Soft-linking the UKTM and Foreseer models

An iterative process to assembling energy system pathways that respect wider environmental limits

Zenaida Sobral Mourao[a], Birgit Fais[b], Dennis Konadu[a]

[a] University of Cambridge
[b] UCL Energy Institute, University College London

Annual wholeSEM Conference 2016
Cambridge, 4th – 5th July 2016

Contents

Aim

Analysis of implications of potential low-carbon energy transitions in the UK on the wider resource use (water and land use)

Methodology: Soft-linking the optimizing energy system model UKTM with the resource nexus accounting tool Foreseer UK

UKTM and Foreseer (context)

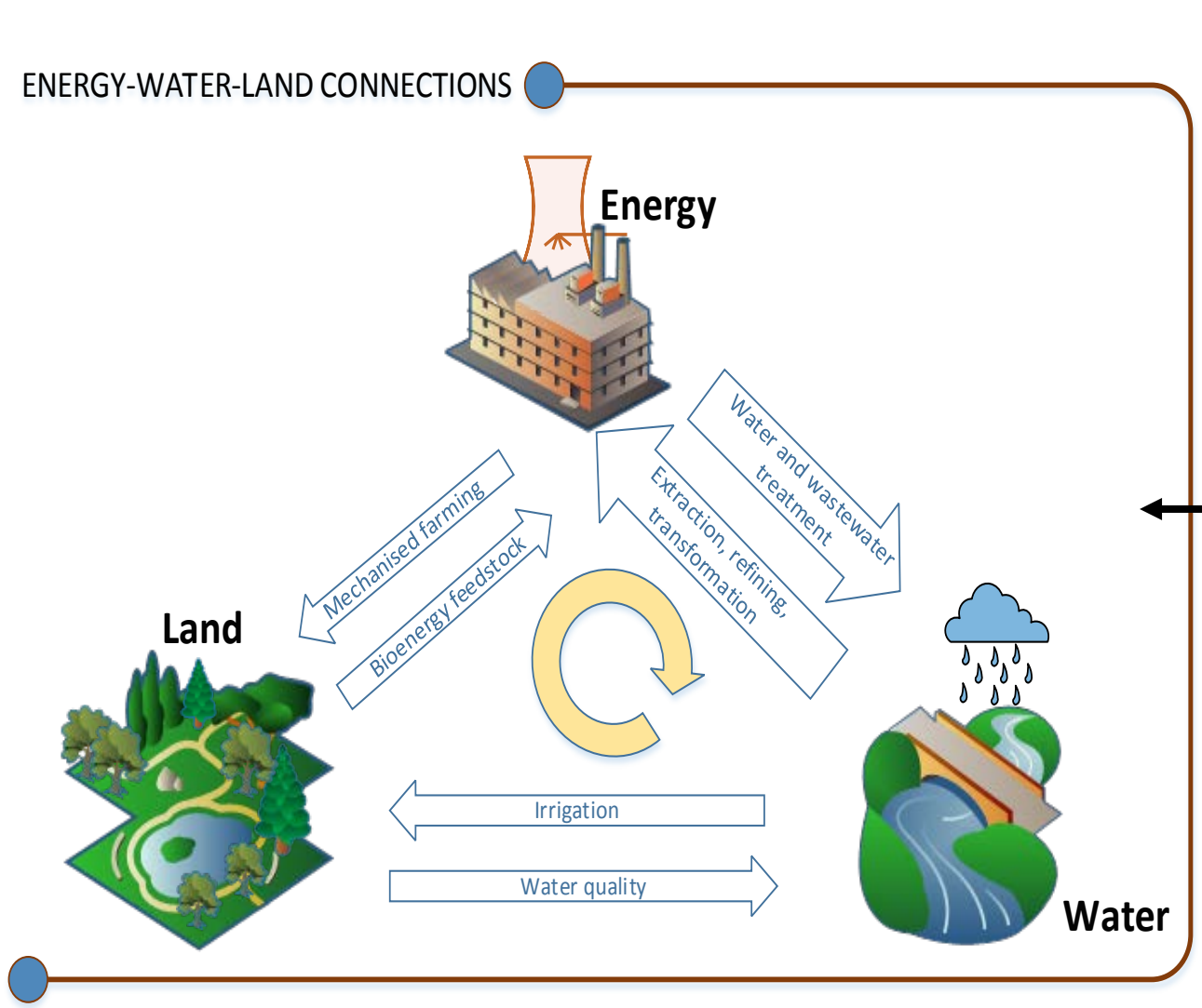
UKTM

- Energy system configuration (supply and demand) that meets 80% GHG emissions reductions at minimum system cost
- No explicit constraints on use of water and land for the energy system
- Integrated energy systems model
- Least cost optimization, technology rich, bottom-up & Partial equilibrium
- Sensitivity and uncertainty analysis

Foreseer

- Land availability for energy system based on land that can be spared after allocation to different services such as food production, built up area and environmental protection.
- Water use capped by current use for energy system, national licensing regime for water abstractions and location of future power plant sites.
- Limits defined for water and land use that energy system can access, based on sustainability constraints.

Foreseer UK



DEMAND DRIVERS

POPULATION GROWTH

Increased demand for
- Food
- Water
- Housing
- Energy

CLIMATE CHANGE

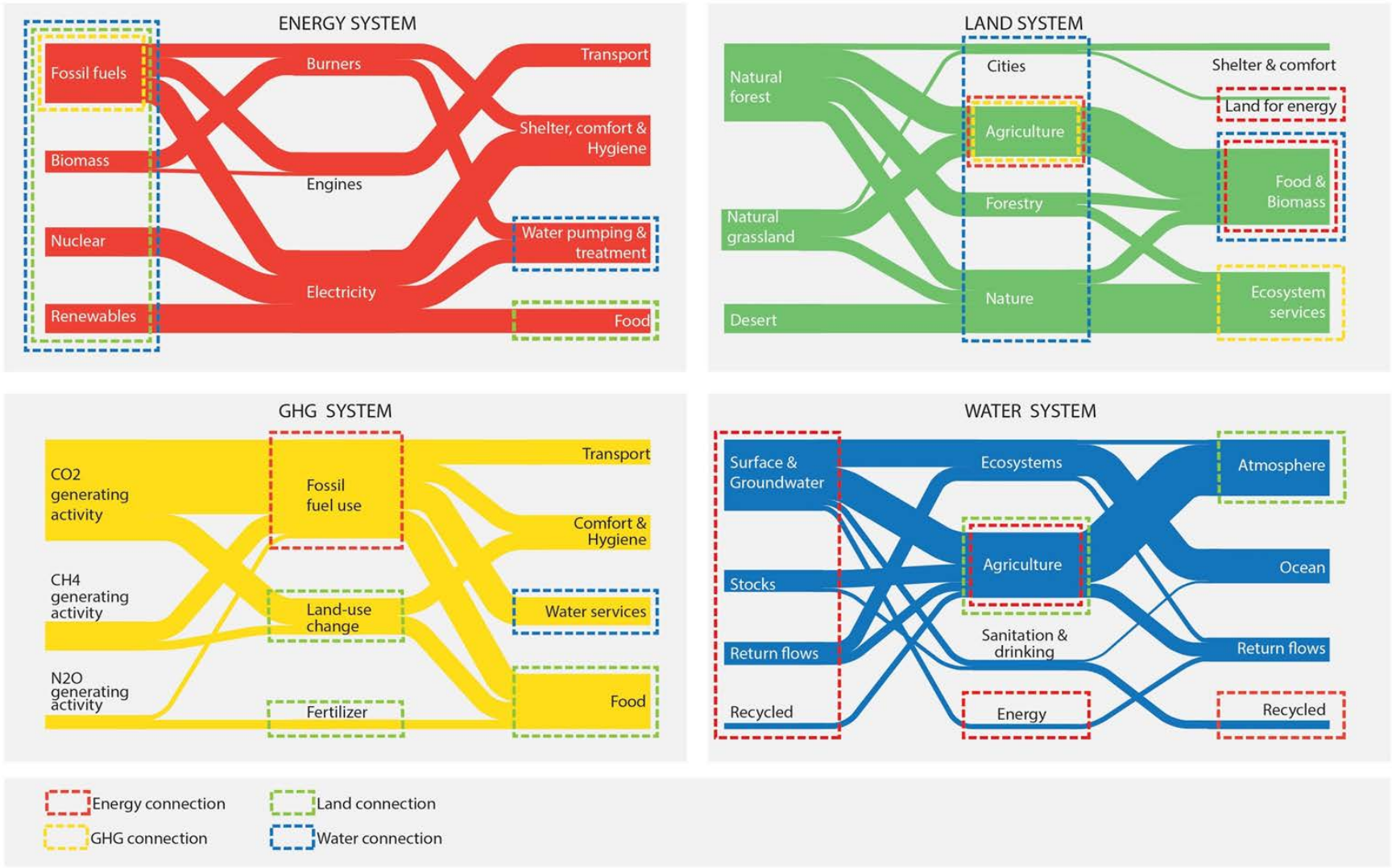
Increased
- Irrigation
- Drought
- Floods
- Cooling and heating

GHG REDUCTION

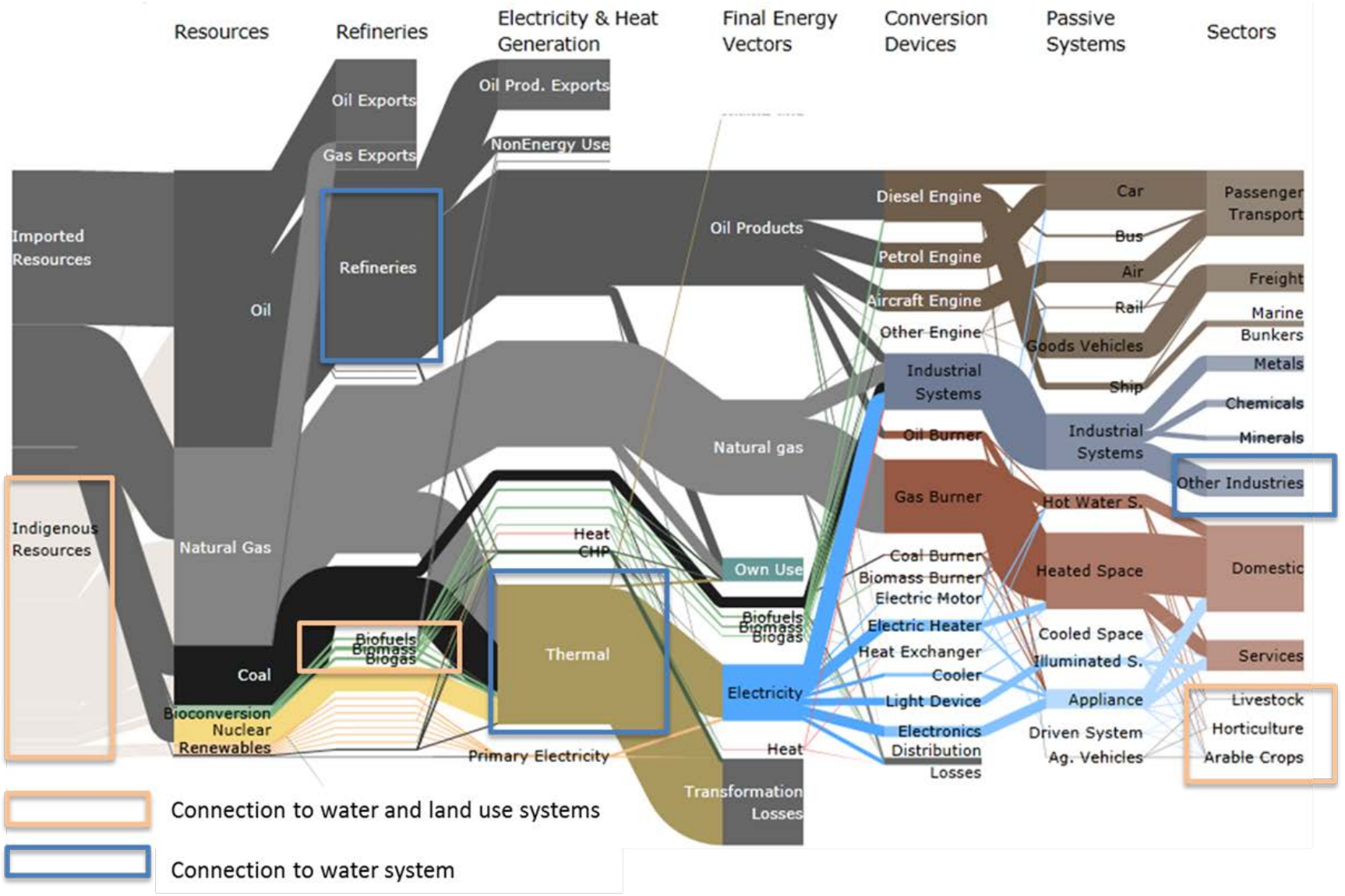
Demand for Low-carbon energy
- CCS
- Bioenergy

- Accounting tool to analyse and visualize impact of future resource demand
- Water and land requirements for energy system under different demand and technology scenarios

Foreseer UK – linked Sankey diagrams



UK Energy System 2010 – land & water connections



Previous studies nexus

- **Energy – land**:
  - Konadu et al.: land for indigenous bioenergy can be a problem, at the levels used in some Carbon Plan scenarios, especially if no significant improvement in yields is observed
- **Energy – water**:
  - Byers et al., water issues at basin level if CCS is deployed (Trent)
  - Konadu et al., Carbon Plan energy system scenarios present problems if coastal sites not available & scenarios with high penetration of CCS increase total use of water resources relative to current levels

Linking models in two stages

Stage 1: UKTM to Foreseer

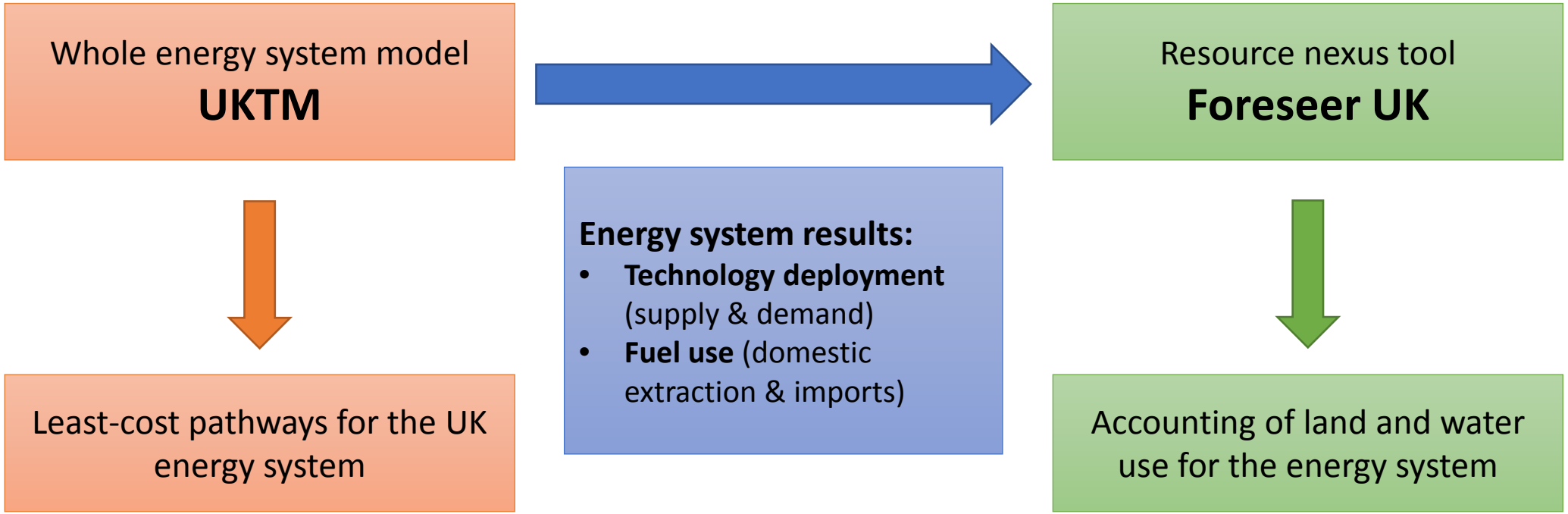
Water and land requirements for energy system – from UKTM output

Comparison of UKTM outputs in terms of land and water impacts

Stage 2: Iterative process – feedback between models

Stage 1

- Analysis triggered by UKTM
- Foreseer estimated land and water requirements and compares these with environmental limits



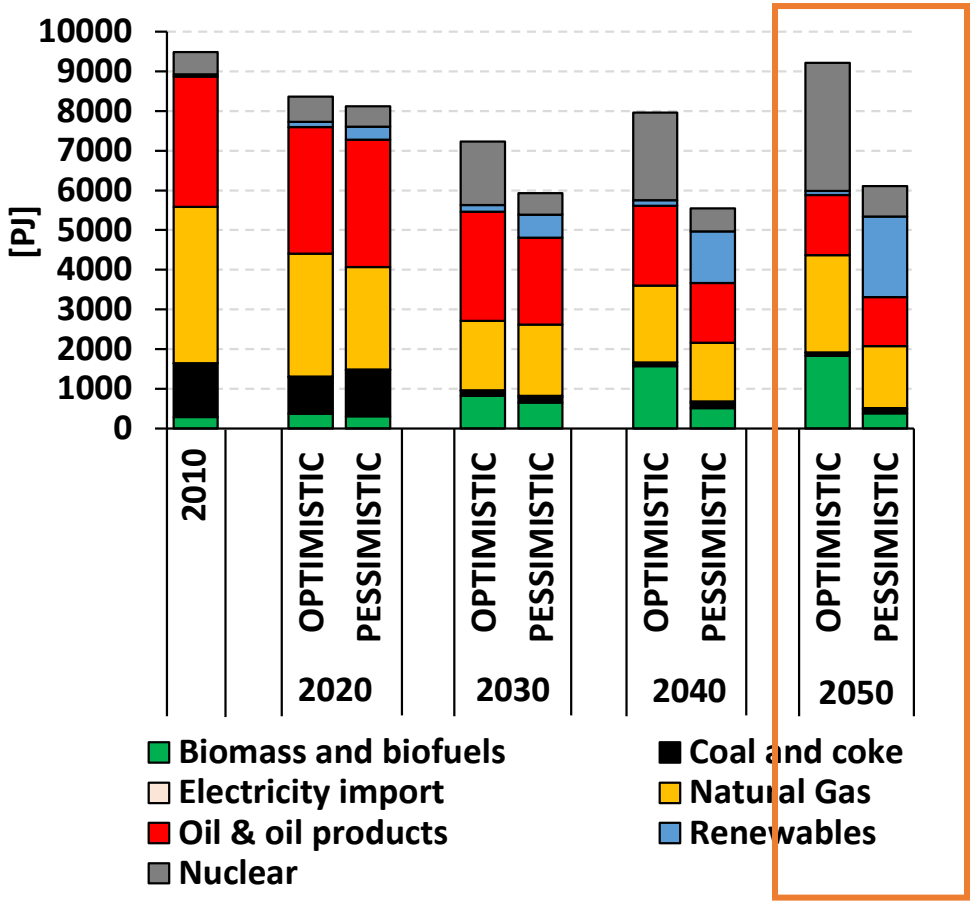
Stage 1 – Energy scenarios

- Energy system scenarios from UKTM

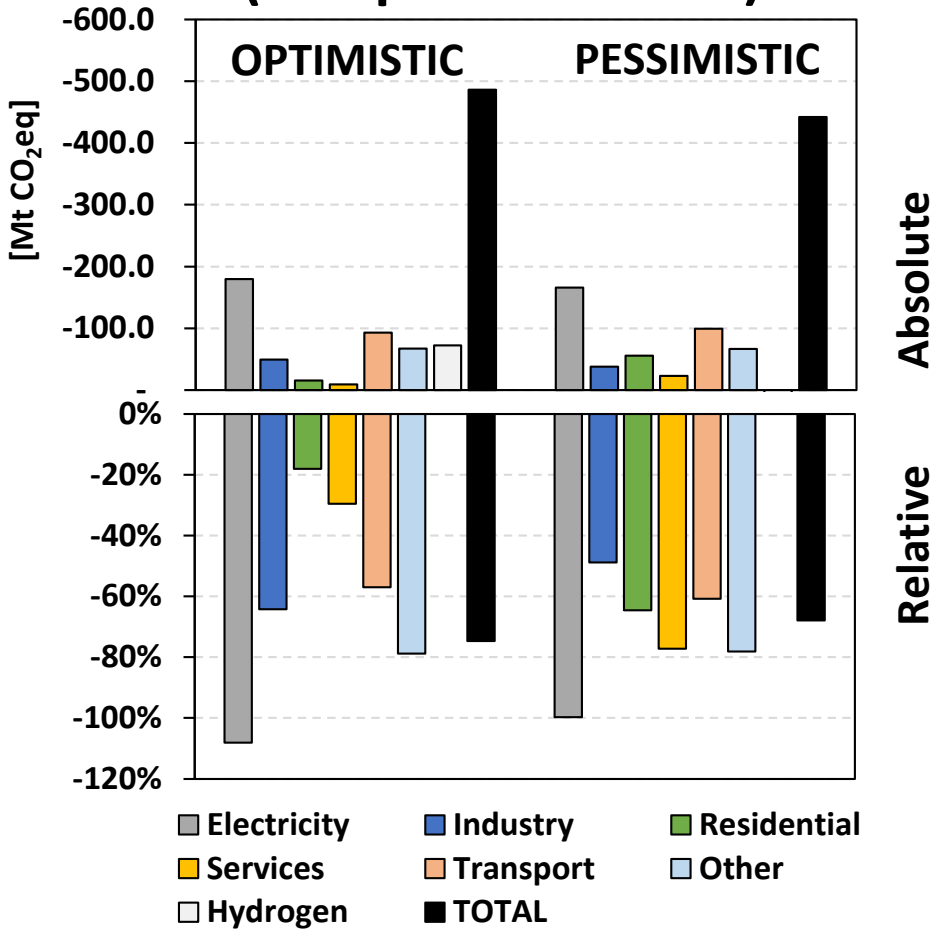
OPTIMISTIC	PESSIMISTIC
High availability of: **Biomass**: > 1900 PJ in 2050 **Nuclear**: up to 79 GW in 2050 **CCS**: up to 50 GW in 2050	**Low** availability of: **Biomass**: < 400 PJ in 2050 **Nuclear**: up to 10 GW in 2050 **CCS**: not available

Stage 1 – UKTM Output

Primary energy consumption

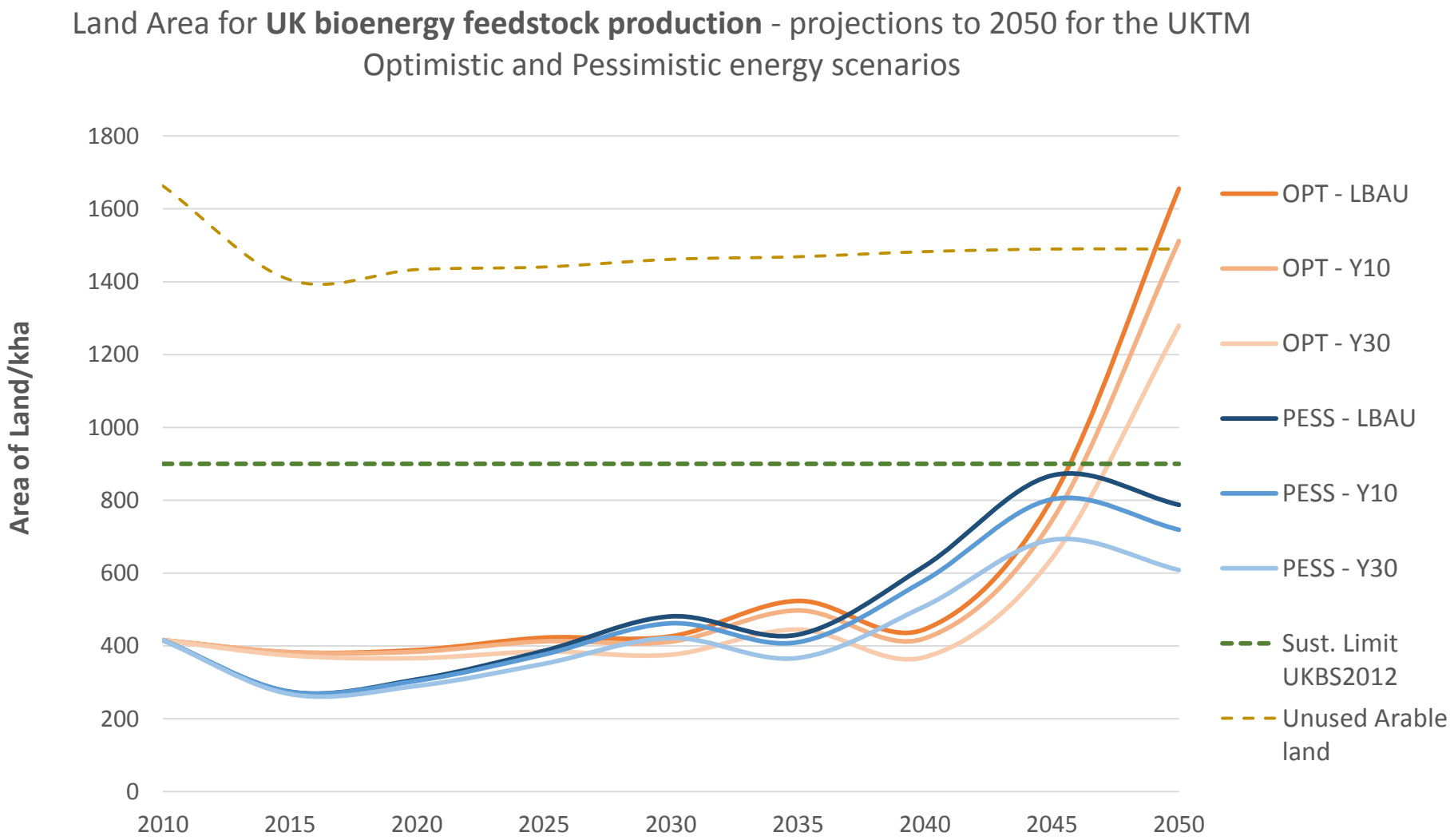


GHG emission reduction in 2050 (compared to 2010)

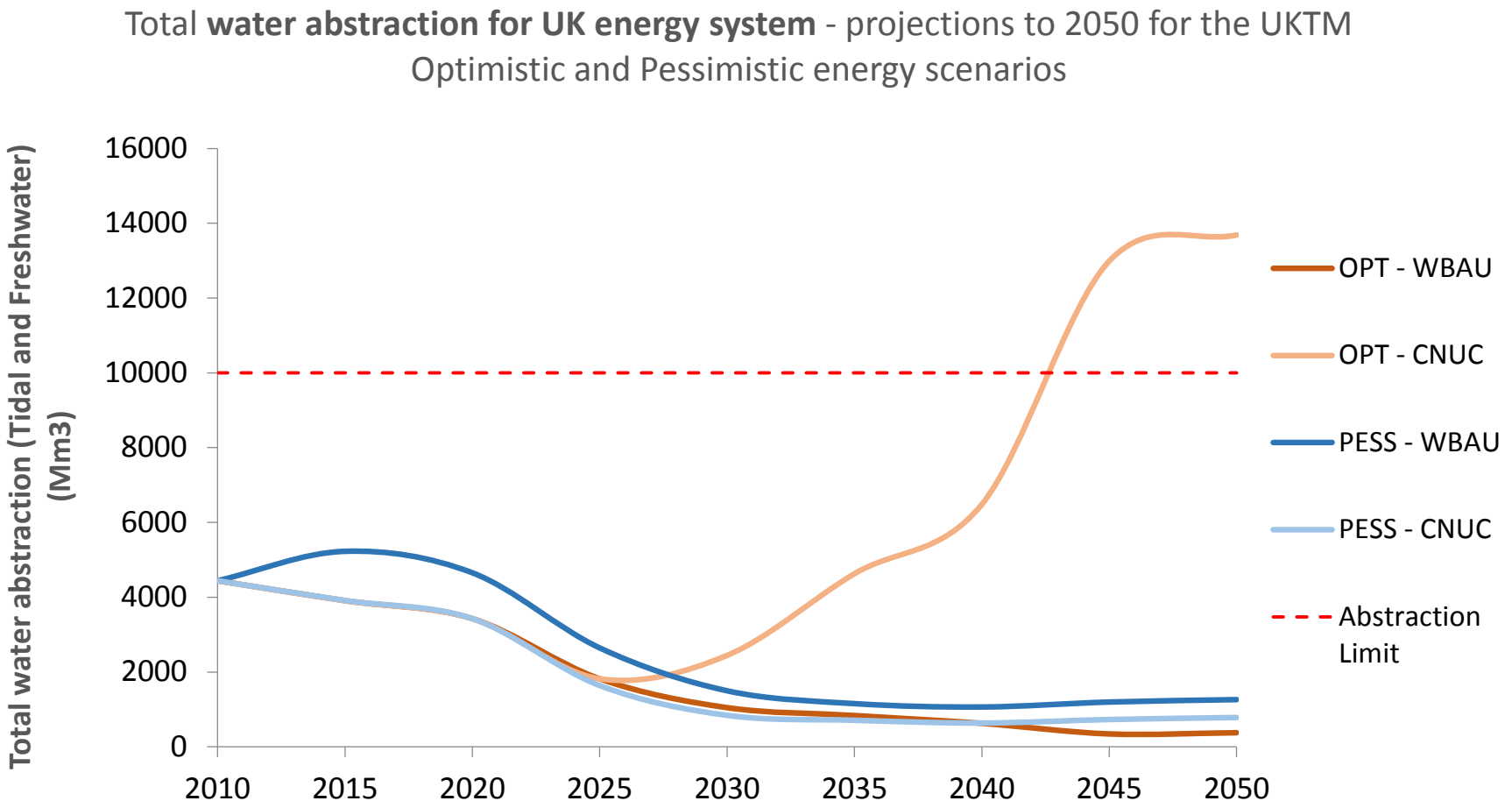


Lower Nuclear and Biomass

Stage 1 – Foreseer Analysis



Stage 1 – Foreseer Analysis



Stage 1 – Results

Optimistic energy scenario has **higher land and water impacts** across most land and water scenarios

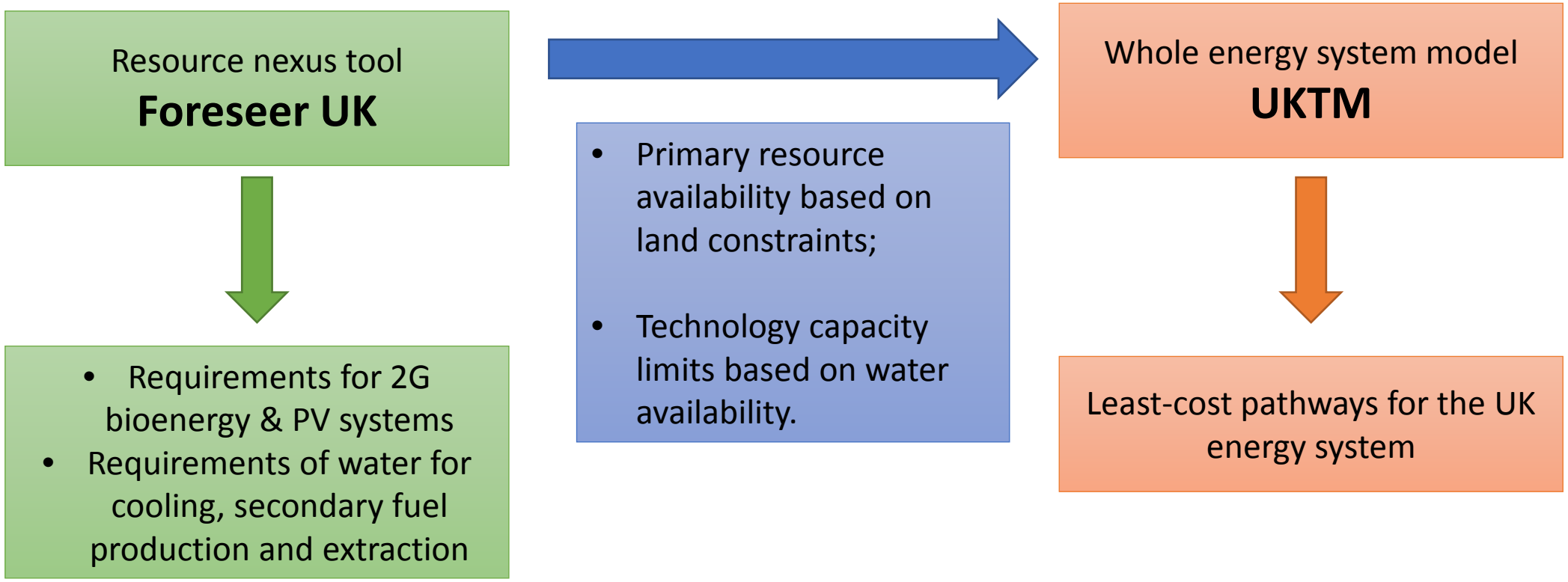
Optimistic energy scenario with **potential conflicts with water and land use management policies**

OPTIMISTIC	PESSIMISTIC
Impact on land – does not meet sustainability criteria (900kha for bioenergy), availability of land borderline in 2050	**Impact on land –** meets sustainability and availability criteria
Impact on water – constrained nuclear significant impact on water resources – above 2010 water abstraction levels	**Impact on water –** bellow 2010 abstraction levels for both water scenarios

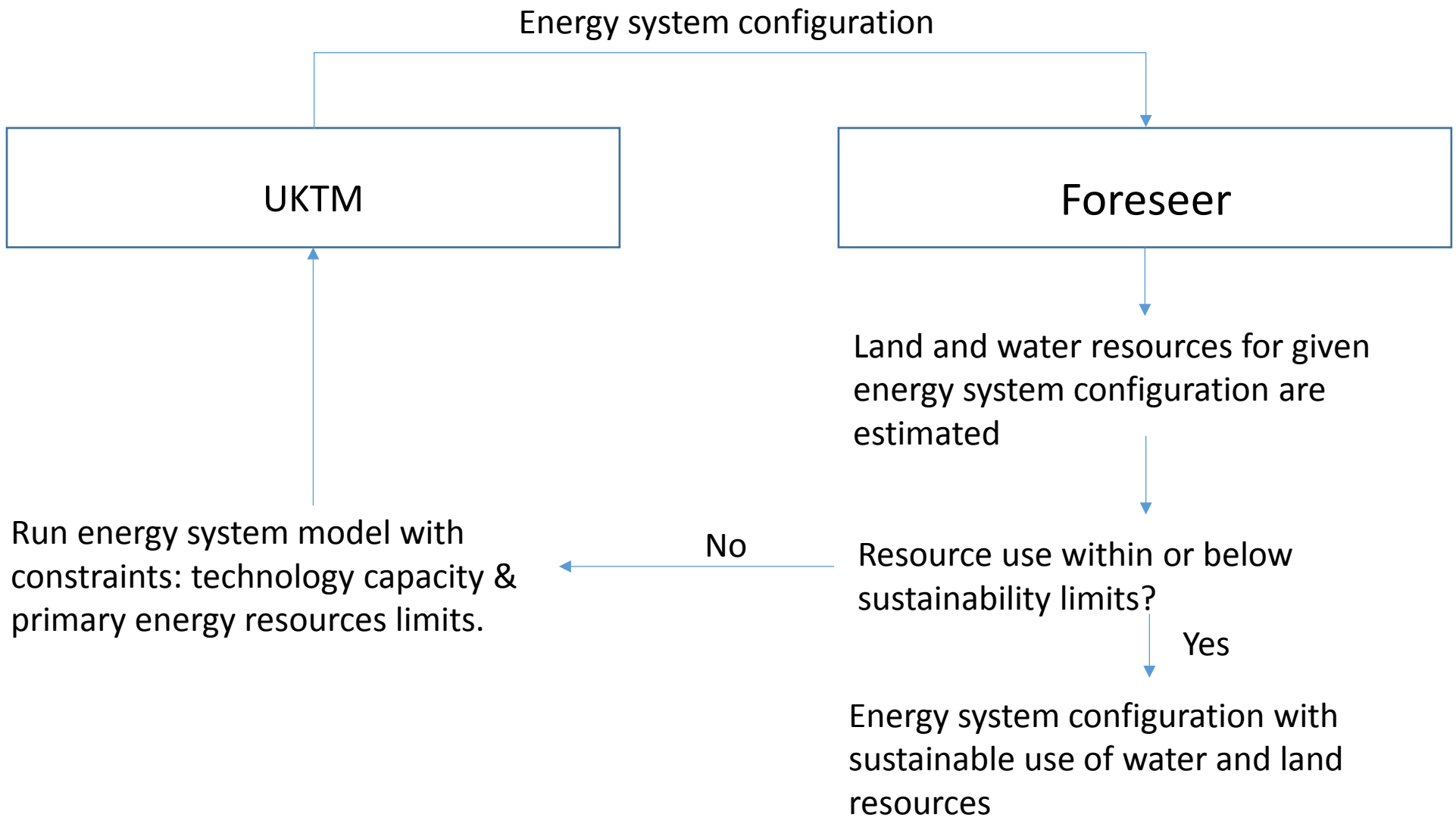
Difference in cumulative cost (2010 – 2050) between two scenarios: **+6%**

Stage 2

- Once water and land requirements are estimated by Foreseer, these are fed back into UKTM in form of capacity constraints for technologies or caps on bioenergy feedstock



UKTM and Foreseer – Iterative Process



Definition of limits - land

Projected land availability and distribution for bioenergy

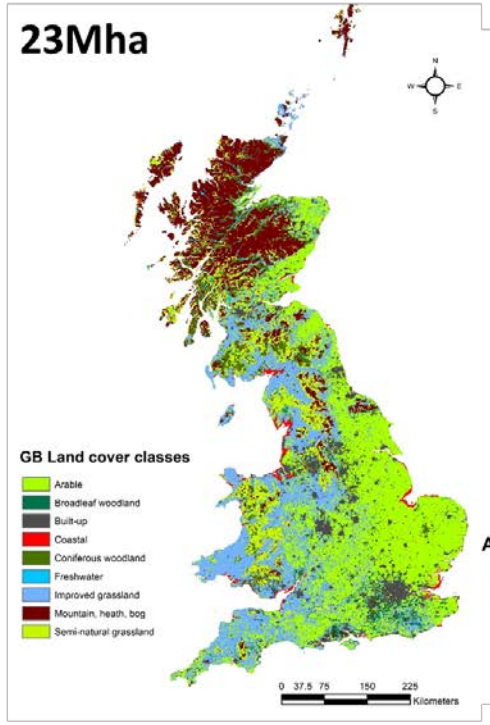


***Fig. 1**: Great Britain Land Cover Map (CEH, 2010)*

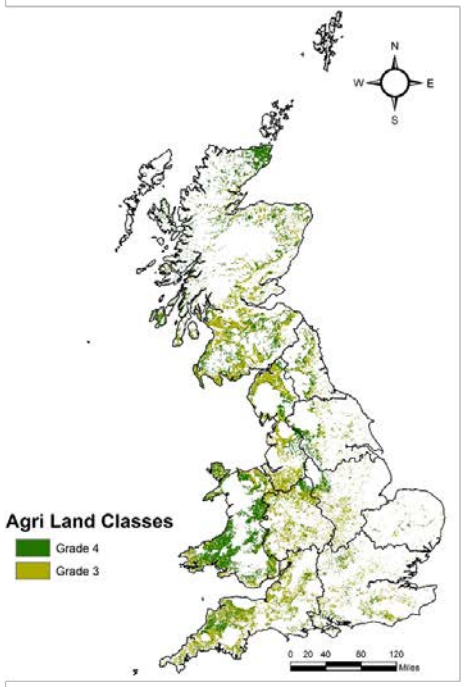


***Fig. 2**: Land availability for bioenergy – grades 3 & 4*

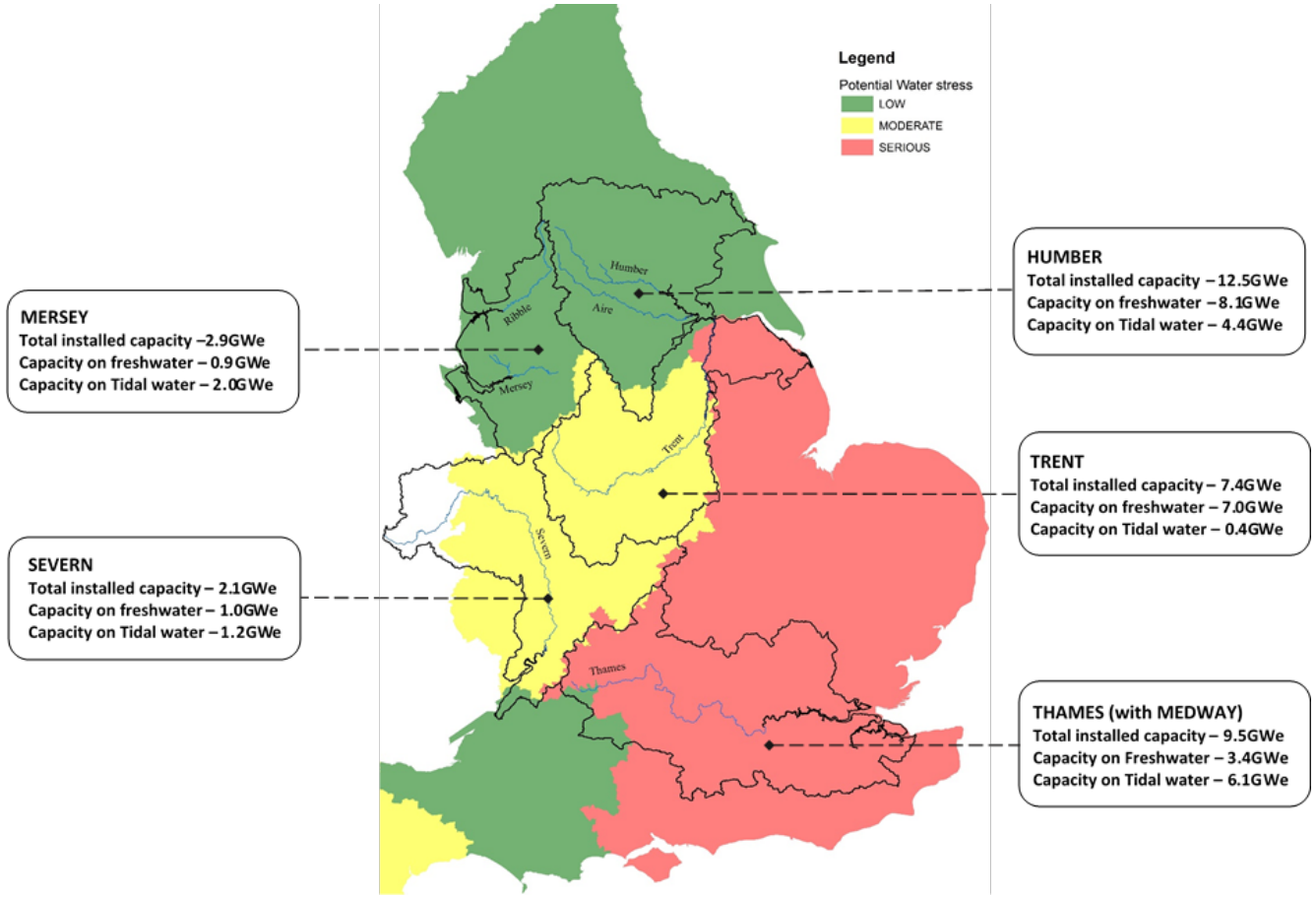
***Table 1**: Land availability for bioenergy – grades 3 & 4*

GB Region	Available area (km2)
Scotland	16318
Wales	8593
East Anglia	287
East Midlands	1897
West Midlands	3771
Yorkshire & Humber	1561
North East	1493
North West	4715
South East	2710
South West	7039
Total	48384

Limit (in 2050): 1,173 kha

- Land cover and agricultural classification maps for the UK
- 1km^2 resolution
- Land use restricted to only grade 3 & 4
  - Grade 1 & 2, and grade 3 arable are excluded for food production
  - Grade 5 & all non agricultural land excluded
- Land use constraints
  - Environmentally designated areas
  - Peat soils

Definition of limits - water



- Limit: 4809 Mm^3

- Water abstraction licenses defined according to ecological limits
- 2010 water for energy system:

  4809 Mm^3 (Fresh & Tidal)
- Most capacity today concentrated in few basins
- Given that currently the system already has over-abstraction in some areas we have defined the 2010 water abstraction volume as the sustainability limit

Water and land scenarios to 2050

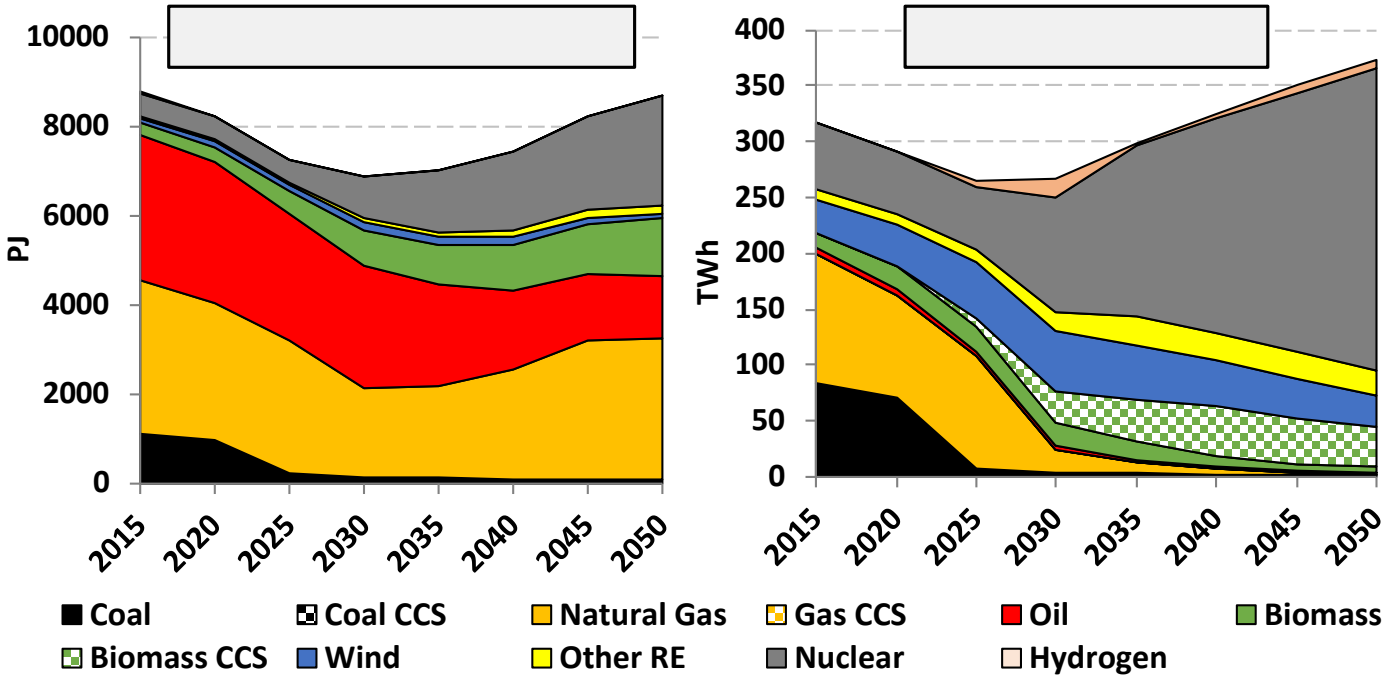
- **Land through to 2050**:

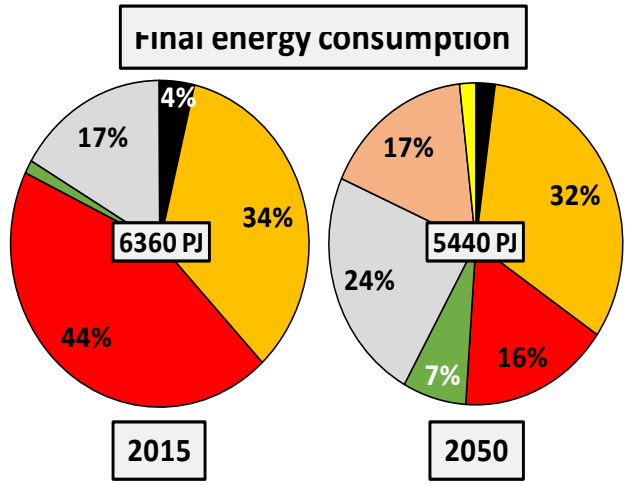
  - Population increase according to official statistics – influences land for food & built-up area
  - Same percentage of food produced in the UK today
  - No change in diets
  - No change in crop yields (all)
  - Mix of bioenergy (2G): from UKTM

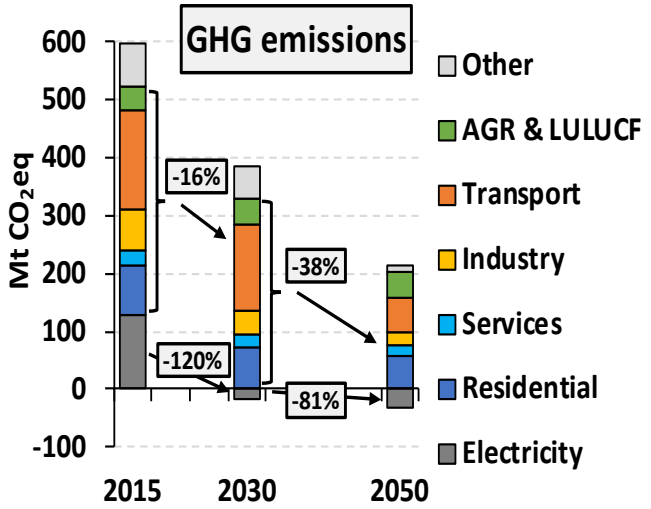
Water and land scenarios to 2050

- **Water through to 2050**:
  - Coastal sites restricted to current licensed & legacy
  - Mix of cooling technologies assumes new nuclear inland to be closed loop and other thermal as hybrid or air cooling

Results Stage 2 – Energy system results (REF)

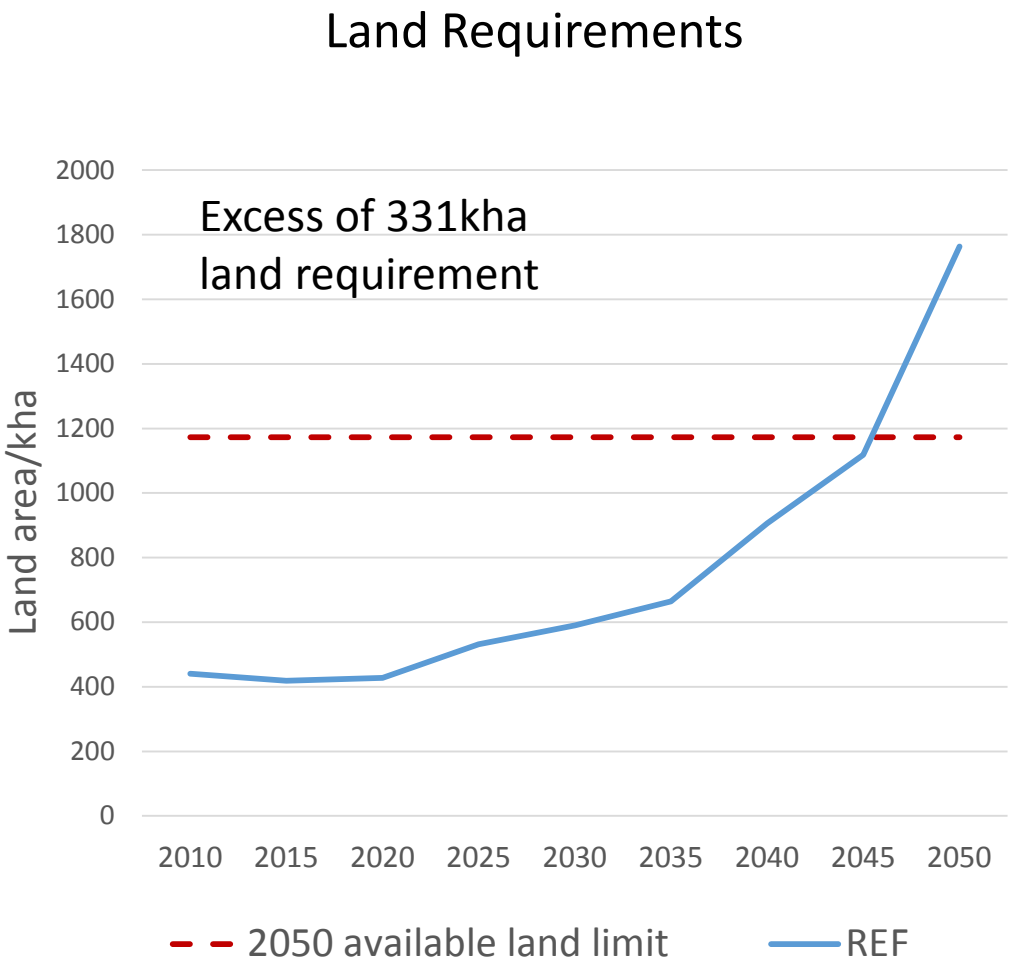


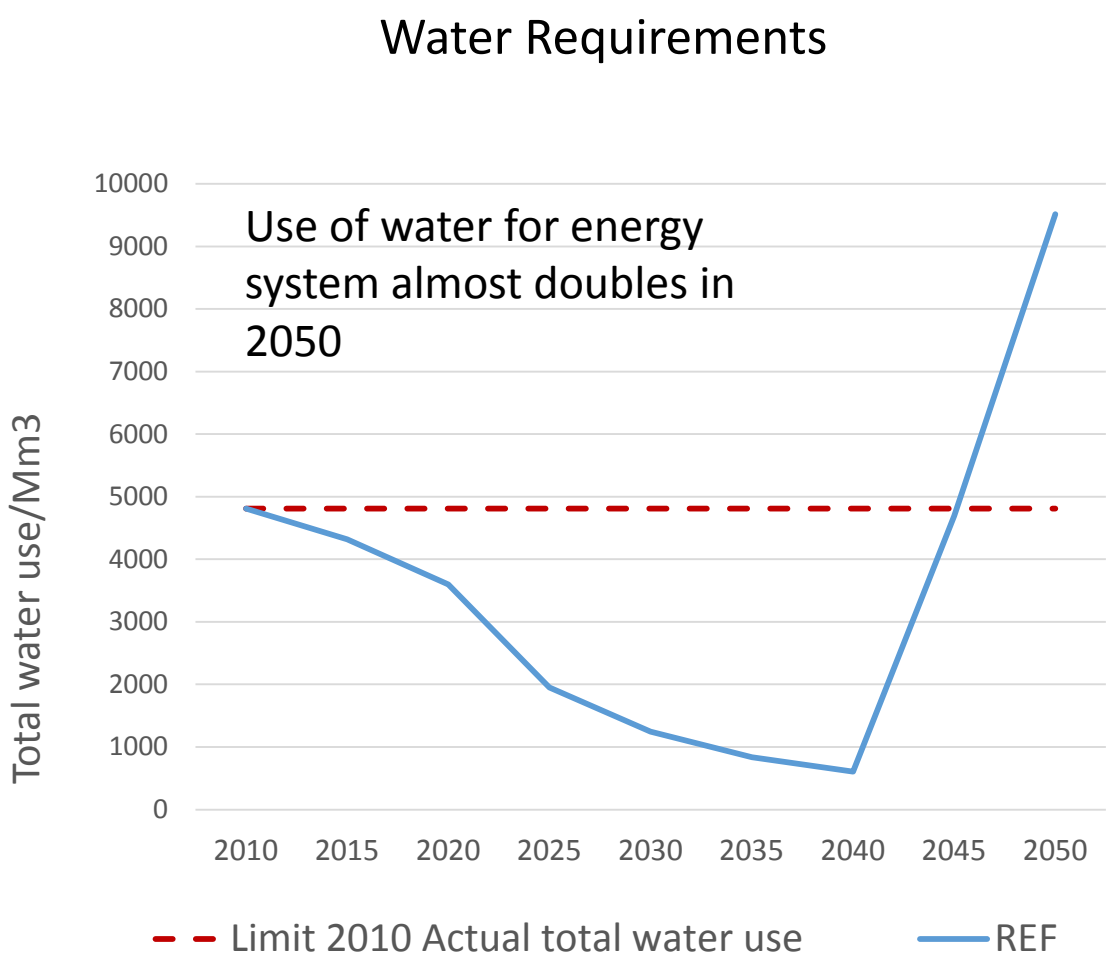




- Nuclear deployment in 2050: 33GW
- Primary (domestic) bioenergy: 730PJ

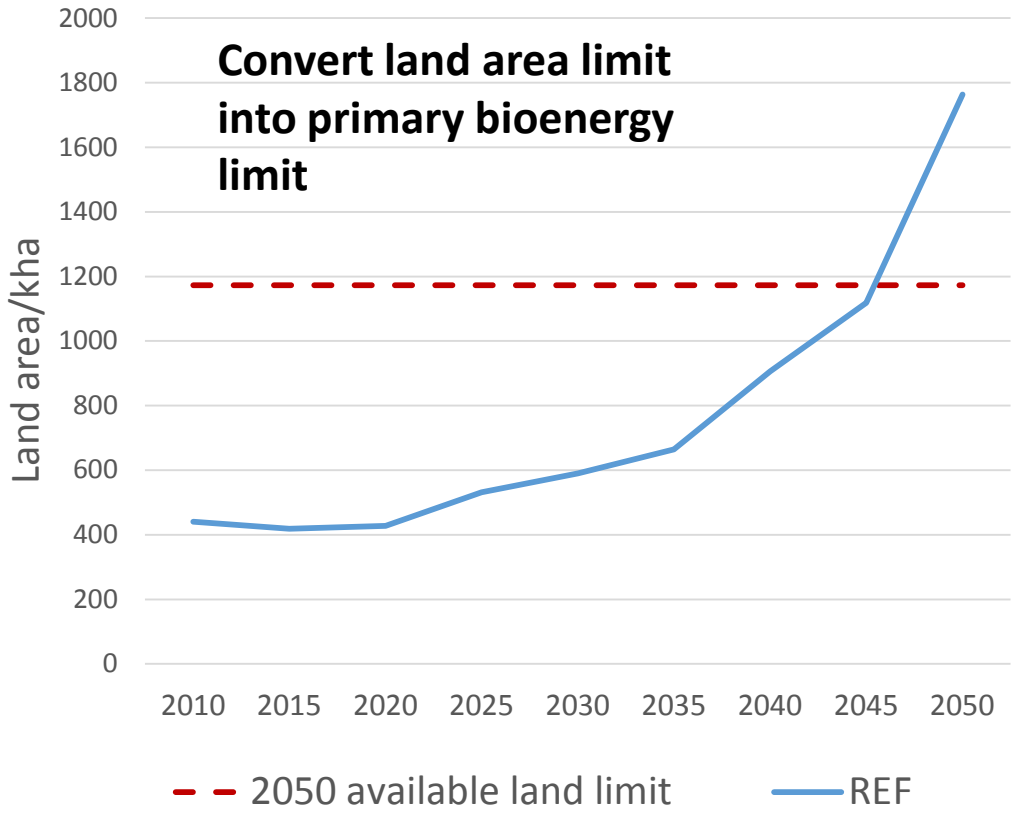
1st Iteration – Water and land limits are not met



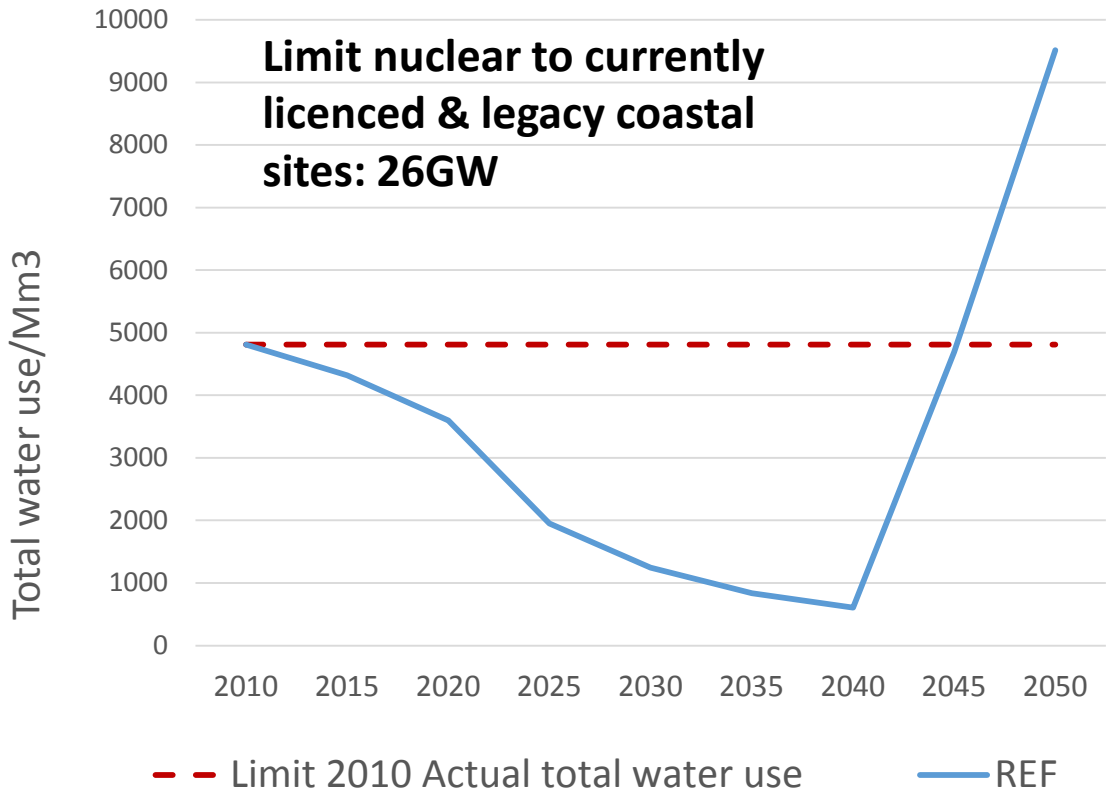


Limits for 2nd iteration

Land Requirements

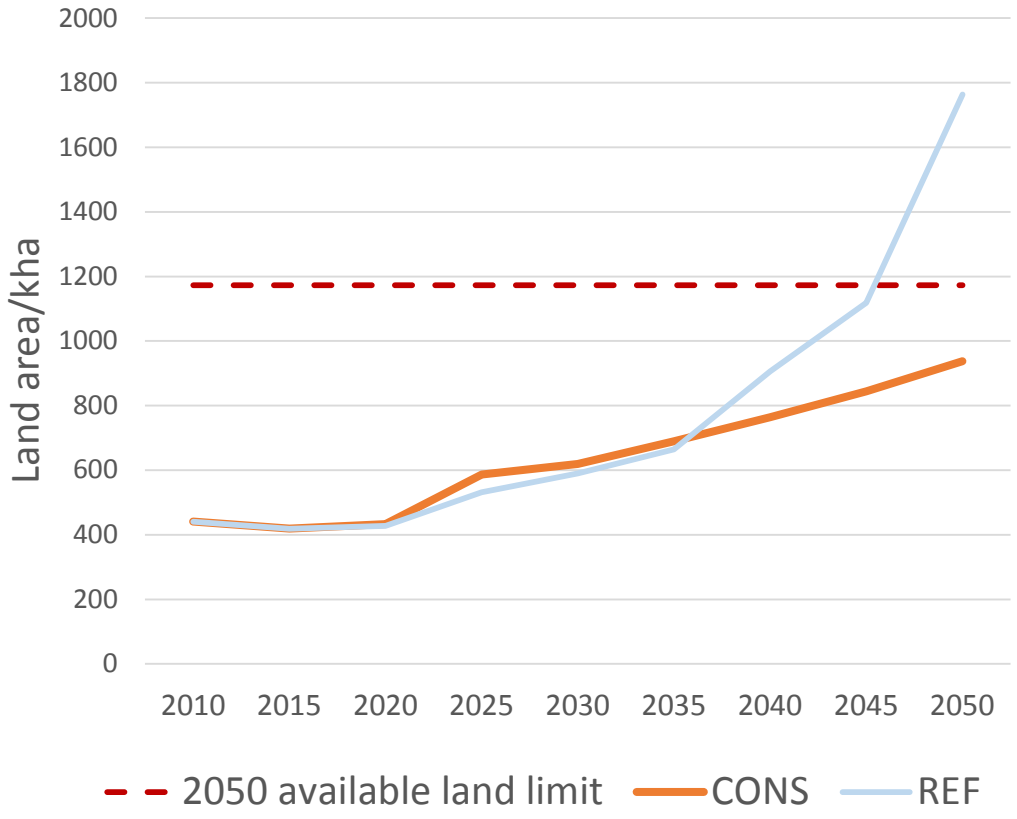


Water Requirements

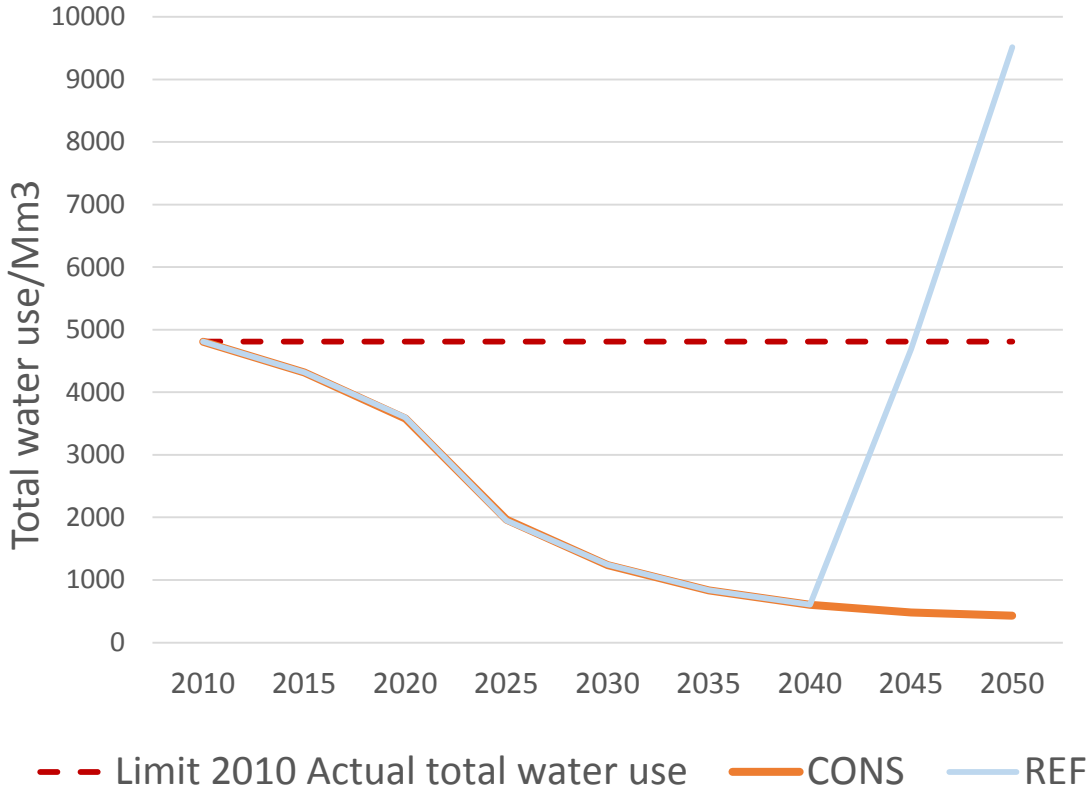


2nd Iteration – Limits met!

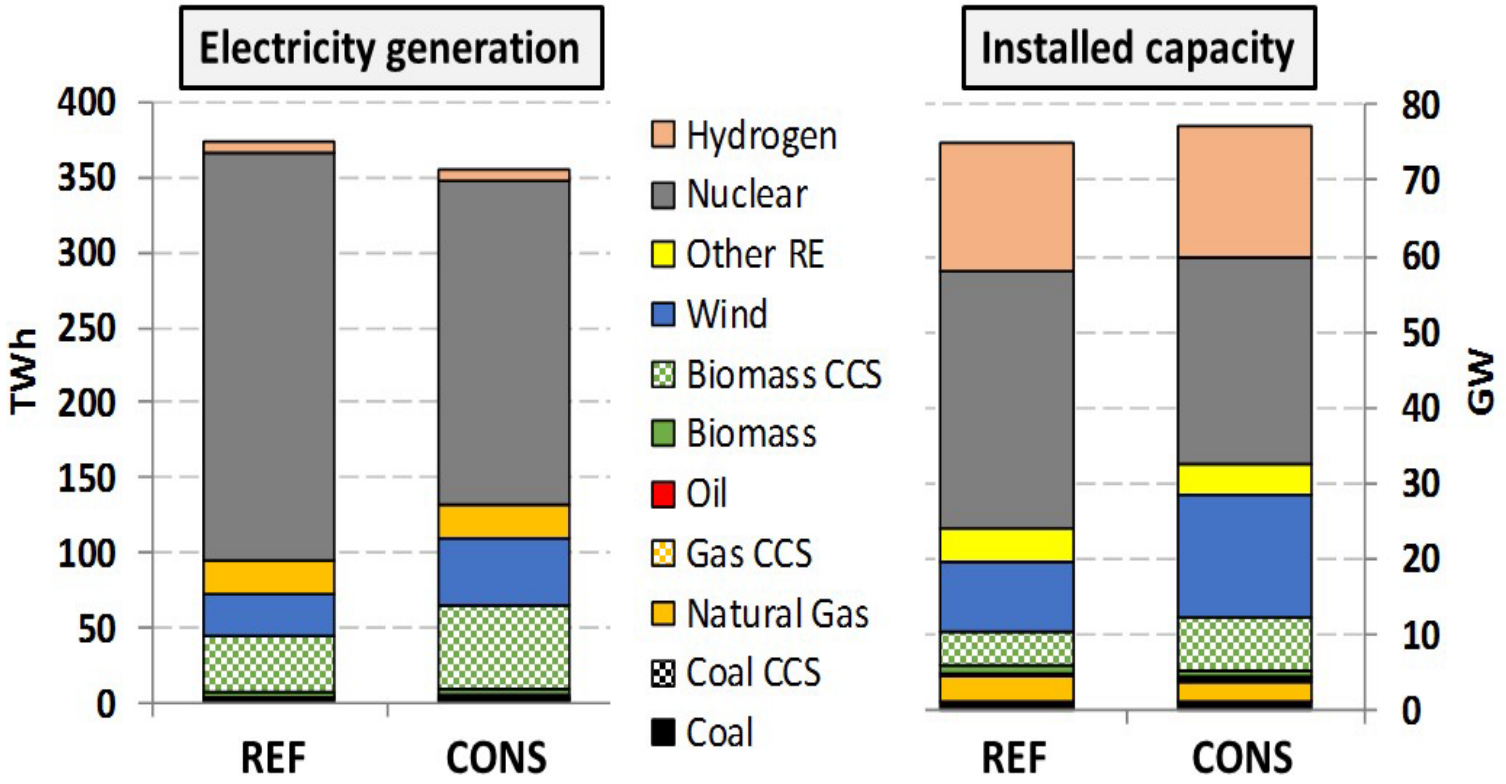
Land Requirements



Water Requirements



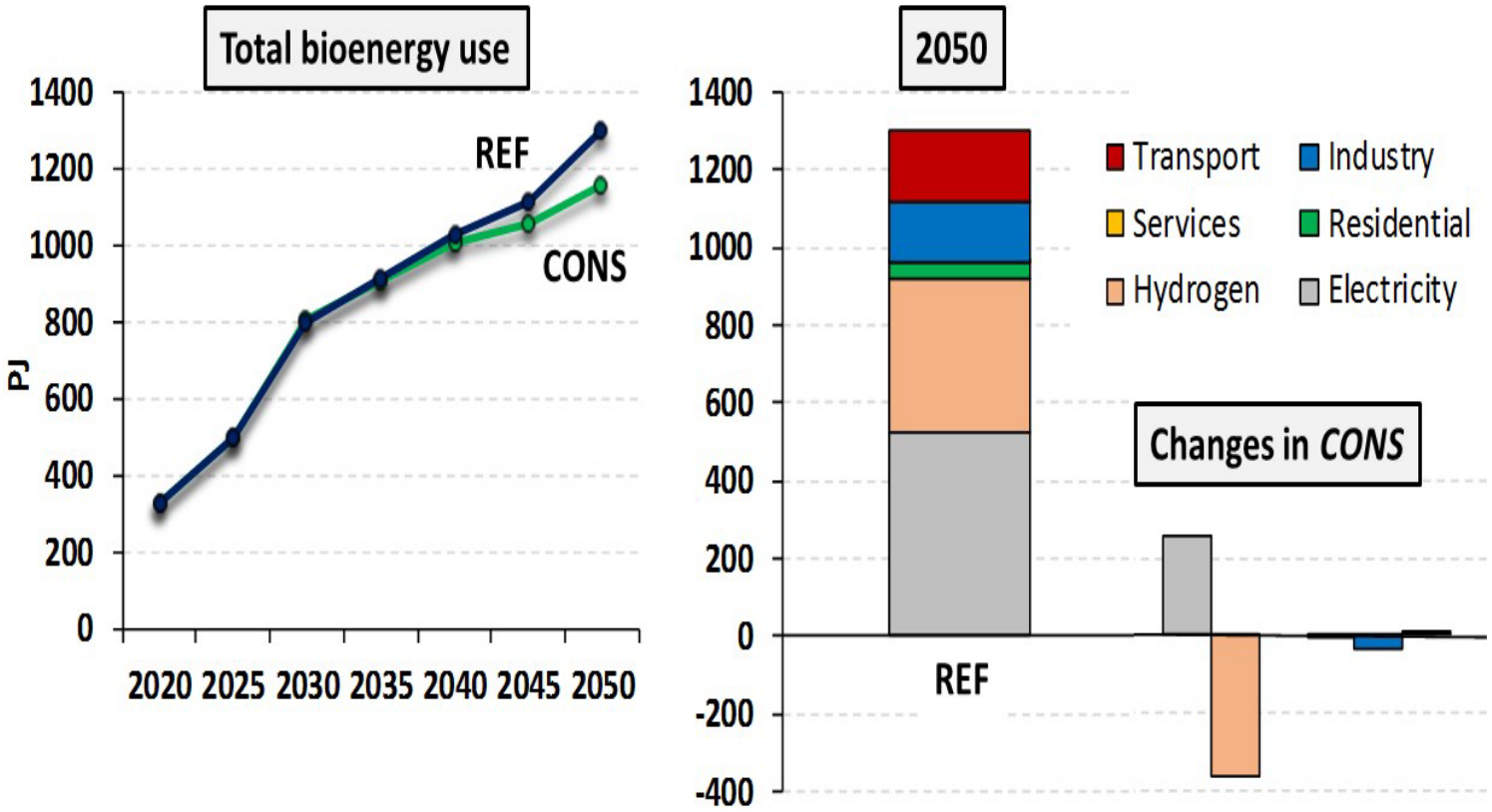
Results Stage 2 – REF vs CONS (electricity) - water



Changes in the energy system:

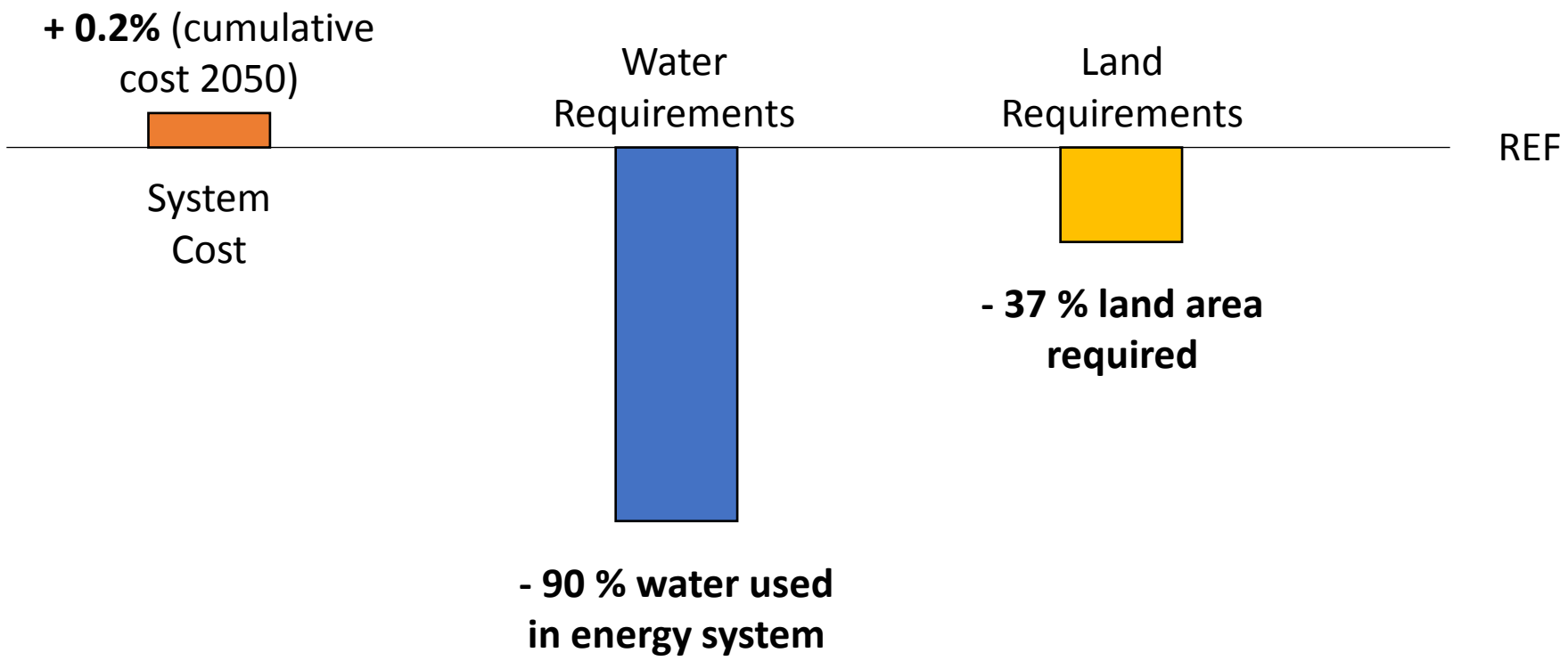
- Lower Nuclear
- Increase in Biomass + CCS

Results Stage 2 – REF vs CONS (bioenergy) - land



- Higher Biomass + CCS capacity;
- Lower use of bioenergy in the system – mainly due to lower use of bioenergy for H_2 production;
- But production of H_2 (from NG reforming) still increases in the overall system to be used in transport and industry. This has an impact on water for the energy system.

REF vs CONS – Costs & Impacts



Conclusion

For scenarios tested, with national scale for water system and high resolution land – limits to **sustainable resource use** can be incorporated in UKTM at **small additional welfare costs** (+0.2%).

For water scenario with no additional coastal sites available, changes in the energy system lead to a very significant improvement in total water used.

But energy system deploys more H_2 & more biomass with CCS, to replace lower nuclear availability – this has a trade off in terms of water use.

Limitations of study

Study has been done at a **national scale** for water – should be done at **basin scale** & also **temporal scale** – seasonal variations in flow and temperature of water are important.

Climate change impact on land and water resources was not considered.

Demand and supply of **energy at higher resolution** may be helpful to detect synergies at local level, such as use of local biomass for rural regions that are off gas grid.

No feedback between Foreseer and UKTM in terms of **cost penalties** of use of alternative, less water intensive technologies for water cooling.