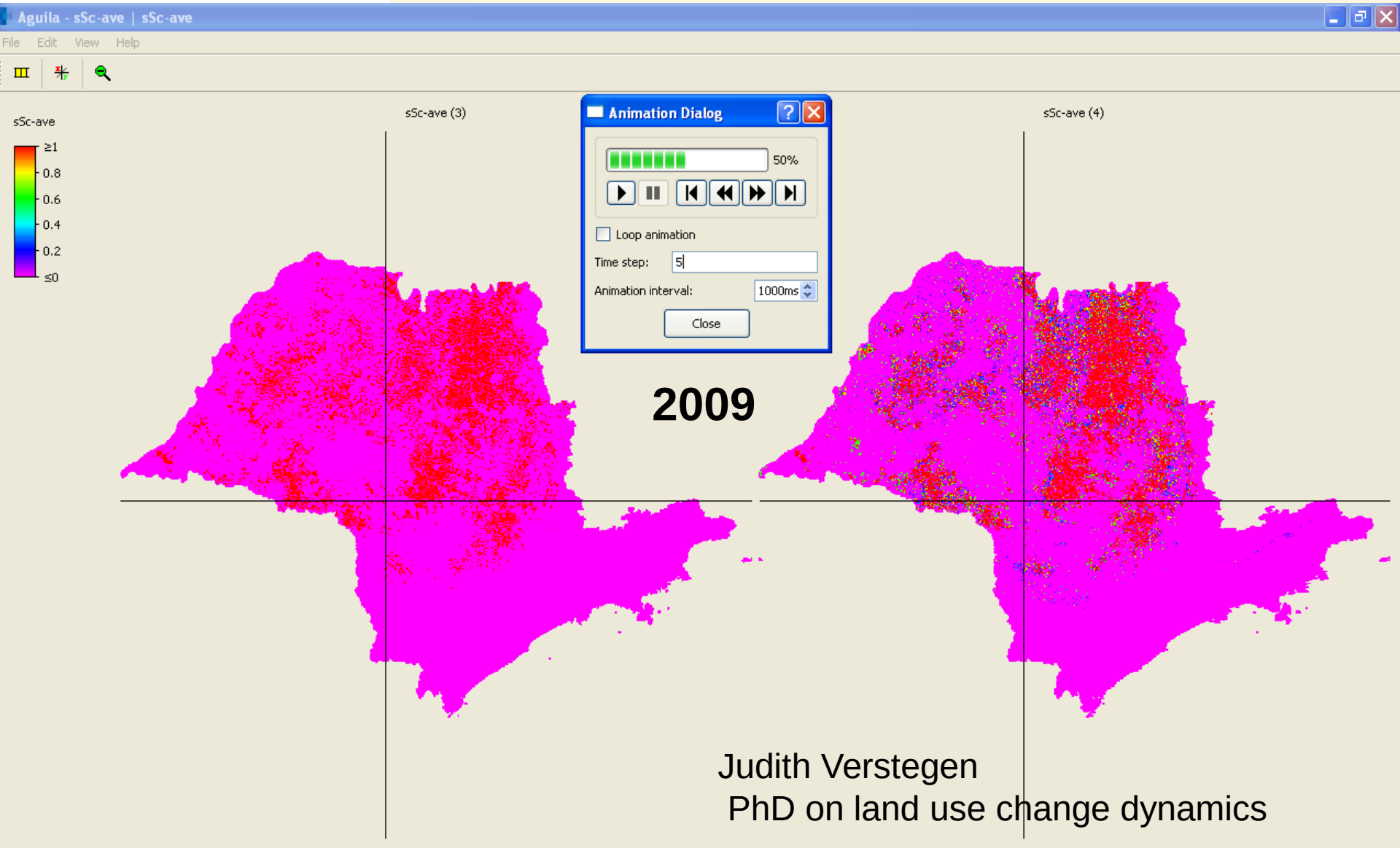

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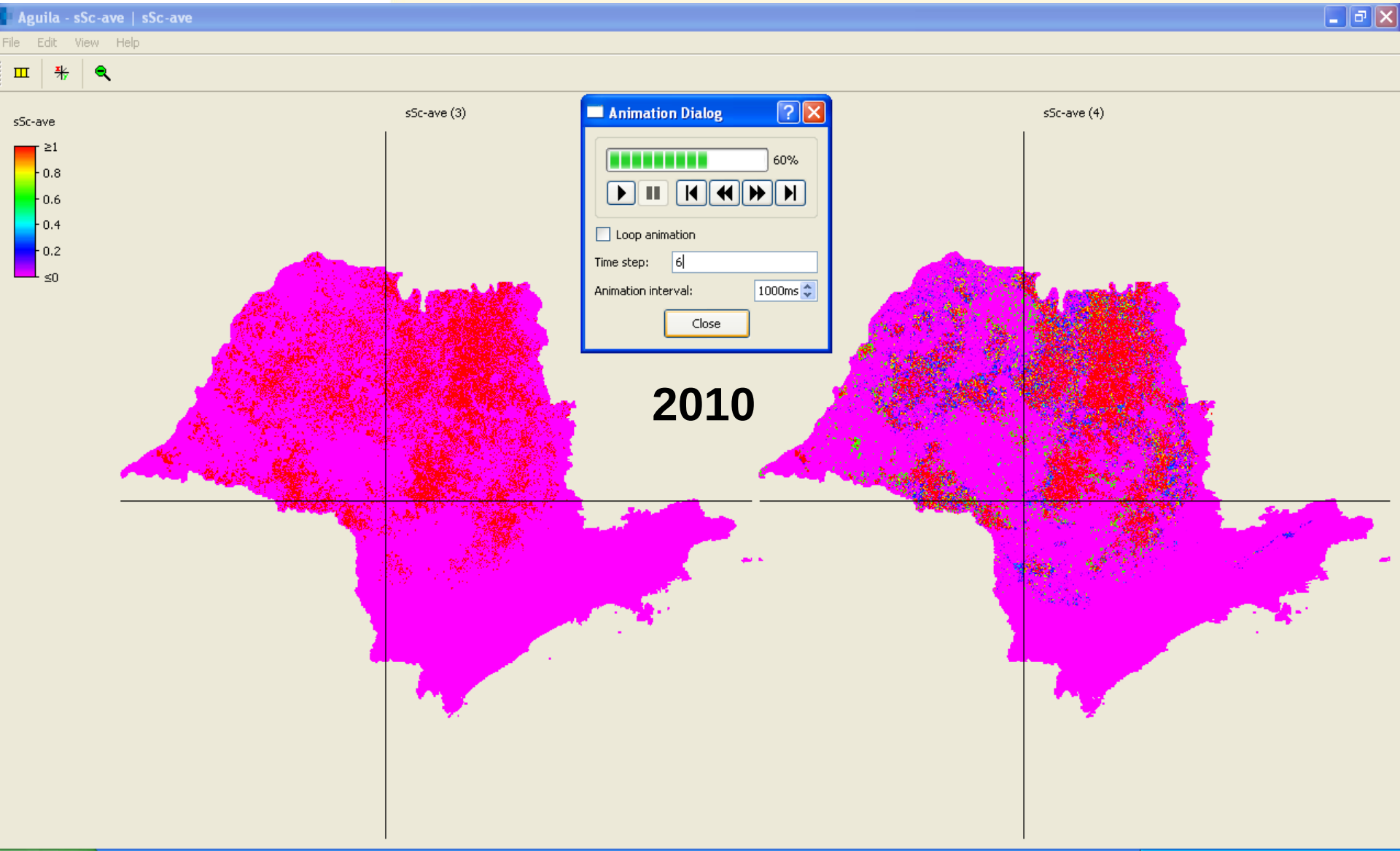

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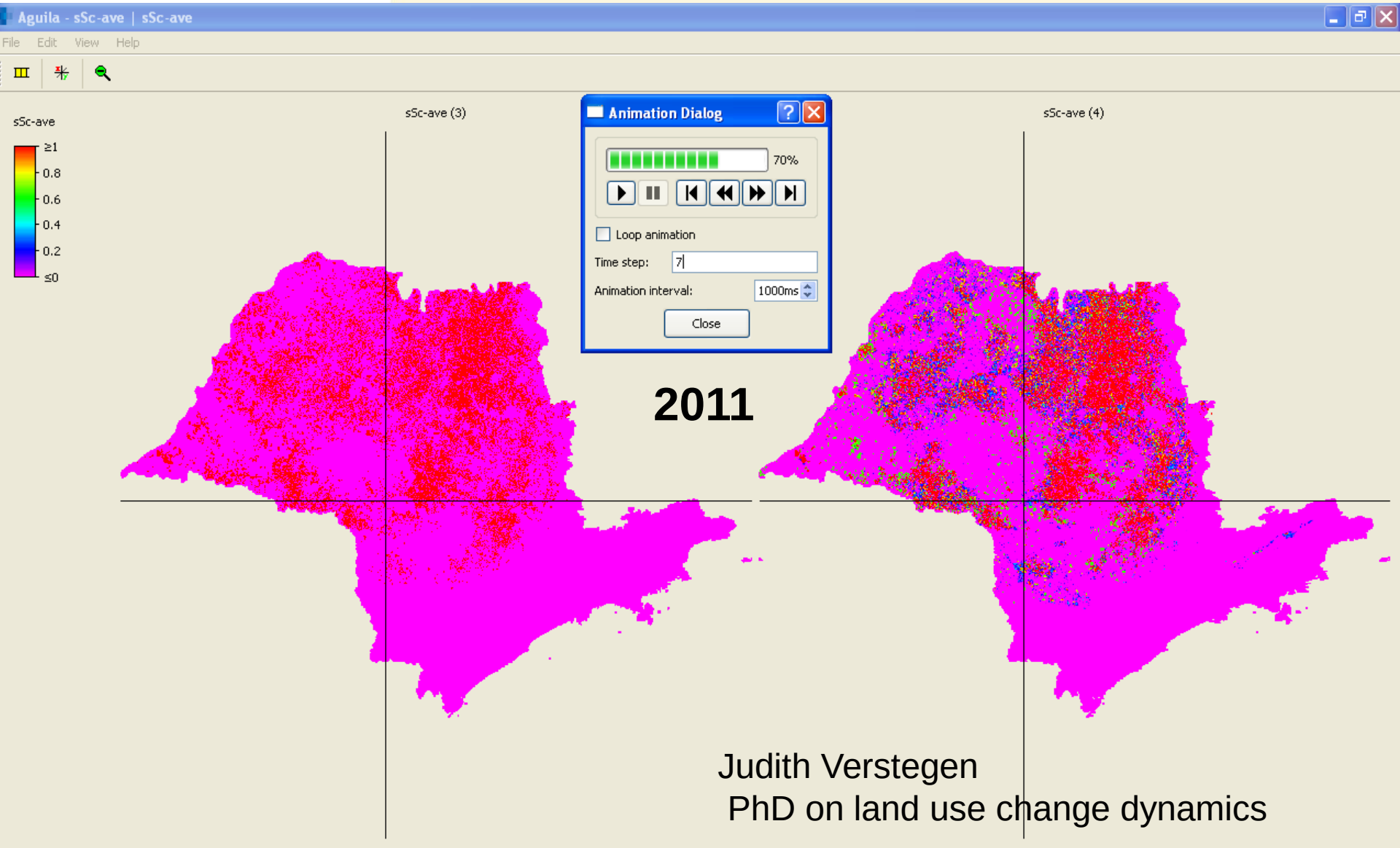

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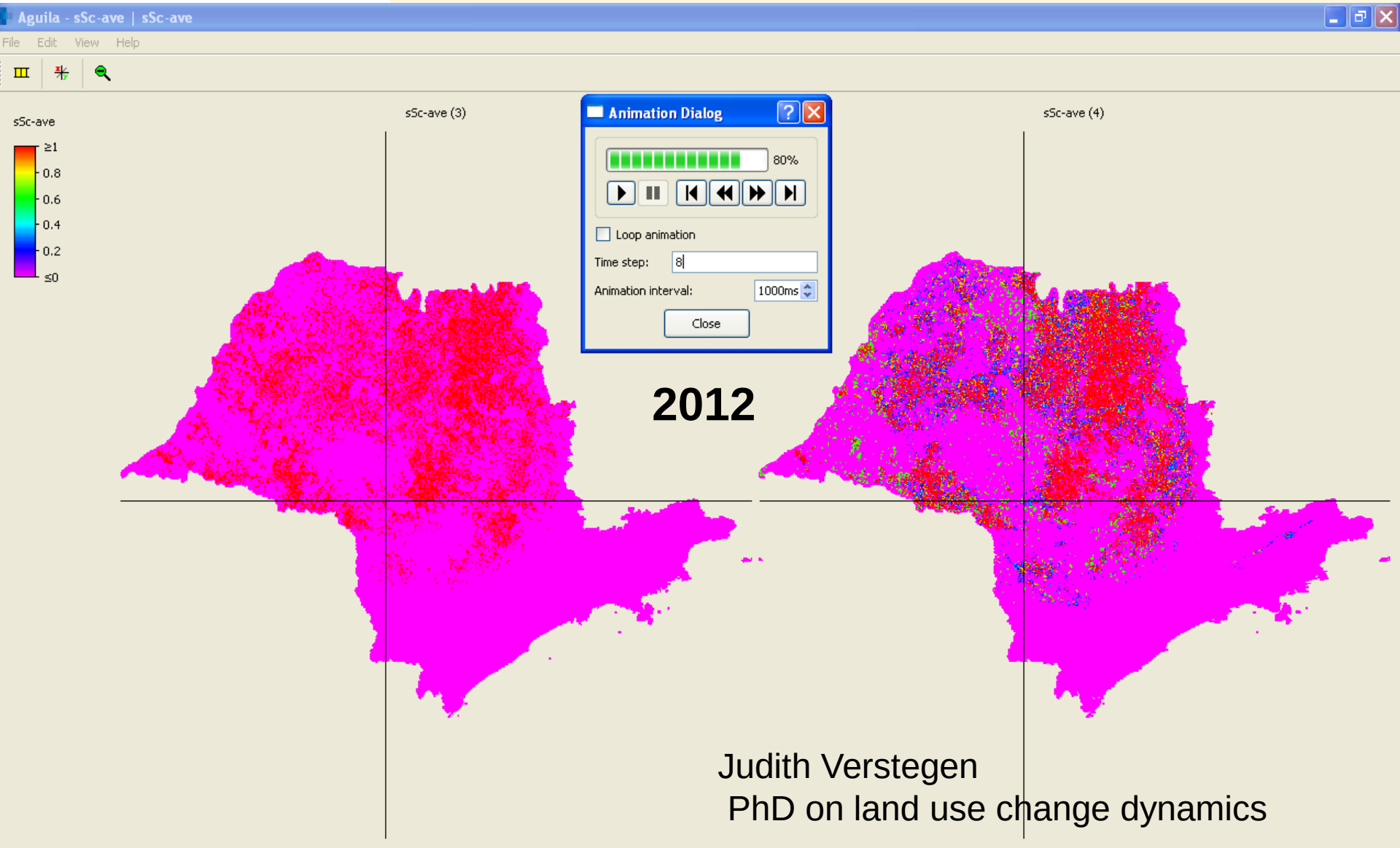

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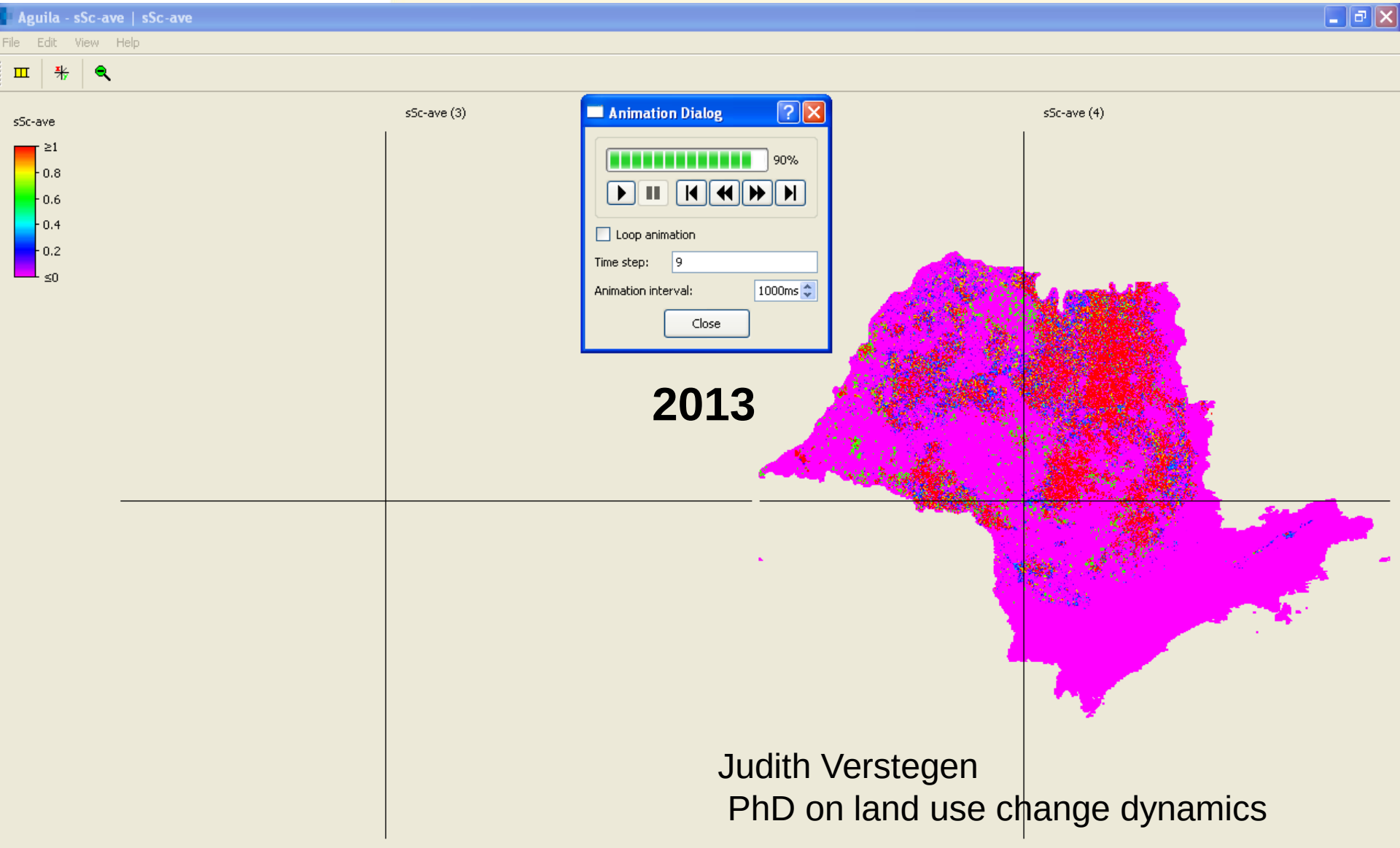

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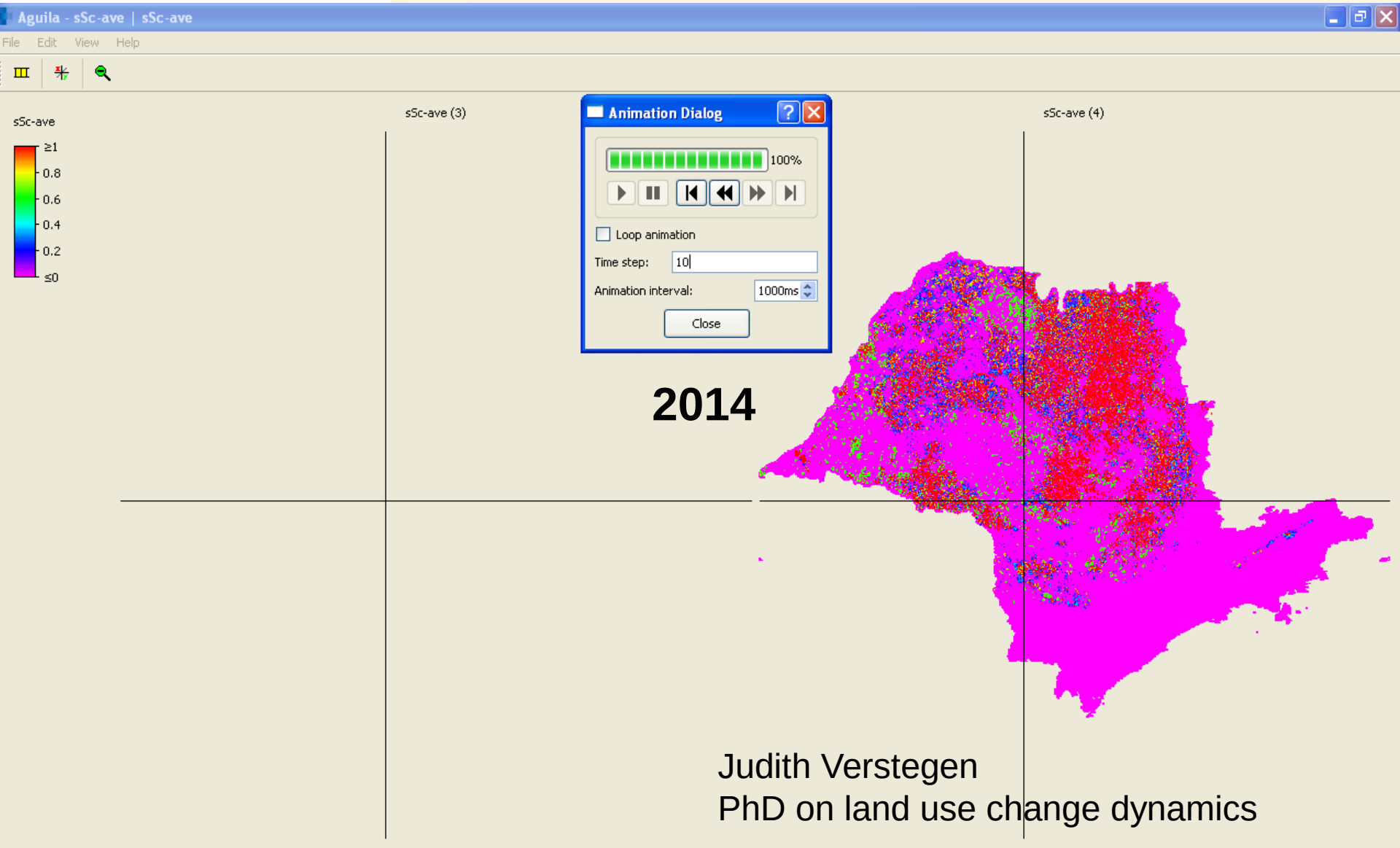

Judith Verstegen
PhD on land use change dynamics

PLUC

- Initial land use map for Brazil for reference year
- Harmonization with statistics in CGE model MAGNET
- Implementation of demand (derived from MAGNET of several land uses in PLUC (sugar cane, eucalyptus, cropland, pasture, rangelands, forest)
- Allocation of land uses for every year towards 2030 for every scenario
- Uncertainty analyses of land use change modeling

Results (highlights scientific output)

- Immerzeel, D. J., P. A. Verweij, F. van der Hilst and A. P. C. Faaij (2013). "Biodiversity impacts of bioenergy crop production: a state-of-the-art review." GCB Bioenergy: DOI: 10.1111/gcbb.12067.
- Verstegen, J. A., D. Karssenberg, F. van der Hilst and A. P. C. Faaij (2014). "Identifying a land use change cellular automaton by Bayesian data assimilation." Environmental Modelling & Software 53(0): 121-136.
- Verstegen, J.A., Karssenberg, D., van der Hilst, F., Faaij, A.P.C., Identifying systemic change in a land use system by Bayesian data assimilation. Environmental Modelling & Software. (Under review)
- Wicke, B., van der Hilst, F., Daioglou, V., Banse, M., Beringer, T., Gerssen-Gondelach, S., Heijnen, S., Karssenberg, D., Laborde, D., Lippe, M., van Meijl, H., Nassar, A., Powell, J., Prins, A.G., Rose, S., Smeets, E.M.W., Stehfest, E., Tyner, W.E., Verstegen, J.A., Valin, H., van Vuuren, D.P., Yeh, S., Faaij, A.P.C., 2014, Model collaboration for the improved assessment of biomass supply and its impacts, GCB Bioenergy.
- Hedlund-de Witt, Annick, & Hedlund-de Witt, Nicholas H. (2014, In Press). Reflexive communicative action for climate solutions: Towards an integral ecology of worldviews. In S. Mickey, S. M. Kelly & A. Robbert (Eds.), *Integral ecologies: Culture, nature, knowledge, and our planetary future*. New York: SUNY Press.

Results (highlights scientific output)

- Hedlund-de Witt, Annick. (2014, In press). The integrative worldview and its potential for sustainable societies: A qualitative exploration of the views and values of environmental leaders. *Worldviews: Global Religions, Culture and Ecology*.
- Jonker, G.J. et al, 'Economic outlook for ethanol production in Brazil up to 2030'. (Forthcoming)
- Heijnen, S. et al, 'Quantifying impacts of bioenergy production on regional development in Brazil: an Input-Output analysis on the level of micro-regions' (Forthcoming)
- Nijsen, M. et al, 'The potential of rainwater harvesting to rehabilitate degraded rangelands in semi-arid and arid environments'. (Forthcoming)
- Verstegen, J.A. et al, 'Linking CGE and LU models for the assessment of ILUC resulting from biofuel expansion'. (Forthcoming)
- Van der Hilst, F. et al, 'Can iLUC be avoided: biofuel expansion and land use change dynamics in Brazil'. (Forthcoming)
- Shutes, L. et al. Theoretical economic framework of measuring food security impacts of biomass production (forthcoming)