Modelling European Agriculture with Climate Change for Food Security

Multi-scale Modelling of Adapting European Farming Systems

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Acknowledgement to:

- **Gabriele Dono**
- **Heikki Lehtonen**
- **Pytrik Reidsma**
- **Martin Schönhart**
- **Martin Köchy**
- **Andrea Zimmermann**

Content

- Introduction to modelling impacts of and adaptations of farming systems to climate change
- Role of integrated modelling – frameworks and progress made in IAM of adaptation options
- Results from the MACSUR integrated regional assessments
- The way ahead

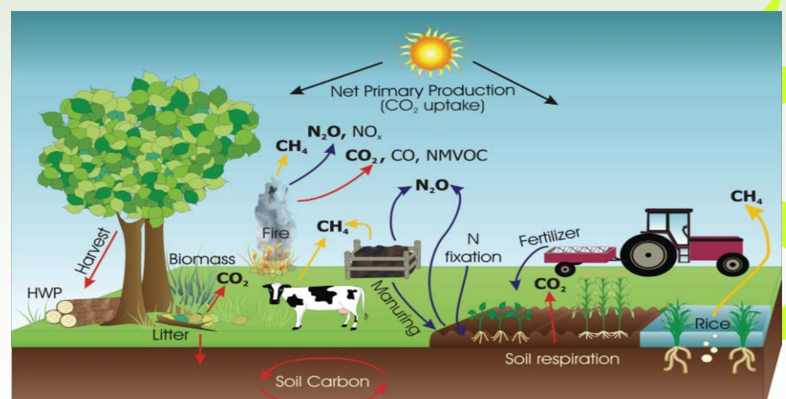
Challenges

⇒**Food and Nutrition Security**

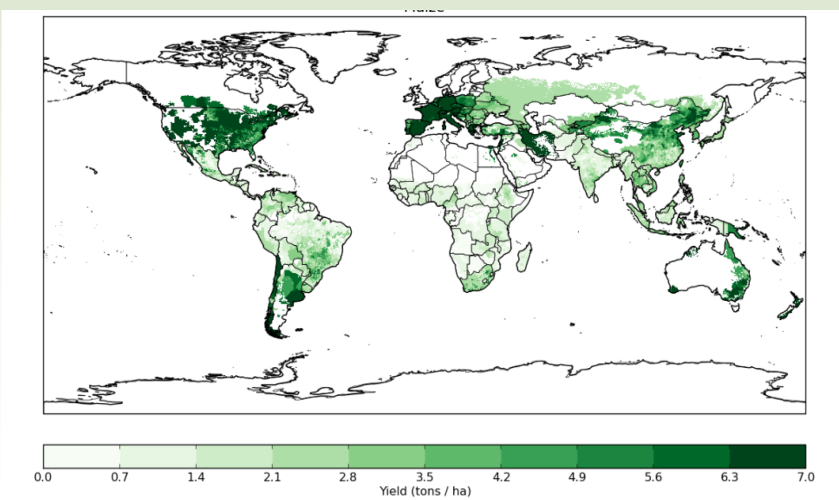
Agriculture's dual role:

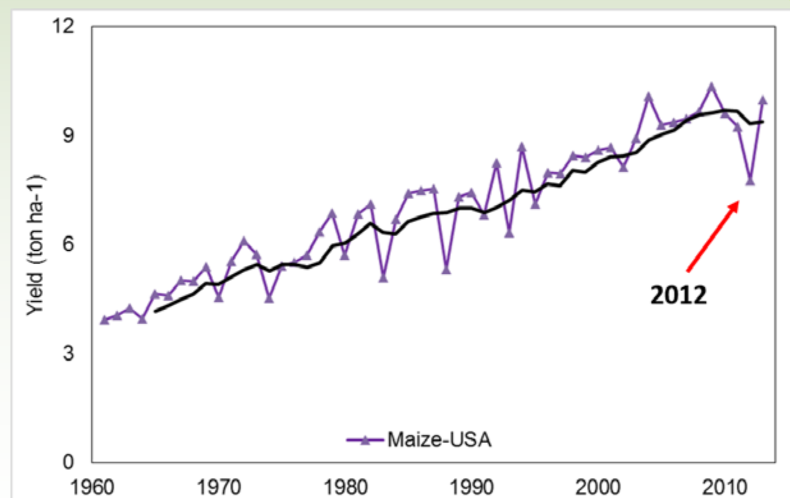
(i) **Being affected by CC**

(ii) **Affecting CC**



Impact of MORE FREQUENT extreme WEATHER MATTERS





CONCEPTS: „Adaptation is an activity that is „CC impact modifying“ *(Lobell, 2014)*

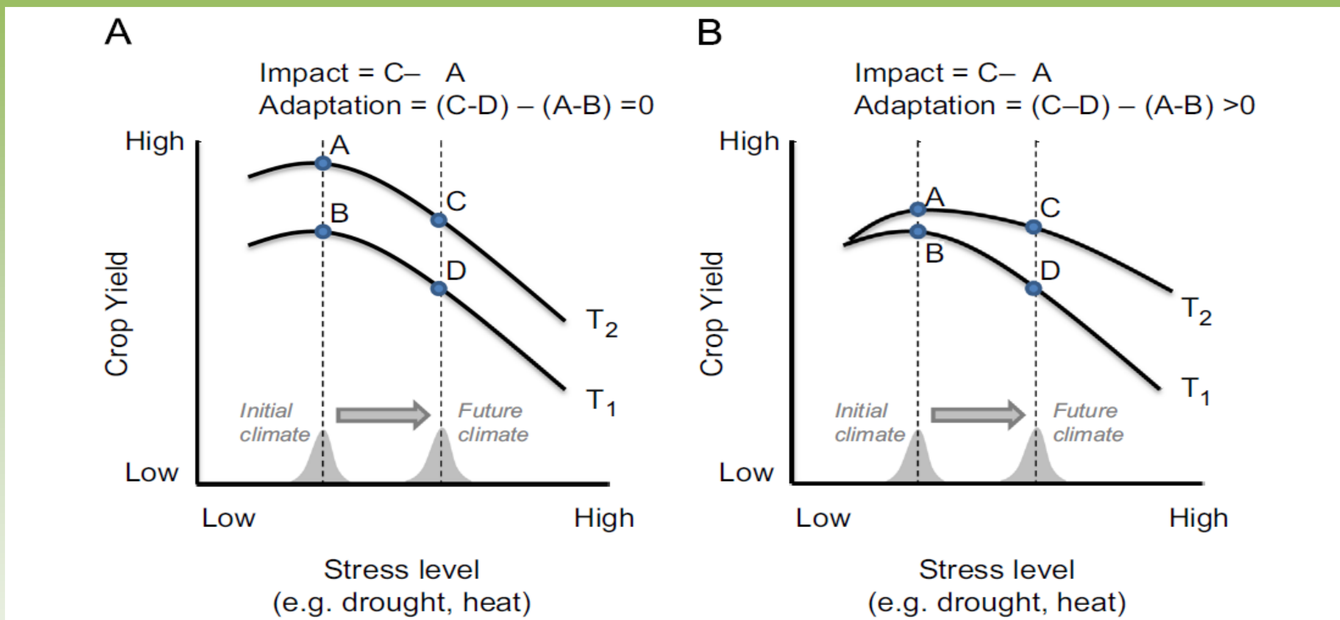


Fig. 1. A schematic of how adaptation should be calculated for new agricultural technologies.

(Lobell, DB, 2014. Global Food Security 3, 72-76)

IPCC definition: „Adaptation is the adjustment in natural and human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities.“

Brief history: On the use of ag models in Climate Change IAV research

- history ag system model use in IPCC reports (1995ff)
- crop simulation models continue to play central role => here both CropM progress & and in IAM is dealt with
- re-vitalization ag modelling in wake of IPCC, AR4 accelerated by AgMIP /MACSUR (2010/11 ff)
- enormous progress & collaboration => yet success in generation new data & model improvement still limited; => little change in focal crops/ag systems & regions

Different approaches to adaptation analysis and planning need to be combined at ”regional” level

Also called:
projection - based /top down

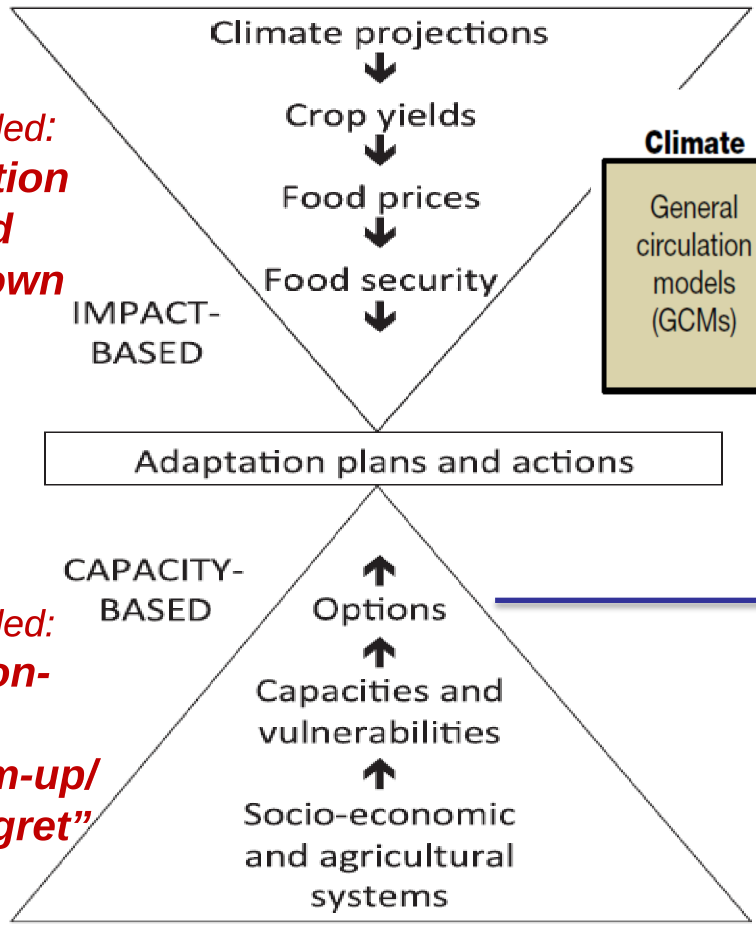
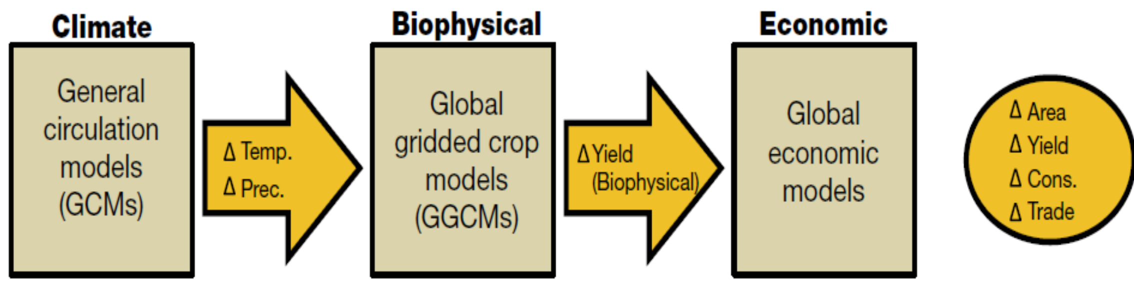


Fig. 1. Impact and capacity approaches to adaptation planning.

Also called:
decision-based /bottom-up/ ”no regret”

Source: Vermeulen et al, 2013, PNAS

AgMIP and MACSUR (EU-wide)

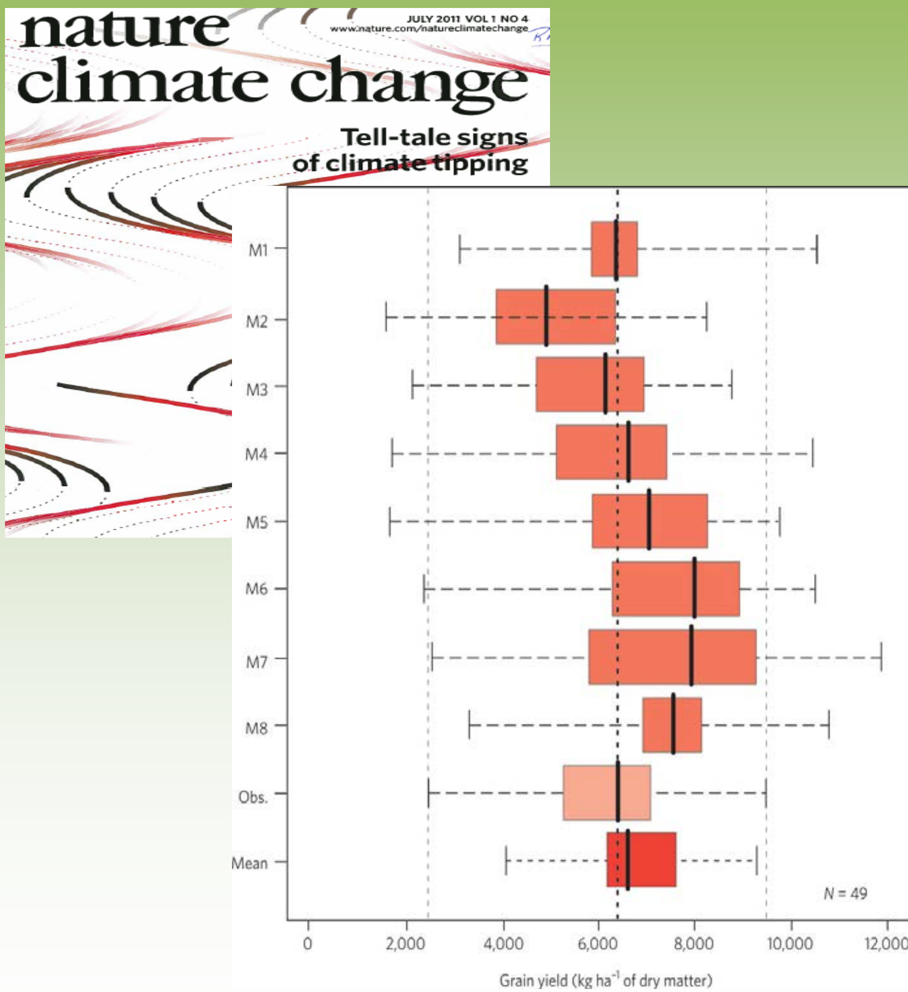


Source: Nelson et al., 2014 PNAS

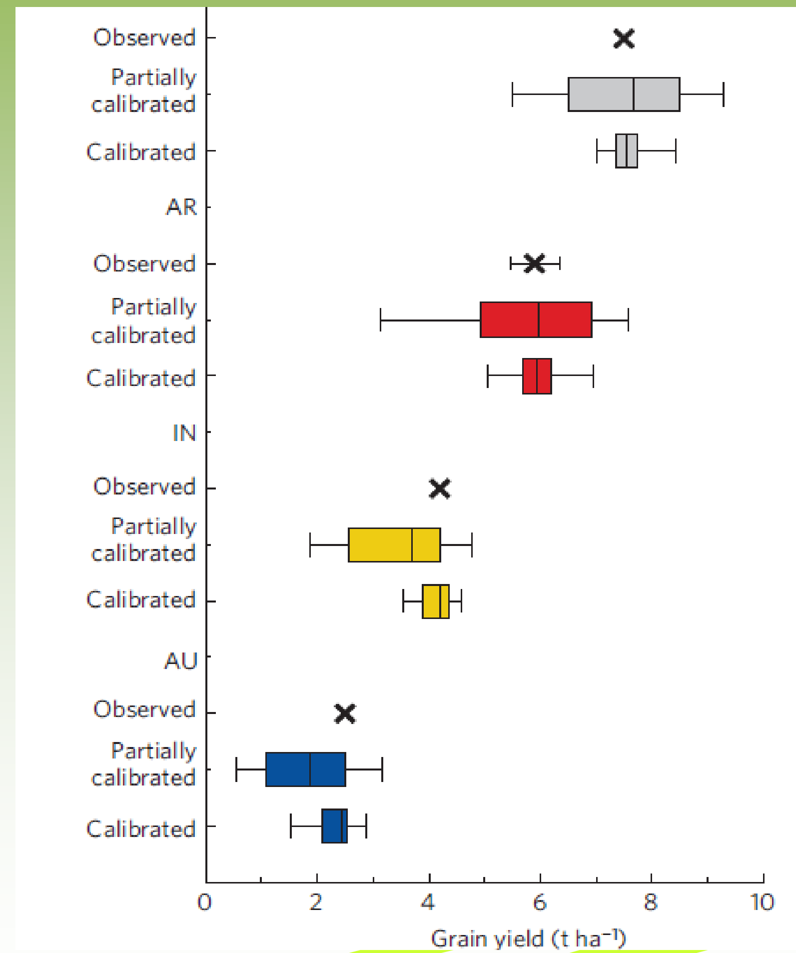
CCAFS and MACSUR (regional pilots)

Model intercomparison and improvement

COST 734 (blind test, curr. climate); AgMIP wheat (partially & fully calibrated, curr. & future)



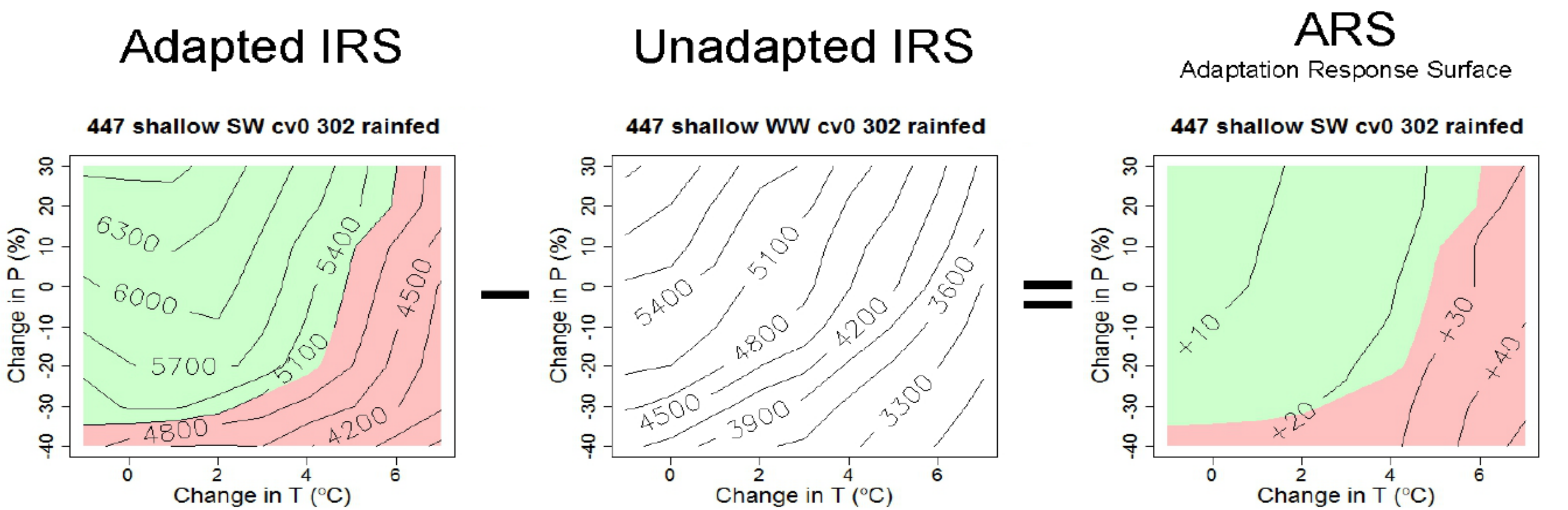
Source: Rötter et al., Nature Clim. Change 1, 175-177 (2011)

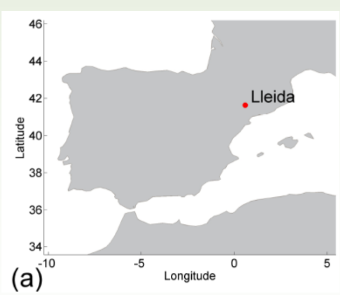


Source: Asseng et al., Nature Clim. Change 3, 827-832 (2013)

IRS2 Study- Results for wheat at Lleida/ES

Construction of Adaptation Response Surfaces



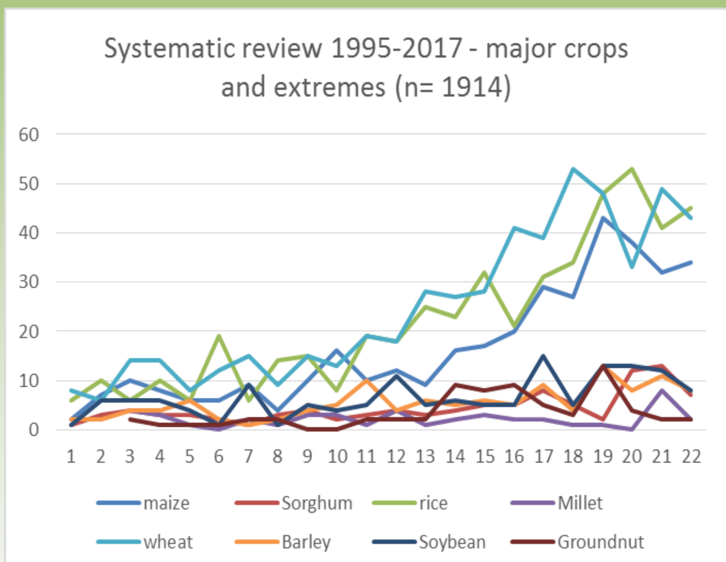


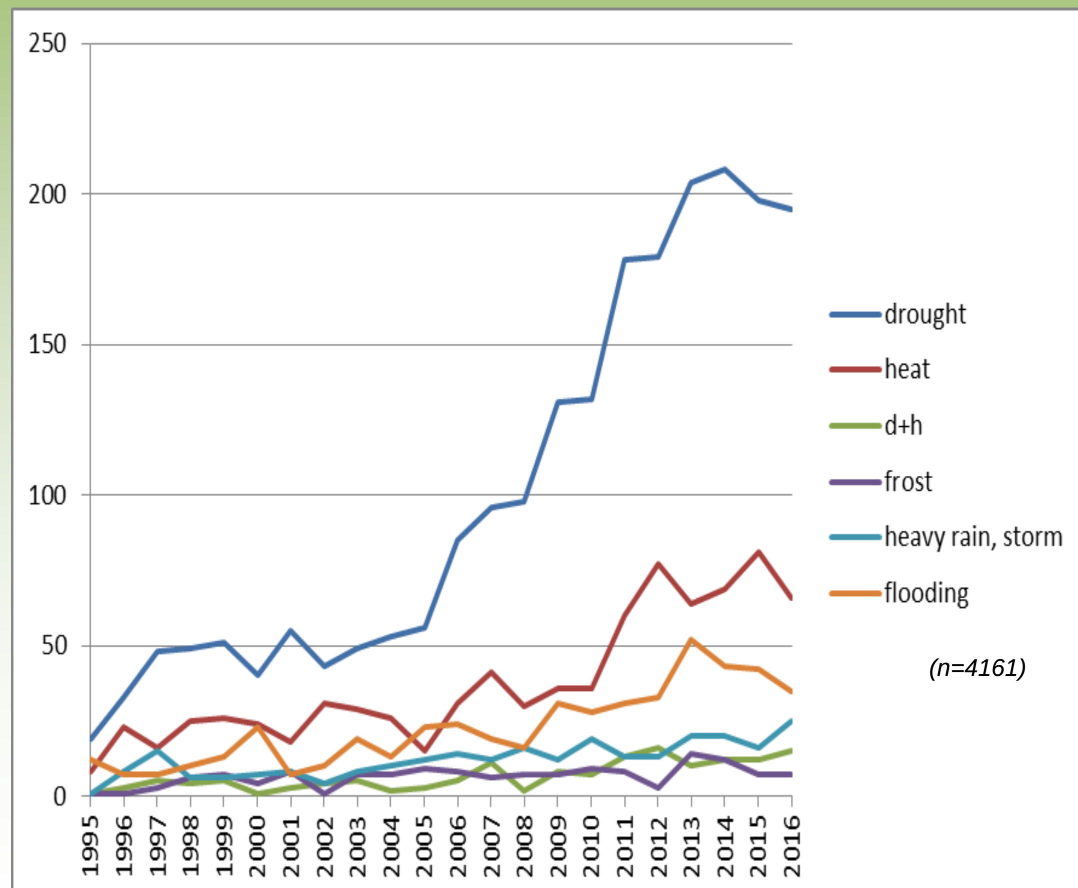
Example of adaptation response surface (ARS) construction. An ARS results from subtracting two impact response surfaces (IRSs): one considering the adaptation to be evaluated (here using spring wheat), and the other the standard, unadapted option. In this case, the isolines of yield in the IRSs are in kg ha^{-1}, while the results in the ARS are expressed as % of change from the unadapted option. Both IRSs correspond to the same [CO_2] (here 447 ppm) and the same soil

Source: Ruiz-Ramos et al., 2017. Agric Syst SI

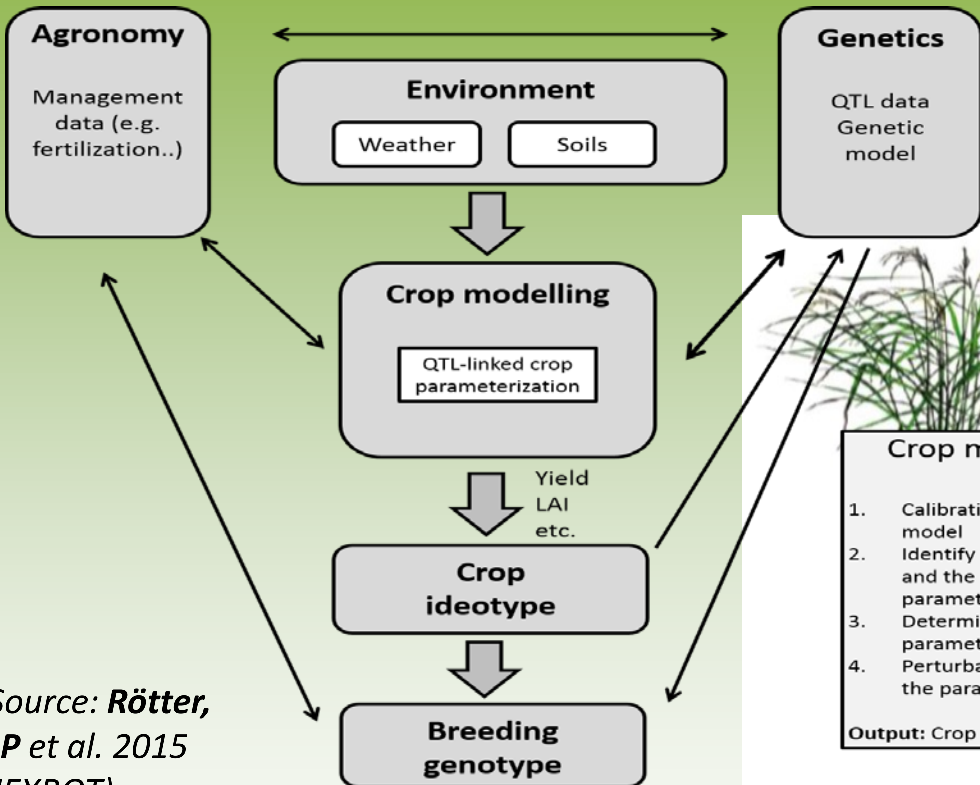
SHORTCOMINGS: imbalances in the modelling of EXTREMES, CROPS

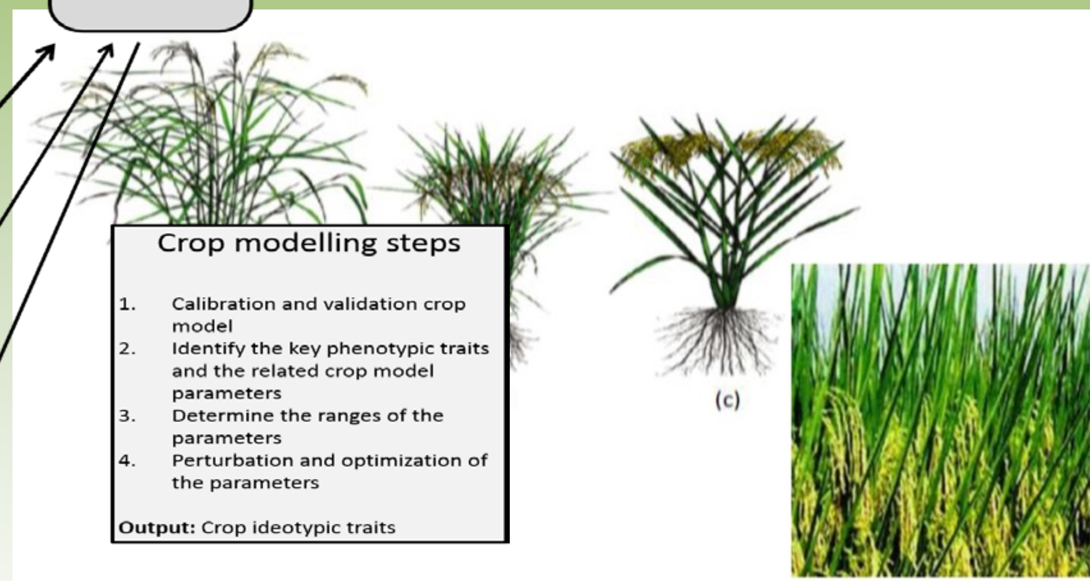
(systematic reviews 1995-2016; FCR SI in prep.)





MODEL-AIDED IDEOTYPING TO ACCELERATE BREEDING





Source: ***Rötter, RP** et al. 2015 (JEXBOT)*

- ⇒ **Method development model-aided ideotyping**
- ⇒ **More efforts to implement it with comprehensive exp. data in practice (CLIMBAR, IMPAC^3)**

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ELSEVIER

Designing future barley ideotypes using a crop model ensemble

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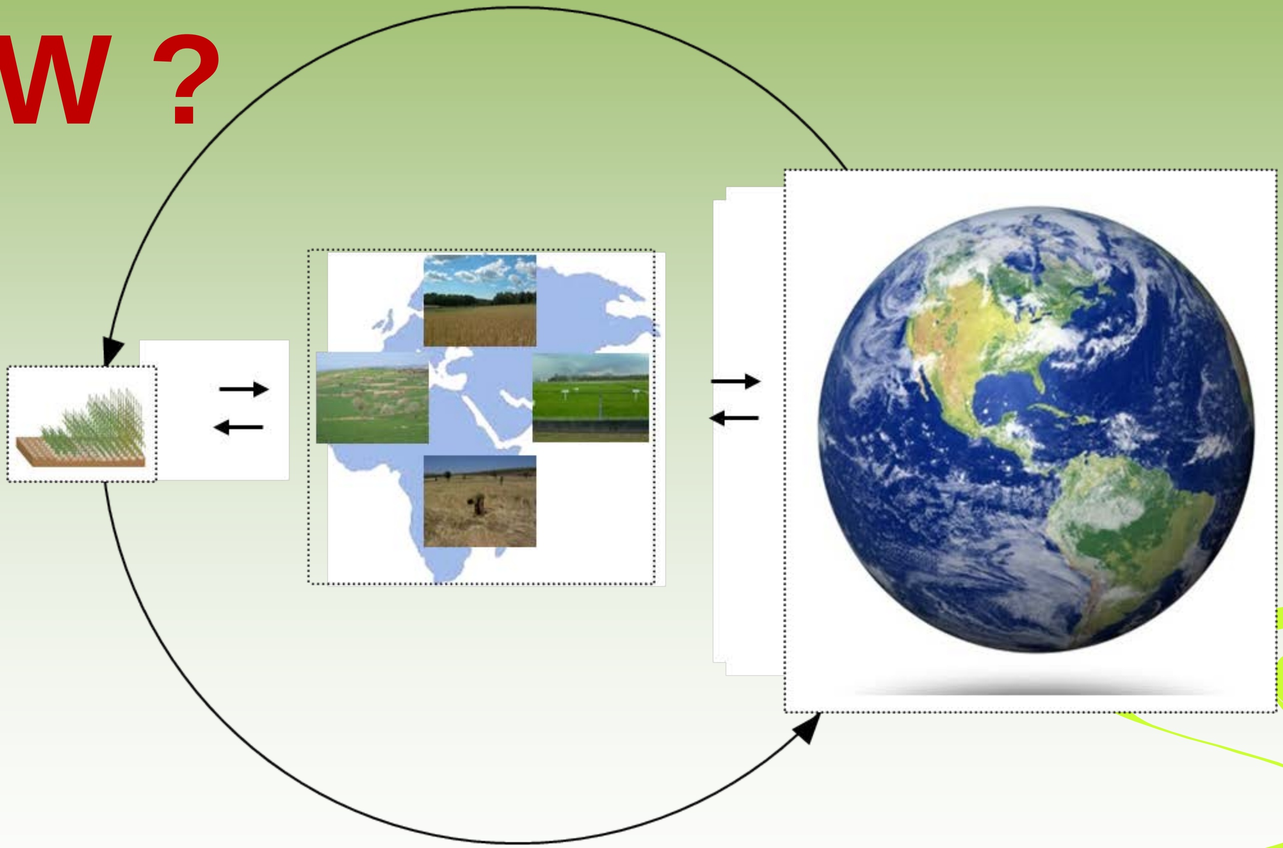
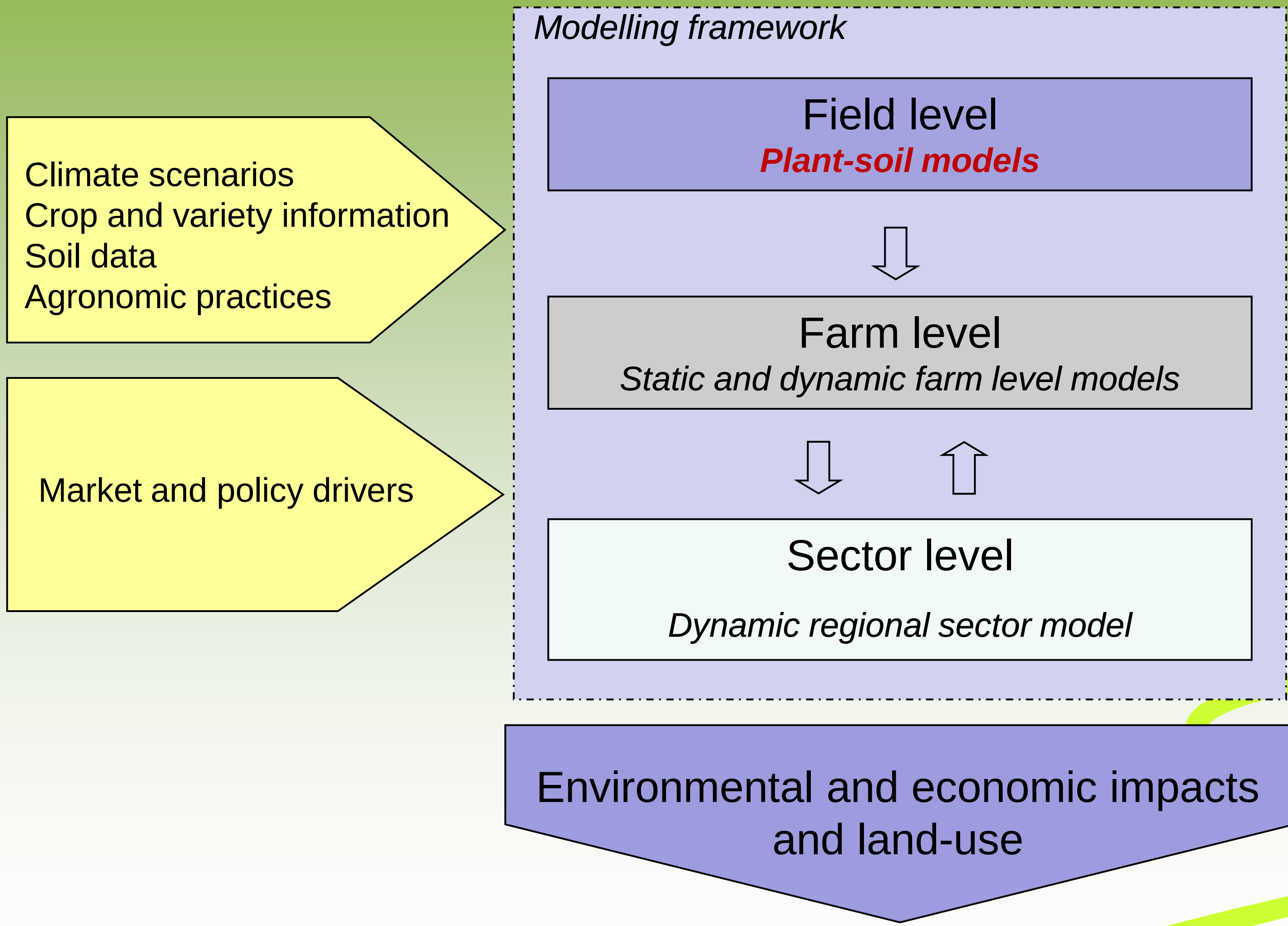
2. Role of integrated modelling – frameworks and progress

Integration /IAM from farm to global: Multi-scale, integrated and iterative analysis

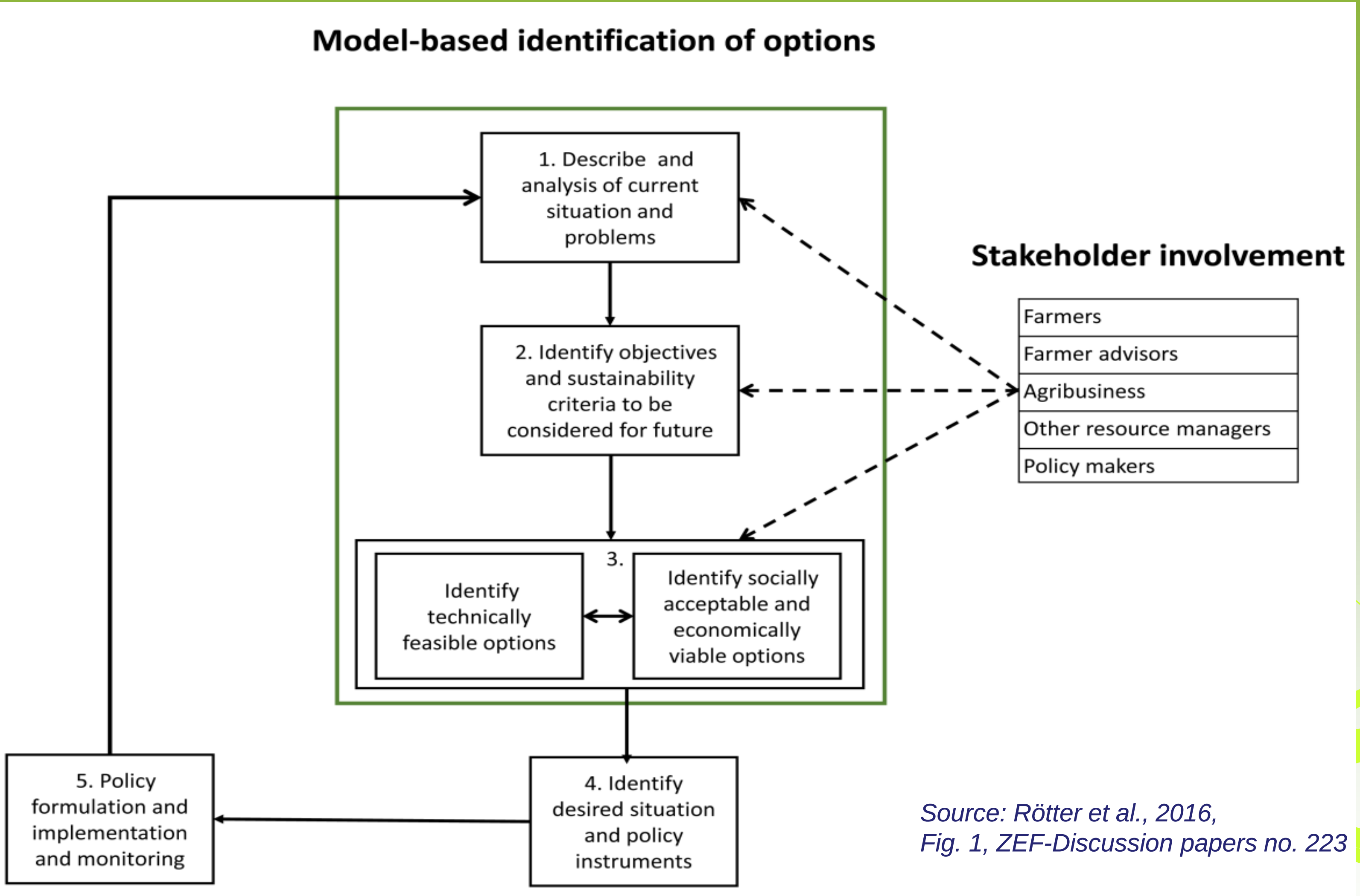
HOW ?



Frameworks for multi-scale IAM



Lehtonen et al. 2010. JAS



Source: Rötter et al., 2016,
Fig. 1, ZEF-Discussion papers no. 223

Fig. Part of the development cycle of policies for natural resource and land use management incl. CC adaptation and mitigation (steps 1-3 in the green box) supported by agricultural system modelling studies and stakeholder interaction (modified from van Ittersum et al., 2004).

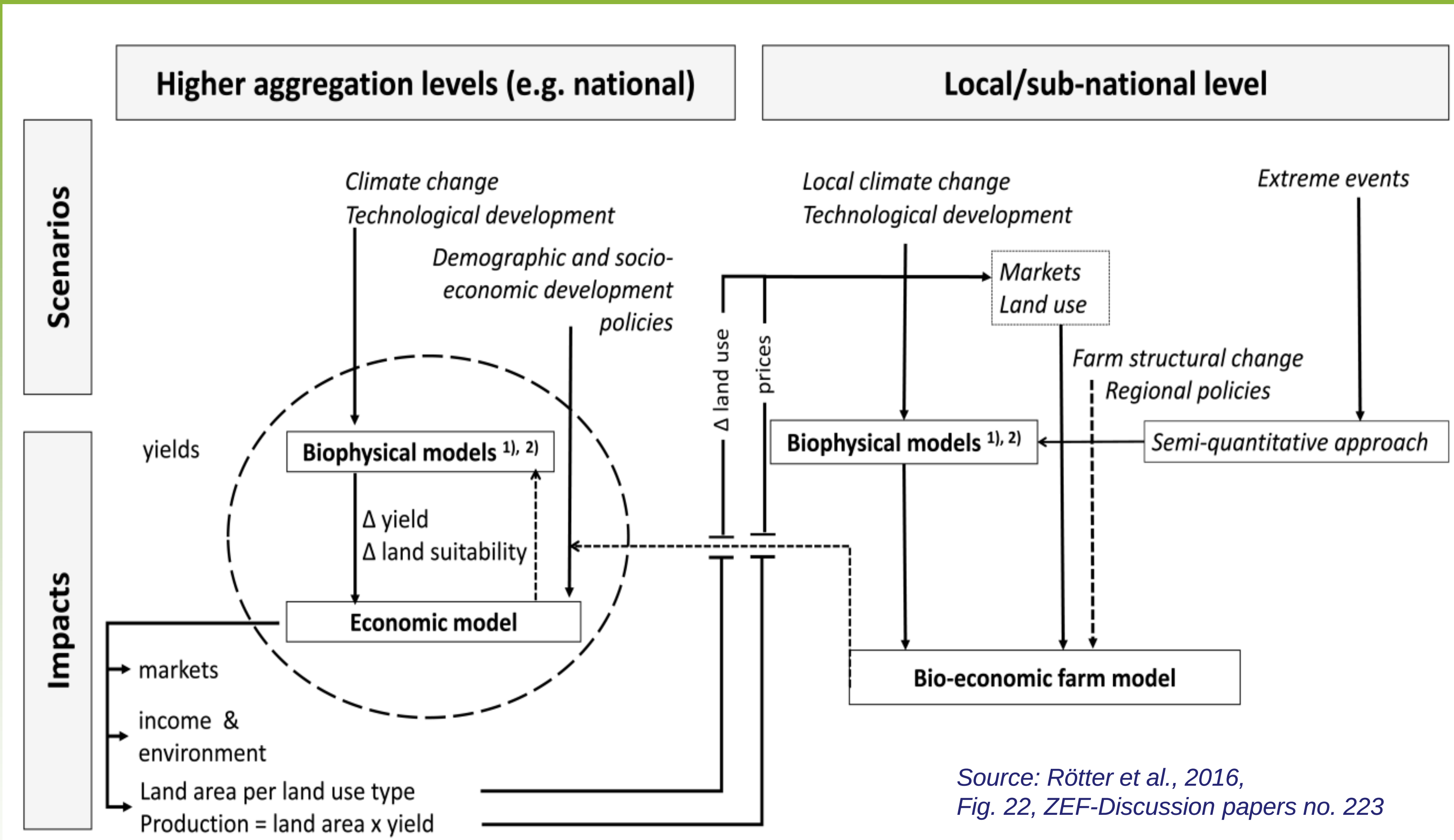
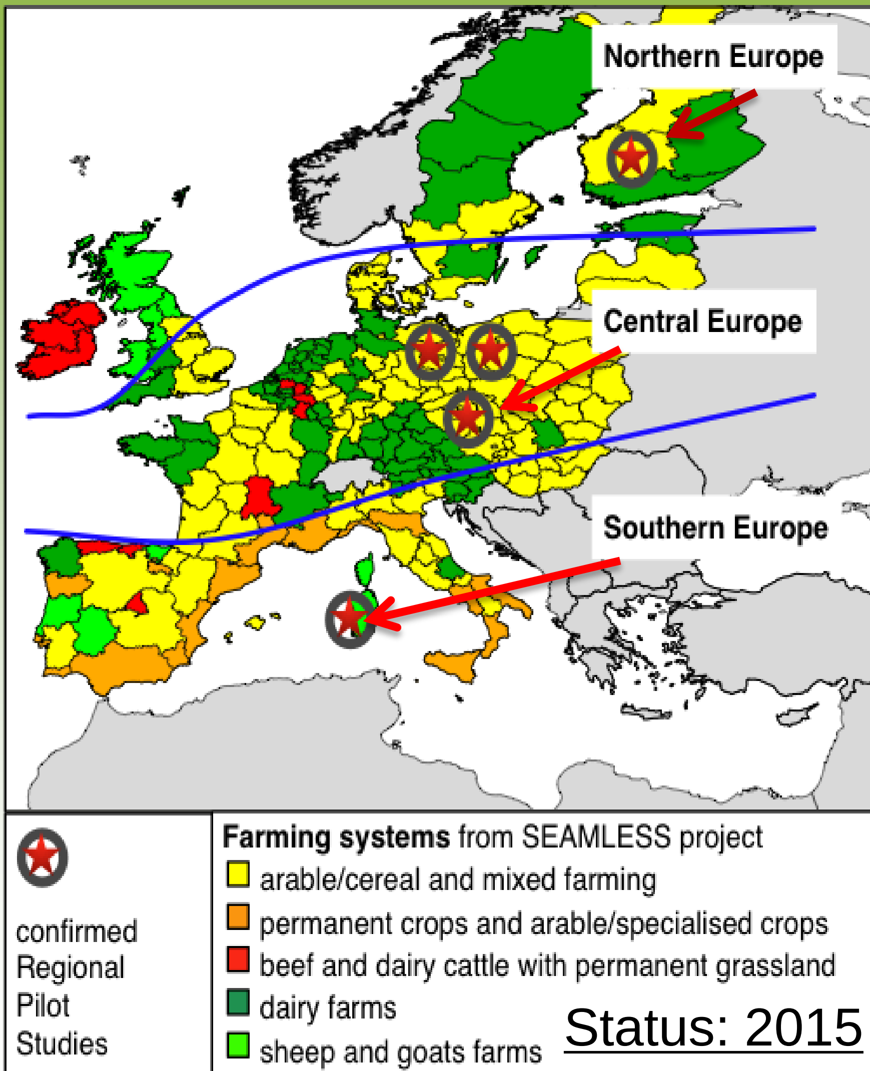
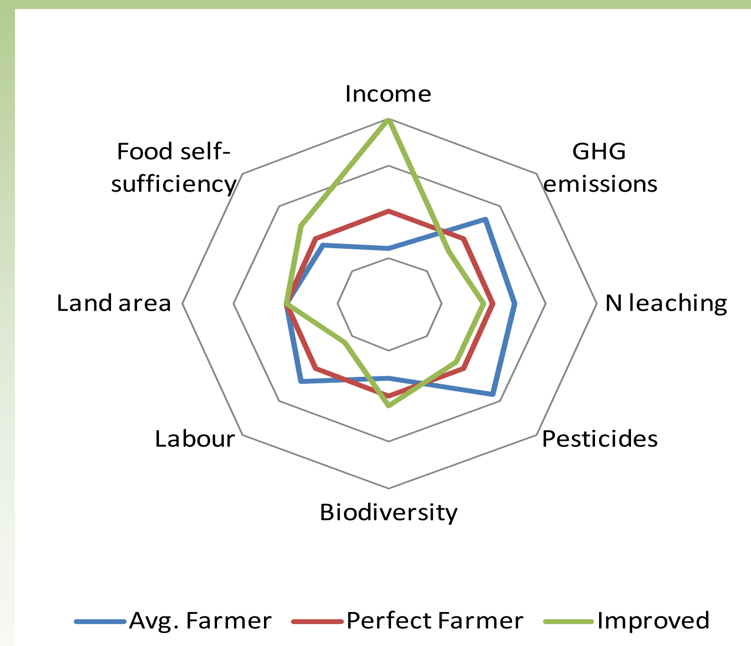


Fig. Generic framework for multi-scaling modelling of adaptations / technological innovations in agriculture – 1. Biophysical models comprise mainly crop models (process-based as well as empirical statistical models), livestock models and models on estimating specific environmental impacts of the agricultural production process 2. Another application type of biophysical modelling focuses on spatially assessing land suitability for different agricultural production activities – these can be conventional semi-quantitative land evaluation tools, or simple biophysical models for land resources assessment (e.g. AEZ method by Fischer et al. 2005). **Modified from Reidsma et al., 2015, published under Creative Commons Attribution 3.0 Unported (CC-BY) license.**

MACSUR Regional Pilots Studies IA adaptations



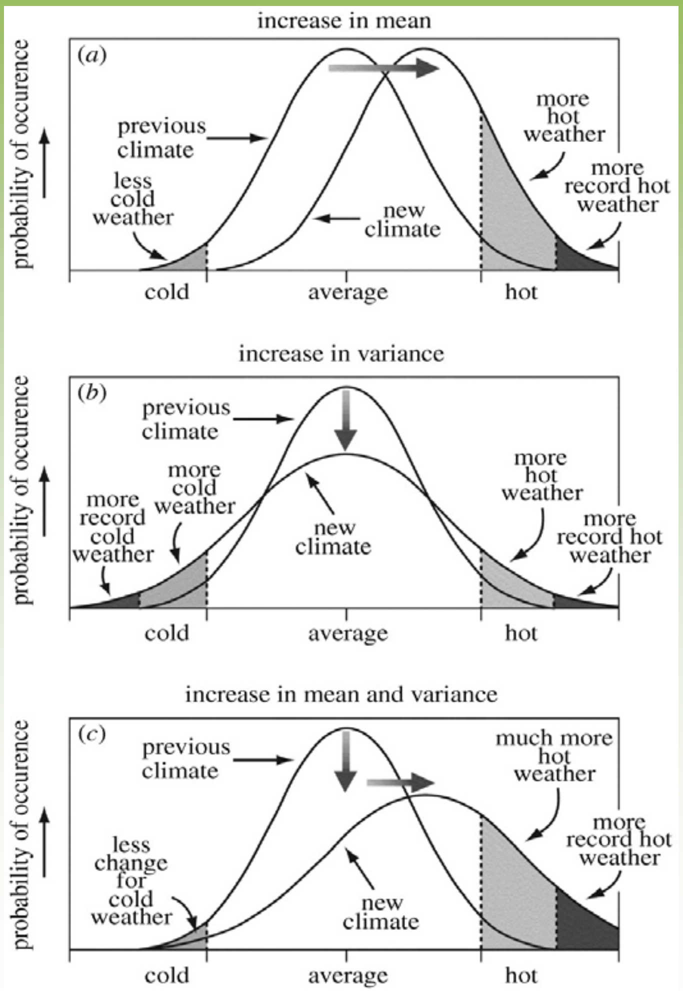
Multitude of appoaches – one direction is upscaling from ***farm level*** (for typical farm types) of mitigative adaptation options via region/national to supra-national scales – also taking into account other Sustainable DevGoals

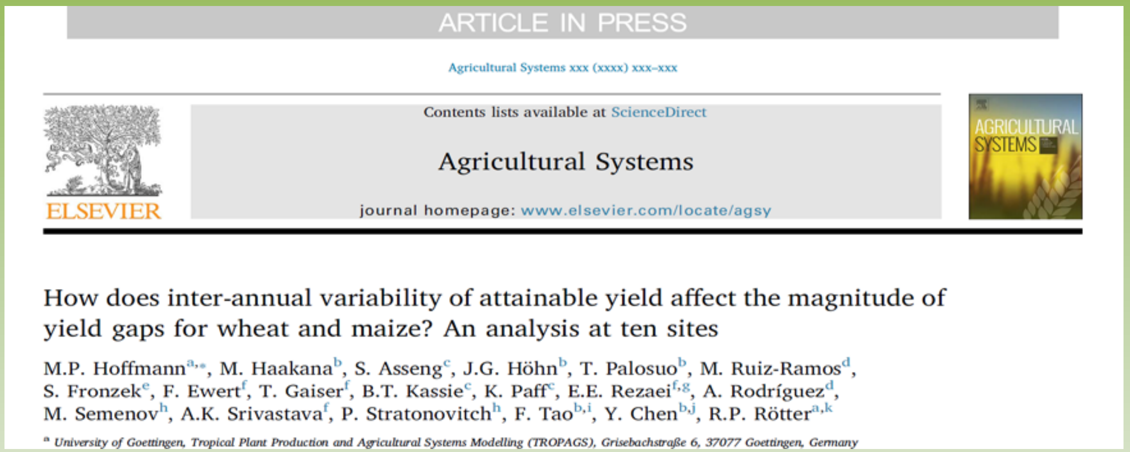


Qualitative illustration goal achievement under alternative management *(not all S-Indicators implemented yet in Macsur pilots)*

> 15 regional pilots by end 2016

EFFCTS OF CLIMATE CHANGE (MEANS & VARIABILITY), CO2 AND MANAGEMENT ON MAIZE & WHEAT PRODUCTION





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ELSEVIER

How does inter-annual variability of attainable yield affect the magnitude of yield gaps for wheat and maize? An analysis at ten sites

M.P. Hoffmann[a,*], M. Haakana[b], S. Asseng[c], J.G. Höhn[b], T. Palosuo[b], M. Ruiz-Ramos[d], S. Fronzek[e], F. Ewert[f], T. Gaiser[f], B.T. Kassie[c], K. Paff[c], E.E. Rezaei[f,g], A. Rodríguez[d], M. Semenov[h], A.K. Srivastava[f], P. Stratonovitch[h], F. Tao[b,i], Y. Chen[b,j], R.P. Rötter[a,k]

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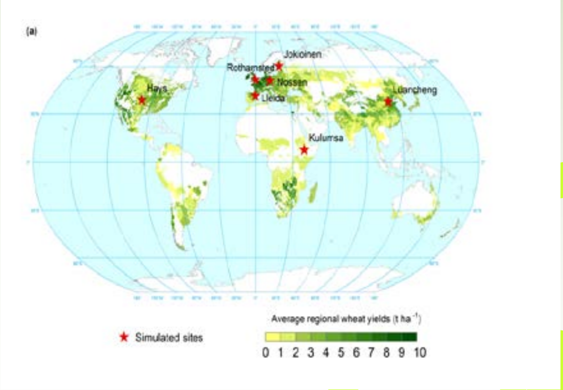
AgMIP-MACSUR - YGV wheat &maize: how do future climate variability/ change and TIs affect crop yields and yield gaps? (*source:* ***Hoffmann, MP.,*** *et al,AgSystems SI, in press)*

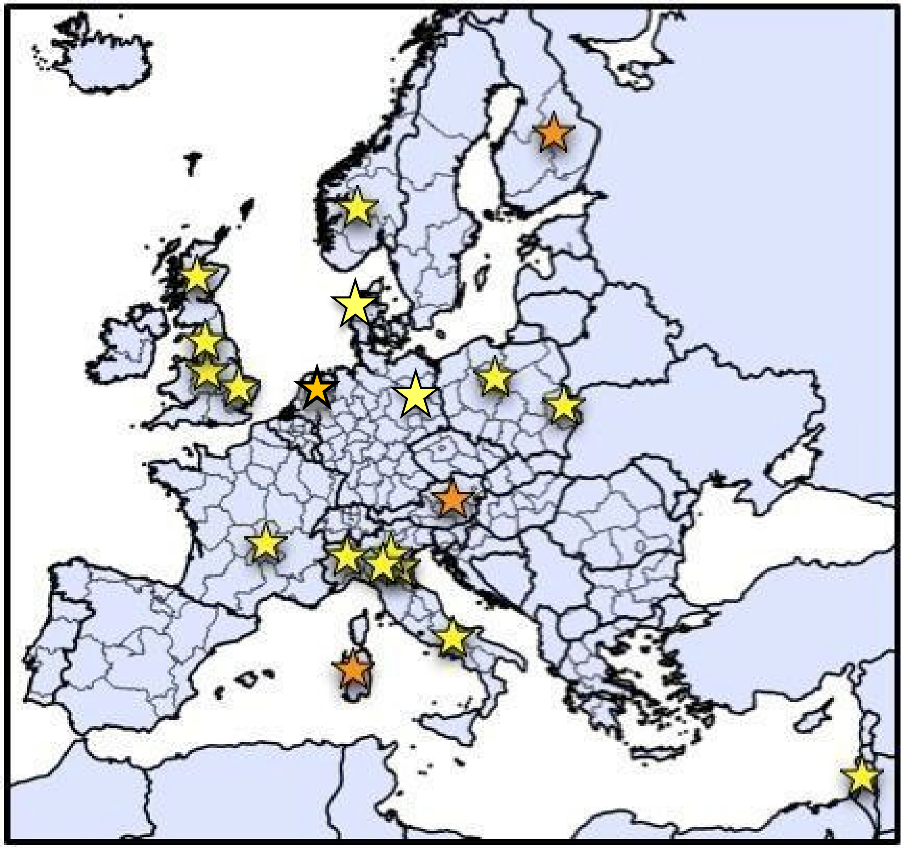


Left: Schematic on effects for T changes

(Source: Porter & Semenov, 2005 adopted from IPCC 2001).

Results from the MACSUR integrated regional assessments

Regional case studies



Finland: Northern Savo
Austria: Mostviertel
Italy: Oristano, Sardinia
Germany: Brandenburg
Netherlands: Flevoland

Focus: 2020, 2030, 2050

Integration of models; participation of regional and national stakeholders

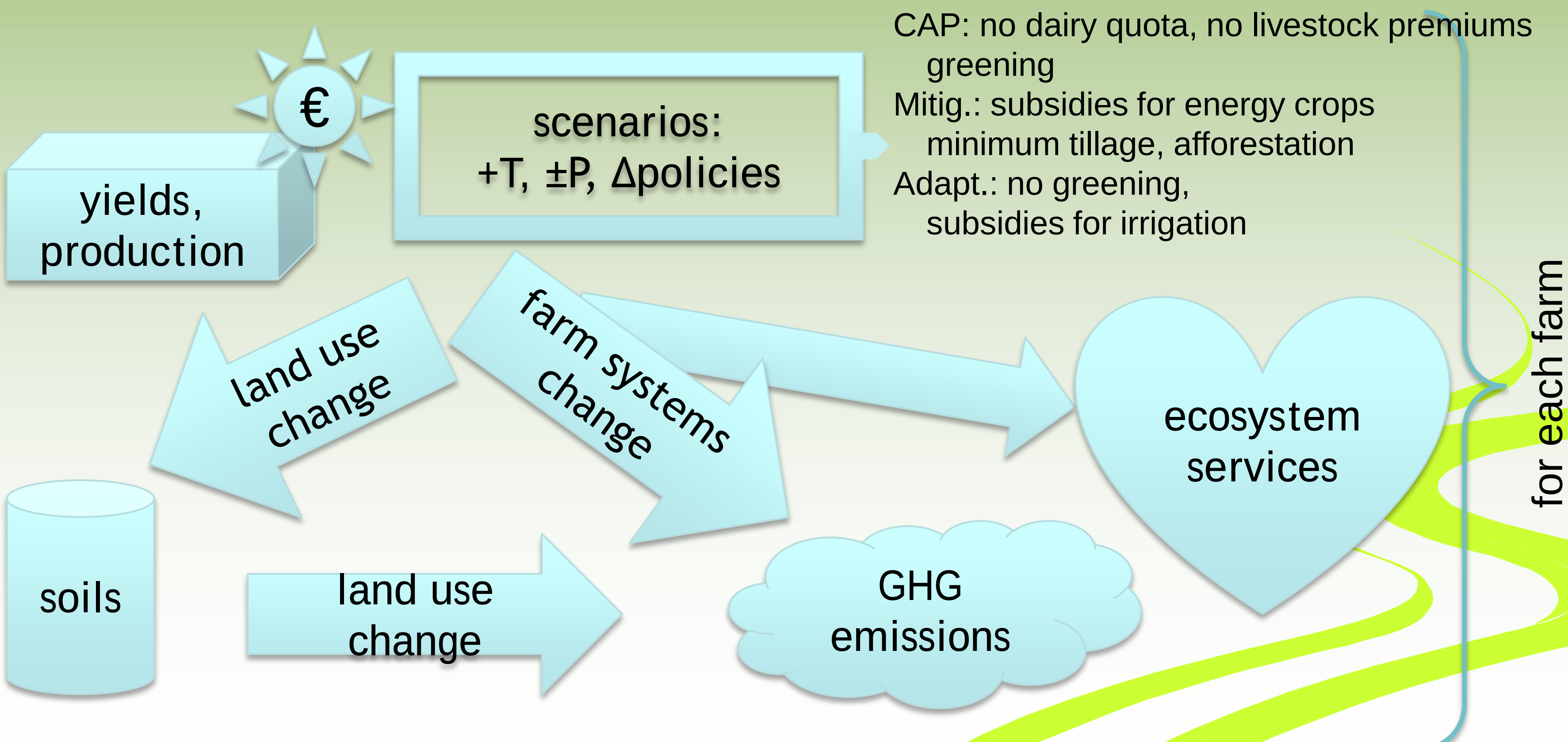
Northern Savo, Finland

- Observed climate change
  - longer growing period, higher mean temperatures, more total rain
  - greater variability, summer droughts, less snow cover, feed quality losses, wet conditions more frequent ⇒ soil compaction by machines
- adaptation in cultivars, fertilization, pest mngmt.,farm machinery, drought risk mngmt, silage storage, crop rotations, sowing dates
- Increasing grass growth benefits dairy and beef
  - limited by EU N directive, greening rules; national land buying regulations
- Increase in yield potential of cereals and oilseeds is uncertain: more frequent summer droughts, daylight
- Positive market development and more flexible and encouraging policies (N, land) needed for adaptation

Mostviertel Austria

S: dairy, orchards

N: cereals



Methods and Data

Input

natural & socio-economic data

input and output prices
CAP
production functions
farm labor supply
livestock – herd sizes
observed land use
spatially explicit field data
landscape elements
climate scenarios
topography
soil characteristics

Models

CropRota

Crop rotations

EPIC

Crop yields

CALDIS VÂTIS

Timber yields

FAMOS[space]

Max. gross margin*

Output

socio-economic & RD indicators

farm gross margin
public budget spending
farm labor demand
landscape diversity & appearance

agri-environmental indicators

agric. & forestry land use change
biodiversity
SOC
soil sediment loss
N & P nutrient balances
GHG emissions

food production indicators

crop & livestock production

+ product sales (plant, livestock) + subsidies + annuities for long-term investment
– variable costs (machinery, inputs and services, off-farm labor)

Mostviertel
Austria

- Impacts from policy scenarios > CC impacts
- Farmers may benefit from climate change, although effects seem to be mixed for farmers specialized in crop production
    - not everyone is a winner
- CC-induced intensification of land by removing landscape elements and increasing use of fertilizers
- Productivity gains from climate change will increase the payment level at which farmers accept compensations in environmental programs

Sardinia, Italy

dairy *extensive grazing* *vegetables* *cereals (rice), forage*

- –30% rainfall, $\Delta\bar{T}$ = +1 K in 2030
  - Yields of forage crops are reduced,
    ⇒ notable income drops for livestock farming.
  - Rain-fed hill sheep farming under threat of abandonment
- Irrigation costs increase in regions with volumetric water pricing; use and salinization of groundwater will increase elsewhere
- More heat waves will affect welfare, milk quality and quantity and mortality of dairy cows
- Higher temperatures during autumn and winter will provide other income opportunities, but farmers need to understand the crop yield changes

Net income per farming system typology

Farming system type	2000-10 (M€)	2020-30 (Δ%)
Rice	4	**+9.9**
Vegetables - Cereals	19	-0.8
Cereals - Forages	8	**+1.4**
Cattle A	26	**-5.1**
Cattle B	7	**-5.9**
Sheep A	2	**-5.3**
Sheep B	2	**-11.8**
Sheep C	4	**-7.4**
Other	4	+0.1

Result of stakeholder involvement: The dairy cattle coop is developing a new win-win pathway linking hi-input dairy cattle farming with low input beef cattle grazing systems

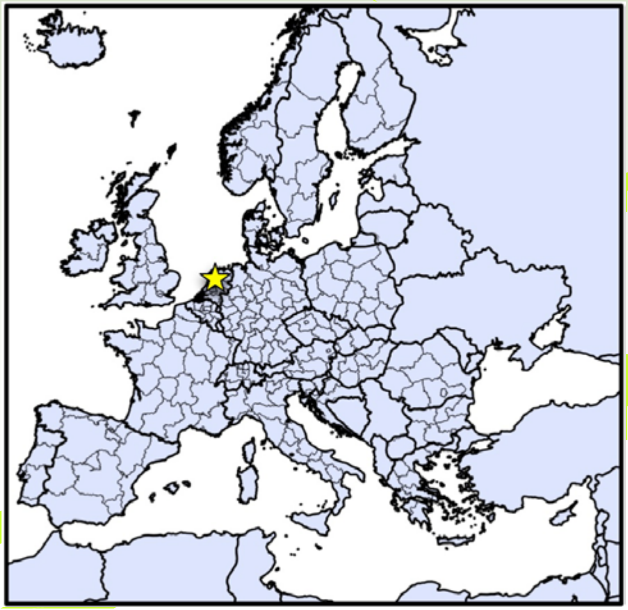
Brandenburg, Germany




- Climate change may aggravate water stress for plant growth
- Rising prices for agricultural commodities can make irrigation profitable
- Irrigation may reduce seasonal variations of crop yield and may increase crop yields by up to 40% for maize and up to 20 % for wheat and sugar beat

Flevoland, Netherlands

- Impact of CC
  - based on multiple GCMs (Van der Hurk et al., 2006)
  - Crop modeling based on WOFOST 7.1
    - Wolf et al. 2012, 2015
  - Economic modeling based on FSSIM 2.0 (farm or farm type)
    - Kanellopoulos et al., 2014; Wolf et al., 2015)
  - CAPRI (Europe)
  - FarmDesign (farm) (Mandryk et al., 2017
- Under CC scenario:
  - area used for wheats will increase
  - yield changes
    - sugar beet (+6-+33%), potato (-3-+22%),
    - wheat (+5-+20%), onion (-1-+44%)



The Way Ahead

Approach

- Prepare for 2030 targets, and test options for European agriculture to be climate neutral by 2050
- Cross-sectoral, with more climate and water focus (e.g. establish interaction with JPI Climate; JPI Water)
- Link spatial scales: regional – national – continental – global
- Multi case study method
  - Consistent case studies
  - Upscaling to European level

‘Surprising’ scenarios - biophysics

A 1984 workshop already emphasized that the oceans are a major source of uncertainty, including North Atlantic Deep Water Formation.

A reduction of deep water formation could cause European regions to become colder.

This will require knowledge on extreme climate events, including sudden shifts in temperatures and rainfall.

How to address ‘tipping points’’ in agricultural modelling?

‘Surprising’ futures – socio-economic

Low energy prices seem to run parallel to energy saving.

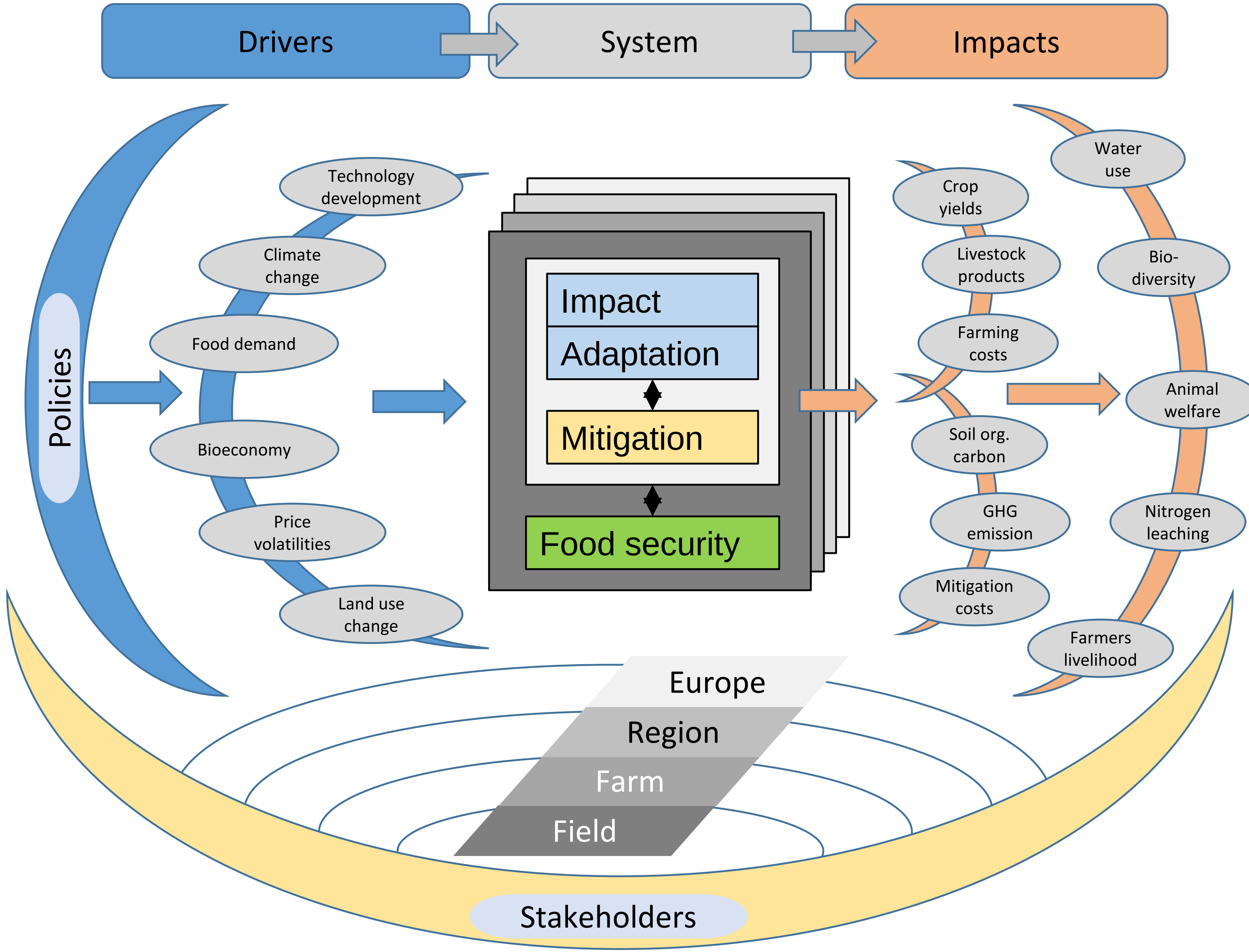
Such counter-intuitive trends require modelling for in-depth understanding, including agricultural problems.

What are the options for European agriculture to cope with diversifying consumption patterns?

How are sustainability concerns in agriculture affected by climate change?

Prepare for

- adaptation to climate uncertainty and variability, as well as the synergy with mitigation
- evaluate those options in terms of their capacity in achieving climate-smart farming systems



Drivers
System
Impacts
Policies
Technology development
Climate change
Food demand
Bioeconomy
Price volatilities
Land use change
Impact
Adaptation
Mitigation
Food security
Crop yields
Livestock products
Farming costs
Soil org. carbon
GHG emission
Mitigation costs
Water use
Bio-diversity
Animal welfare
Nitrogen leaching
Farmers livelihood
Europe
Region
Farm
Field
Stakeholders

THANK YOU!

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