Progress and research gaps in spatial/temporal scaling and coupling of models to support landscape decisions

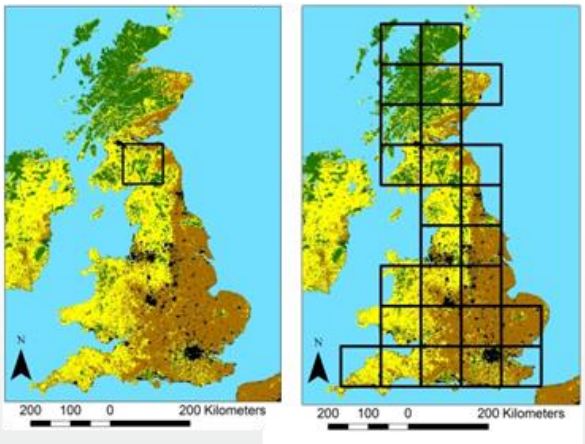
Felix Eigenbrod and Paula Harrison

(with input from many INI Programme participants)

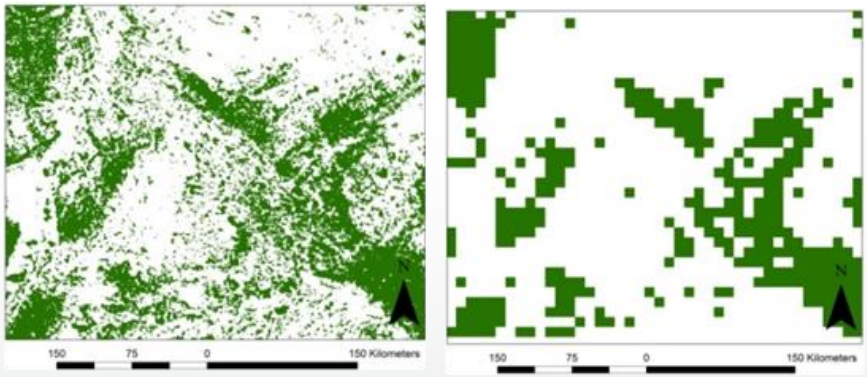
What do we actually mean by ‘scale’?

- Measurement scale – extent and resolution

Spatial Extent



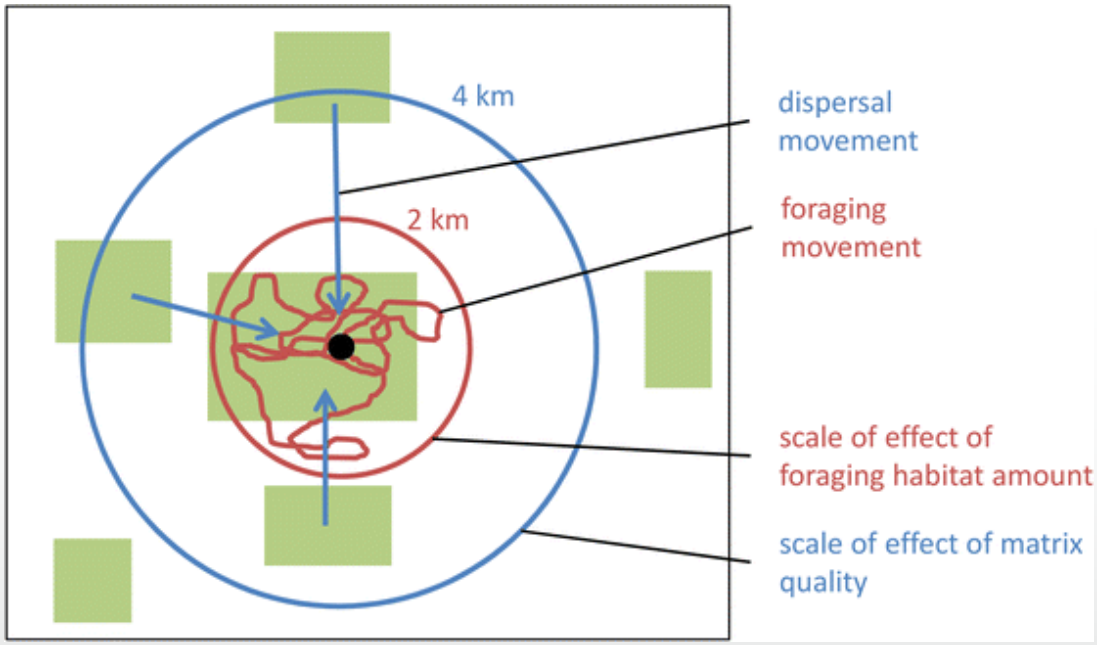
Spatial Resolution



- Can equally apply to time as space

What do we actually mean by scale?

- Phenomenological scale



Miguet et al. 2016, Landscape Ecology

- These are (usually) different from the scale at which landscapes are managed

Why scale is an issue?

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- The Modifiable Areal Unit Problem (MAUP)
  - patterns and therefore processes observed at one scale will vary depending on the scale of observation
  - also statistical relationships and inference will vary
  - This is a problem for one variable; it is an even bigger deal if modelling landscape decision trade-offs

Trade-off

Synergy

Why scale is an issue?

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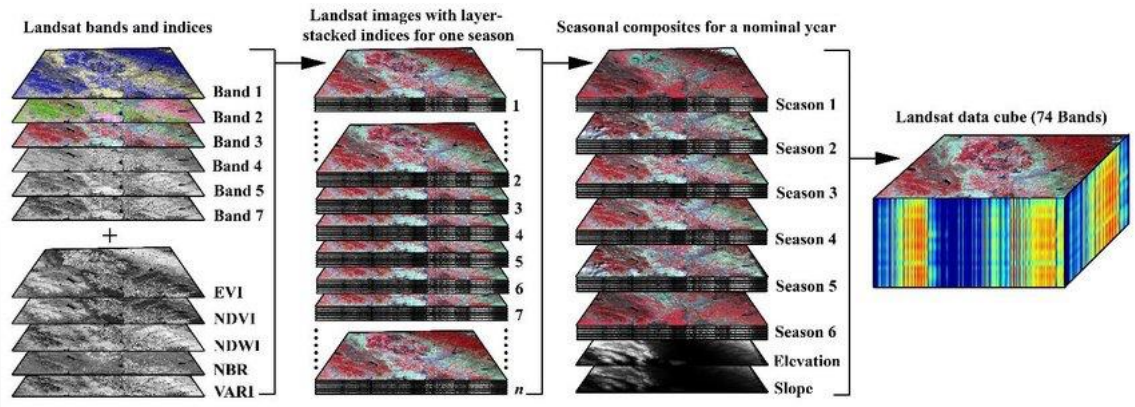
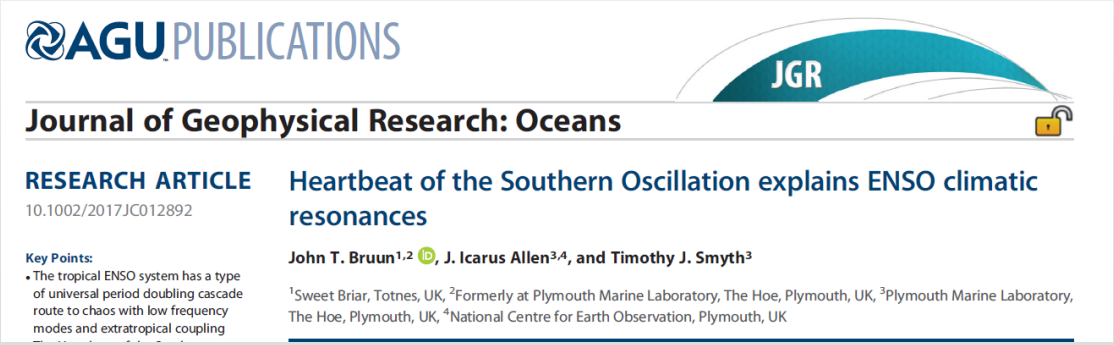
- Given the MAUP, changing spatial scale (upscaling or downscaling the spatial resolution) is tricky
- However, moving between scales is necessary as we are interested in managing things in landscapes that operate at different scales, and that are driven by processes that operate at different scales.
- So – what insights have we made on scale in the last month?

New methods for spatio-temporal scaling

- Dealing with space AND time is even harder, but vital
- But we now have data cubes of remote sensing data…



- And new maths for disentangling spatial and temporal signals from such data (e.g. Dominant Frequency State Analysis)


AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2017JC012892

Heartbeat of the Southern Oscillation explains ENSO climatic resonances

John T. Bruun[1,2], J. Icarus Allen[3,4], and Timothy J. Smyth[3]

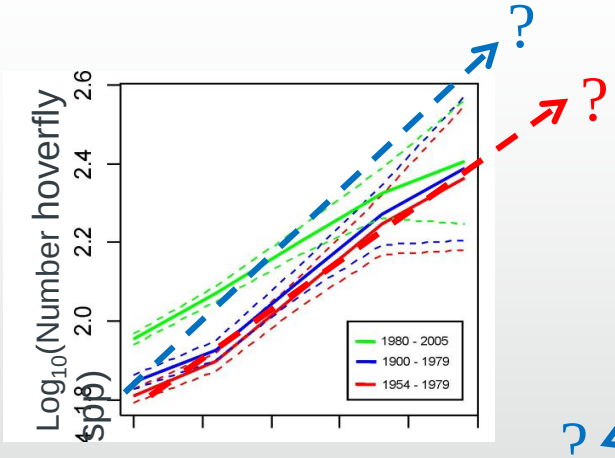
[1]Sweet Briar, Totnes, UK, [2]Formerly at Plymouth Marine Laboratory, The Hoe, Plymouth, UK, [3]Plymouth Marine Laboratory, The Hoe, Plymouth, UK, [4]National Centre for Earth Observation, Plymouth, UK

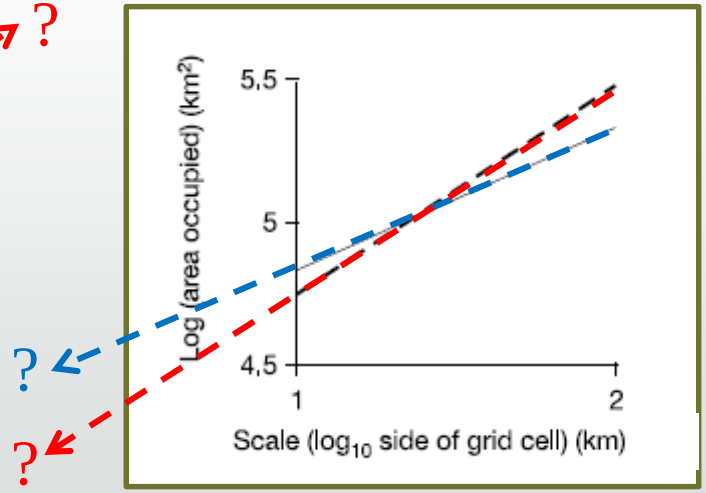
Key Points:

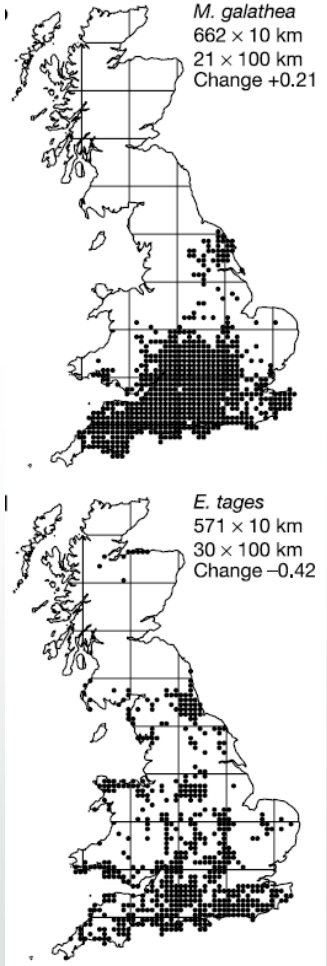
- The tropical ENSO system has a type of universal period doubling cascade route to chaos with low frequency modes and extratropical coupling

Upscaling and downscaling

- Downscaling is important for understanding how to manage biodiversity
- Upscaling biodiversity lets us make broad-scale inferences from detailed field studies

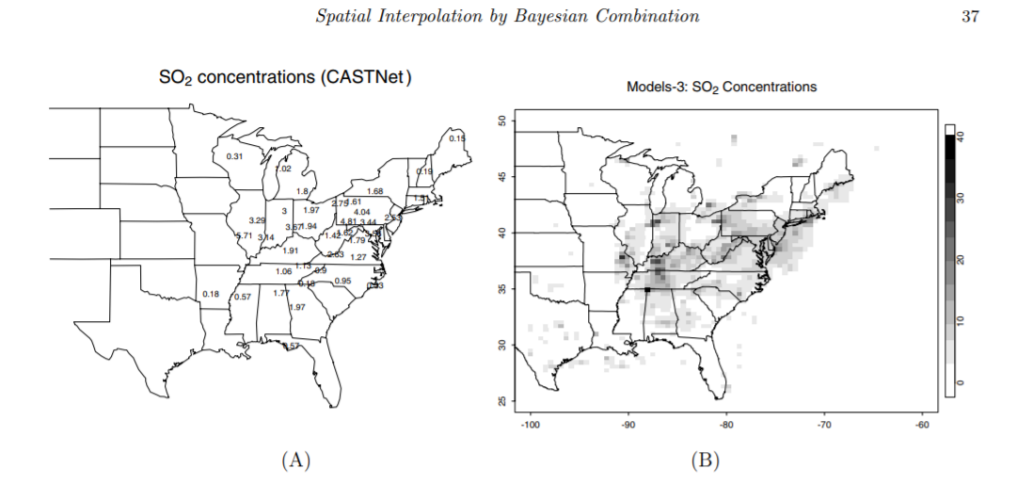






Can we use spatial fusion methods to upscale and downscale?

- Spatial fusion approaches that link point data with gridded continuous surface data (i.e. Bayesian melding) are frequently used in air quality modelling
- Could such approaches be used for upscaling and downscaling biodiversity (and other land services)?



Fuentes & Rafferty, Biometrics, 2005

Can we develop and use universal scaling laws for landscape decisions?

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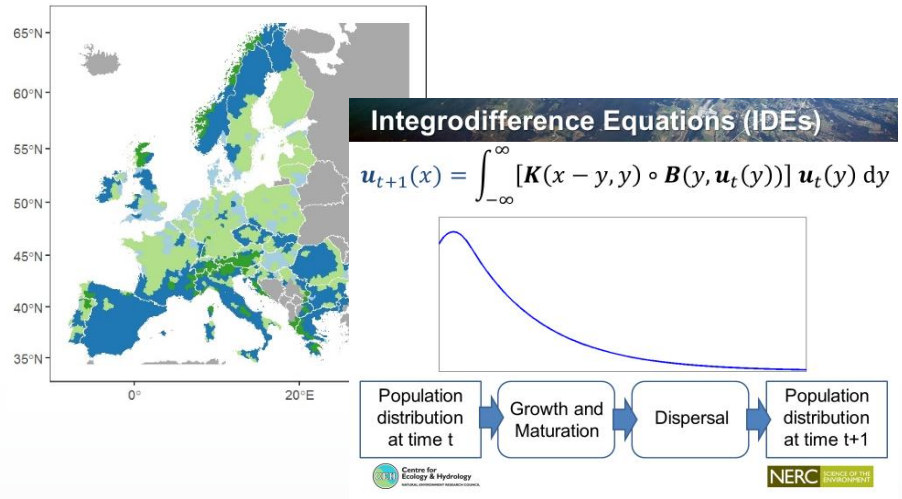
- Can we link scale to movement?
- Can we use maximum entropy to define minimum adequate constraints for modelling land cover?
- Can we use emergent constraints for landscape decisions?



Ecology, 94(10), 2013, pp. 2138–2144

Statistical patterns in tropical tree cover explained by the different water demand of individual trees and grasses

Jason Bertram[1] and Roderick C. Dewar

nature climate change
PERSPECTIVE
https://doi.org/10.1038/s41558-019-0436-6

Progressing emergent constraints on future climate change

Alex Hall[1*], Peter Cox[2], Chris Huntingford[3] and Stephen Klein[4]

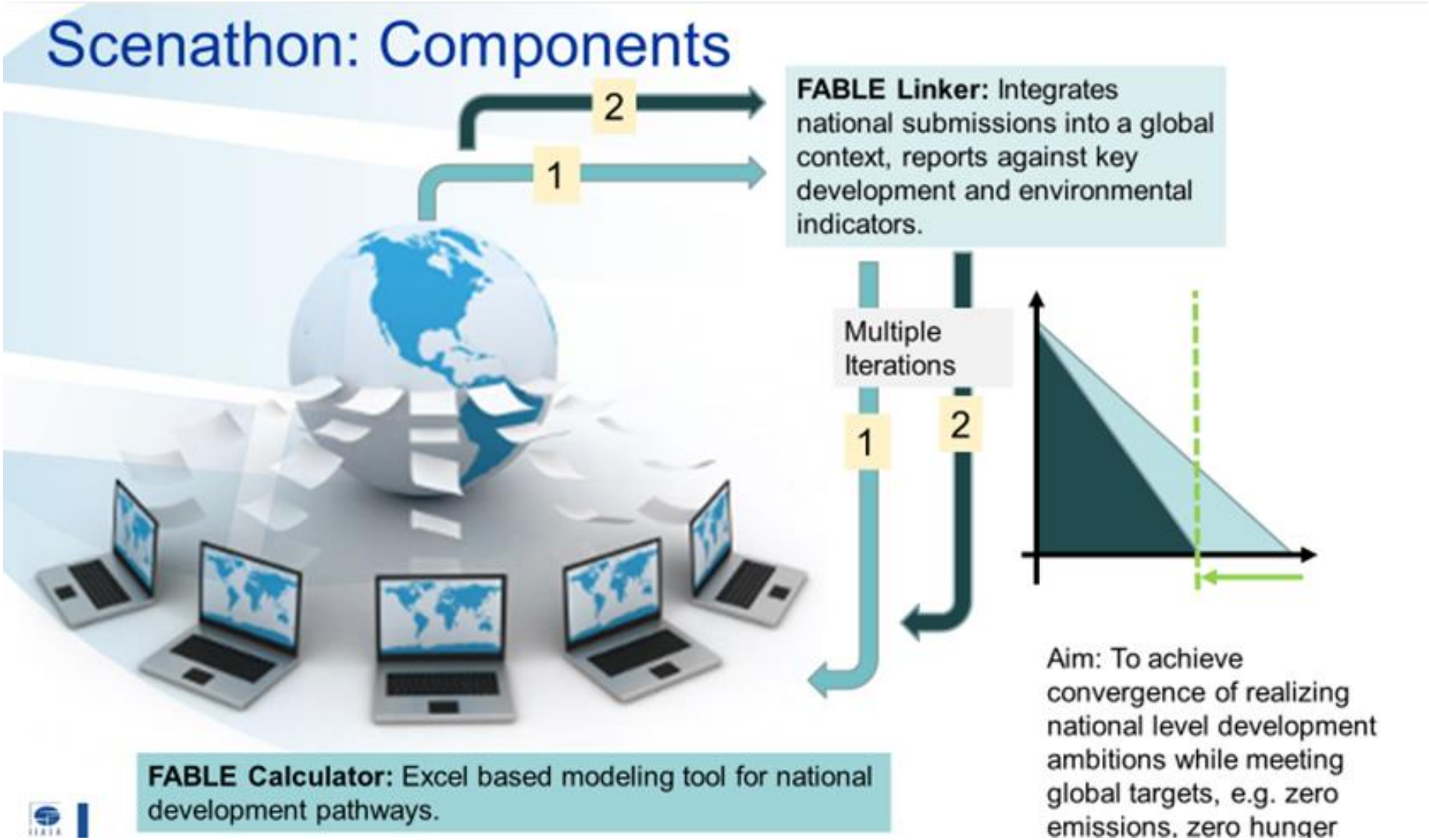
Model coupling: progress and research needs

Why couple models?

1. To capture cross-scale interactions/interdependencies
   - Global drivers (e.g. international trade, policy, migration)
   - National to Local implementation (Devolved administrations to Land owners)
   - Telecoupling (exporting the UK's environmental footprint)
2. To capture cross-sector interactions/interdependencies
   - Systemic interactions between biophysical and human processes in multiple sectors (e.g. synergies, unintended consequences of decisions)
   - Competition for resources (e.g. land and water)

Coupling models across scales: FABLE

Building pathways to sustainable food and land use systems



Scenathon 1 global results

Target 1: Zero net deforestation from 2020 onwards

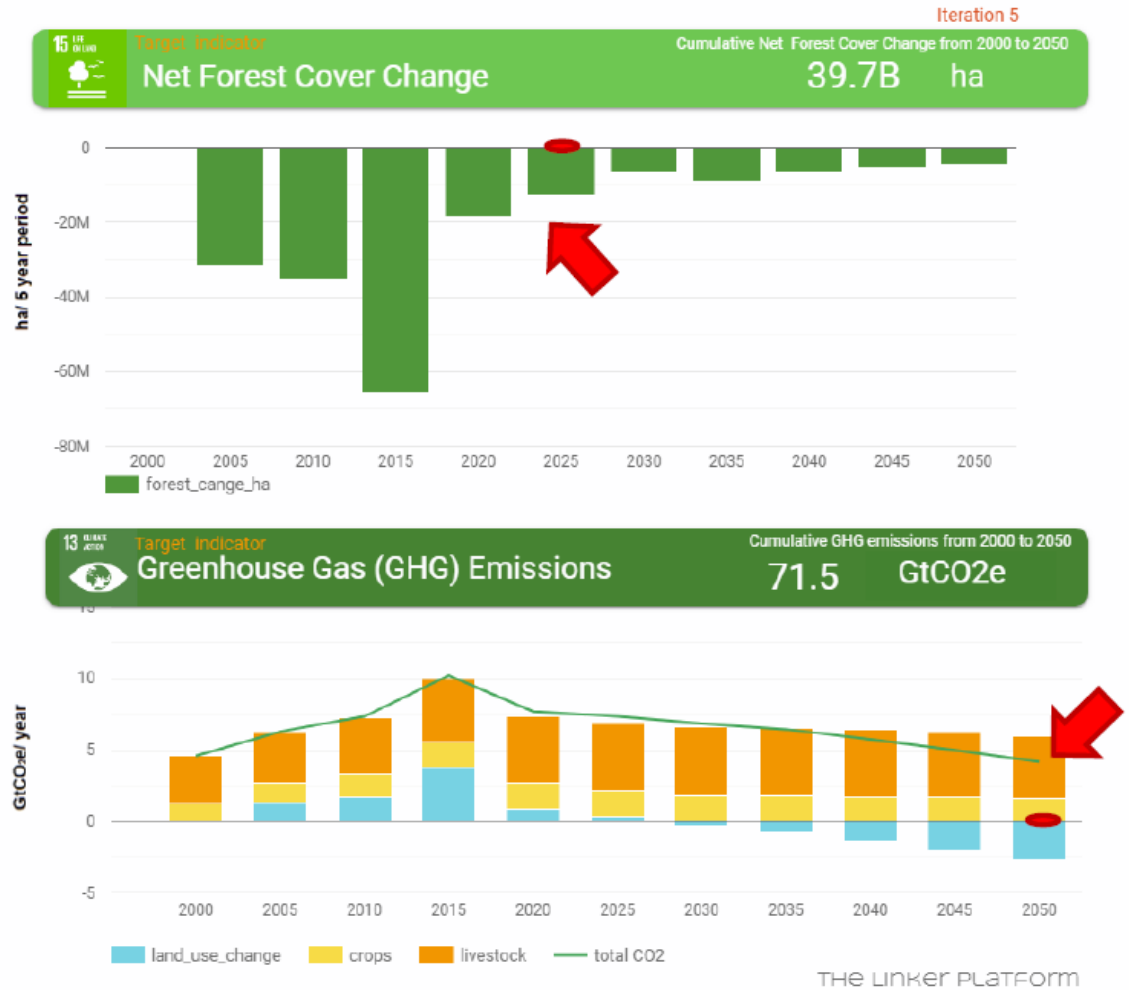
We did not meet the target after iteration 5:

- Net deforestation over 2021-2025 = 13 Mha
- Net deforestation over 2046-2050 = 4.5 Mha

Target 2: Zero net GHG emissions by 2050 from agriculture and land-use change

We did not meet the target after Iteration 5:

- In 2030 = 6.8 Gt CO_2e yr^{-1}
- In 2050 = 4.1 Gt CO_2e yr^{-1}



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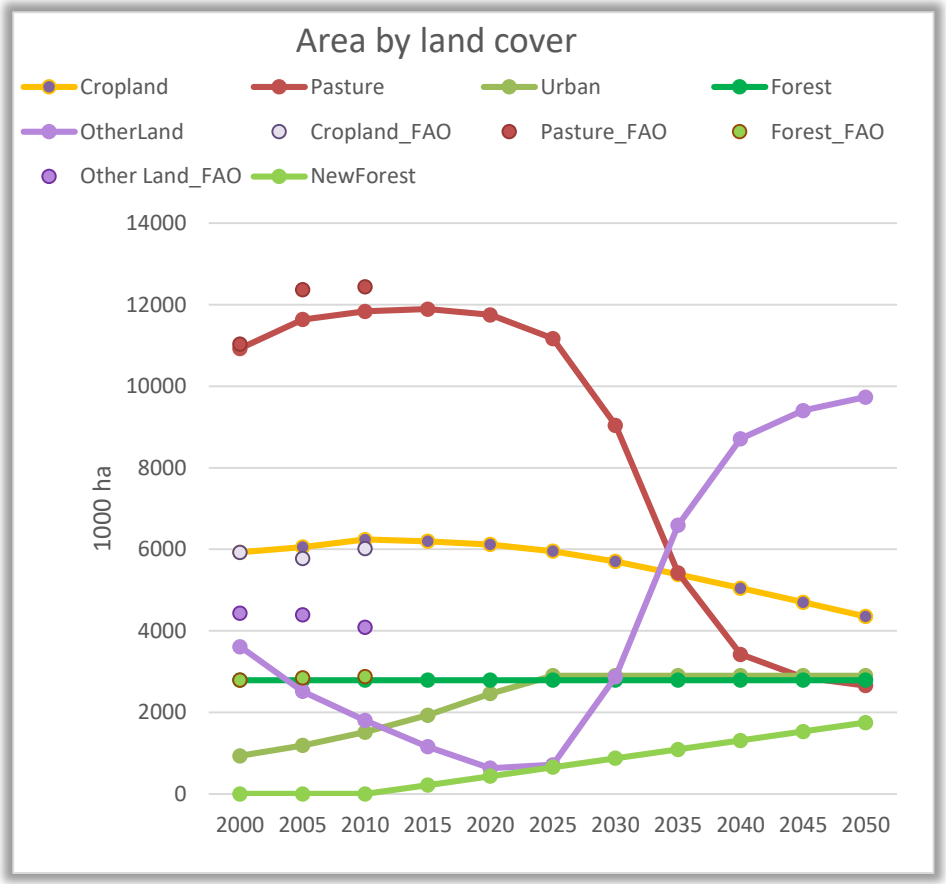
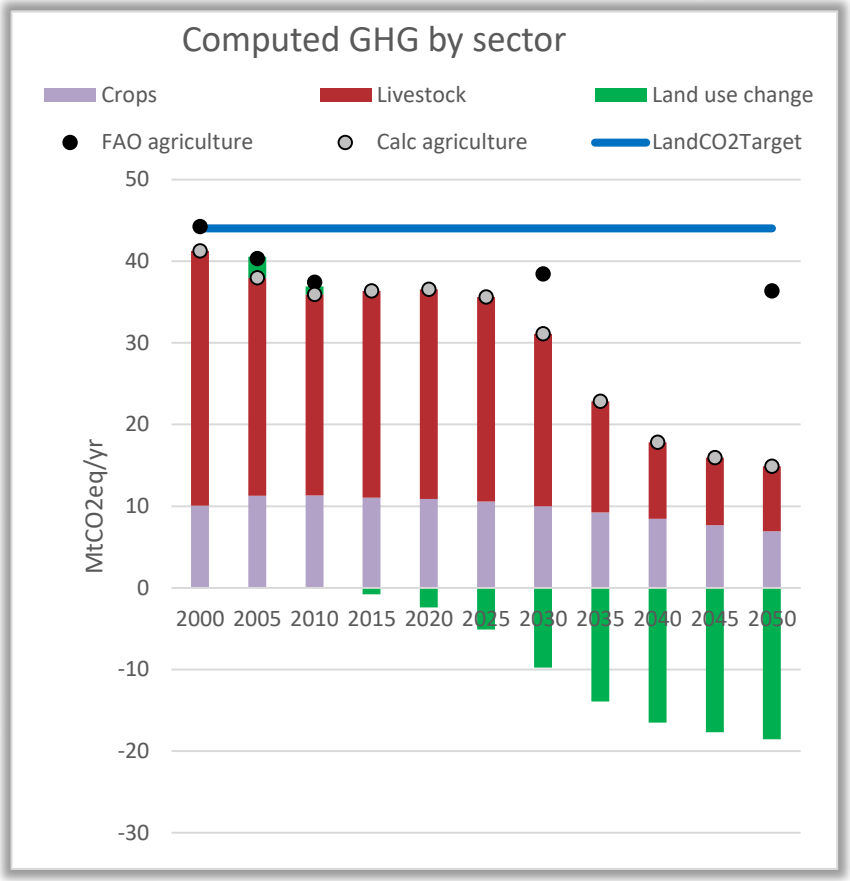
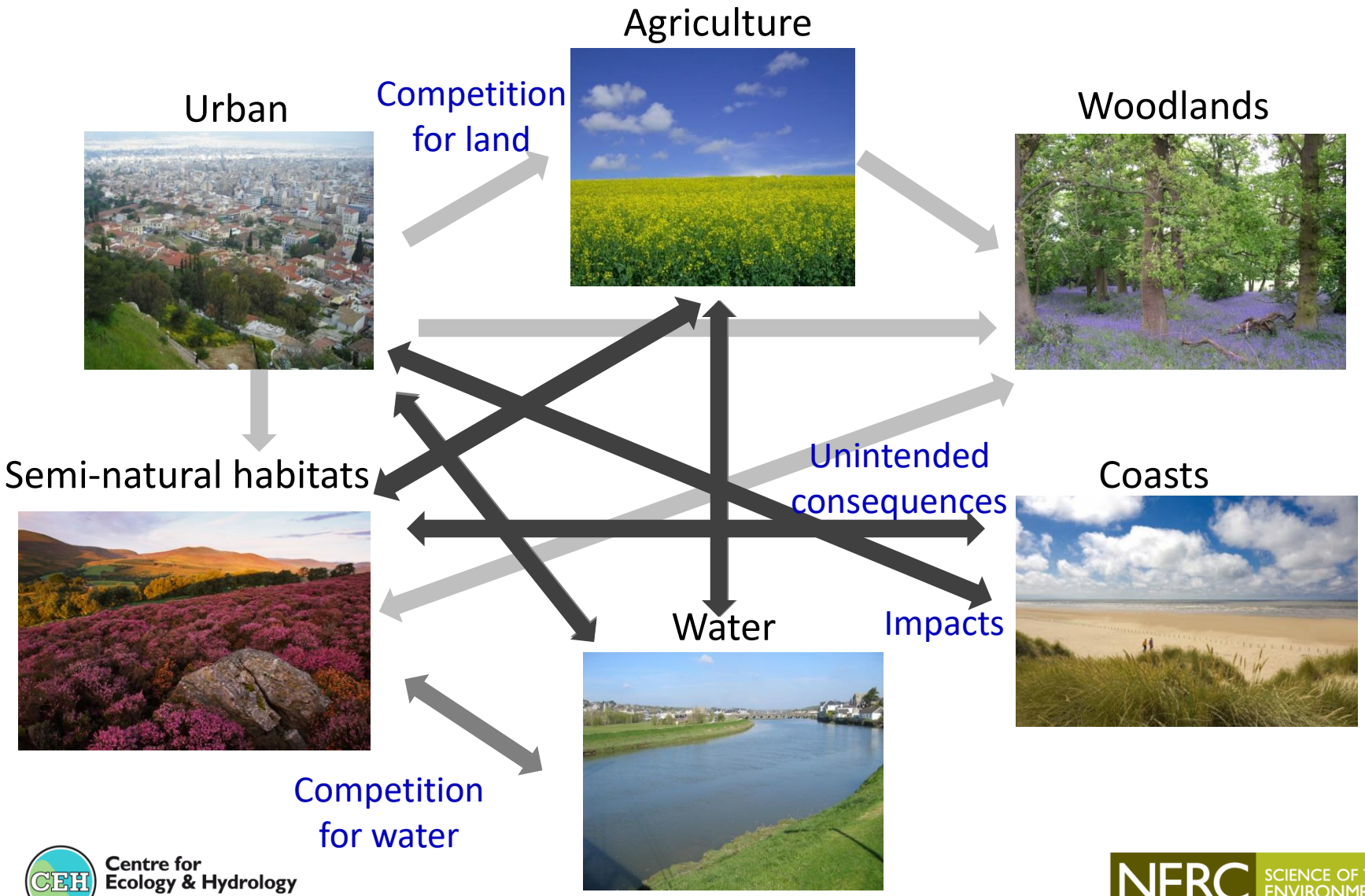
Scenathon 1 results for UK





Scenathon 2 results available in the FABLE Interim 2019 Report at https://www.foodandlandusecoalition.org/fableconsortium

Coupling models across sectors



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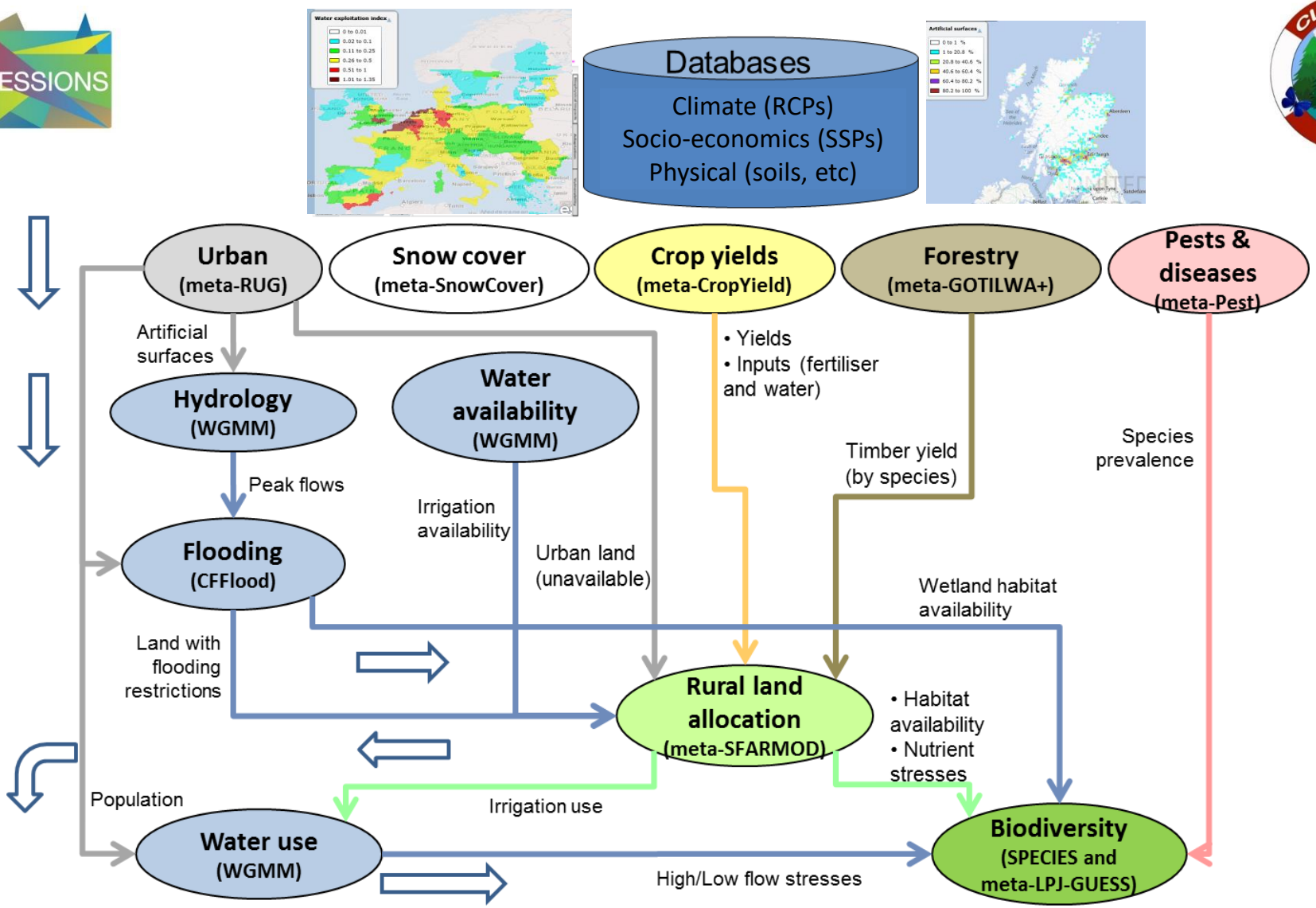
IMPRESSIONS Integrated Assessment Platform



Harrison et al. (2015). Cross-sectoral impacts of climate change and socio-economic change for multiple European land- and water-based sectors. *Climatic Change,* 128: 279-292

Benefits of integrated modelling

Differences between single sector and integrated models by regions within the EU:

	European Union	Alpine (EU)	Atlantic (EU)	Continental (EU)	Northern (EU)	Southern (EU)
Biodiversity (arable)		↕		↕	↕	
Unmanaged land						
Biodiversity (forest)						↕
Arable land	↕		↕	↕		↕
Intensive agriculture	↕		↕	↕		↕
Extensive grassland	↕		↕	↕		↕
Irrigation						
Carbon storage				↕		↕
Water exploitation index		↕		↕		
Food provision						
Flooded people		↕		↕		↕
Unmanaged forest						
Managed forest						
Urban area						

Change > 100%	
Change > 50%	
Change > 25%	
Change > 5%	
Change < 5%	

↕ Direction of change differs between single sector and integrated models

Harrison et al. (2016). Climate change impact modelling needs to include cross-sectoral interactions. *Nature Climate Change*, 6(9): 885-890.

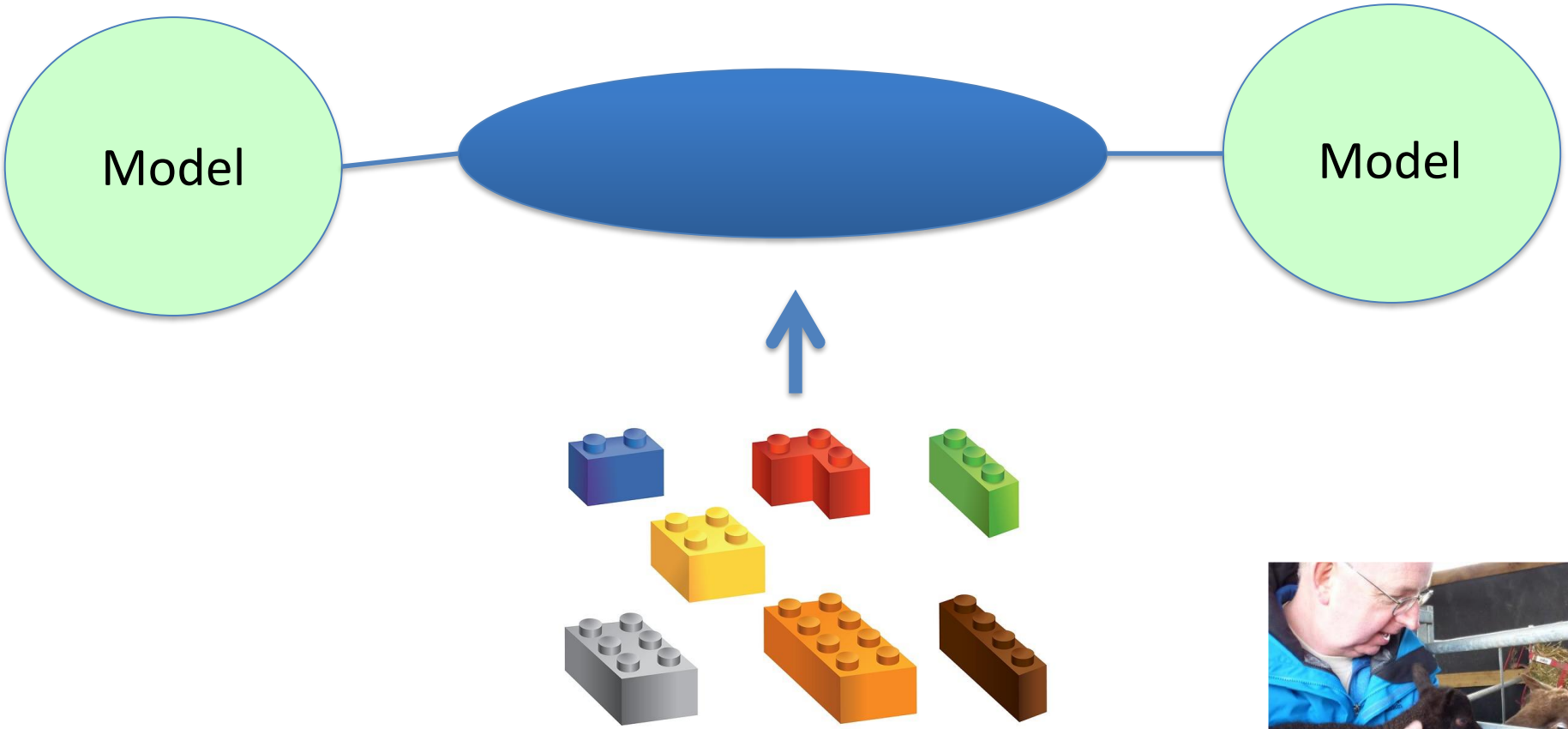
Methods for model integration

- Different methods for model integration, each having their own pros and cons. Certain methods may be more appropriate for certain research questions or decision contexts.
- Alternatives include:
  - direct integration of model code;
  - development of model emulators;
  - use of model wrappers;
  - use of data cubes (look-up tables of pre-run model output).
- Considerations:
  - one-way passing of model data through a linked model chain or two-way representation of feedbacks and interactions;
  - need for cross-scale and cross-domain model integration;
  - speed of application.

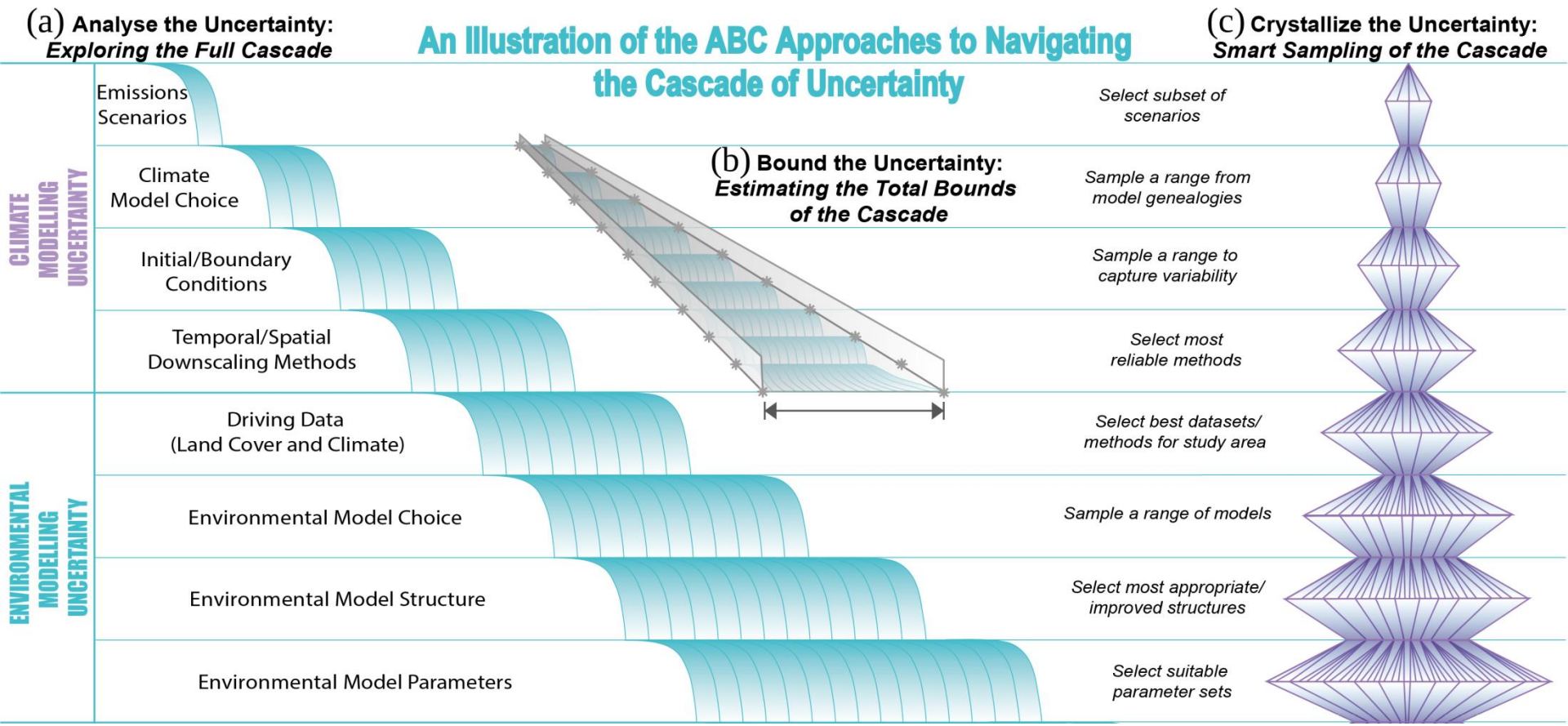
All rely on good model documentation and good communication between modellers -> takes time!

Methods for model integration

Ambition: A configurable coupling framework within a virtual lab environment to make it easier to run models in the cloud, couple models, access statistical and visualisation tools …



Understanding uncertainty in integrated models



Smith et al. (2018). Navigating cascades of uncertainty - As easy as ABC? Not quite ….
Journal of Extreme Events, 5(1): 1850007

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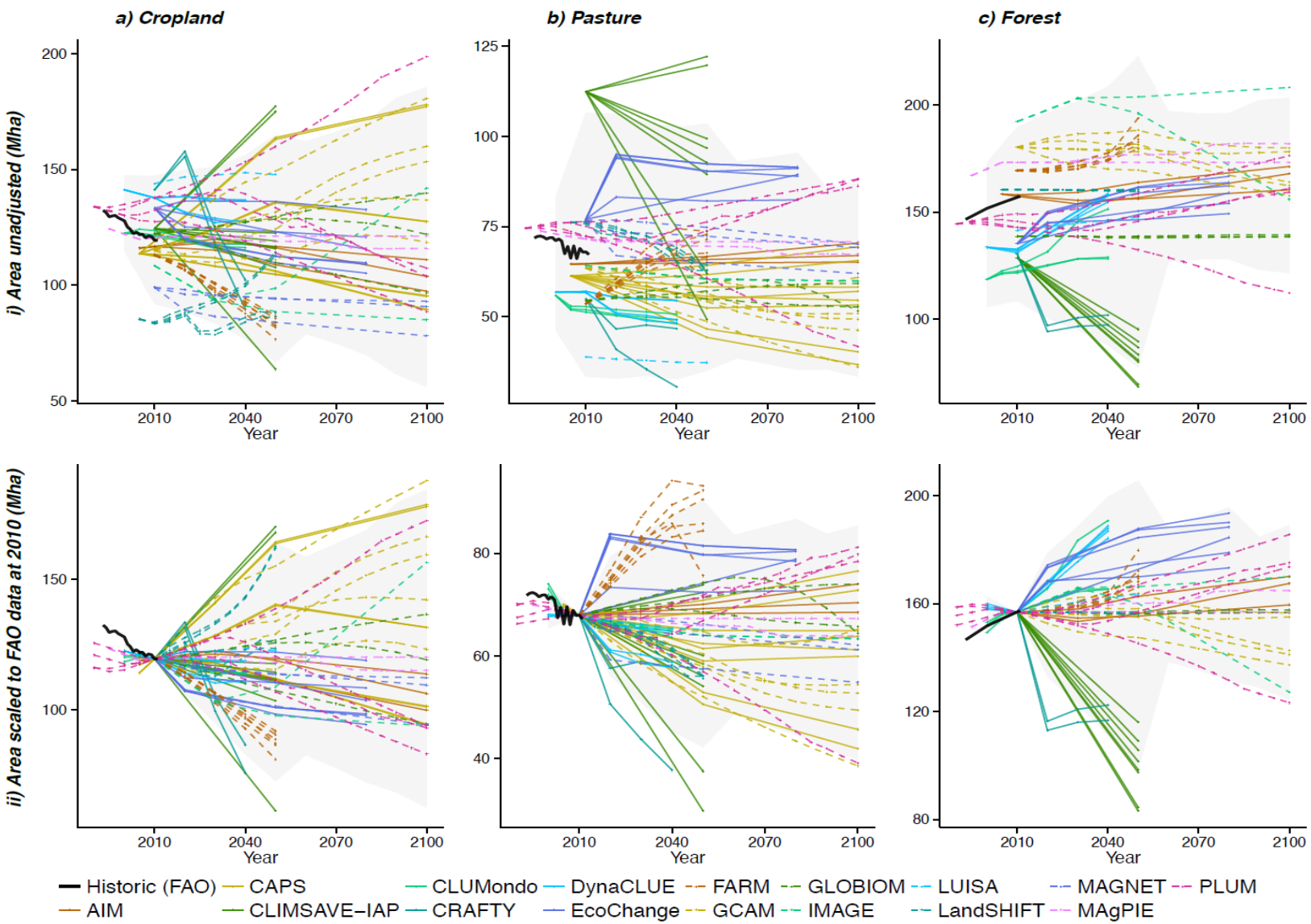
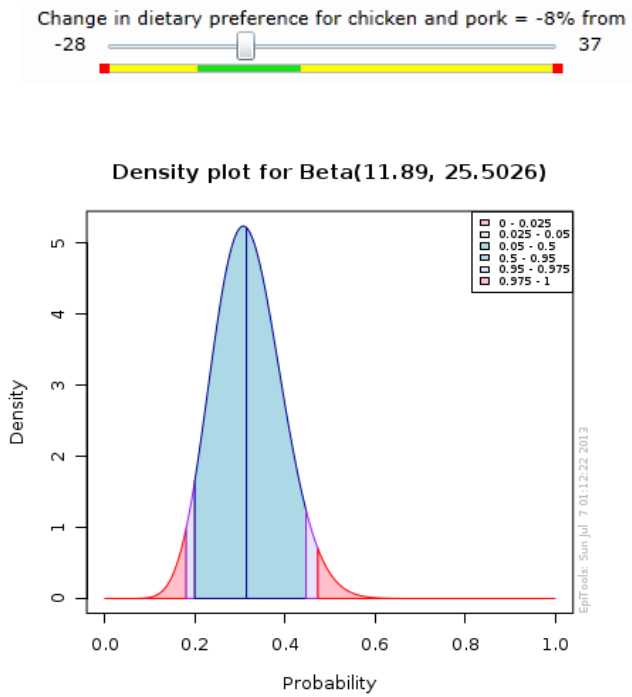
Inter-model comparison of IA Models: Europe

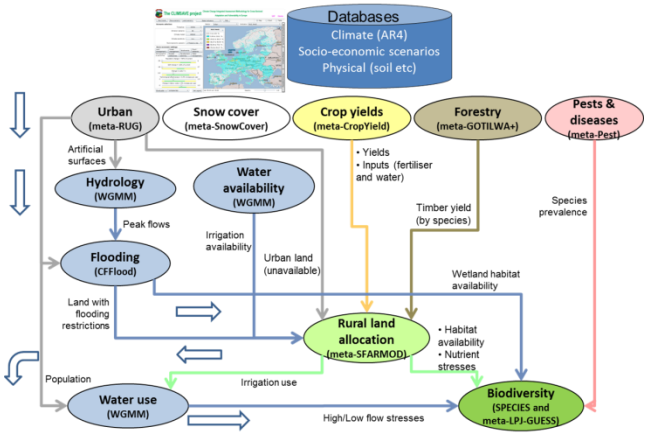


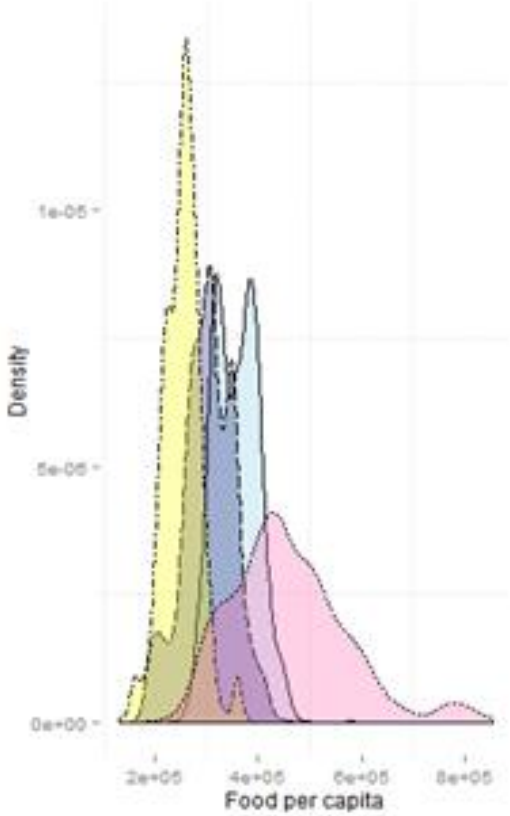
Alexander et al. (2017). Assessing uncertainties in future land cover projections. *Global Change Biology*, 23: 767-781.

Quantitative uncertainty assessment



21 model inputs sampled across four contrasting socio-economic scenarios





Brown et al. (2015). Analysing uncertainties in climate change impact assessment across sectors and scenarios. *Climatic Change*, 128: 293-306.

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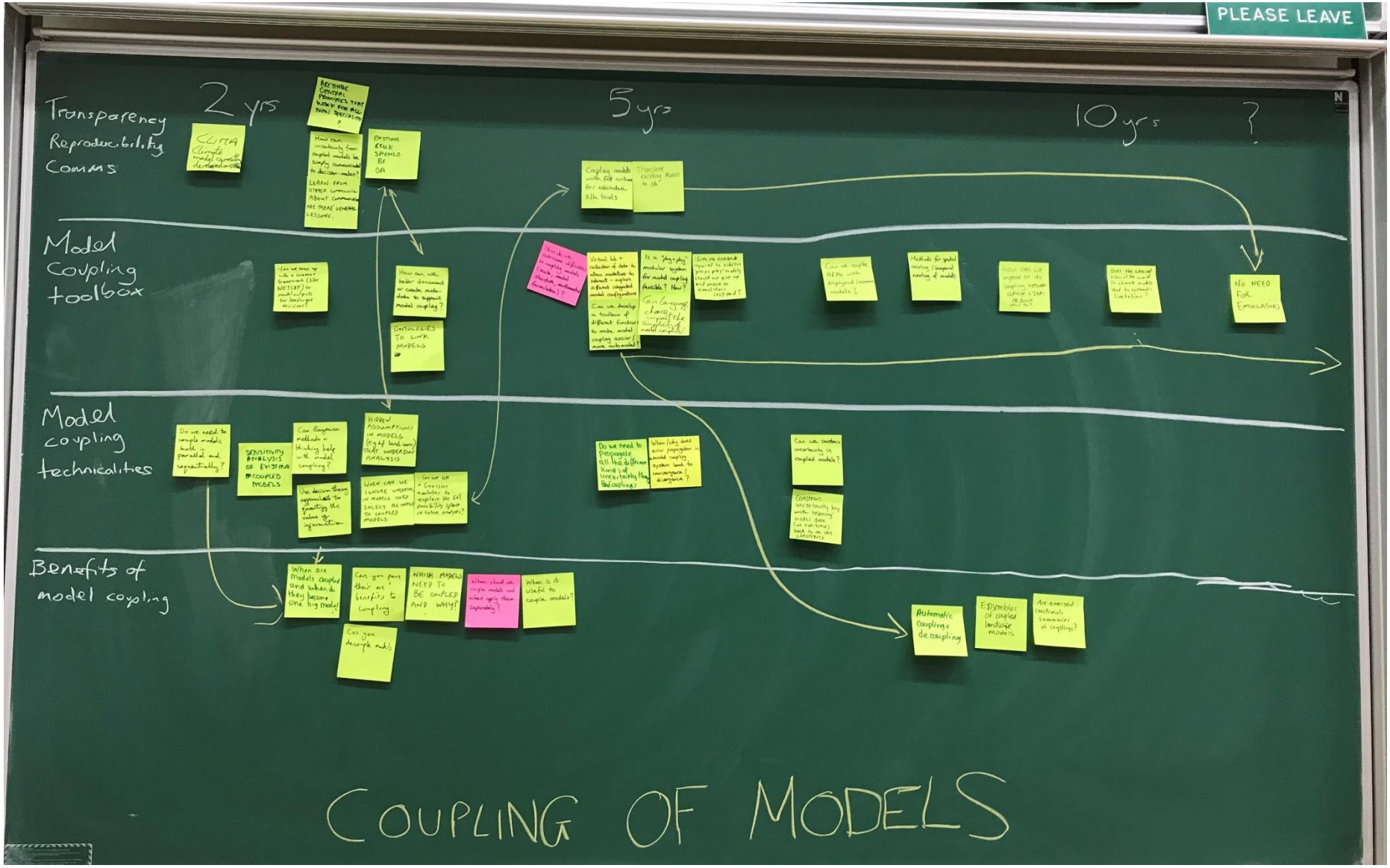
Key research priorities from the Programme



Key research priorities from the Programme

Model coupling toolbox:

- Meta-data and ontologies to support model coupling, including open access
- Toolbox of different functions to make model coupling easier / more automated
- Collaborative environments for working together on data and model integration (virtual labs)
- Coupling different model types: ABMs and biophysical/economic models; Climate models and IAMs

Model coupling technicalities:

- Decision theory approaches to quantify the value of information
- Bayesian methods to help with model coupling and uncertainty quantification
- Gaussian process emulators to explore the full possibility space of decisions
- Full propagation of all the different types of uncertainties
- Can we constrain uncertainty in coupled models

OUTCOME:

- Ensembles of complex landscape models

Thank you