International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

science for global insight

Spatial land use in the GLOBIOM model

Petr Havlík, Michael Obersteiner, Aline Mosnier
Tatiana Ermolieva, Mykola Gusti
with contributions from: Stefan Frank, Mario Herrero, Erwin Schmid, Hugo Valin + >10 others

ENERGY MODELING FORUM
Workshop on Climate Change Impacts
And Integrated Assessment (CCI/IA)
Snowmass, Colorado, July 23–August 3,2012

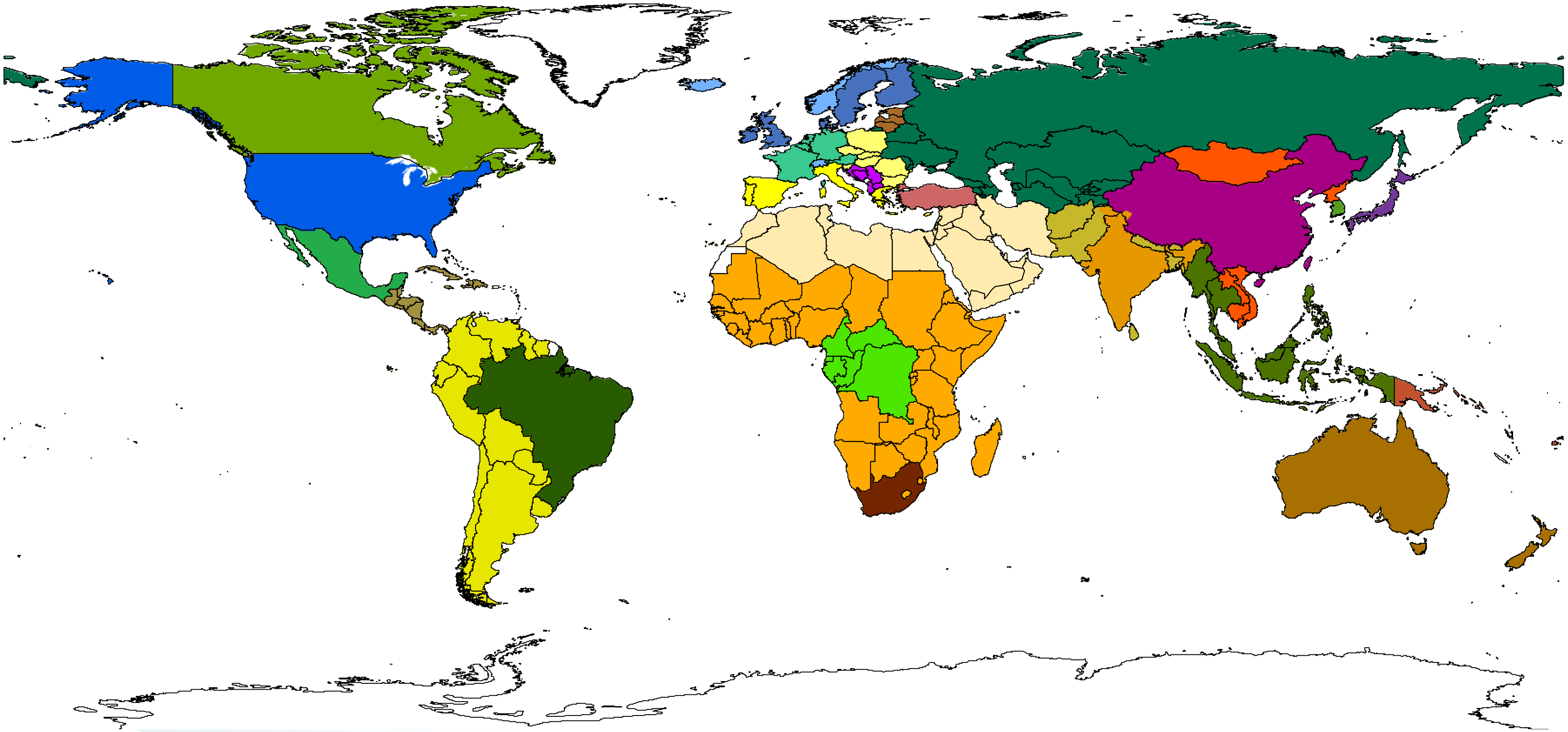
Outline

1. GLOBIOM: General overview
2. Spatially explicit input
3. Spatially explicit output
4. Concluding remarks

1. GLOBIOM: General overview

GLOBIOM: Global Biosphere Management Model

30 market regions



Partial equilibrium model

Agriculture: major agricultural crops and livestock products

Forestry: traditional forests for sawnwood, and pulp and paper production

Bioenergy: conventional crops and dedicated forest plantations

Spatial equilibrium model a la Takayama & Judge

Maximization of the social welfare (PS + CS)

Recursively dynamic (10 year periods)

Supply functions

implicit – based on spatially explicit Leontief production functions:

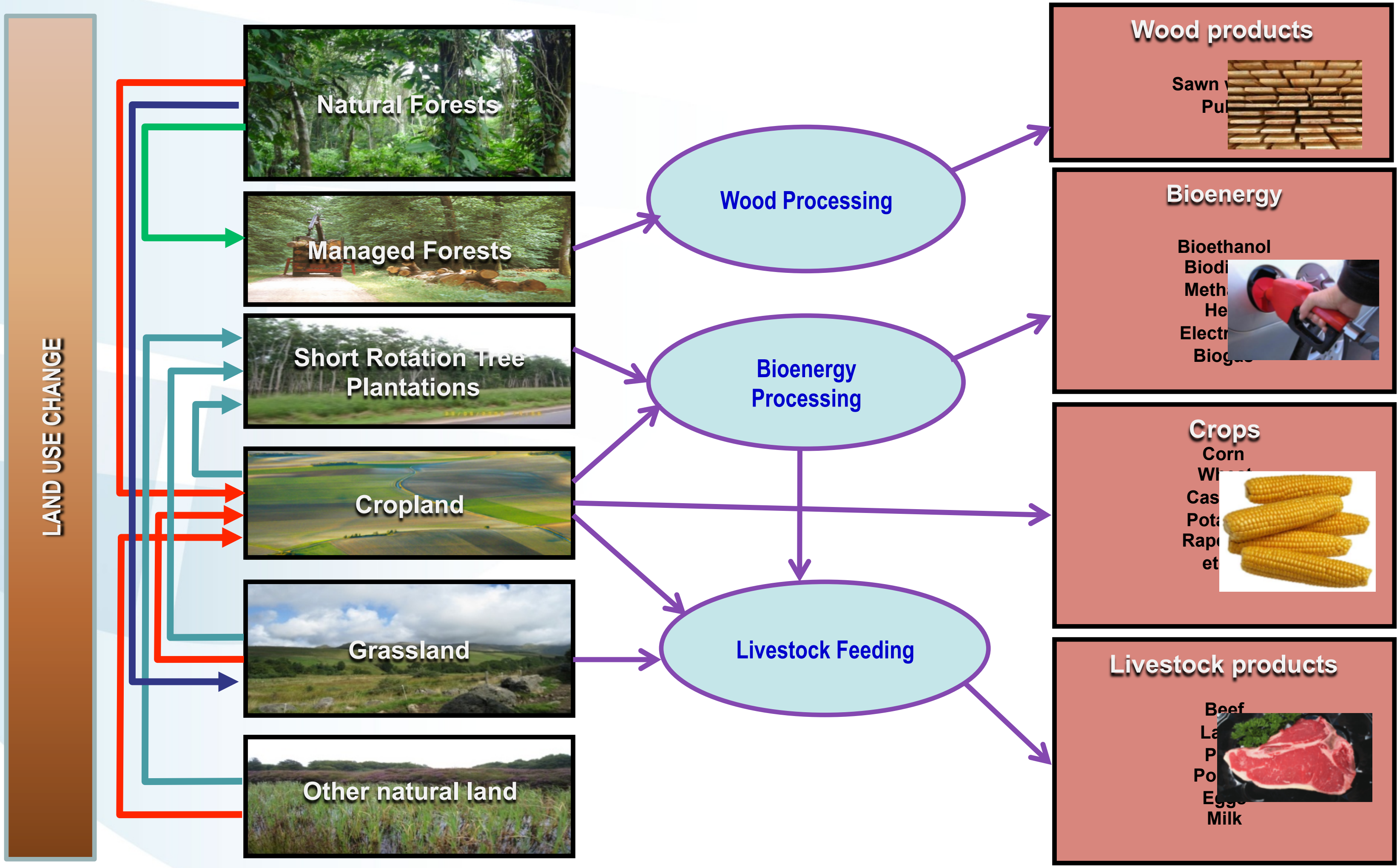
production system 1 (grass based) → productivity 1 + constant cost 1

production system 2 (mixed) → productivity 2 + constant cost 2

Demand functions

explicit: linearized non-linear functions $p = \hat{p} * (q / \hat{q})^{1/e}$

Supply Chains



Main exogenous drivers:

- Population
- GDP
- Technological change
- Bio-energy demand (POLES team)
- Diets (FAO, 2006)

Output:

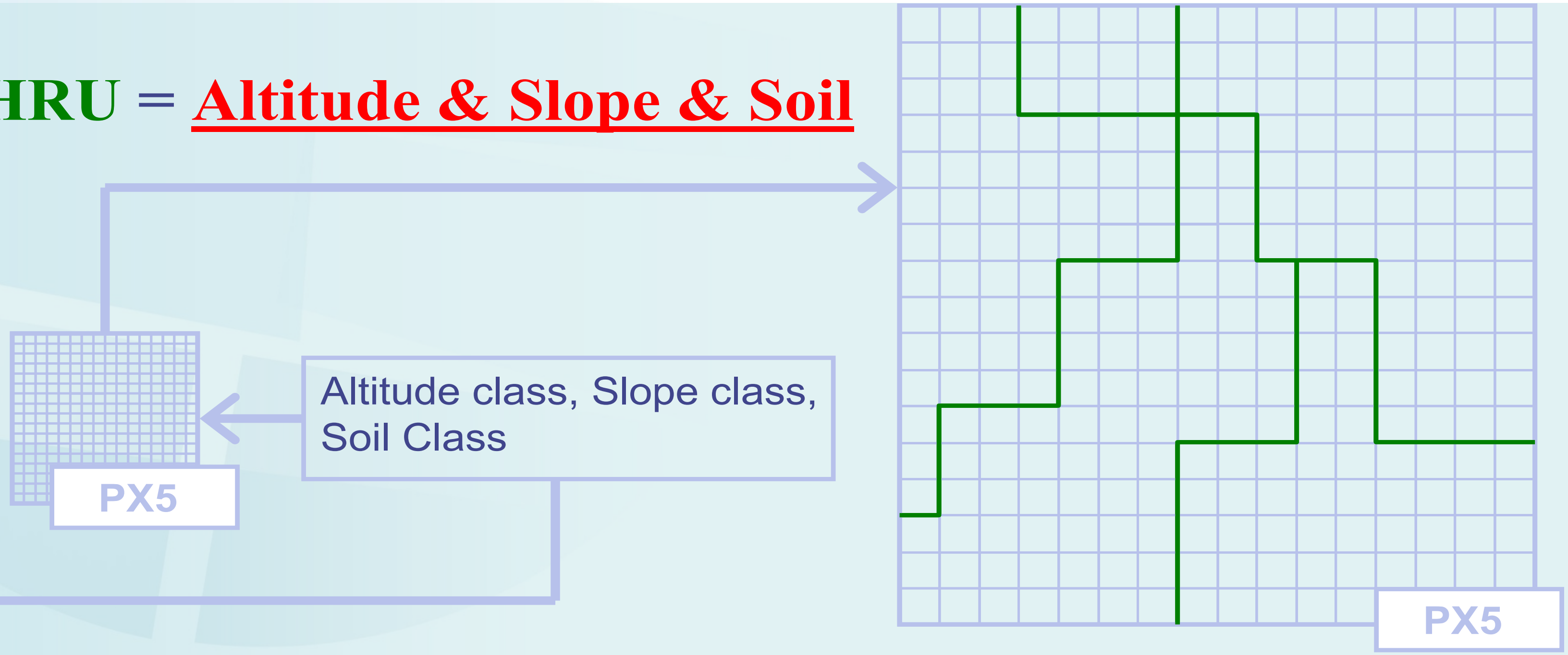
- Production Q
  - land use (change)
  - water use
  - GHG,
  - other environment (nutrient cycle, biodiversity,…)
- Consumption Q
- Prices
- Trade flows

2. Spatially explicit input side

Spatial resolution

Homogeneous response units (HRU) – clusters of 5 arcmin pixels

HRU = Altitude & Slope & Soil



Altitude class (m): *0 – 300, 300 – 600, 600 – 1200, 1200 – 2500 and > 2500;*

Slope class (deg): *0 – 3, 3 – 6, 6 – 10, 10 – 15, 15 – 30, 30 – 50 and > 50;*

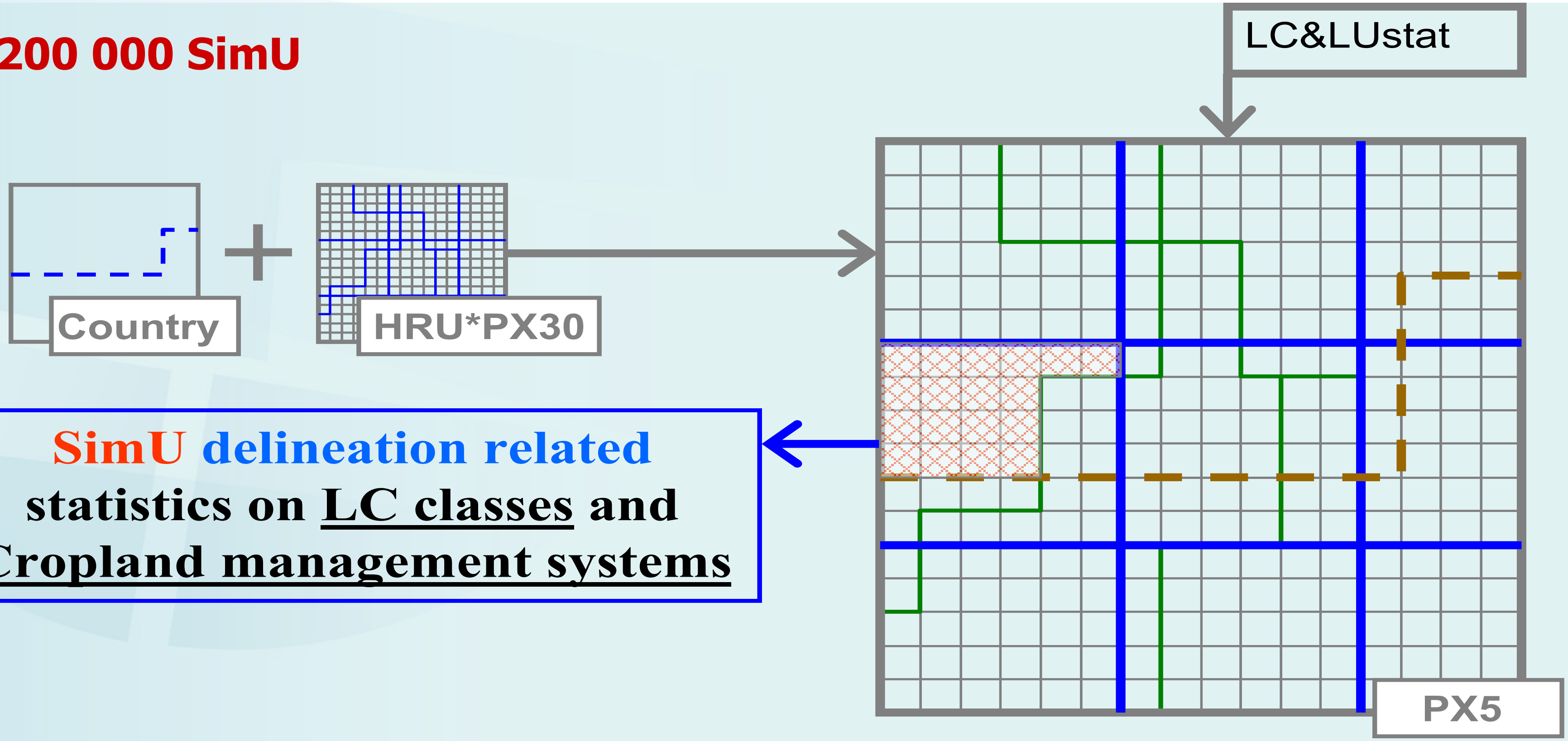
Soil texture class: *coarse, medium, fine, stony and peat;*

Source: Skalský et al. (2008)

Spatial resolution

Simulation Units (SimU) = HRU & PX30 & Country zone

> 200 000 SimU



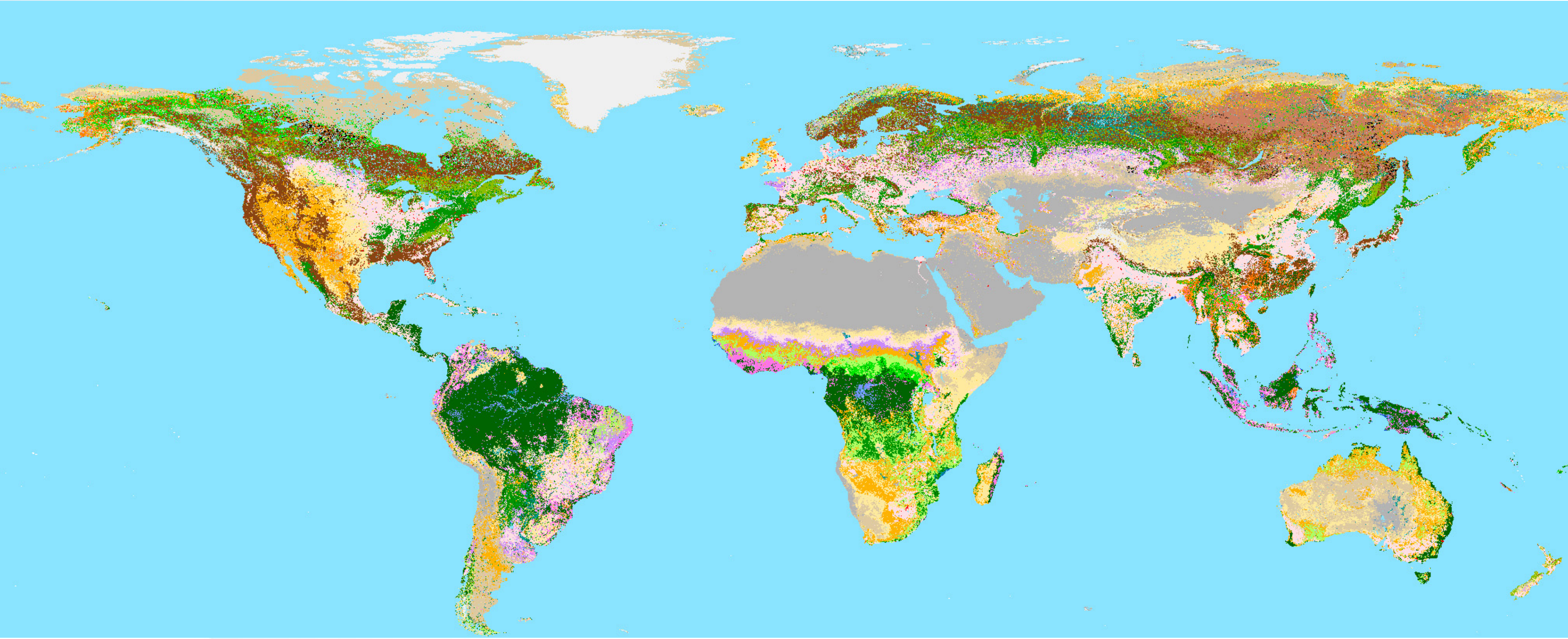
SimU delineation related statistics on LC classes and Cropland management systems

- **reference for geo-coded data on crop management;**
- **input statistical data for LC/LU economic optimization;**

Source: Skalský et al. (2008)

Initial land cover distribution

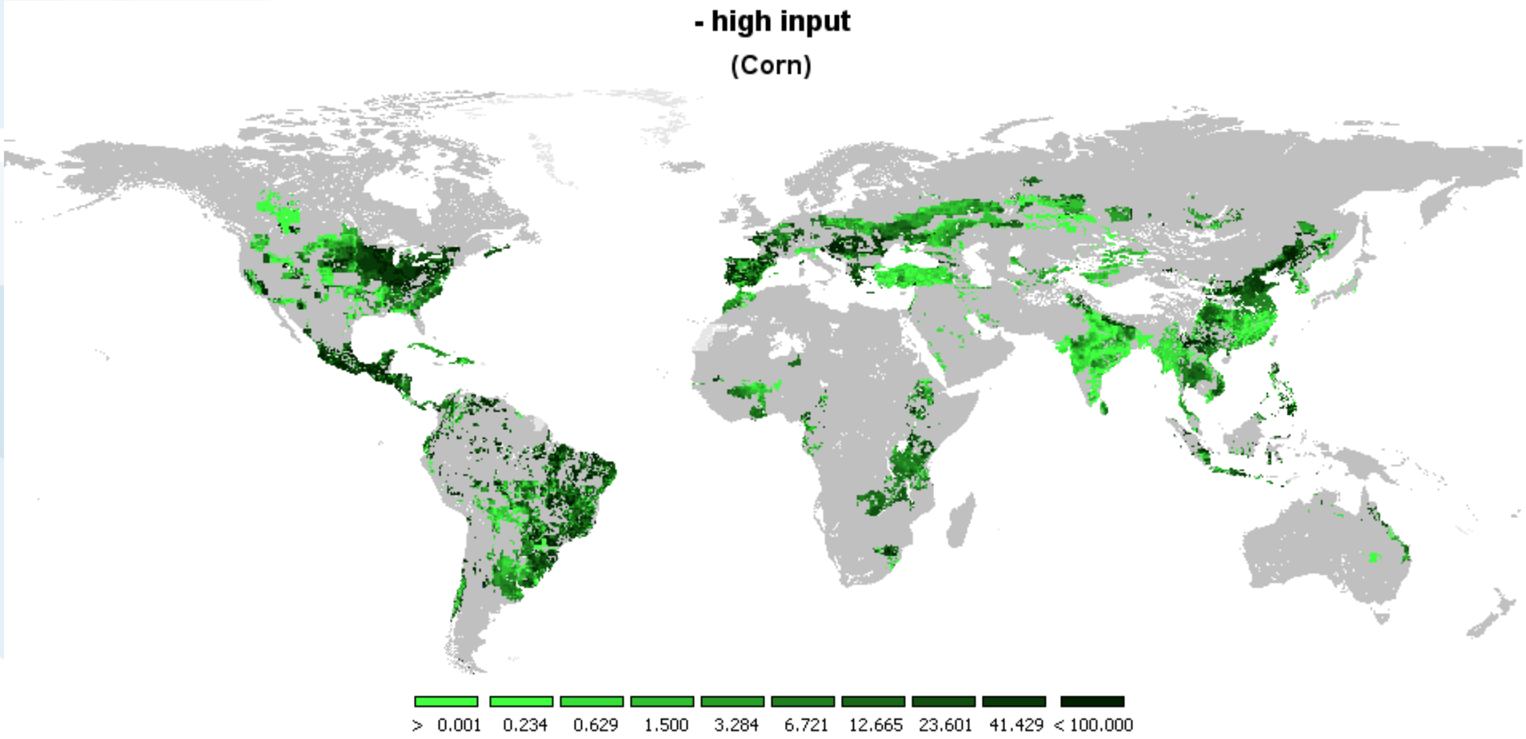
Global Land Cover (GLC) 2000 – by JRC



Initial crop areas distribution

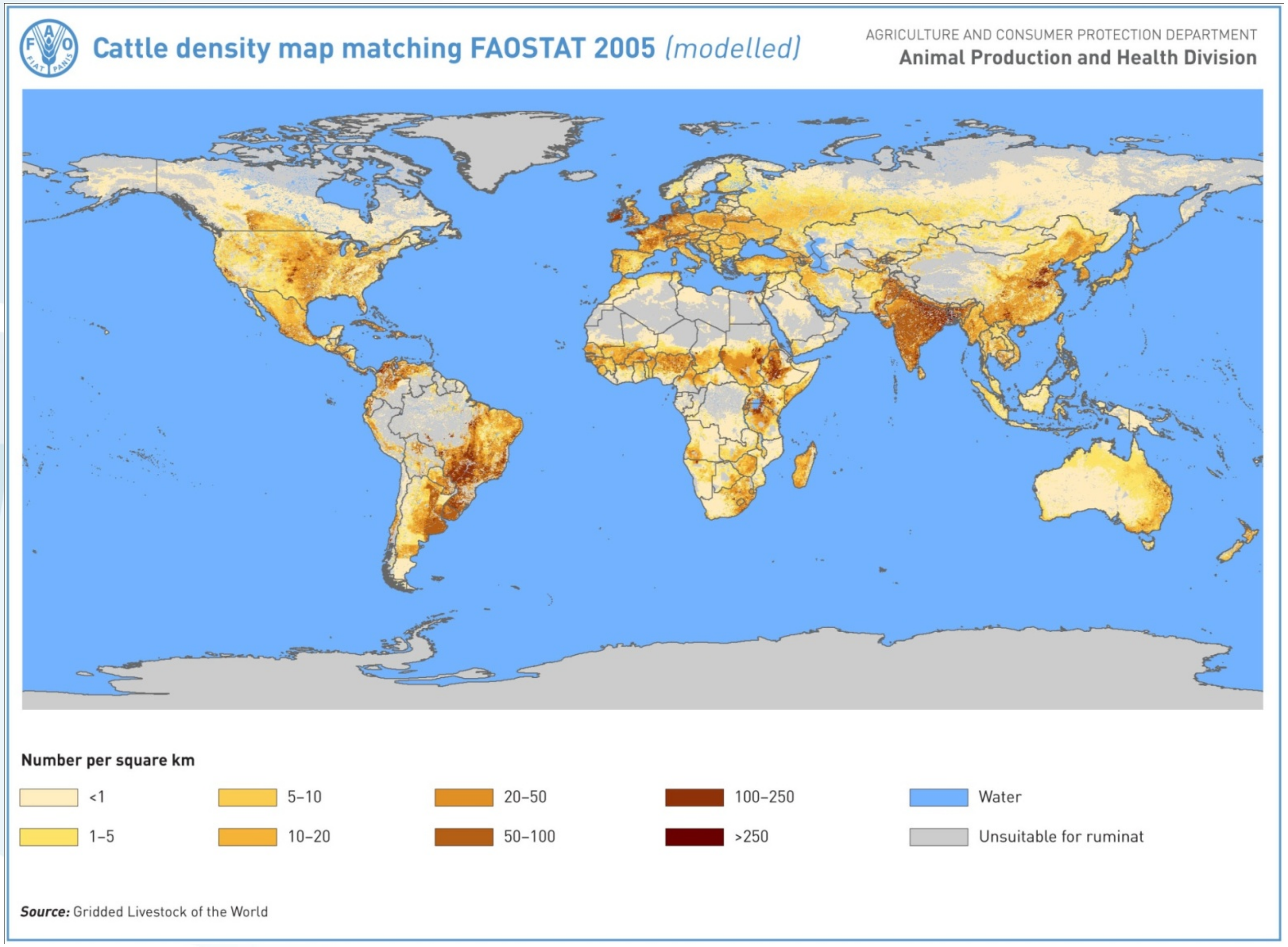
Spatial Production Allocation Model (SPAM) by You et al. (IFPRI)

- provides harvested area and physical area for 20 crops and 3 input systems



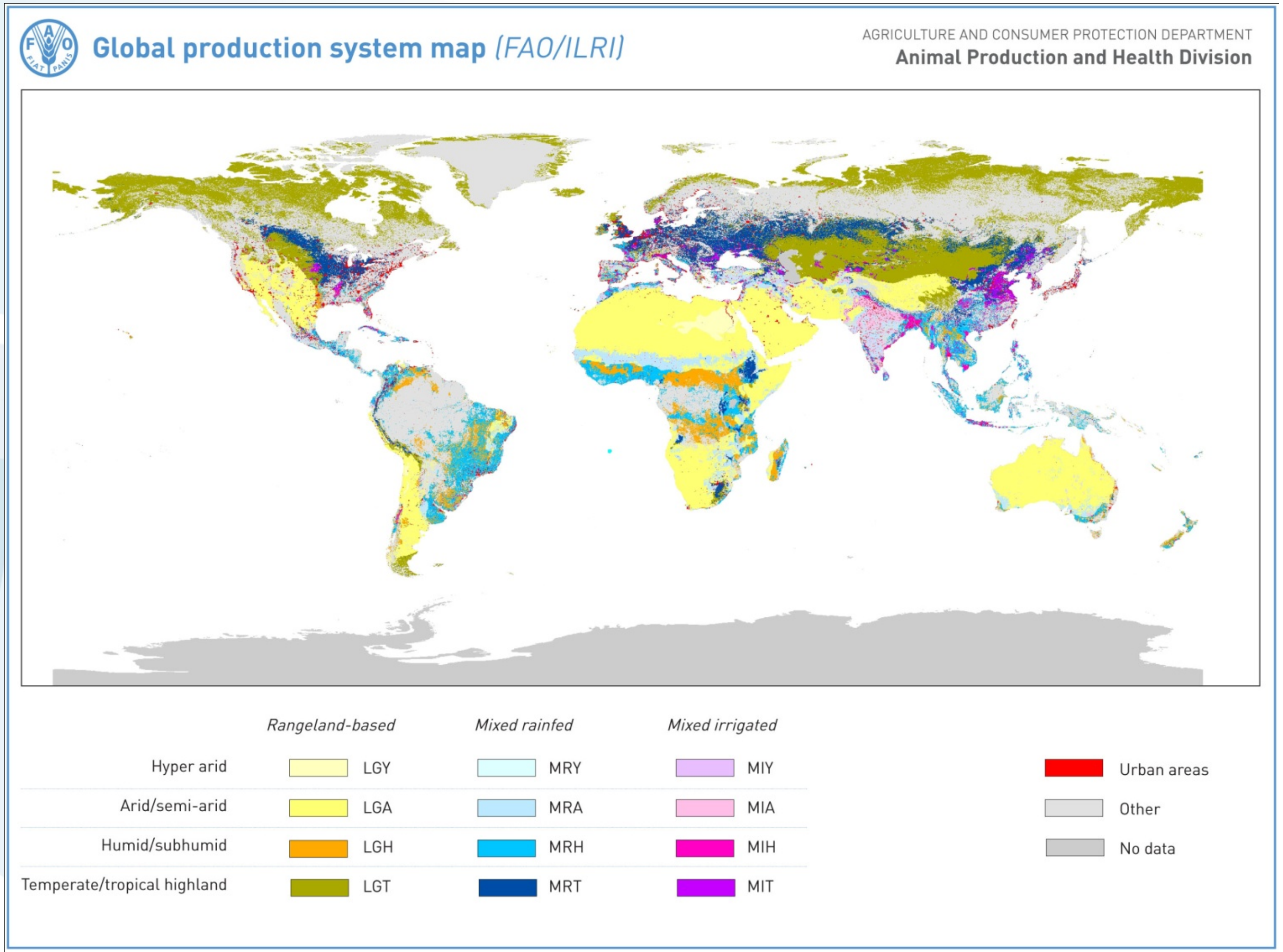
Initial livestock numbers distribution

Gridded Livestock of the World – Robinson et al. (2011)



Initial livestock production systems distribution

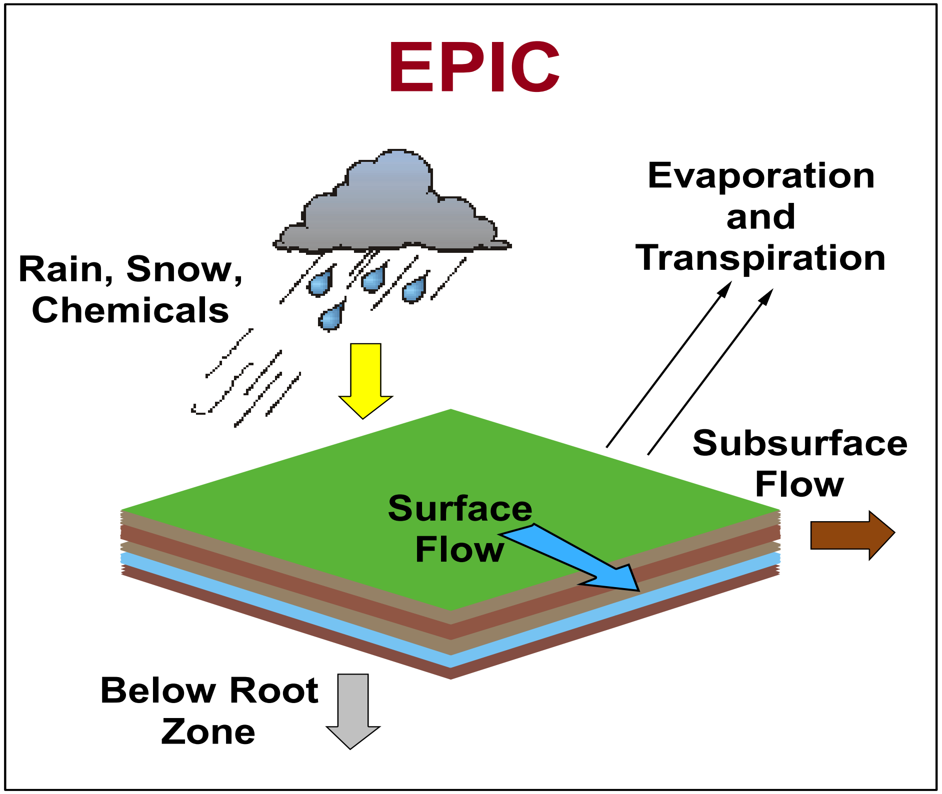
Sere and Steinfeld (1996) classification updated by Robinson et al. (2011)



Crop production parameterization - EPIC

Processes

- Weather
- Hydrology
- Erosion
- Carbon sequestration
- Crop growth
- Crop rotations
- Fertilization
- Tillage
- Irrigation
- Drainage
- Pesticide
- Grazing
- Manure



Major outputs:

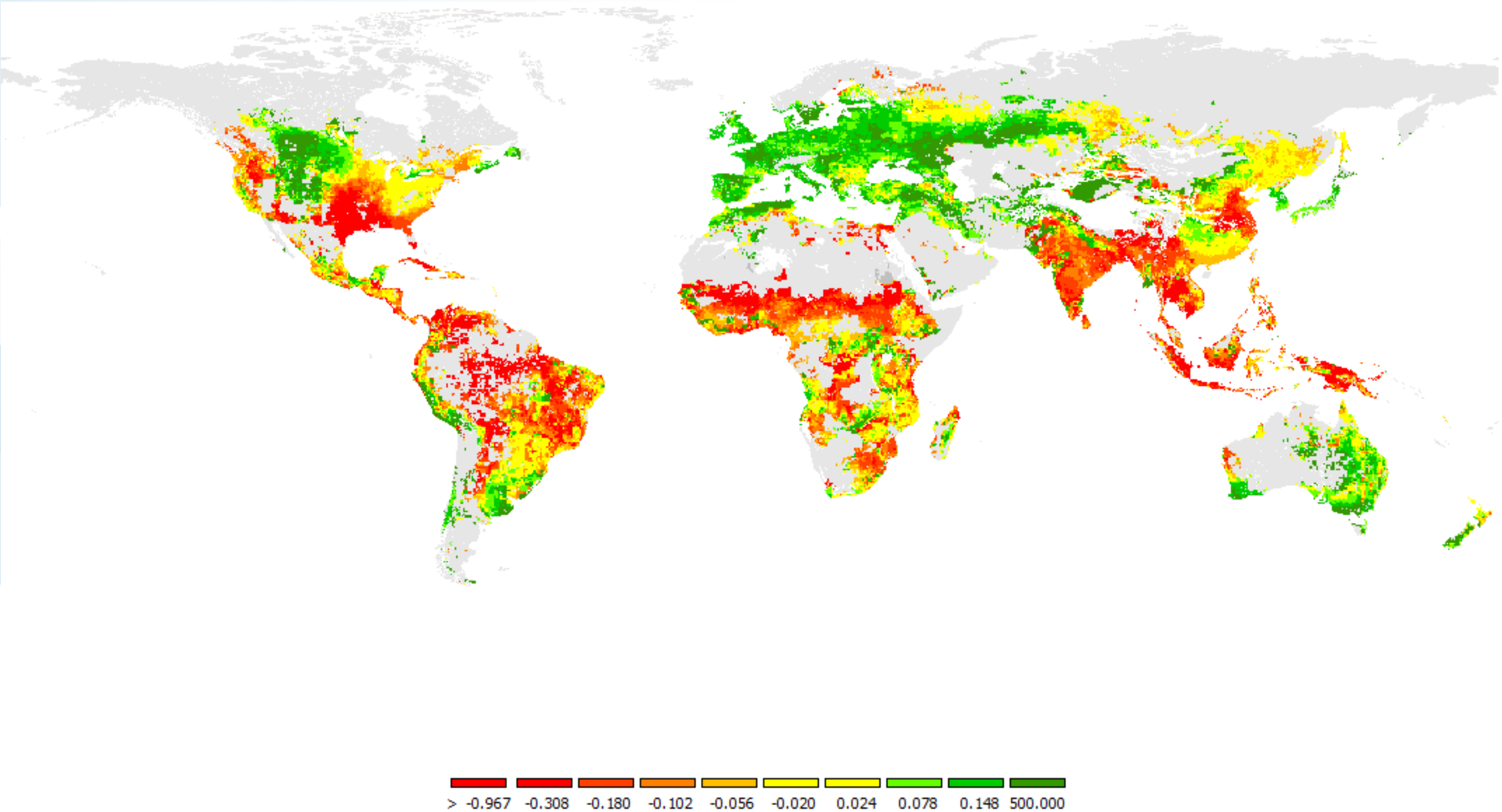
Crop yields, Environmental effects (e.g. soil carbon, nitrogen leaching)

20 crops (>75% of harvested area)

4 management systems: High input, Low input, Irrigated, Subsistence

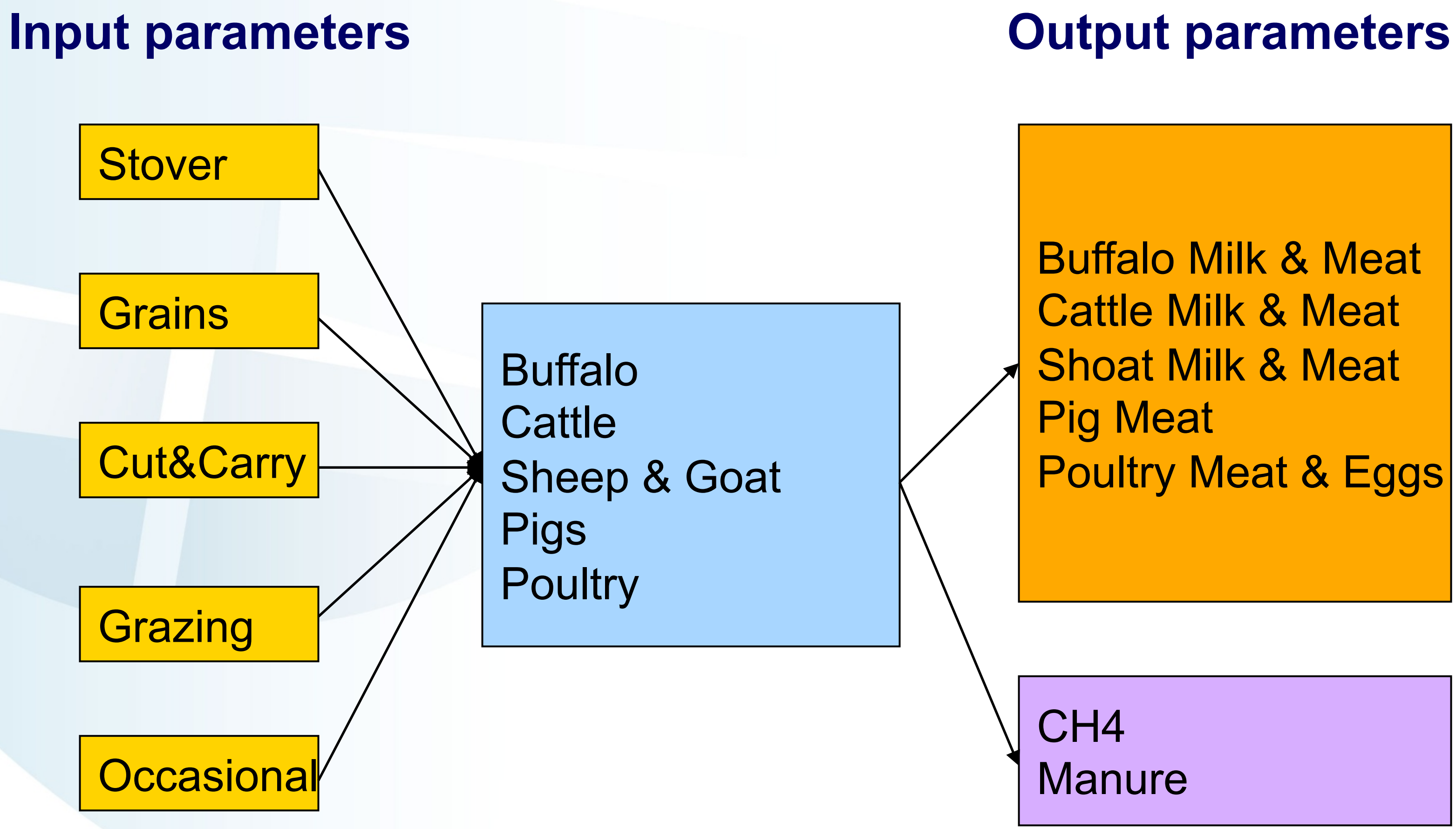
Climate change impacts

Relative Difference in Means (2050/2100) in Wheat Yields
[Data: Tyndall, Afi Scenario, simulation model: EPIC]



Livestock production parameterization

- by region and system



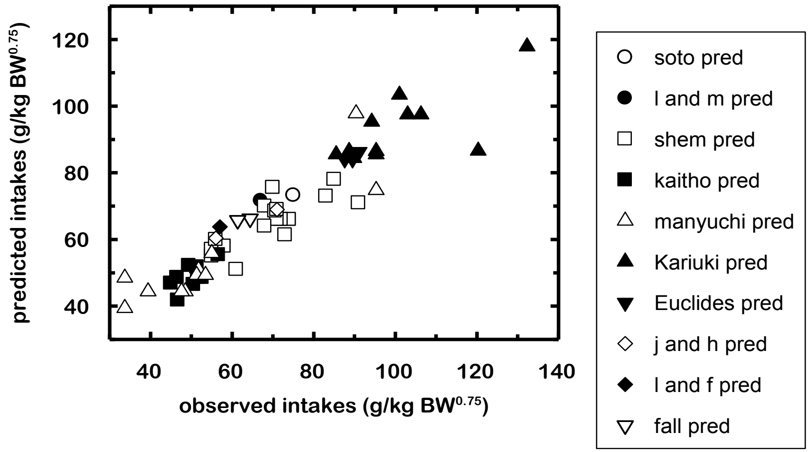
Herrero, Havlik et al
(PNAS forthcoming)

Livestock production parameterization

The RUMINANT Simulation model

- **Dynamic simulation model of digestion in ruminants** (Herrero et al 2004) largely based on IPCC methods
- **Predicts intake, production (milk, meat), and excretion** (faeces and urine) using a dynamic model of digestion (Illius and Gordon 1991)
- **Predicts metabolism end products** (**METHANE**, Volatile fatty acids, etc)

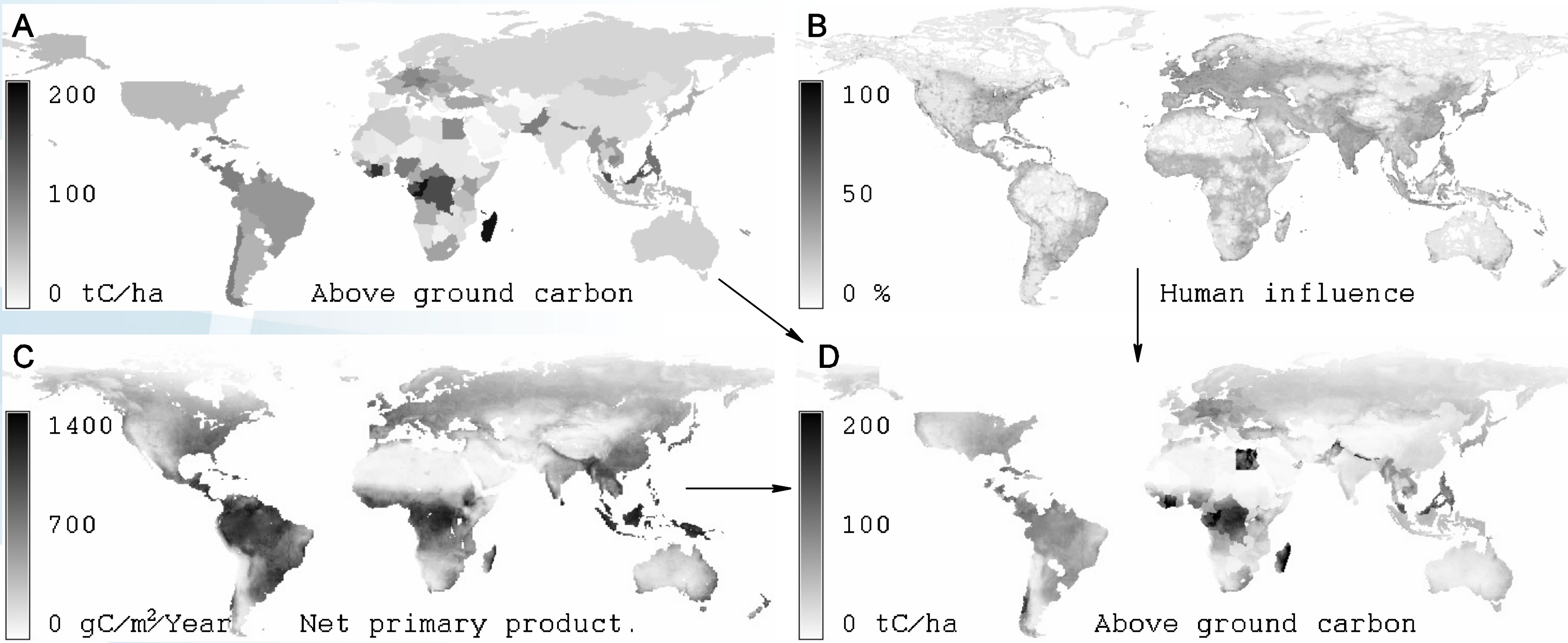
Prediction of intake



- CH4 coefficients have recently been approved by the IPCC GHG emissions taskforce (Herrero et al 2008, 2009)

Forest production parameterization – G4M

Step 1: Downscaling FAO country level information on above ground carbon in forests (FRA 2005) to 30 min grid



Source: Kindermann et al. (2008)

Forest production parameterization – G4M

Step 2: Forest growth functions estimated from yield tables

Major outputs:

- Mean annual increment
- Tree size
- Sawn wood suitability
- Harvesting cost

Short rotation plantations

- poplar, willow, eucalyptus

Land availability (approach inspired by Zomer et al., 2008)

- eliminates unsuitable area on the basis of:

aridity, temperature, elevation, population density

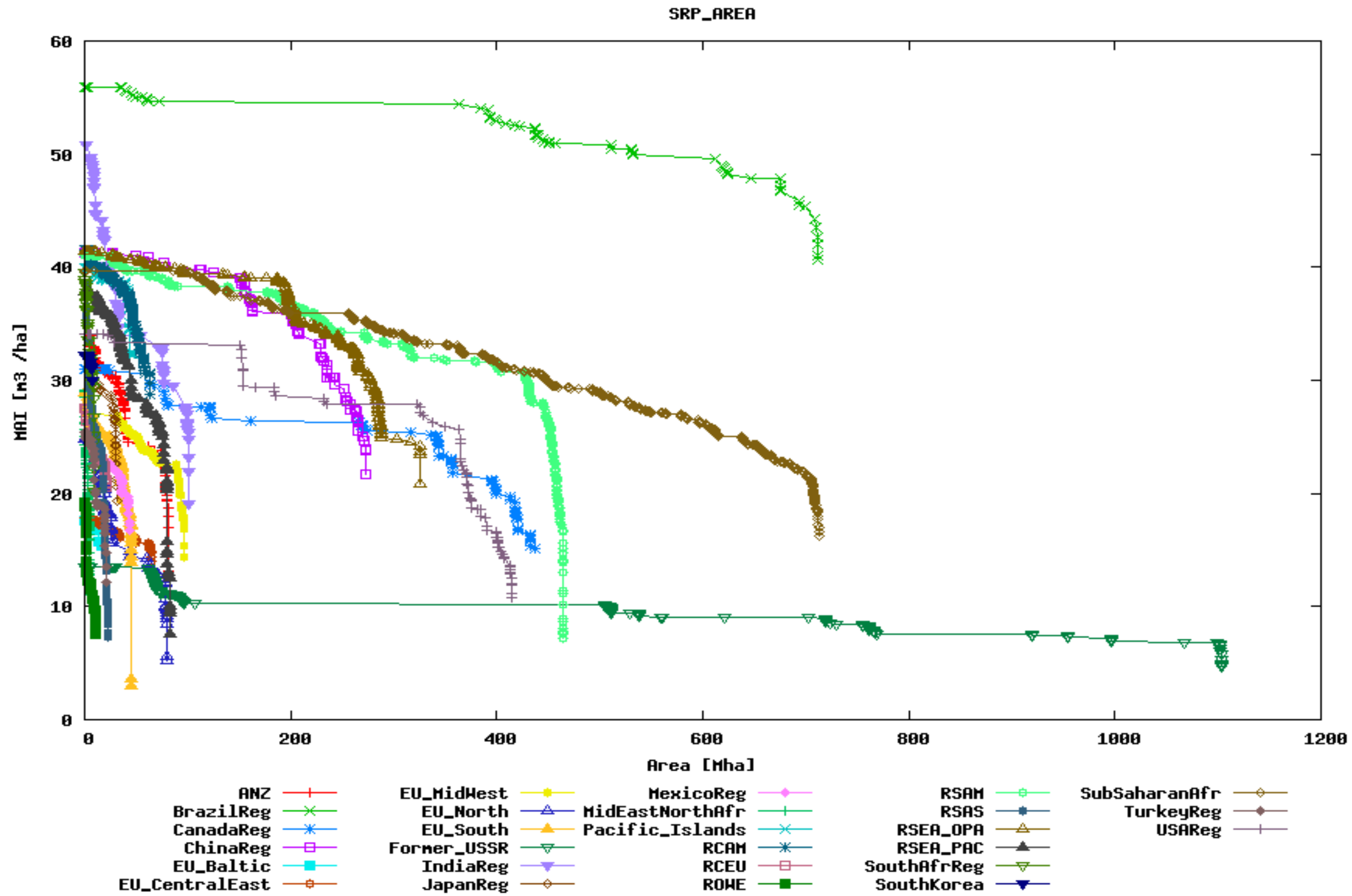
Category	Afforestation Potential [Mha]
Forest	3 151
Agriculture/Cropland	1 171
Grassland	299
Other Natural Vegetation	510

Land productivity

- regional potentials from literature review
- scaled by NPP (Cramer *et al*, 1999)

Short rotation plantations

Productivity distribution



3. Spatially explicit output

Spatially explicit model variables

- crop and crop management system areas
- land cover areas (grasslands, managed forests, short rotation plantations,…)
- land use change
- ruminant numbers by species and system

- Solved at SimU resolution or their aggregates

→ **Multiple spatially explicit output parameters**

- production quantities
- input use (nitrogen, phosphorus, water)
- greenhouse gas accounts

However, direct model output suffers from

1. Overspecialization

- no more variables in the solution than constraints (LP)

2. Lack of regional detail in behavioral drivers

- even if data were available,
  trade-off between the detail and computational feasibility

Three approaches considered

a) Regional zooming-in

b) Linking with other models

c) Ex-post downscaling methods

3a. Regional zooming-in

Regional zooming-in

For specific studies, a region is

- dis-aggregated to the highest resolution (SimU)
- most important datasets are updated to the best regional available
- additional features are added

    e.g. transportation costs, legal resource management plans, spatial representation of demand

However, the region is kept within the global model benefiting from the usual feedbacks trough international trade and policies

Workshops with stakeholders enable to identify and mimic regional particularities

The problem of overspecialization remains

Regional zooming-in

Approach implemented in 2 regions

1. Congo Basin

- World Bank project:

  "Modeling impacts of development trajectories on forest cover and GHG emissions in the Congo Basin"

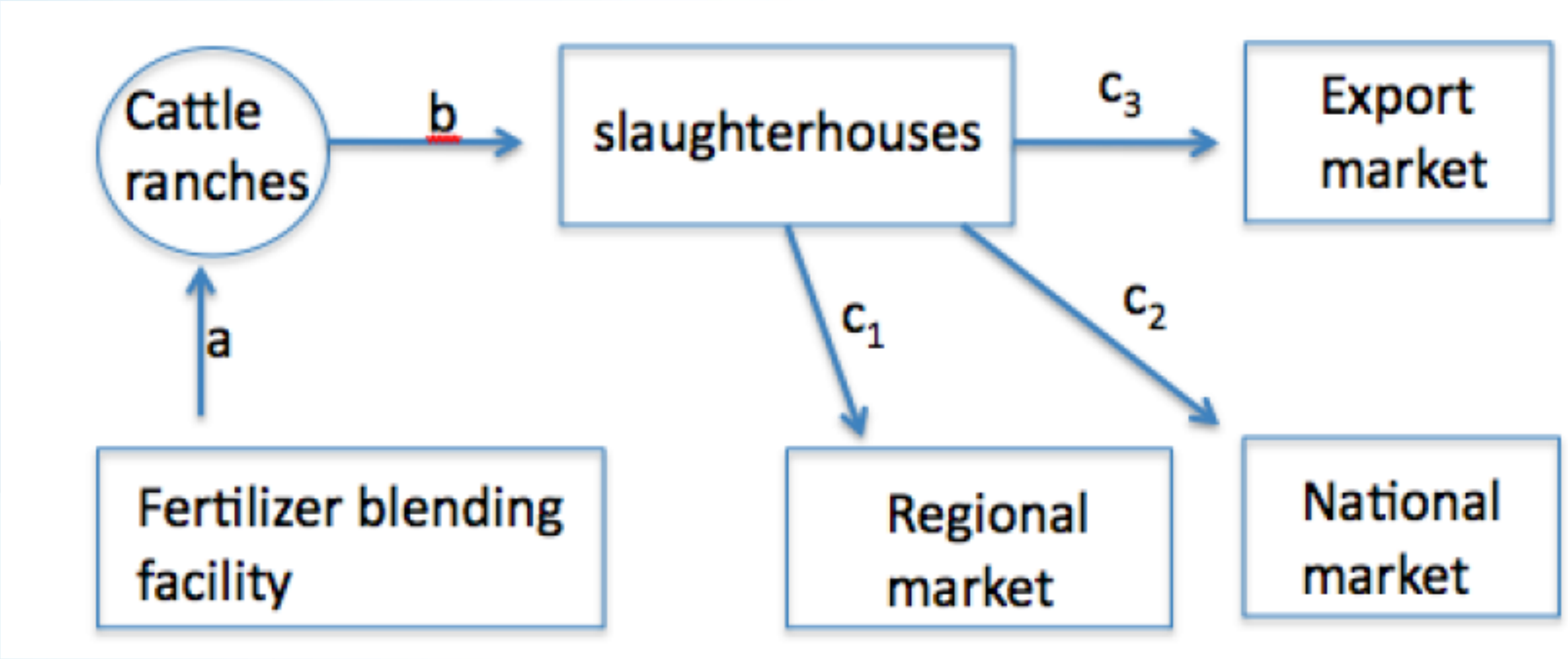
2. Brazil

- Research project by Avery Cohn (YSSP):

  "Potential of pasture intensification policies to reduce CO2 emissions from deforestation"

Brazil: REDD potential of pasture intensification policies

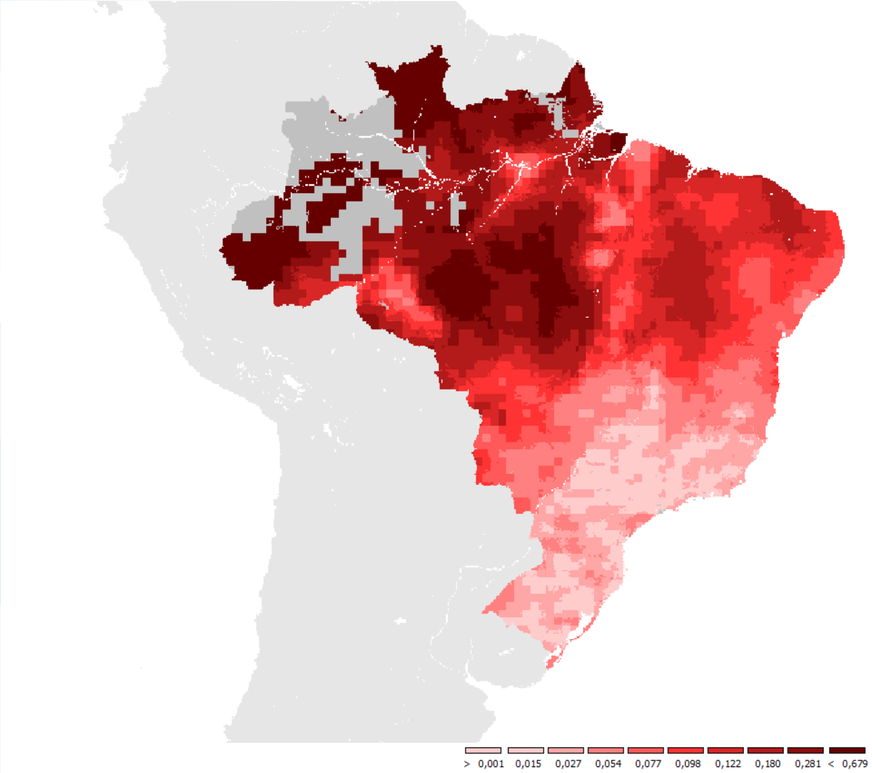
Spatially explicit supply chain transportation cost – Example: Beef



Source: A. Cohn

Brazil: REDD potential of pasture intensification policies

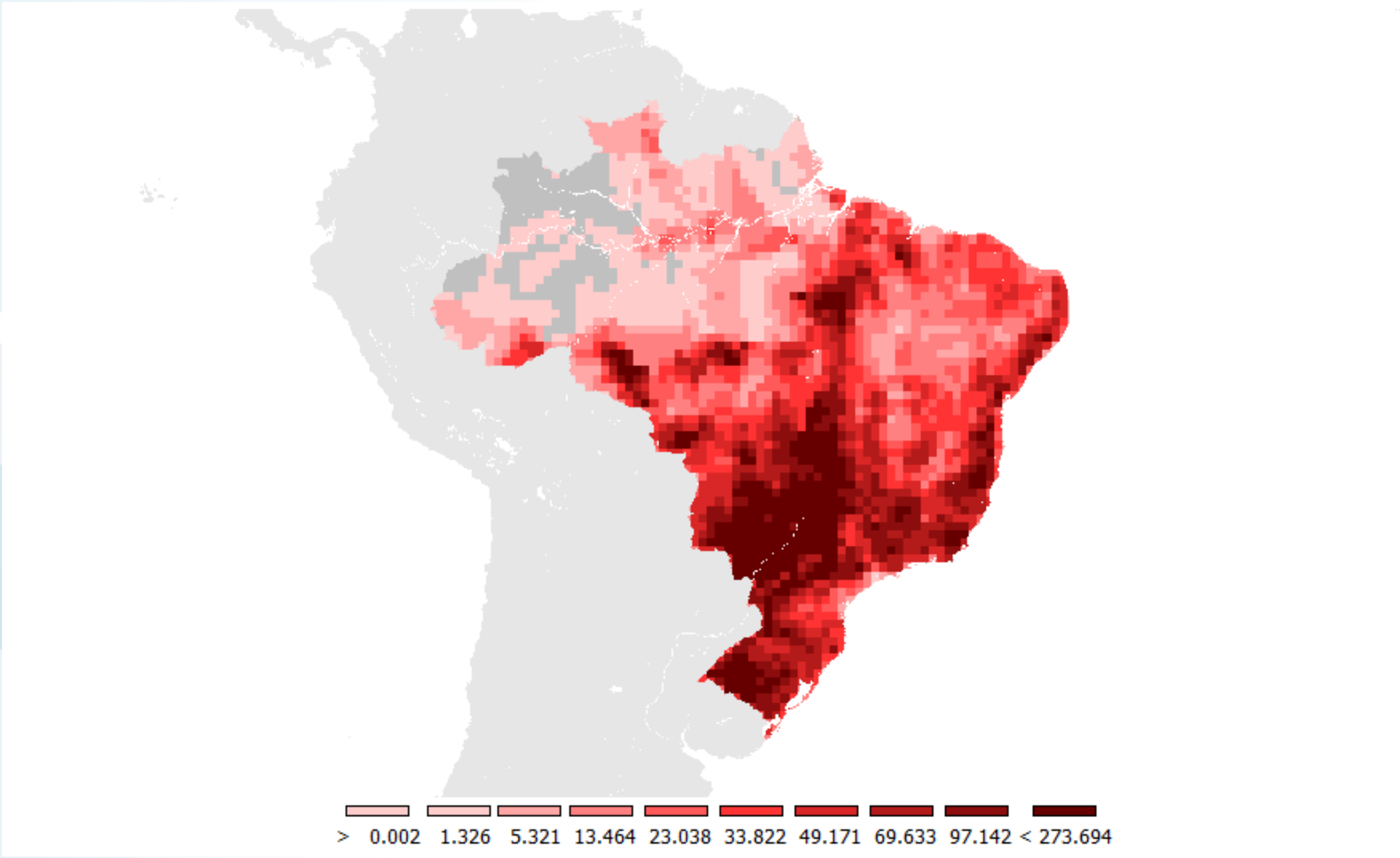
Beef transport cost as percentage of final selling price



Source: A. Cohn

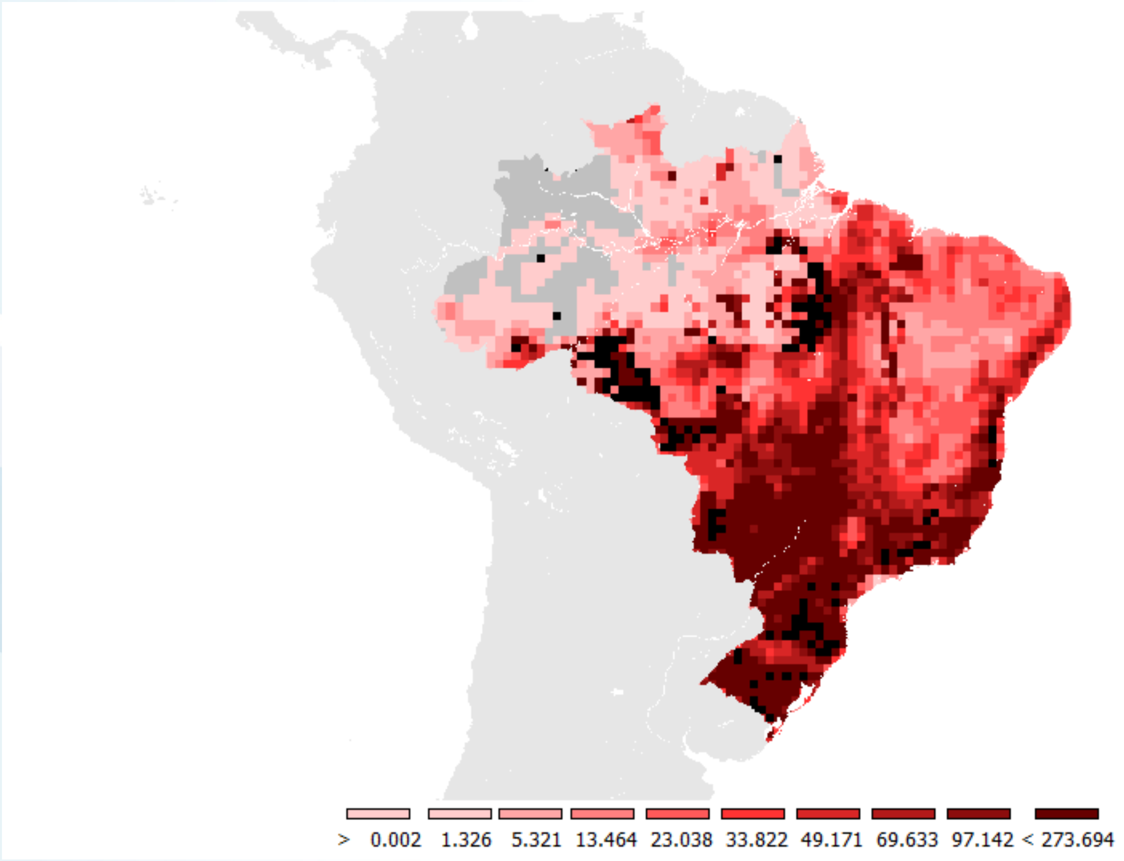
Brazil: REDD potential of pasture intensification policies

Beef herd in 2000 [1000 TLUs]



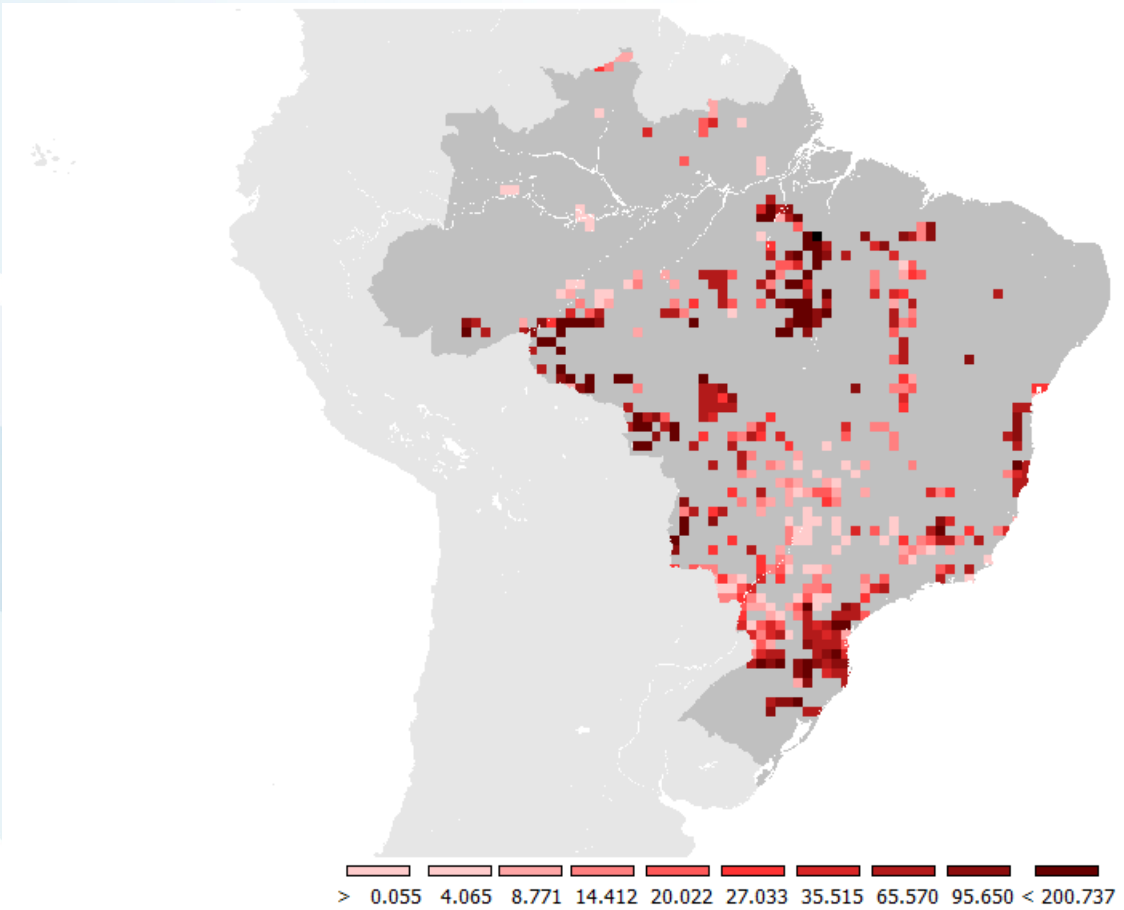
Brazil: REDD potential of pasture intensification policies

Beef herd in 2030 [1000 TLUs]



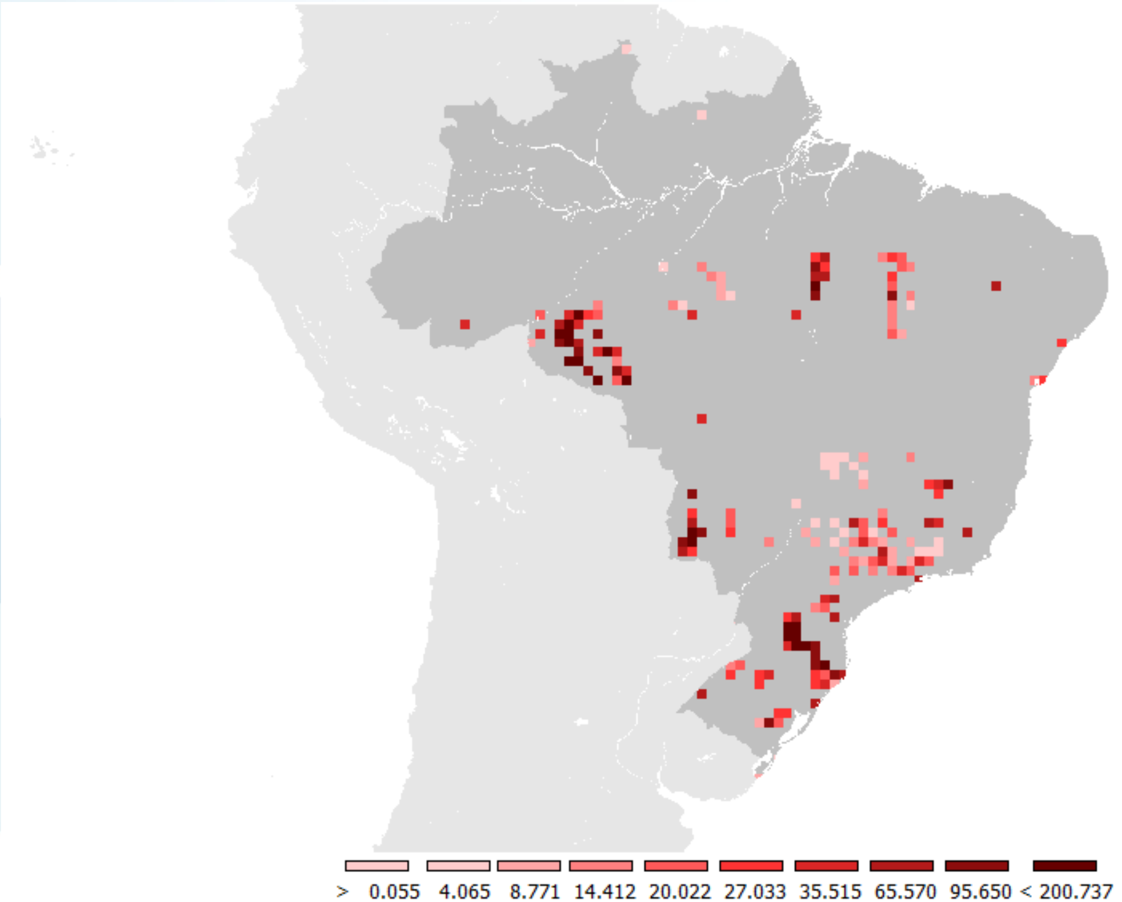
Brazil: REDD potential of pasture intensification policies

Deforestation due to pasture expansion: 2030 baseline [1000ha]



Brazil: REDD potential of pasture intensification policies

Deforestation due to pasture expansion:
2030 with subsidy for intensification [1000ha]



3b. Linking with other models

Linking with other models

Explores complementarities between different models

Major LULUCF/REDD+ assessments carried out with GLOBIOM rely on the link with the forest model **G4M** (Kindermann et al. 2008)

Recent applied projects:

DG Climate Action: EU LULUCF Reference Level for Forest Management accounting

- Baseline runs for the construction of country specific Reference Levels
- Accounting of emissions from FM will compare development of emissions from forestry against RL

DG Climate Action: EU Roadmap for moving to a low-carbon economy in 2050

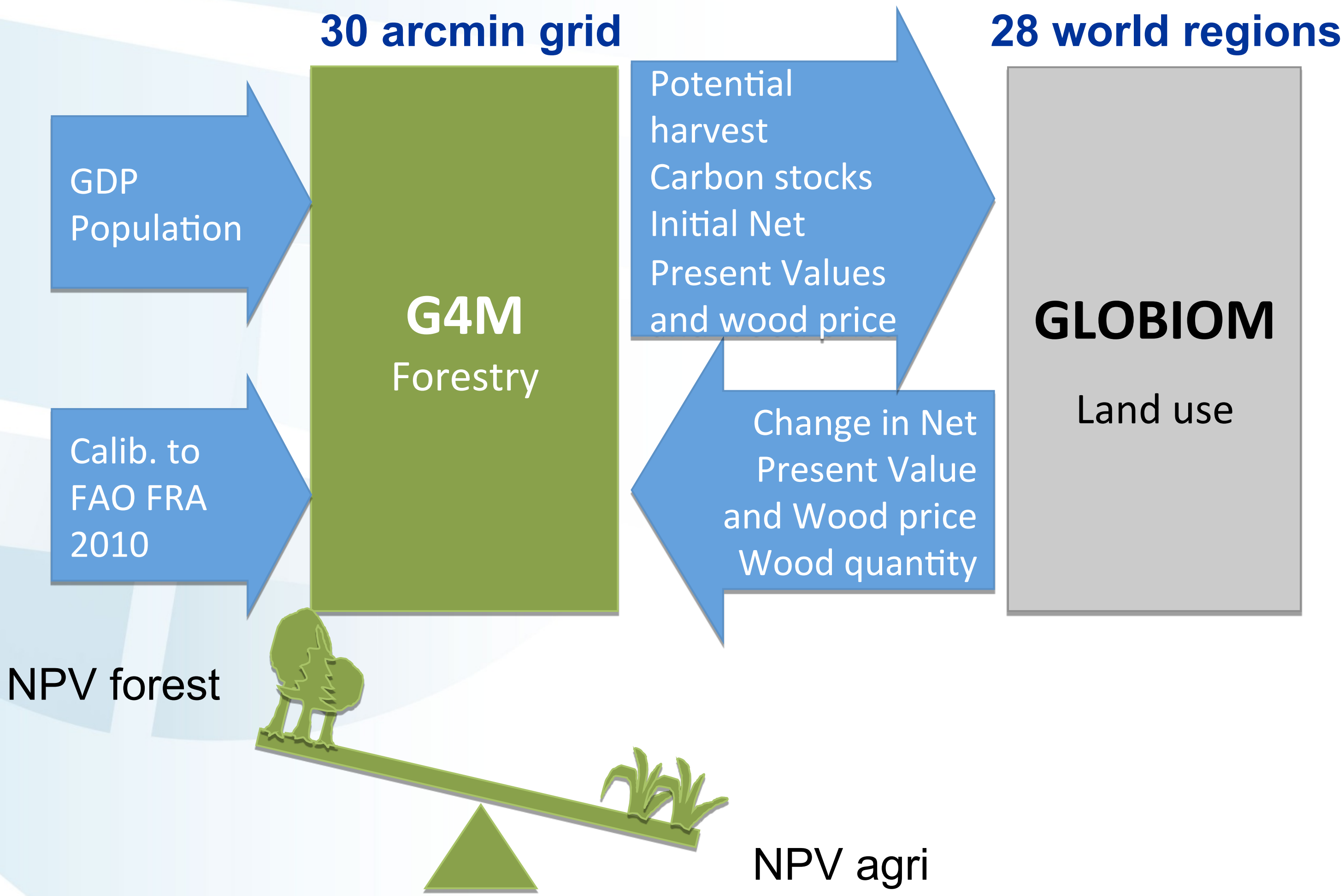
- Contribution to the impact assessment

DECC (UK, depatment of enrgy and climate change), **DEA** (Dannish Energy Agency)

- Global Forestry Emissions Projections and Abatement Costs
- Feeding MACCs for forestry activities into GLOCAF model

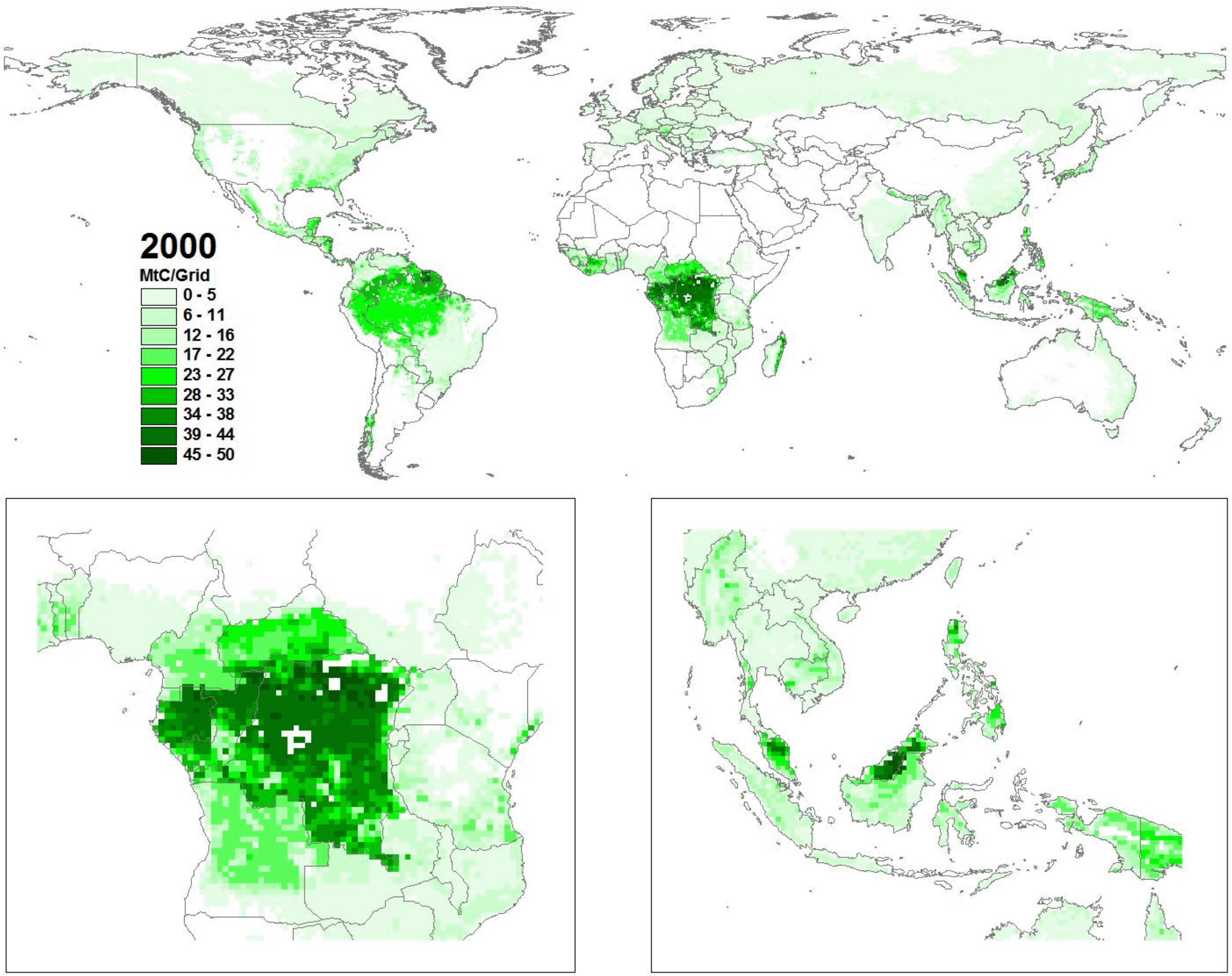
WWF Living Forest Report

G4M – GLOBIOM link



→ gridded afforestation, deforestation, forest management consistent with statistics, including other than agricultural drivers

G4M - Spatially explicit results



3c. Ex-post downscaling methods

Ex-post downscaling methods

Previously presented approaches either limited by regional coverage

or by land cover types considered

For spatially explicit projections of comprehensive land cover at global scale, conventional **cross-entropy minimization** applied

Downscaling: world regions → Simulation Units

Downscaled variable: Land Use Change

Land use change downscaling

At regional level $$A_{ir}^{t} = A_{ir}^{t-1} + \sum_{j} \Delta A_{ijr}^{t} - \sum_{j} \Delta A_{jir}^{t}$$

At SimU level l $$A_{ilr}^{t-1} + \sum_{l} z_{ijlr}^{t} \Delta A_{ijr}^{t} - \sum_{l} z_{jilr}^{t} \Delta A_{jir}^{t} = A_{ilr}^{t}$$

Land use type	i
Region	r
Time	t
Simulation Unit	l
Land in land use	A_{ir}^{t}
Land converted from i to j	ΔA_{ijr}^{t}
Share of area change from i to j	z_{ijlr}^{t}

Downscaling problem

Find such shares z_{ijlr}^{t} of area change transformed from *i* to *j* in *l* that

$$\sum_{j} z_{ijlr}^{t} \Delta A_{ijr}^{t} = \Delta A_{ijr}^{t} \quad \text{i.e.} \quad \sum_{l} z_{ijlr}^{t} = 1$$

$$A_{ilr}^{t-1} + \sum_{l} z_{ijlr}^{t} \Delta A_{ijr}^{t} - \sum_{l} z_{jilr}^{t} \Delta A_{jir}^{t} = A_{ilr}^{t}$$

$$\sum_{i=1}^{m} A_{ilr}^{t} = L_{r}^{l}$$

Cross-entropy: Maximize Kulback-Leibler information

$$\sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{l=1} \left(z_{ijlr}^{t} \ln(z_{ijlr}^{t} / q_{ijlr}^{t}) \right)$$

Prior probability $\sum_{l} q_{ijlr}^{t} = 1$

Priors

Consistency between regional model results and downscaled values through shared parameters between GLOBIOM and downscaling

Cropland to Plantations

$$q^{t}_{l,r,CropL\_Plt} = \frac{(\varphi^{t}_{lr})^{-1} y^{t}_{Plt,l,r} A^{t-1}_{Plt,l,r} \left(\Pi^{t}_{lr}\right)^{-1}}{\sum_{l}\left((\varphi^{t}_{lr})^{-1} y^{t}_{Plt,l,r} A^{t-1}_{Plt,l,r} \left(\Pi^{t}_{lr}\right)\right)^{-1}}$$

Yield of planted forest $y^{t}_{Pltlr} A^{t-1}_{Pltlr}$

Crop land production value $\Pi^{t}_{lr} = \sum_{s} P^{t}_{jr} y^{t}_{slr} A^{t-1}_{slr}$

Normalized transportation time $\varphi^{t}_{lr} = \frac{T^{t}_{lr} - T^{t}_{\min r}}{T^{t}_{\max r} - T^{t}_{\min r}}$

Average time to closest market T^{t}_{lr}

Grassland to Plantations

$$q^{t}_{l,r,GrassL\_Plt} = \frac{(\varphi^{t}_{lr})^{-1} \, y^{t}_{Pltlr} A^{t-1}_{Pltlr} \left(y^{t}_{Grass,l,r} A^{t-1}_{Grass,l,r} \right)^{-1}}{\sum_{l} \left((\varphi^{t}_{lr})^{-1} \, y^{t}_{Pltlr} A^{t-1}_{Pltlr} \left(y^{t}_{Grass,l,r} A^{t-1}_{Grass,l,r} \right)^{-1} \right)}$$

Yield of planted forest $y^{t}_{Pltlr} A^{t-1}_{Pltlr}$

Grassland yield $y^{t}_{Grass,l,r} A^{t-1}_{Grass,l,r}$

Normalized transportation time $\varphi^{t}_{lr} = \frac{T^{t}_{lr} - T^{t}_{\min r}}{T^{t}_{\max r} - T^{t}_{\min r}}$

Average time to closest market T^{t}_{lr}

Forest to Cropland

$$q^{t}_{l,r,ForestL\_CropL} = \frac{\left(y^{t}_{l,r,Forest} A^{t-1}_{l,r,Forest} P^{t}_{l,r,Forest}\right)^{-1} \Pi^{t}_{l,r}}{\sum_{l} \left(\left(y^{t}_{l,r,Forest} A^{t-1}_{l,r,Forest} P^{t}_{l,r,Forest}\right)^{-1} \Pi^{t}_{l,r}\right)}$$

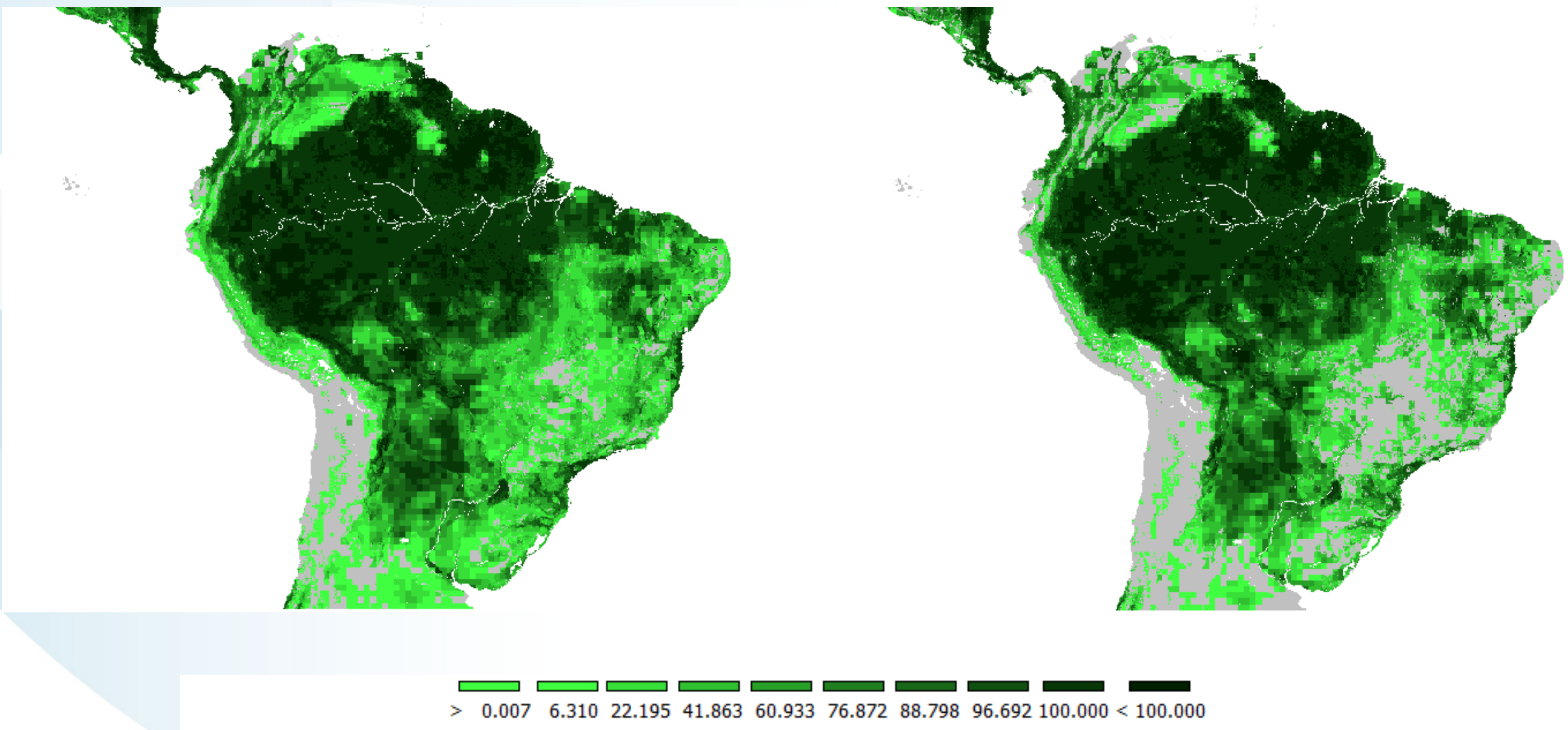
Cropland production value $\Pi^{t}_{lr} = \sum_{s} P^{t}_{jr} y^{t}_{slr} A^{t-1}_{slr}$

Forest production value $y^{t}_{l,r,Forest} A^{t-1}_{l,r,Forest} P^{t}_{l,r,Forest}$

Downscaled results

Forest area share in %

2010 2030



4. Concluding remarks

1. Detailed spatially explicit input datasets for resource heterogeneity representation
2. Challenge to fully integrate spatialisation of the economic activities in a global model
3. Linking with other models or downscaling mechanisms as a medium-term solution
4. Major challenge - missing data
    a) To parameterize economic activities at sub-national resolution
    b) To calibrate and validate the model based on past trends

        e.g. long time series on global land use change matrix
5. Explosion in data availability, e.g. from Earth Observation Systems, and in computational resources guarantees an exciting future