Models of future land use change

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Plan

- Scenarios as conceptual models
- Top-down quantitative land use modelling (European scale)
- The problem of data quality and validating land use models and future scenarios
- Bottom-up, Agent-Based Models (landscape scale)

Why scenarios?

« *The whole problem with the world is that fools and fanatics are always so certain of themselves, but wiser people so full of doubts.* »

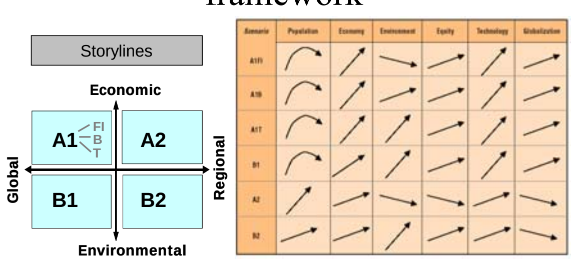
Bertrand Russell

How to develop scenarios*

- Select a *scenario logic* (to aid internal consistency and coherence)
- Develop *narrative storylines* (descriptions of plausible, alternative futures) of the *key drivers*
- Translate narratives into *quantitative model inputs* (at multiple scales)
- *Simulate* land use change quantities and location using models

*Shell plc in the 1970s

Scenario logic: the IPCC SRES* framework



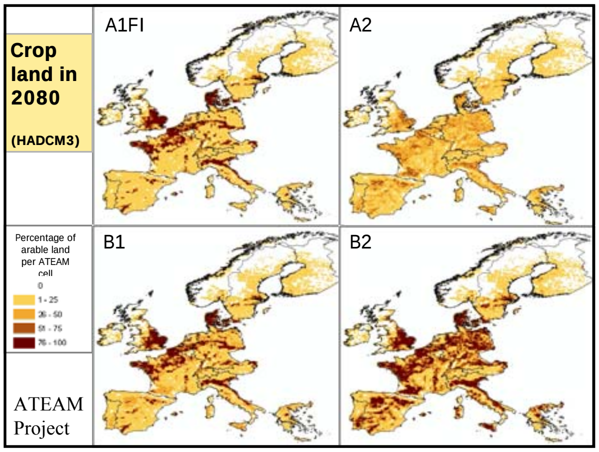
*Special Report on Emissions Scenarios

European scale drivers (qualitative)

	A1	A2	B1	B2
Economy - GDP	rapid growth, convergence	growth, uneven	growth, convergence	slow growth, uneven
Population	declining	growing	declining	stable
Technological change	rapid	slow and uneven	rapid	uneven
Institutions and government	weak	weak, diverse	strong	weak, except local
Rural development	not a focus area	result of self-reliance	key issue	increase (self-reliance)
Recreation, tourism	increase	increase, decrease resp.	increase, decrease resp	increase, decrease resp
Spatial planning	convergent, less restrictive	heterogeneous	convergent, restrictive	heterogeneous restrictive
EU enlargement	rapid	slow	moderate	stopped

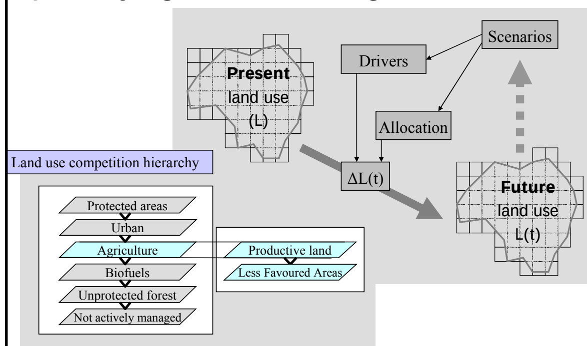
Crop land in 2080

(HADCM3)



ATEAM Project

Quantifying land use change



Land use specific quantity models and spatial allocation rules

European agricultural drivers

Policy	**Macro-(socio)economics**	
	Demand	Supply
Market intervention (subsidies, quotas)	Population (consumption)	Resource competition (e.g. urban)
Rural development (LFAs)	Consumer preferences (meat, organic)	Climate change (temp, precip, CO_2)
Environmental policy (NVZs, ESAs)	Market liberalisation (WTO)	Technology & management
	EU enlargement	

Change in agricultural land use areas

Based on a simple supply and demand model:

$$\frac{L_t}{L_{t_0}} = \frac{D_t}{D_{t_0}} \cdot \frac{P_{t_0}}{P_t} \cdot \frac{O_{r,t}}{O_{r,t_0}}$$

L …	Agricultural land use *[ha]*
t …	Time
t_0 …	start moment, baseline
D …	Demand for production *[t]*
P …	Productivity *[t/ha]*
O …	Overproduction, relative *[-]*

$$L_t = L_{t_0} \cdot \frac{D_t}{D_{t_0}} \cdot \frac{P_{t_0}}{P_t} \cdot \frac{O_{r,t}}{O_{r,t_0}}$$

Unknown Parameters to estimate

- Ewert, F., Rounsevell, M.D.A., Reginster, I., Metzger, M. and Leemans, R. (2005). Future scenarios of European agricultural land use. I: Estimating changes in crop productivity. *Agriculture, Ecosystems and Environment*, **107**, 101-116
- Rounsevell, M.D.A. Ewert, F. Reginster, I., Leemans, R. and Carter, T.R. (2005). Future scenarios of European agricultural land use. II: projecting changes in cropland and grassland. *Agriculture, Ecosystems and Environment*, **107**, 117-135

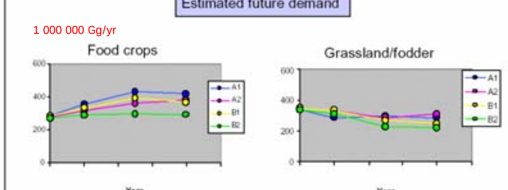
IMAGE2.0 demand values

Approach

$$\frac{L_t}{L_{t_0}} = \frac{D_t}{D_{t_0}} \cdot \frac{P_{t_0}}{P_t} \cdot \frac{O_{r,t}}{O_{r,t_0}}$$

IMAGE model

Estimated future demand



Productivity changes

Approach

$$\frac{L_t}{L_{t_0}} = \frac{D_t}{D_{t_0}} \frac{P_{t_0}}{P_t} \frac{O_{r,t}}{O_{r,t_0}}$$

$$P_t = P_{t_0} r_{P_{t-t_0}}$$

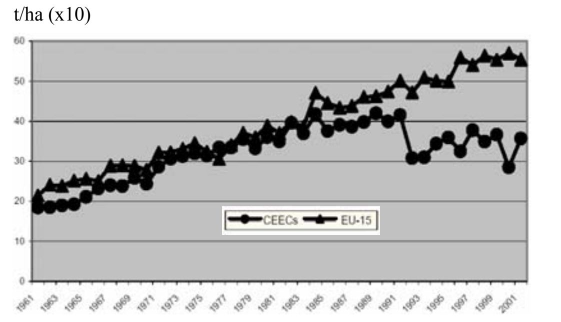
$$r_{P_{t-t_0}} = g(\Delta CO_2, \Delta C, \Delta T)_{t-t_0}$$

P …	Productivity *[t/ha]*
r_p …	Relative change in productivity *[-]*
CO_2 …	Atmospheric CO_2 concentration
C …	Climate
T …	Technology

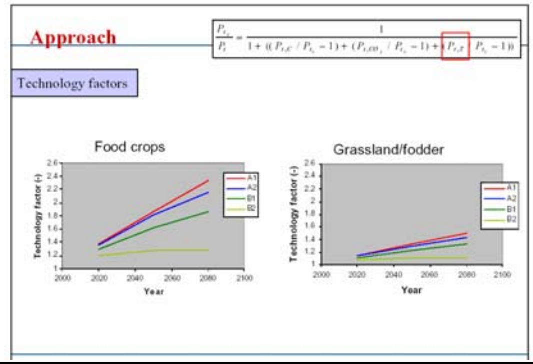
$$P_t = P_{t_0} + ((P_{t,C} - P_{t_0}) + (P_{t,CO_2} - P_{t_0}) + (P_{t,T} - P_{t_0}))$$

$$\frac{P_{t_0}}{P_t} = \frac{1}{1 + ((P_{t,C}/P_{t_0} - 1) + (P_{t,CO_2}/P_{t_0} - 1) + (P_{t,T}/P_{t_0} - 1))}$$

Change in wheat yields

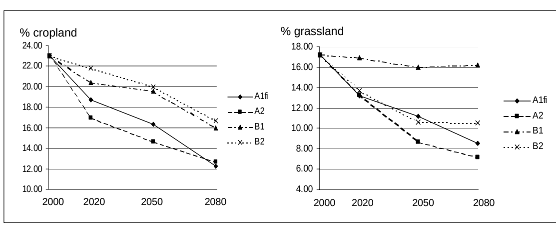


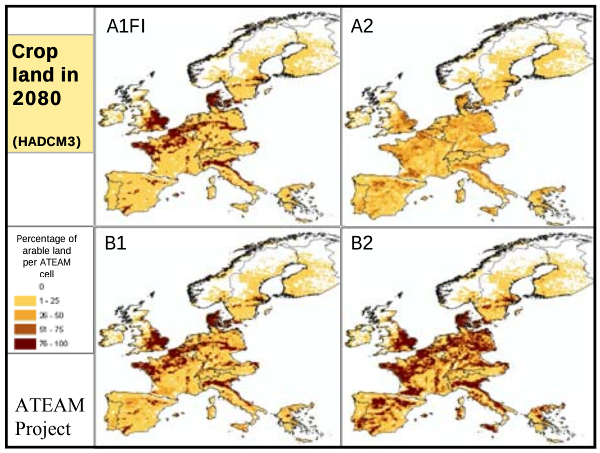
Technology change factors

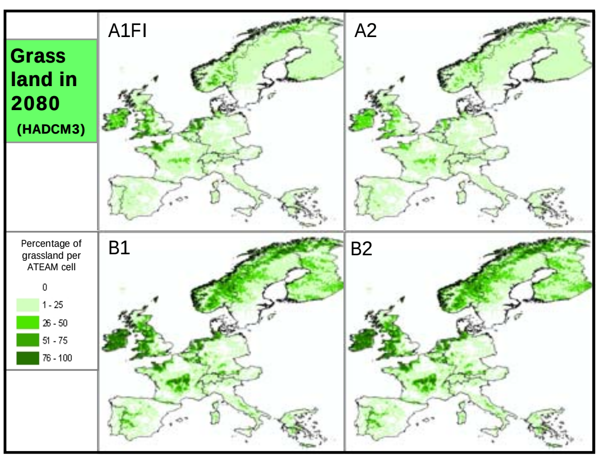


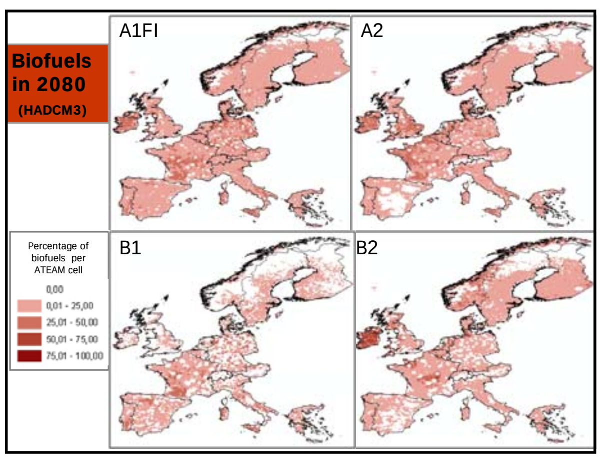
European change quantities

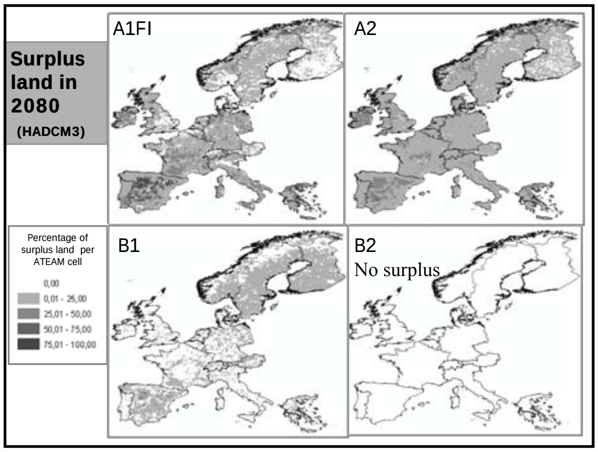
- Ca. 50% declines in agricultural (food) production areas by 2080!



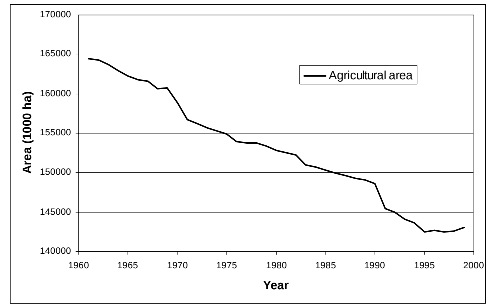






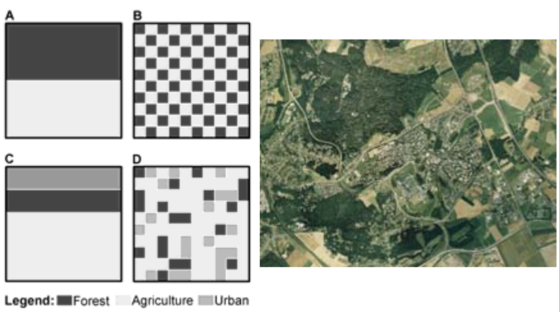


Past changes in agricultural areas

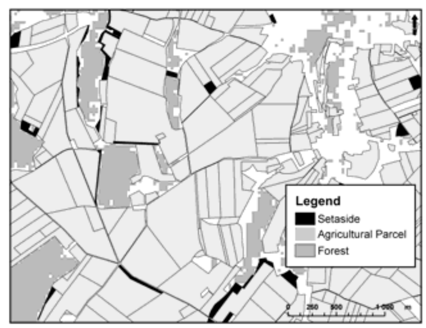


Source: FAO (EU15)

Spatial patterns within landscapes

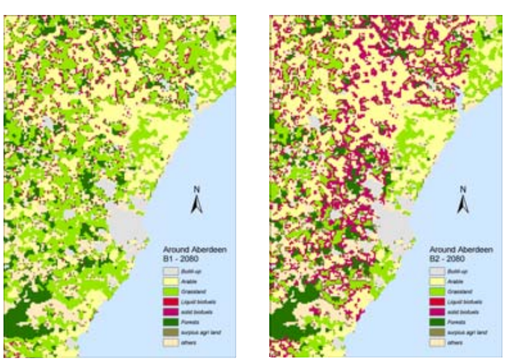


Distribution of Set-aside



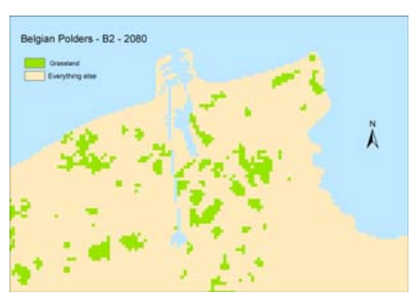
Setaside is located at the border with woodland and on small parcels

Around Aberdeen – 4 scenarios - 2080



Source: Nicolas Dendoncker, UCL

Grassland – Belgian Polders – 4 scenarios

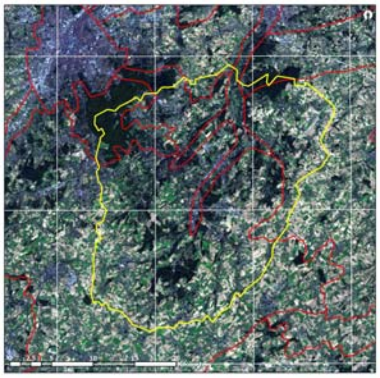


Source: Nicolas Dendoncker, UCL

Data quality issues

Problem:

It can be difficult to explain and model fine resolution agricultural land use with coarse resolution input data.



Landscape Data

At the scale of a catchment:

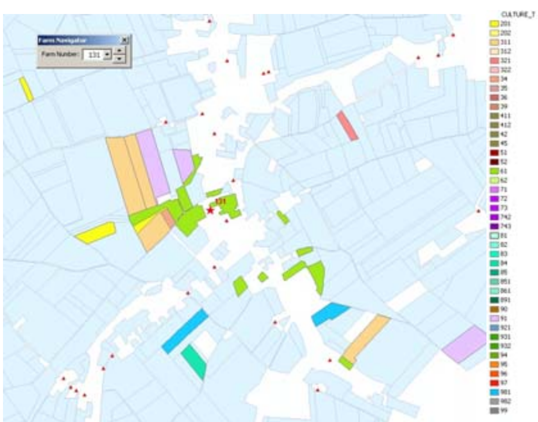
Individual parcel data:

- Parcel Id
- Farm Id
- Land use in 1999

Individual farm data:

- Farm id
- Farm location

- IACS (Integrated Administration and Control System)



Rasterising land use data

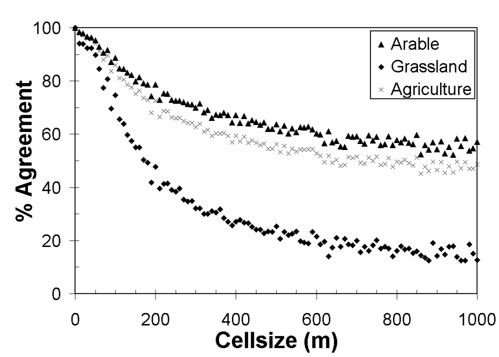
10 to 1000m = 10m steps
1000-5000m = 100m steps
5000-10000m = 500m steps

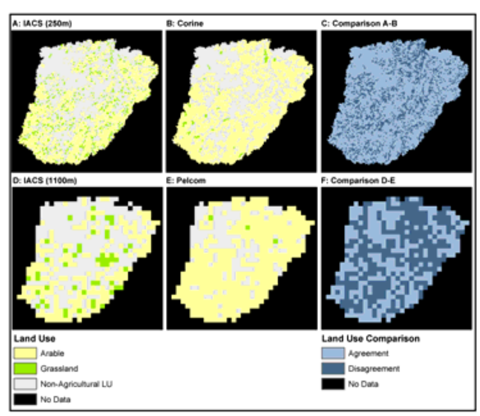
Land use change model

Cropland

Other

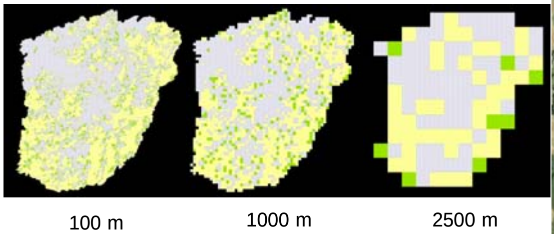
Grassland



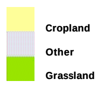


Kappa Corine Comparison: 0.78; Kappa Pelcom Comparison: 0.14

What is the observation?



Implications for model validation?



How to validate scenarios?*

- No observation for the future!
- But, we have observations from the past
- But, the past is only one realisation of what could have happened (other « histories » were possible)
- So, we need « parallel universes » from which observations could be obtained to validate models
- But, …

*The scenario assumptions and models used to quantify them

Spatial and temporal analogues

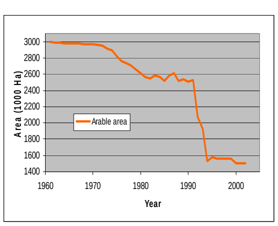
- Compare the « world » described in a particular scenario to similar world's at different geographic locations or at different points in time
- New Zealand post 1984 – test hypotheses about free market scenarios

Post 1984 New Zealand

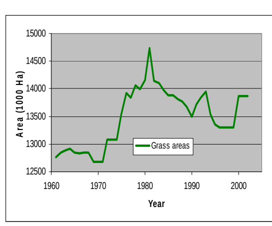
- Deregularion of agricultural sector in 1984 (almost complete removal of subsidies)
- Our scenarios assume that this would lead to agricultural land abandonment
- But, at the same time an increase in crop yields arising from more efficient and innovative management and technology use
- And, constant or increasing production (supply) depending on the demand for agricultural goods

NZ land use area changes

Arable land use



Grassland use

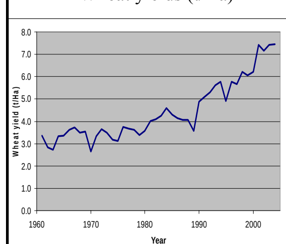


Source: FAO

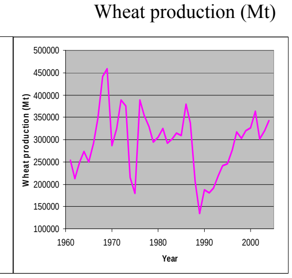
- The biggest changes (abandonment) occured in marginal areas, although less than expected;
- Farmers also diversified their activities;
- Surprisingly, it is not necessarily the worst farmers that abandon farming

NZ crop yield changes

Wheat yields (t/Ha)



Wheat production (Mt)



Source: FAO

Putting the 'socio' in socio-economic

- The potential role of Agent-Based Models (ABM)
- Not a panacea for land use modelling, but warrants further exploration
- Capacity to adopt multi-sectoral approach (policy consequences), and endogenised policy responses

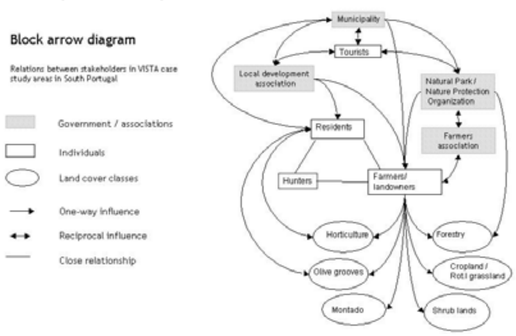
Regional to landscape scale analyses

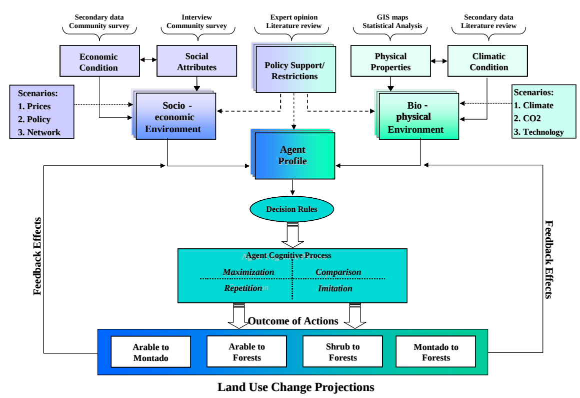
VISTA Project…

Vulnerab**I**lity of Ecosystem **S**ervices to Land Use Change in **T**raditional **A**gricultural Landscapes

Source: Lilibeth Acosta-Michlik and Martha Bakker, UCL & Anne Van Doorn, University of Evora

Agent-Based Modelling (ABM) of land use change in the Alentejo, Portugal





Model Components

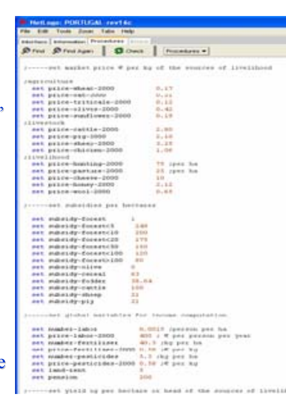
Components ...

1. Agents' environment
   - Economic Condition
   - Social Network
   - Political/Institutional
   - Biophysical Properties
   - Climatic Condition
2. Agents Profile
   - Cognitive Strategies
   - Decision Rules
3. Environmental changes (scenarios)
   - Socio-economic, technology
   - Climate, CO_2

Agents' environment

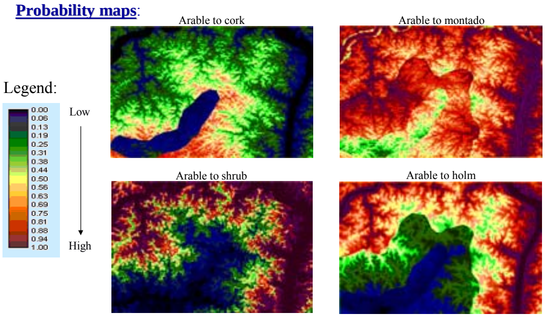
Economic data (2000):

- Prices of crops (cereals, cork, livestock, forest products)
- Prices of inputs (fertiliser, labour, pesticides)
- Subsidies (product, area)
- Inputs required per hectare
- Land rent and pension
- Yield
- Social relationships & culture



Agents' physical environment

Probability maps:

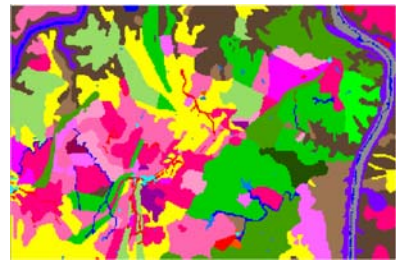


Note: Computed using logistic analysis of landscape attributes such as elevation, slope, south exposition, soil depth, texture and organic carbon.

Source Martha Bakker, UCL and Anne Van Doorn, University of Evora

Agents' environment

Land use map (2000):

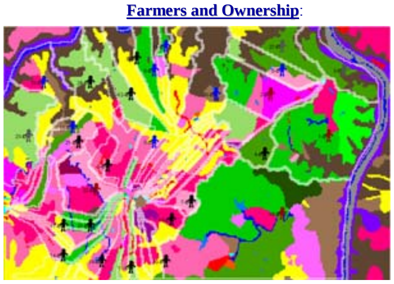


Legend:
agro-sylvo pastoral – magenta
arable or pasture – yellow
forest plantations – green
dense shrubs – dark brown
natural pasture with some
mixed forest – lime
shrubs – brown
olive groove – red
horticulture – orange
waterlines – blue
reservoirs – sky blue
bare rocks – gray
mediterranean shrubs – violet
hamlet and farm buildings – cyan

Source Anne Van Doorn, University of Evora

Agents' profile and cognition

Farmers and Ownership:



Legend:	Social attributes	Economic attributes
Innovative – red	1. age	1. farm size
Active – blue	2. residence	2. income source
Absentee – gray	3. education	3. number workers
Retiree – black	4. profession	4. available successor

Source Anne Van Doorn, University of Evora

ABM: agents' attributes

Profiles of the reactive agents:

Code	name	hectares	age	gender	educa	prof	residence	time	start	obtain	hect	pers	succ	sell	basis	markt
ADS1		127	4	"M"	1	2	1	"P"	1	"I"	3	"N"	"Y"		"F"	
AdS10		136	4	"M"	1	1	1	"F"	3	"I"	3	"N"	"Y"		"L"	
AdS11		149	3	"M"	1	1	1	"F"	2	"I"	1	"N"	"N"		"L"	
AdS12		107	2	"M"	4	1	2	"F"	1	"I"	2	"Y"	"N"		"L"	
AdS13		187	4	"M"	1	1	1	"F"	2	"I"	3	"N"	"N"		"L"	
AdS14		14	3	"M"	1	2	2	"P"	2	"I"	1	"N"	"N"		"L"	
AdS15		31	2	"M"	1	2	2	"P"	3	"I"	2	"N"	"Y"		"L"	
AdS16		42	4	"F"	1	1	1	"F"	3	"I"	1	"N"	"N"		"R"	
AdS17		140	2	"F"	4	2	2	"P"	1	"B"	3	"Y"	"Y"		"L"	
AdS18		78	3	"M"	1	2	2	"P"	2	"I"	2	"Y"	"N"		"C/H"	
AdS19		159	3	"M"	3	2	3	"F"	2	"B"	3	"N"	"Y"		"F"	
ADS2		73	4	"M"	1	1	1	"F"	3	"I"	2	"Y"	"Y"		"NONE"	
AdS20		780	2	"M"	2	1	2	"F"	2	"B"	4	"Y"	"Y"	N	"H"	O
AdS21		20	4	"M"	1	1	1	"F"	3	"I"	1	"N"	"N"	Y	"R"	I
AdS22		343	3	"M"	3	1	2	"F"	2	"B"	3	"Y"	"N"	N	"F/L/M"	O
AdS23		167	4	"M"	1	1	3	"P"	2	"I"	3	"Y"	"Y"	N	"F"	N
AdS24		101	2	"F"	3	2	3	"P"	1	"I"	3	"Y"	"Y"	N	"F"	L
AdS25		144	3	"M"	4	1	2	"F"	2	"I"	3	"Y"	"Y"	N	"F/L"	I
AdS26		43	4	"M"	3	2	3	"P"	2	"I"	1	"N"	"Y"	N	"F"	N
AdS27		75	4	"M"	1	1	1	"F"	3	"I"	2	"N"	"N"	N	"R"	_
AdS28		167	4	"M"	1	1	3	"P"	2	"I"	3	"Y"	"Y"	N	"F"	N
ADS3		25	4	"M"	0	1	1	"P"	2	"I"	1	"N"	"N"		"R"	
ADS4		20	2	"M"	1	1	1	"F"	2	"B"	3	"N"	"N"		"L"	
ADS5		117	4	"M"	1	1	3	"P"	2	"I"	3	"N"	"Y"		"L"	
AdS6		11	4	"F"	0	1	1	"F"	2	"I"	1	"N"	"Y"		"R"	
ADS7		13	4	"M"	4	2	1	"F"	2	"I"	1	"N"	"Y"		"R"	
AdS8		144	2	"M"	1	1	1	"F"	2	"I"	3	"Y"	"Y"		"L"	
AdS9		45	4	"M"	1	1	1	"F"	3	"B"	1	"N"	"N"		"R"	

Source Anne Van Doorn, University of Evora

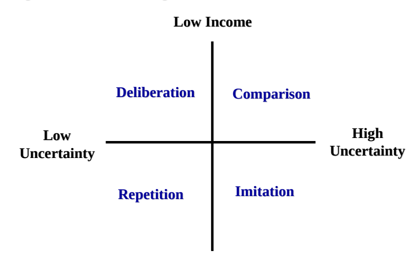
Agents' profile and cognition

Profile	Characteristics	Strategies
Innovative	•Large farm ownership •High education •Young farmers •Diversified source of income	Maximization, repetition
Active	•small to medium farm ownership •Moderate to High education •Young farmers •Traditional source of income	Maximization comparison, repetition
Absentee	•Medium to large farm ownership •Profession other than farming •Young to old farmers •Diversified source of income	Imitation, repetition
Retiree	•Small farm ownership •Low education •Old farmers •Pesion and land rent	Repetition

With the extensive and valued contributions of Anne Van Doorn, University of Evora

Multi-agent model

Cognitive strategies:

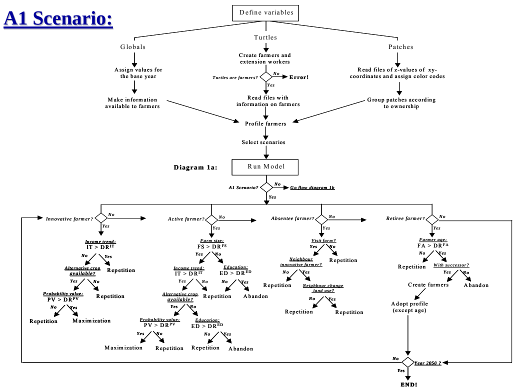


Scenarios on the environment

SRES Scenarios	Social Network Scenarios
A1	•Large and educated farmers have access to technology, but not small farmers •Farmers are individualistic so knowledge not transferred •Old farmers without successor abandon their lands, and large farmers do not buy due to decrease in subsidies
A2	•Transfer of technology based on hierarchal pattern, small farmers no access •Regional self-reliance promotes a sense of community help and interaction •Old farmers without successor abandon their lands, and large farmers buy these lands due to increase in forest subsidy
B1	•Small farmers access technology through extension services •Poor social network so knowledge not transferred •Old farmers without successor can sell their lands because subsidies remain almost stable
B2	•Transfer of technology among small farmers through good social network •Effective social network because of a strong local self-reliance •high level of rural development increases the value of agricultural lands restrict the number of new entrants and limit in-migration

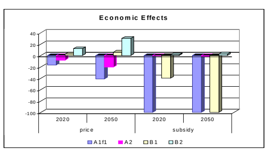
Model platform and results

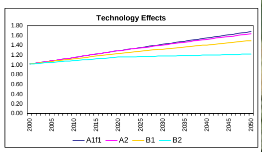
A1 Scenario:

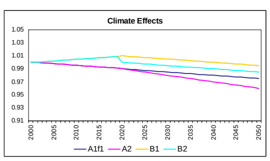


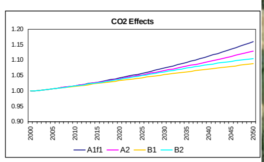
Scenarios on the environment

SRES scenarios:



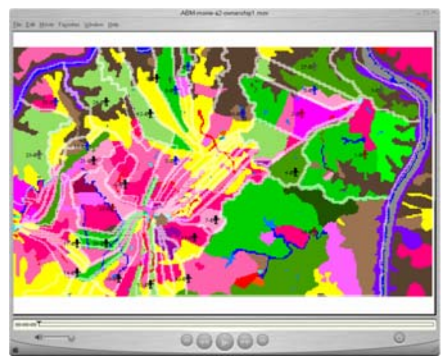






Note: Based on ACCELERATES and ATEAM projects

Model platform and results

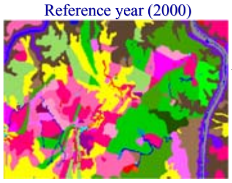


NetLogo ... http://ccl.northwestern.edu/netlogo/.

Model platform and results

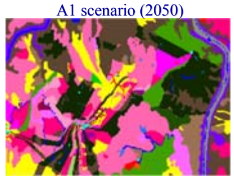
Land use change projections

Reference year (2000)

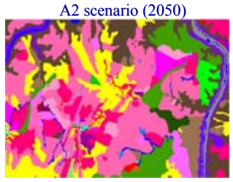


Source: Anne Van Doorn, University of Evora

A1 scenario (2050)



A2 scenario (2050)

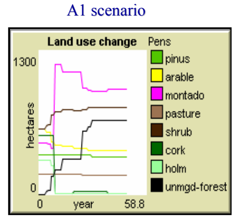


Environmental Impacts?

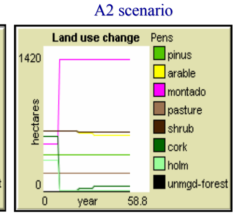
Model platform and results

Land use change projections

A1 scenario



A2 scenario



Concluding remarks

- Can we improve on our capacity to validate models for a range of alternative futures?
- New models should build on existing knowledge, but adopt multi-sectoral strategies, better represent social processes and be more responsive to policy questions (stakeholders): endogenising policy processes (ABM?)
- Land use models need to nest at different spatial scales (from global to landscapes) – a modelling network