Spatial and temporal variabilities of land uses as affected by global change: a focus on Mediterranean agriculture

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Introduction

- Natural resources (NR) are the backbone of every economy.
- Agriculture is the economic activity most strictly linked to the availability of NR's: it depends on quali-quantitative availability of NR's, but it impacts also NR's.
- Agricultural activities are put in place through alterations of natural ecosystems and in particular through LCLUC => agro-ecosystems
- Agro-ecosystems, like any other social-ecological system, evolve though complex interactions between endogenous (e.g. the farmer) and exogenous (e.g. CC) drivers
- Water and soil are resources with stronger interactions with the primary sector (e.g. irrigation) and with potential conflicts with other sectors.

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Motivation

- The analysis of land use change under the effects of multiple drivers is of primary relevance to understand the dynamics of global change at various scales and to make projections of future developments
- Introducing consideration of climatic – and other kind of – variability and sources of uncertainty is necessary to explore realistic behaviour of socio-ecosystems and identifying possible tipping points
- The Mediterranean Region is a hot spot of global change, in which most of the dynamics and the conflicts are brought to extremes
- Focusing on the co-evolution of agriculture and natural resources in Mediterranean socio-ecosystem is of greatest interest for global change studies

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Objectives

- To study the local dynamics and impacts of agriculture and resource use under the pressures of global economic and climatic drivers.
- To explore the feasibility of integration between top-down and bottom-up modelling approaches for adaptation studies.
- To explore the potential for long-term, spatially explicit multi-sector analyses
- To test the potential of freely available global data sets for local/regional simulations in the Mediterranean Region.

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Top-Down and Bottom-Up Approaches to Global Change Adaptation

- **Top-Down (CGE)** models are widely used to simulate future economic developments in relation to climate change, with capability to analyse:
  1) Global dynamics of the markets (focusing on labour and capital inputs)
  2) Prices of commodities in the global markets
  3) International trade and flows of goods
  4) Gross products per country and sectors
- …however Top-Down approaches usually neglect:
  1) Environmental constraints (water, soil, etc.) and their spatial-temporal evolutions.
  2) Heterogeneity and interaction of economic agents with each other or with environment.
  3) Micro socio-economic diversity (decision making and risk, attitudes, learning and neighbours effects, historical and cultural factors, etc.)

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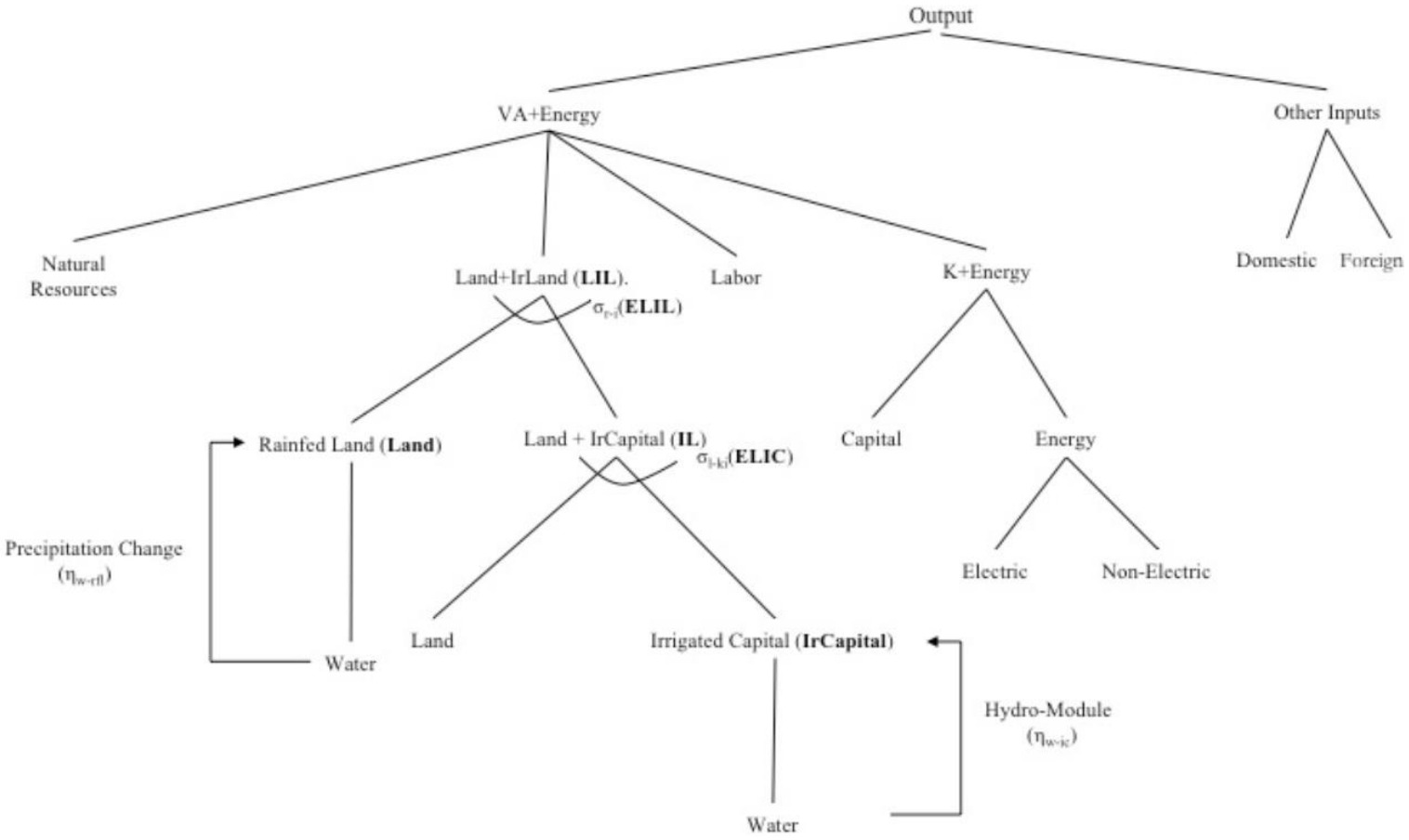
Experiences with CGE models



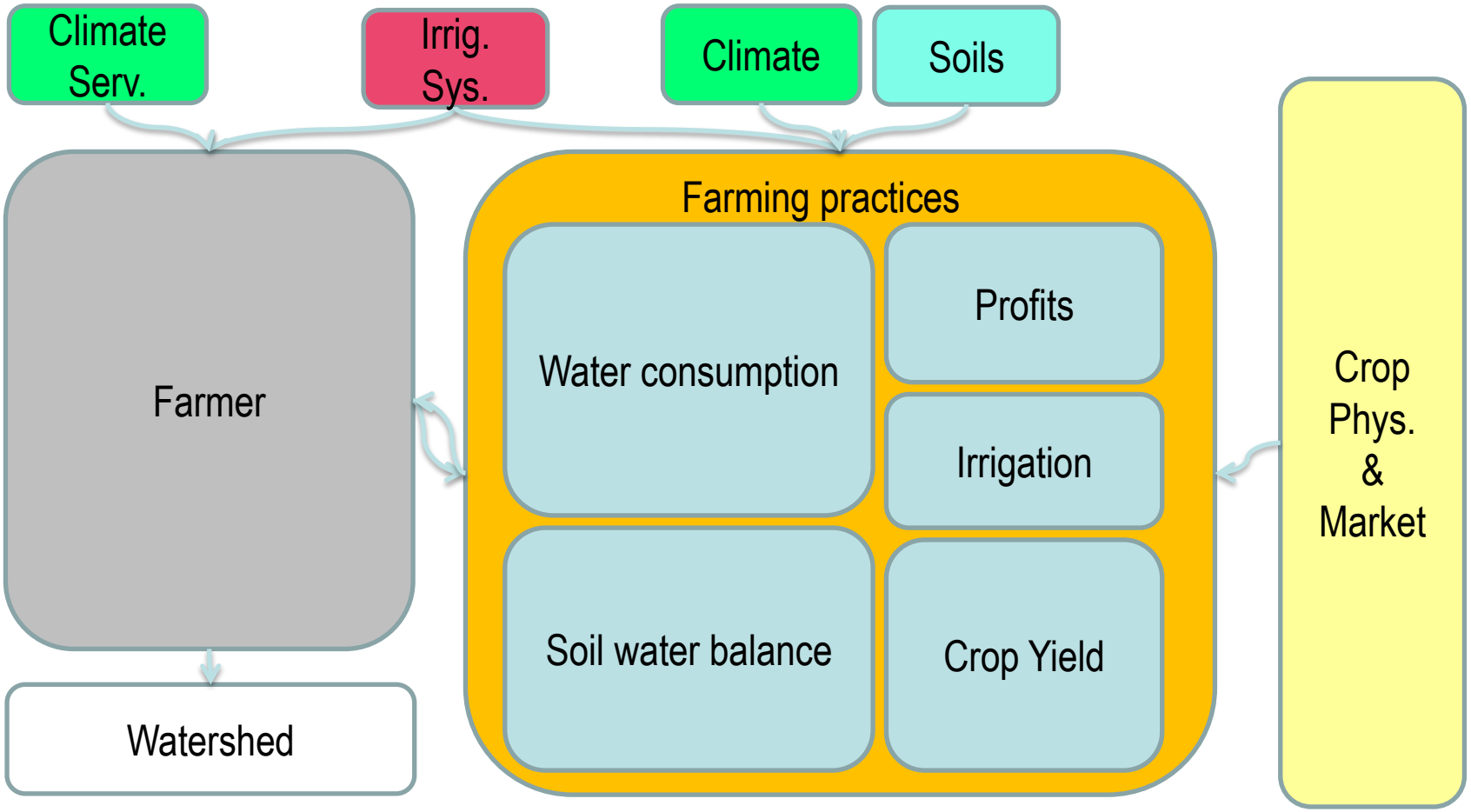
R.D. Ponce, PhD Thesis

Top-Down and Bottom-Up Approaches to Global Change Adaptation

- CGE limitations are the strengths of **Bottom-Up (ABM)** approaches (Agent Based Modelling), and in particular their capabilities to:
  1. utilise mechanistic knowledge of physical/environmental phenomena.
  2. consider behavioural diversity of economic agents, as a consequence of their diverse interactions with the surrounding environment and their bounded perceptions of the changing world.
  3. explore the emergent properties of complex socio-ecological systems

$\Rightarrow$ A combination of the two approaches can provide fruitful developments of current state-of-the-art in global change studies.

Experiences with System Dynamic and Agent Based Modelling



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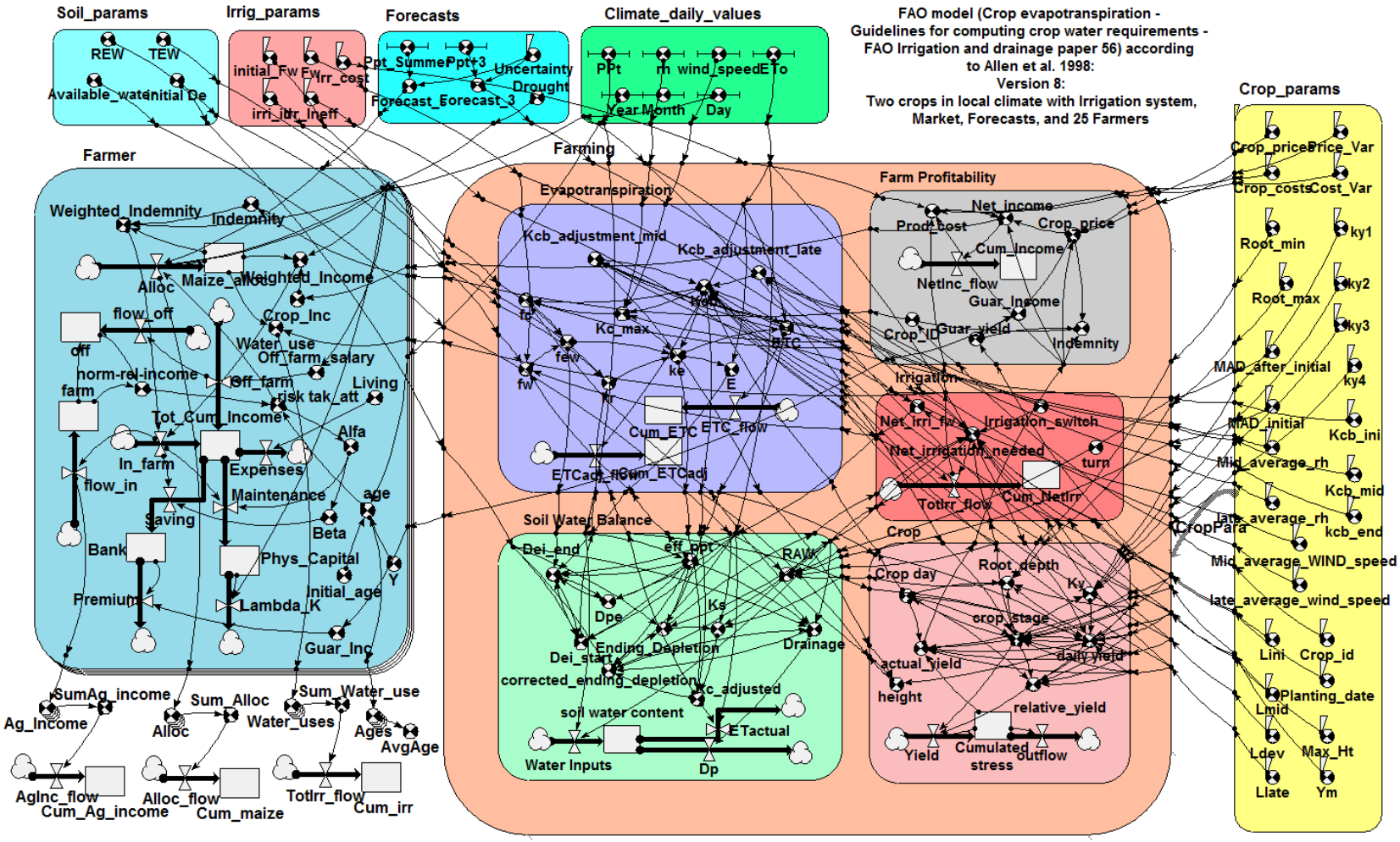
Experiences with System Dynamic and Agent Based Modelling



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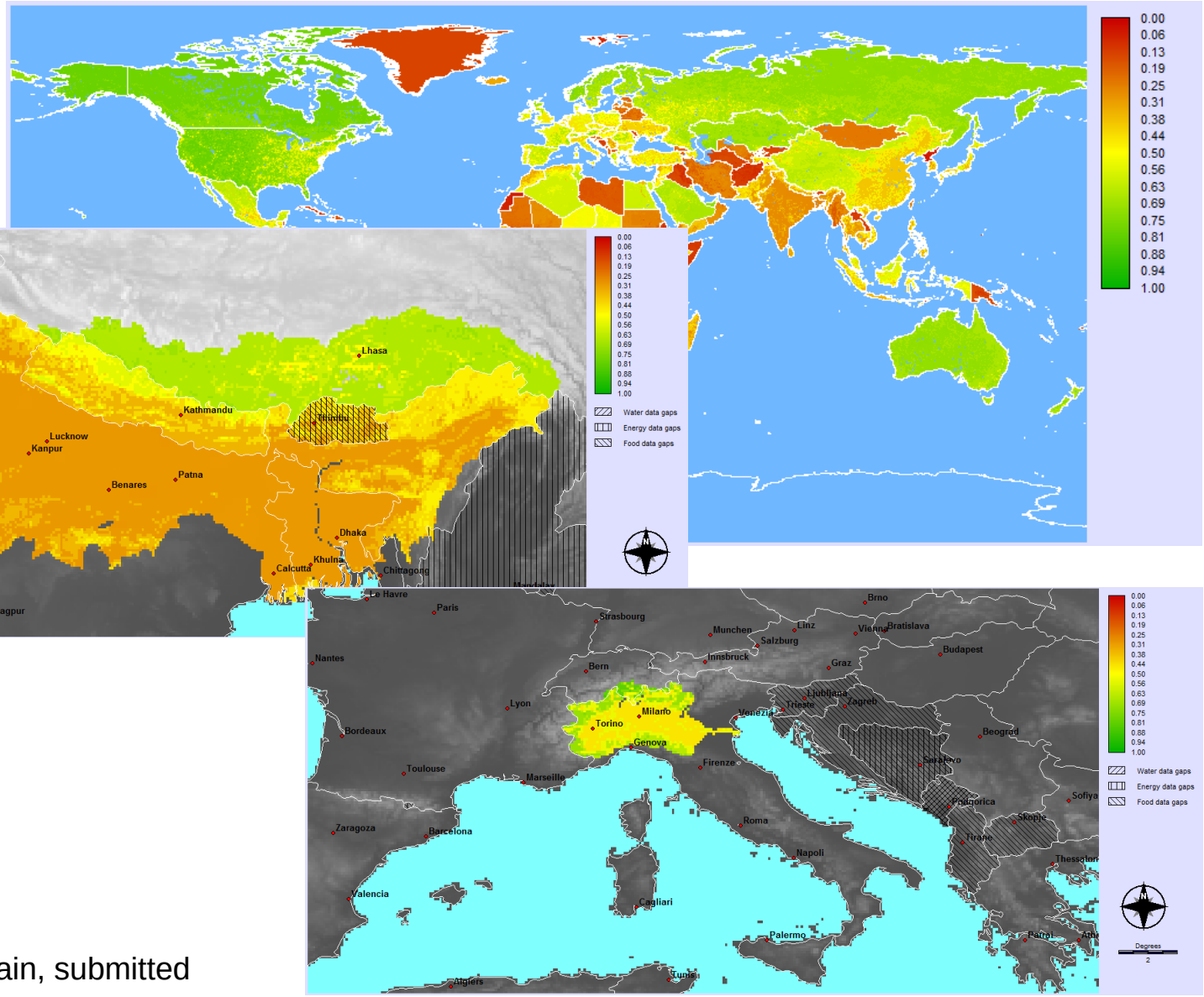
Experiences on global and regional assessment: e.g. WEF Security Index, from countries to pixels



Giupponi & Gain, submitted

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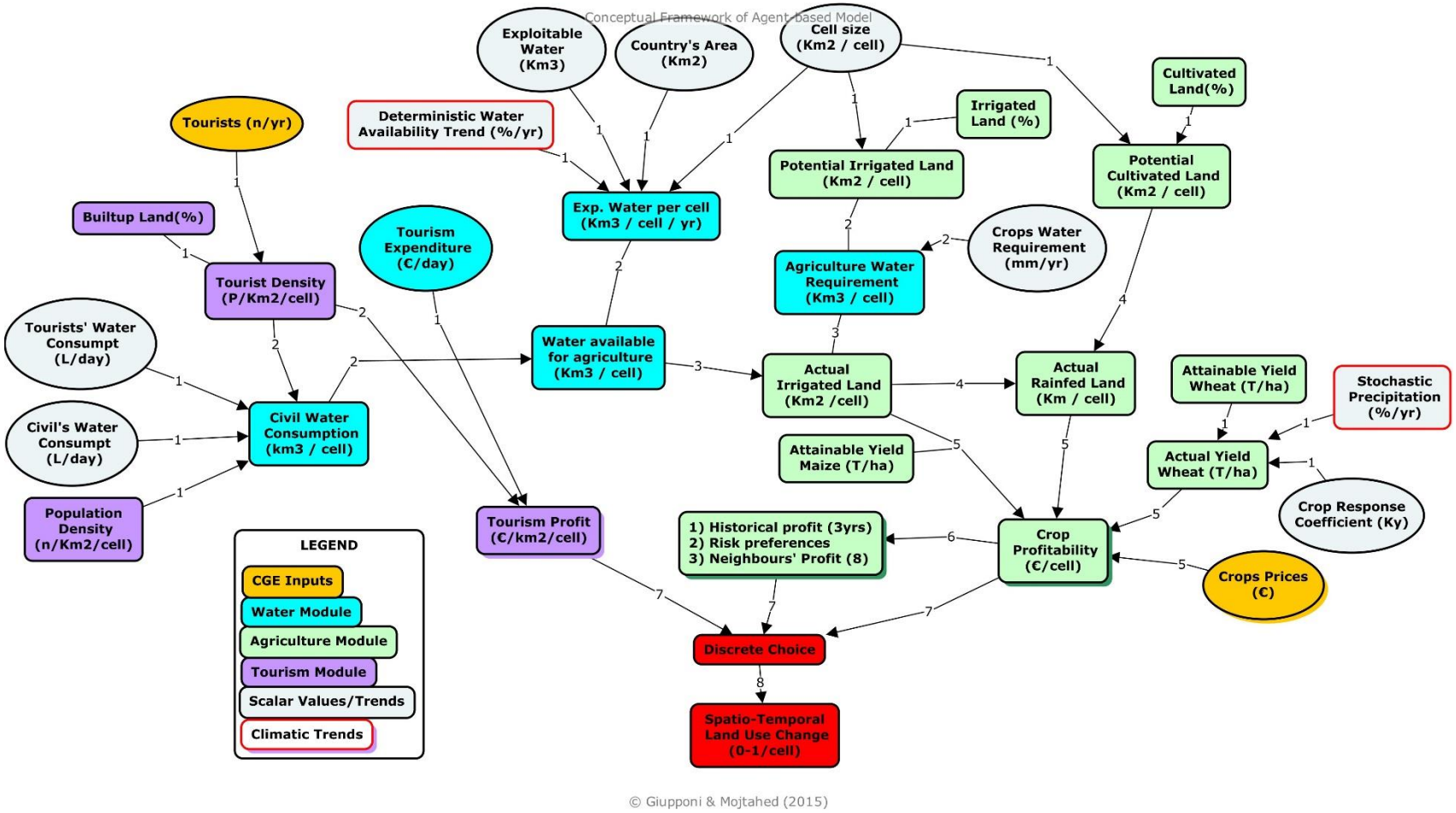
Conceptual Framework of ABM



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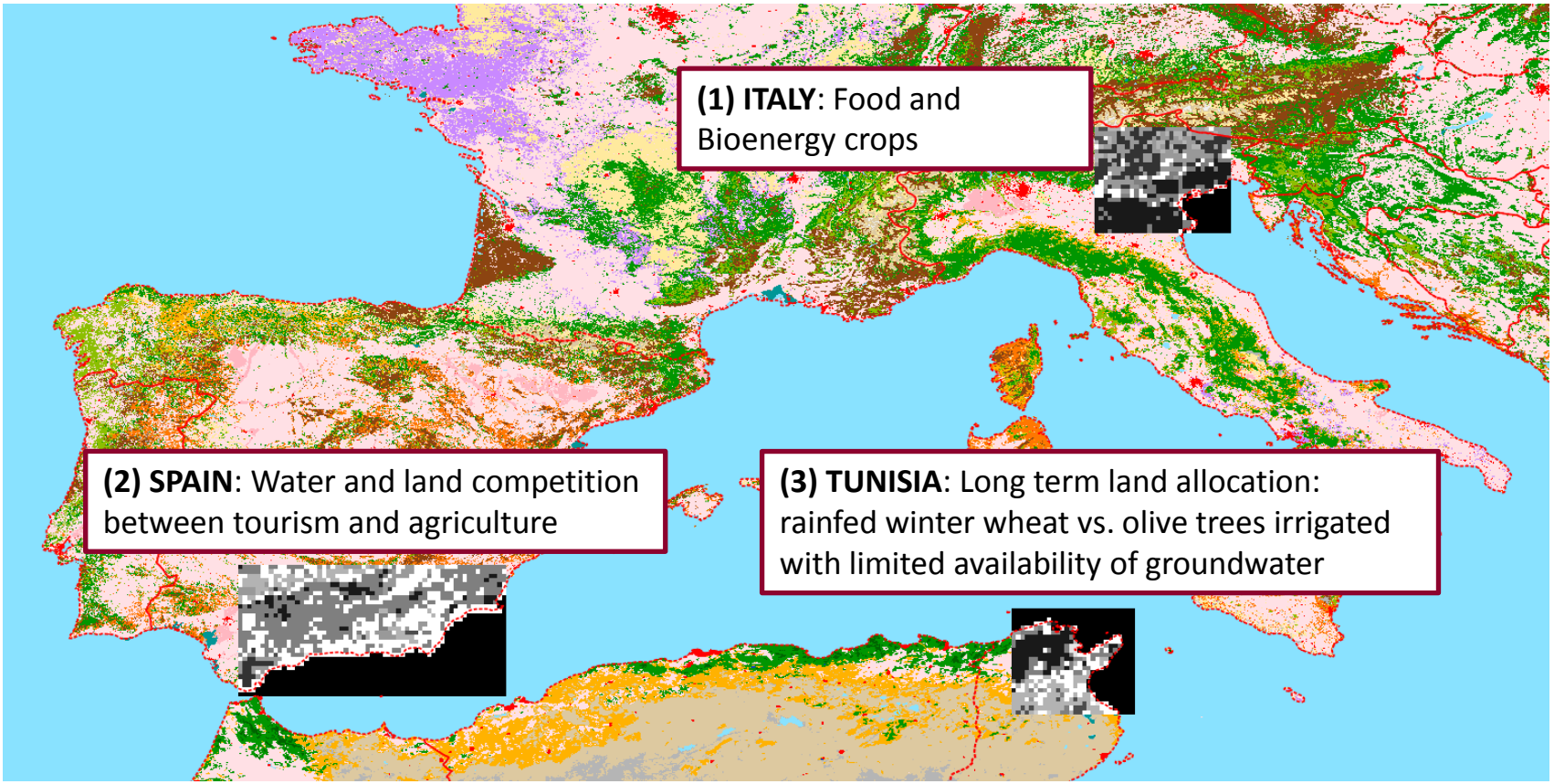
Case Studies Locations



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The ABM model (1)

- Each pixel of the GIS map is considered an an agent who combines all the possible available information to calculate the expected profit from each activity and makes a decision.
- The agents are price takers and their decision has no impact on the global market.
- The ABM consists of several modules that are followed in logical order.

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ABM Model (2)

- The ABM code is written in Matlab.
- More than 12000 lines of code is written for the 3 case studies.
- We run several models in parallel to the baseline model to keep track of changes when new assumptions are introduced such as stochastic CGE prices, risk attitude, learning, impact of historical prices, etc .
- Results are produced in both graphical and graphical (maps and videos) formats.

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CGE Model: Settings & Aggregations

- **Regions:** 15 Mediterranean regions together with Annex1 and Non-Annex1 countries.
- **Sectors:** 15 sectors:
- **Horizon:** 2007 till 2050

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CGE Model: Exogenous Drivers

- Labor productivity
- Total Factor productivity
- Population growth (SSP2)
- Price of energies:
  - Oil: 19% per year
  - Gas: 50% per year
  - Coal: 22% per year
- Land productivity (4 agricultural sectors)

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GIS Inputs

- The GIS inputs are available at global level from FAO's Global Agro-Ecological Zones
- We used the following data sets:

  - % Built-up
  - % Rainfed
  - % Irrigared
  - % cultivated

  - Precipitation
  - Attainable Yield
  - Land Cover
  - Population Density

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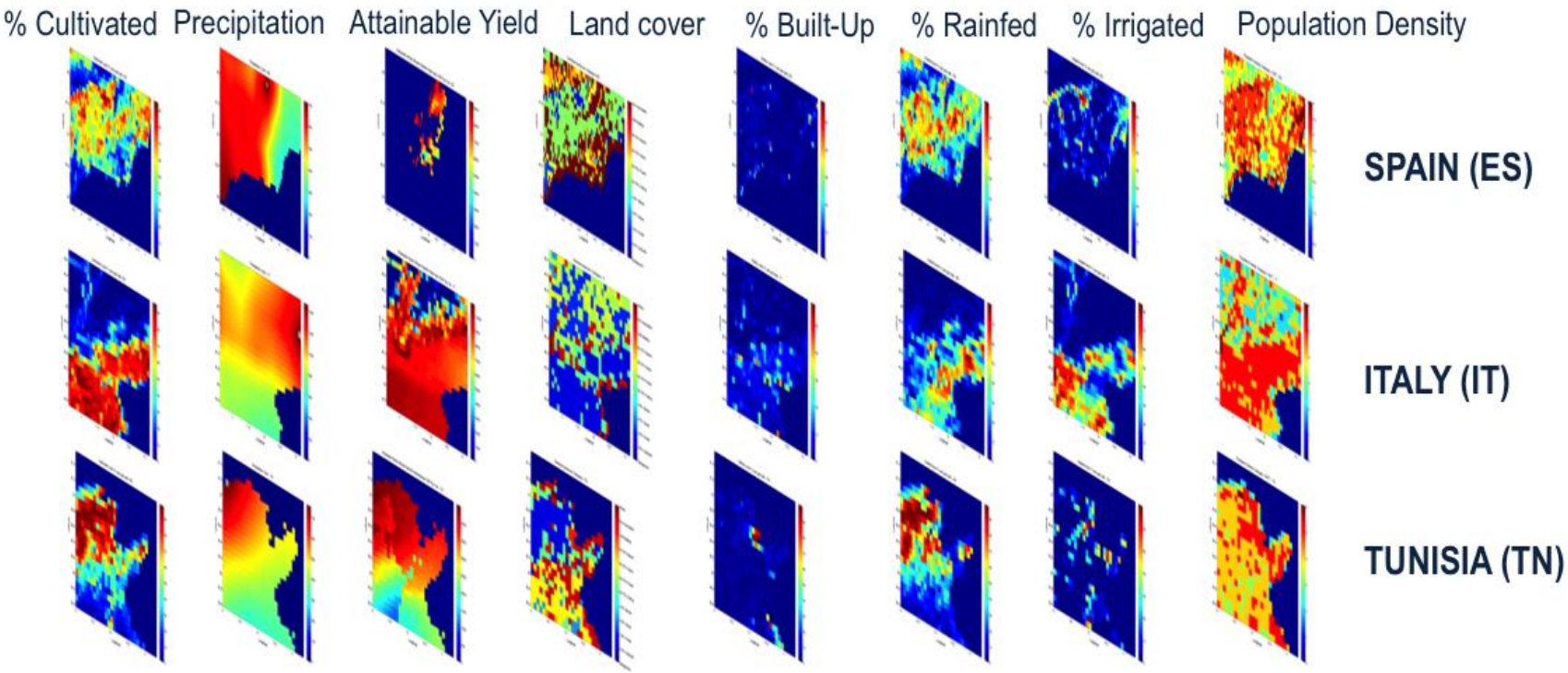

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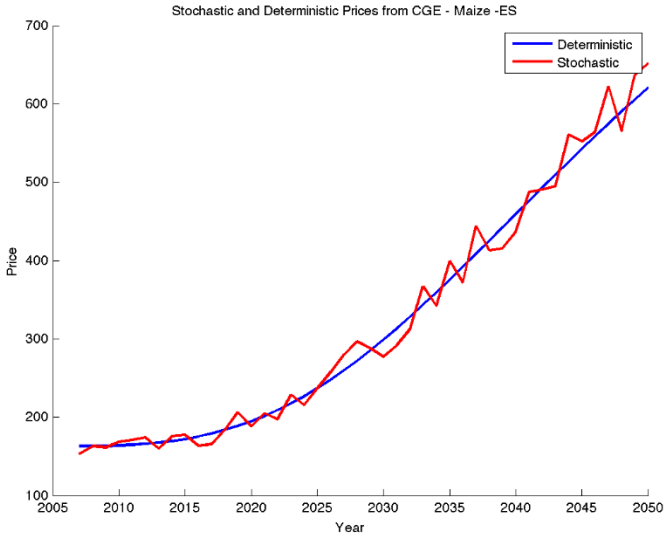
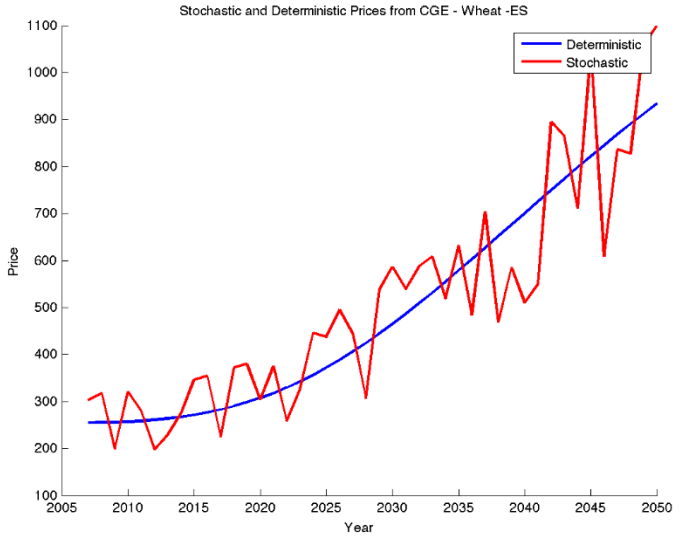
Global Drivers of Change (1)

1. The prices of commodities are globally changing and often raising due to the interactions of population growth and increase in prices of energies as well as productivity of labor force in developing economies.

Maize Price (ES)



Wheat Price (ES)



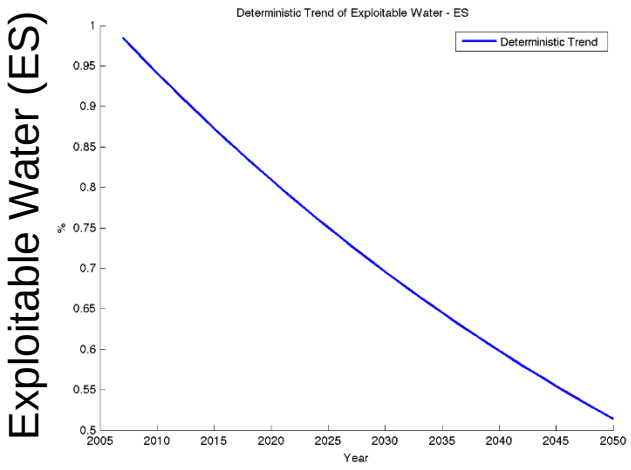
Global Drivers of Change (2)

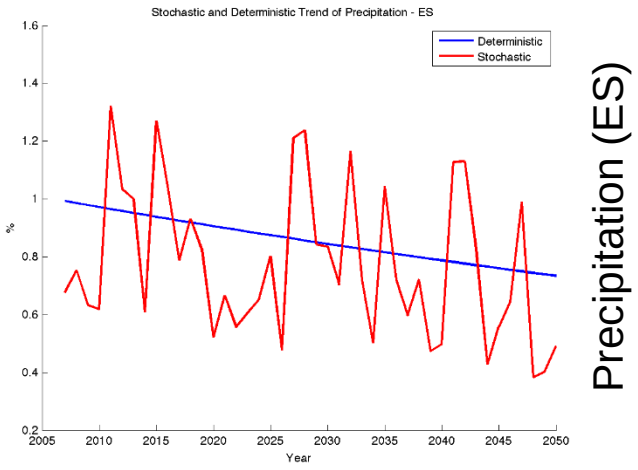
The climatic variables are changing with impacts on socio-ecosystems of southern and northern regions of Mediterranean, e.g.:

a. Decrease in the amount of exploitable water

b. Extreme climate variability (e.g. stochastic fluctuations around a decreasing trend for precipitation)

c. Water resources (e.g. groundwater) and soils may be significantly affected (erosion, desertification, saltwater intrusion, etc.)





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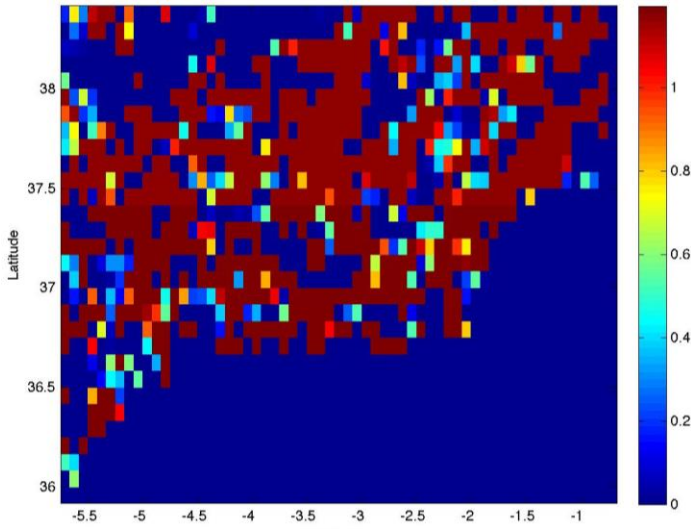
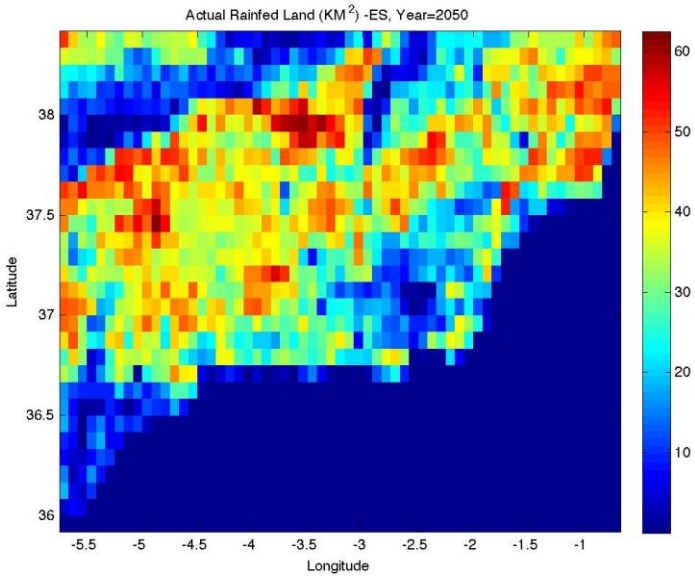
Intermediate Spatial Output

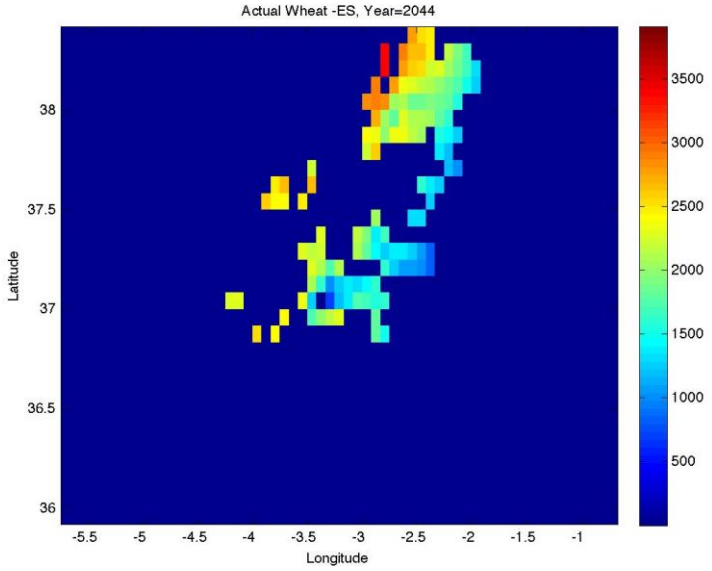
Actual Irrigated land (ES) 2050

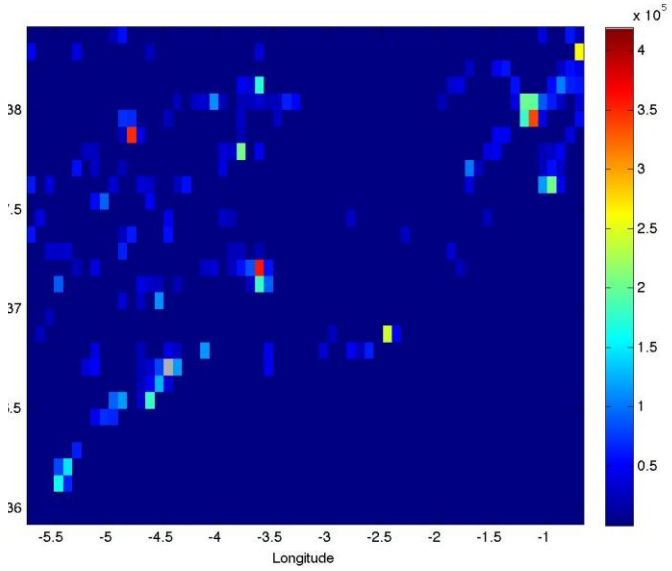




Actual Rain-fed land (ES) 2050

Actual Wheat (ES)





Tourists per cell (ES)

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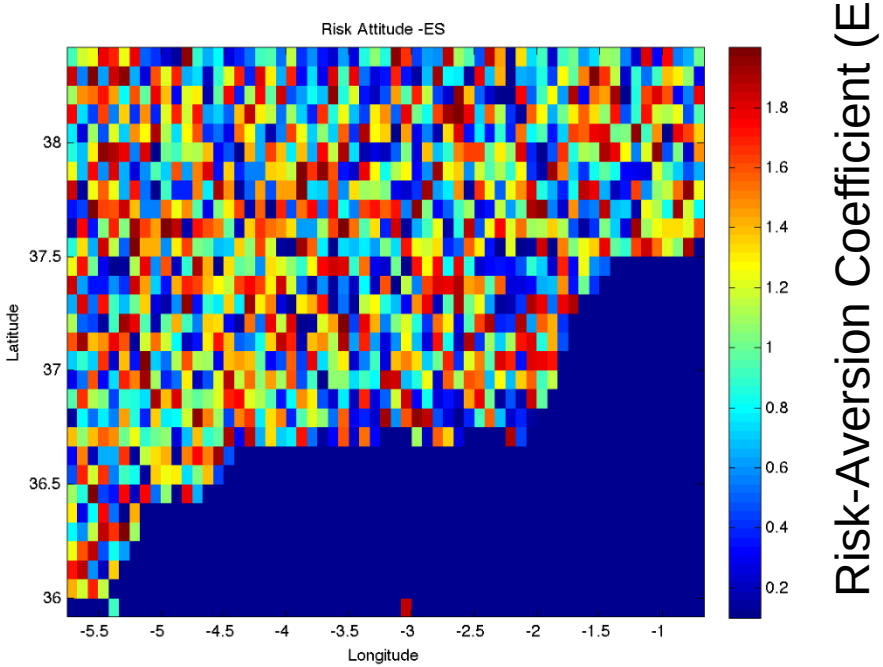
Behavioral Diversity (1)

- Risk attitude: We have considered the spatially distributed risk attitudes of the agents given by a certain distribution:

Risk Aversion:

$$P = \frac{\ln(ap+1)}{a}$$

α is coefficient of risk-aversion



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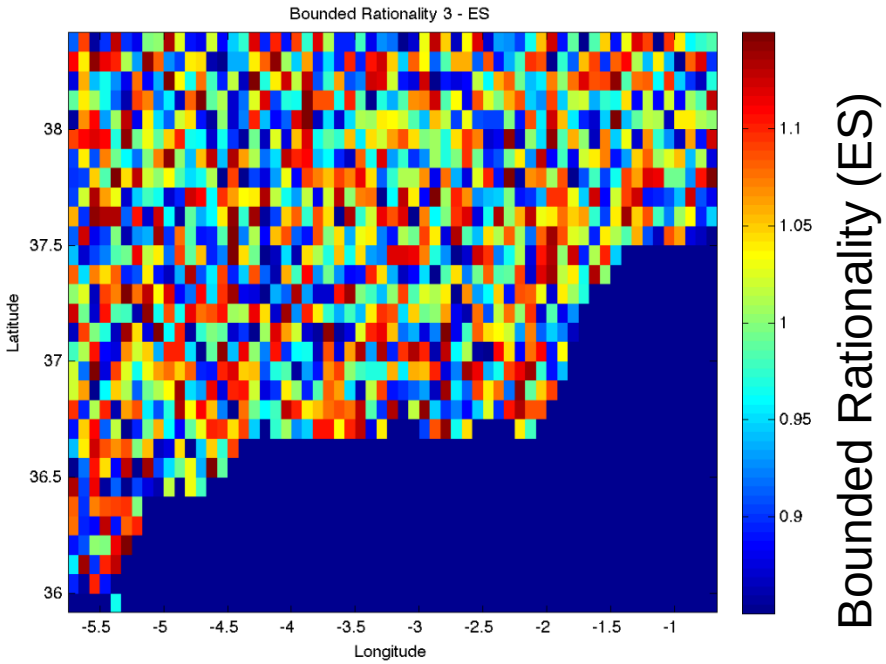
Behavioral Diversity (2)

- Bounded Rationality: Agents can be boundedly rational with respect to the price signals. This is represented in a spatially distributed manner.



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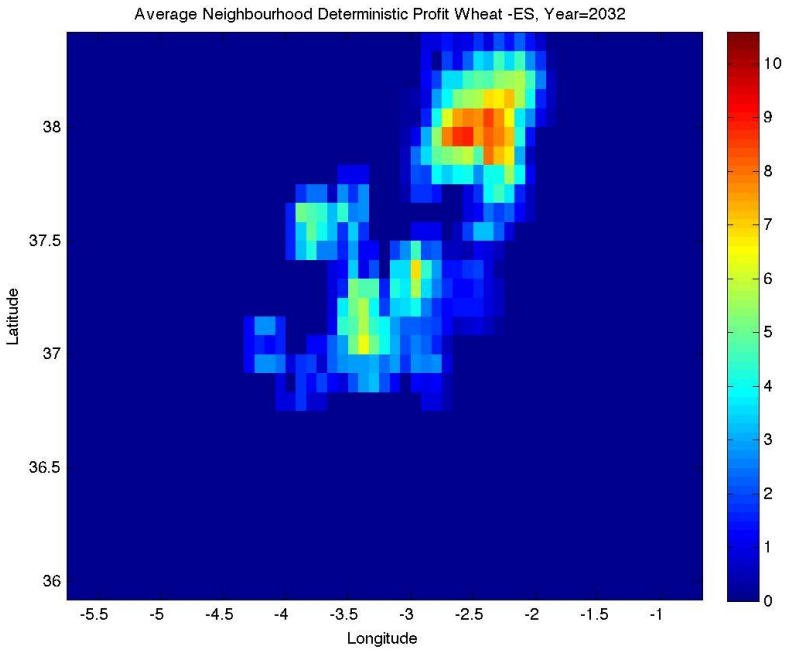
Behavioral Diversity (3)

- Learning from Neighbors: Each agent can observe the performance of the 8 nearby neighbors and this could reinforce one action versus another.



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Land-Use Change

- Each agent is equipped with the Discrete Choice Function given by:

$$P_{it} = \frac{e^{F_{it}}}{\sum_i e^{F_{it}}} \qquad \text{Eq. (1)}$$

- P_{it}: probability of land-use change for activity *i* at time *t* ; F_{it} : *Weighted Forcing driver of activity i that is given by:*

$$F_{it} = b_{1i}(p_{it}) + b_{2i}(Np_{it}) + b_{3i}(Hp_{it}) \qquad \text{Eq. (2)}$$

- p_{it} : Expected profit of activity *i,* Np_{it} : Average neighborhood profit of activity *i (8 neighbors),* Hp_{it}: historical profit of activity *i (3 years average)*

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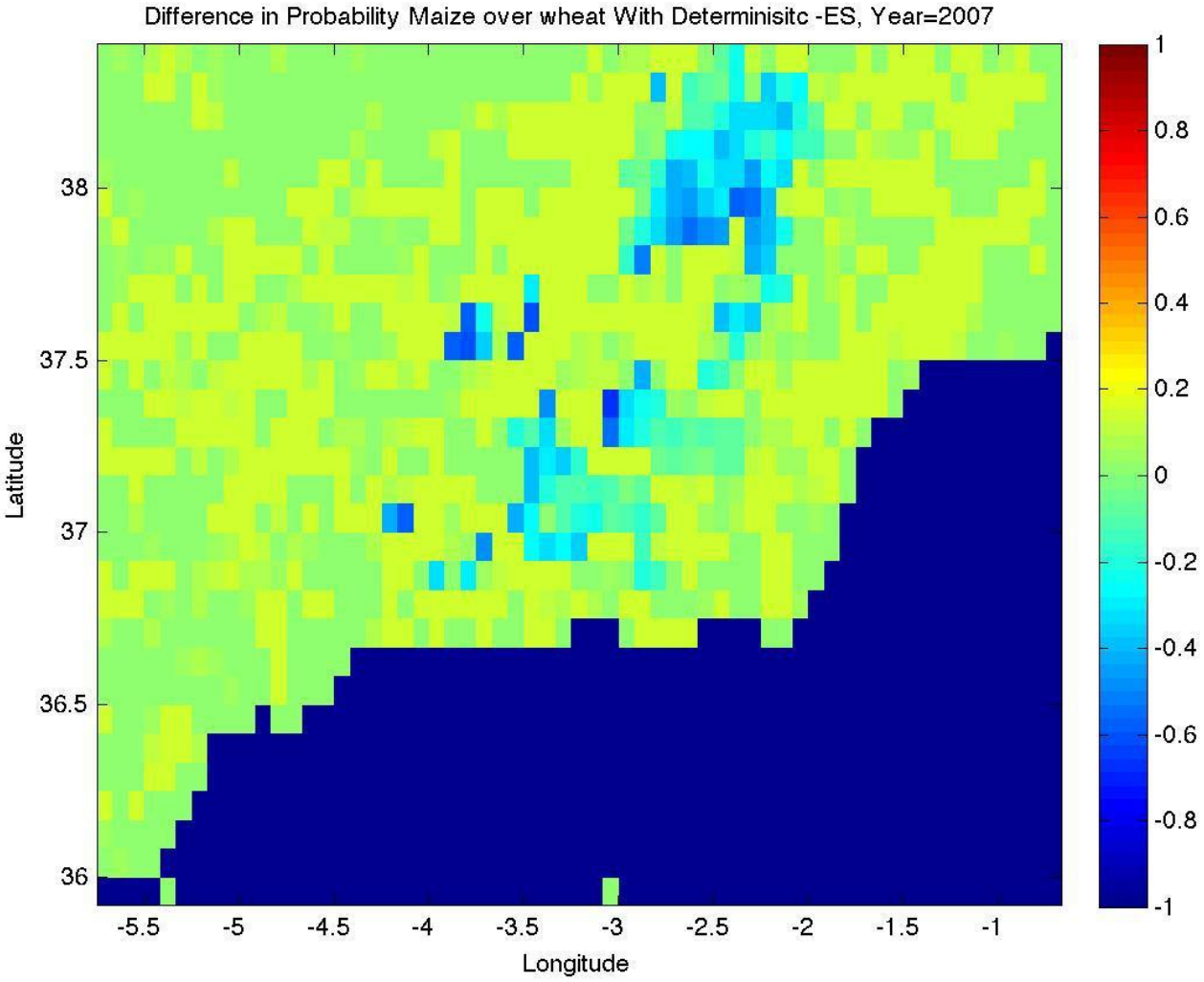
Result (Video)



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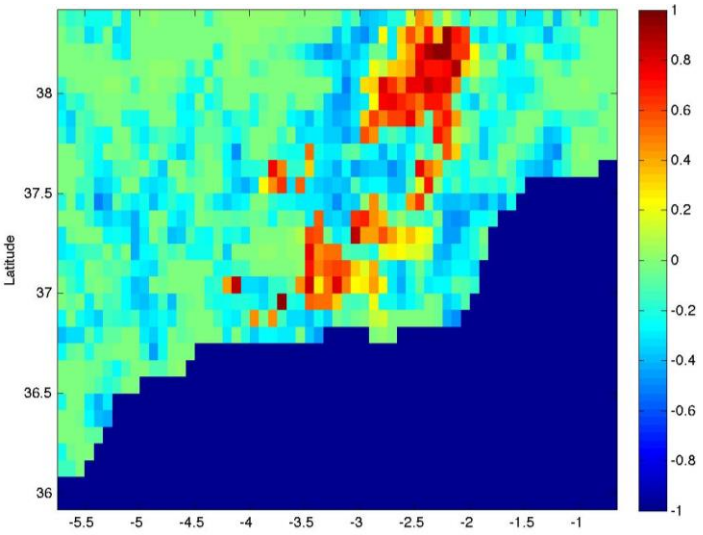
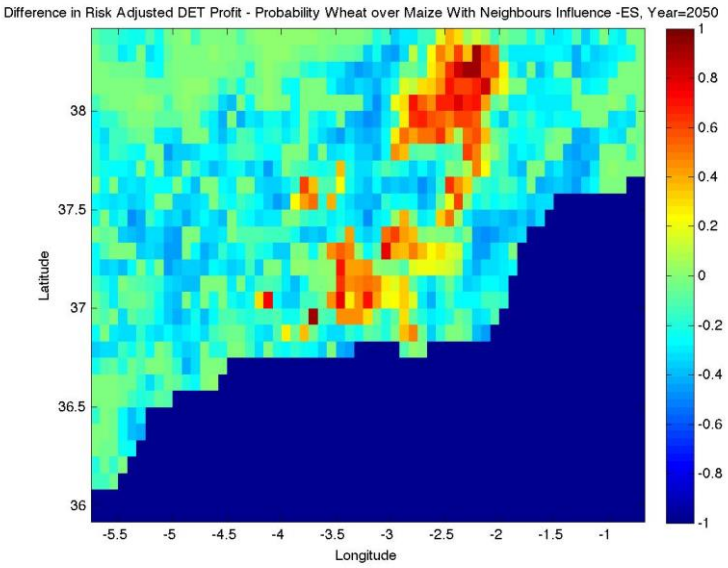
Results (1)



Probability of Wheat over Maize
With Risk adjusted profit
Historical profit impact
Neighborhood profit
Influence (ES) - 2050

Probability of Wheat over Maize
With Risk adjusted profit
<u>No Historical impact</u>
Neighborhood profit
Influence (ES) - 2050



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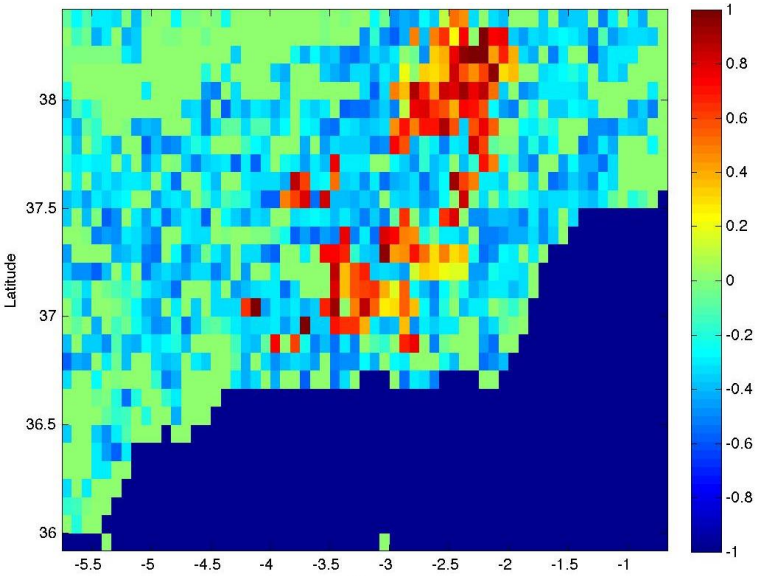
Results (2)



Probability of Wheat over Maize
With Risk adjusted profit
Historical profit Influence
No Neighborhood effect
(ES) - 2050

Probability of Wheat over Maize
With Risk adjusted profit
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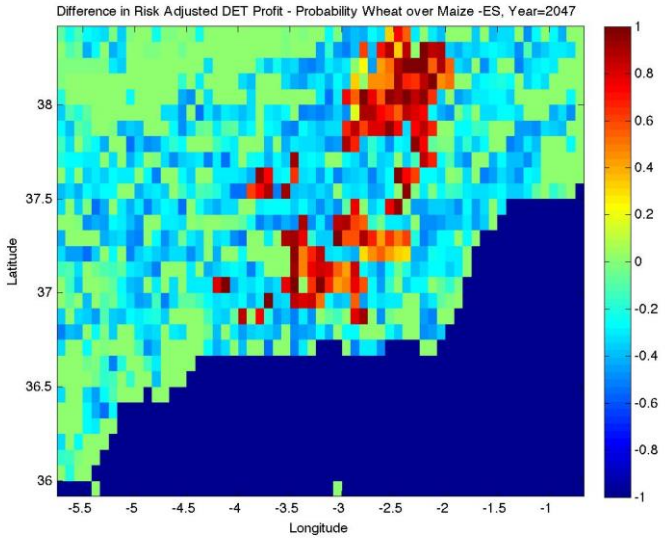
(ES) - 2050



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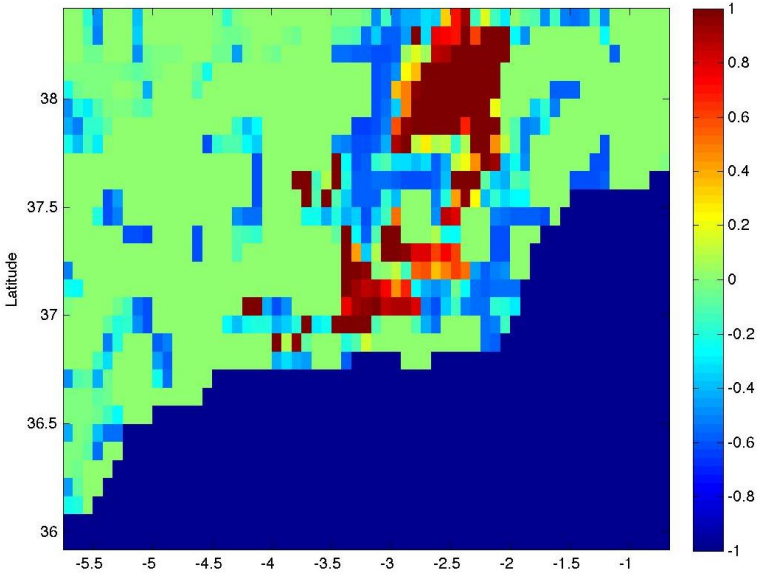
Results (3)



Probability of Wheat over Maize
No Risk adjustment
Historical profit Influence
Neighborhood effect
(ES) - 2050

Probability of Wheat over Maize
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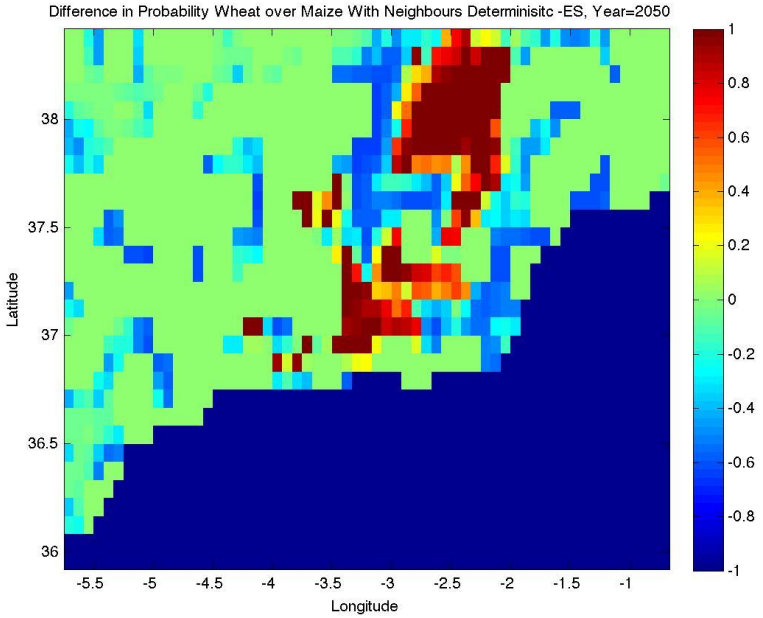

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Conclusion

- The study allowed the exploration of the impact of global change drivers, whether be climate-change or socioeconomic, combined with different behavioral setting on Med socio-ecosystems in a spatially explicit fashion.
- Given the availability of the global datasets such as FAO-GAEZ, this analysis can be replicated in any other part of the world, provided that ABM parameters are available.
- A functional – bi-directional – integration of CGE and ABM models is demonstrated as being theoretically feasible, letting CGE models to be informed by physical limits, constrains, tipping points, … affecting socio-economic development over the long term.
- …next is scenario analysis, and exploration of feedbacks.

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