Incorporating impacts on water and land use in an energy systems analysis – a case study for the UK

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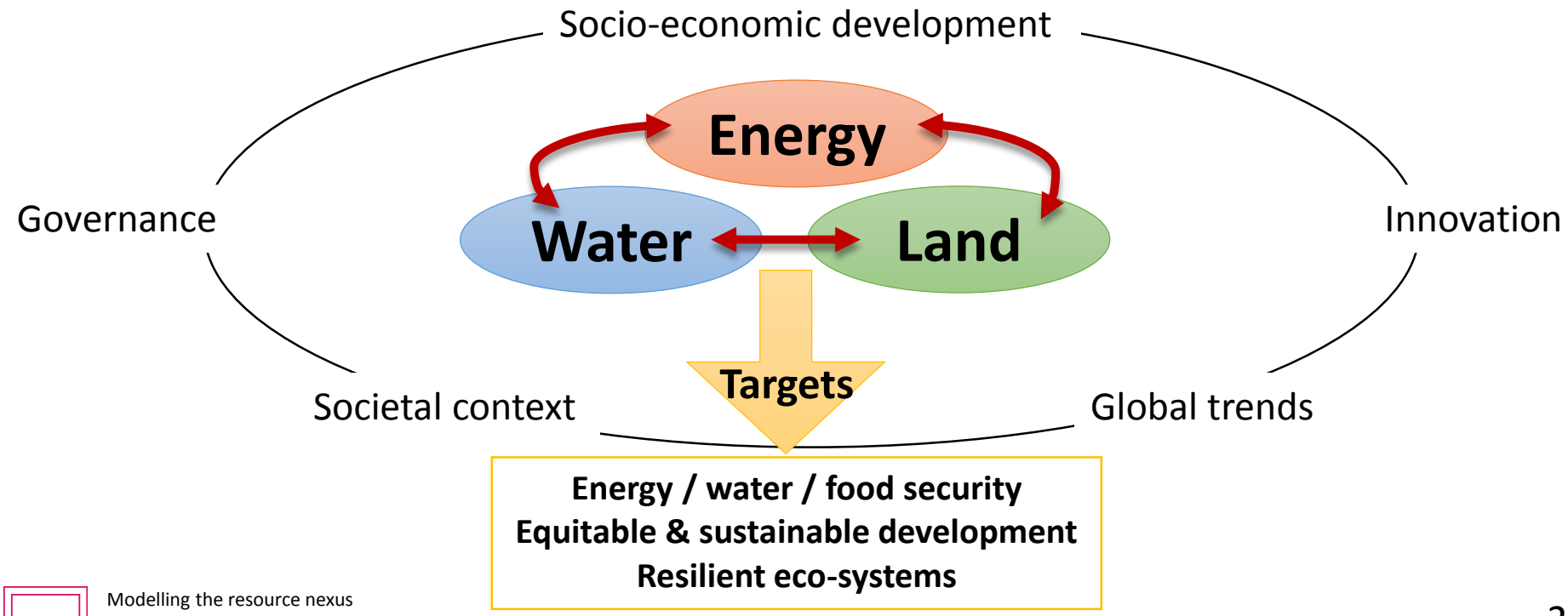
Motivation

- Strong interdependencies between the most important resource systems, esp. energy, water and land use
- Growing research focus on the resource nexus
- Quantitative systems approach needed to analyse the impacts of low-carbon energy transitions on other resource systems



The resource nexus in energy modelling

Overview on existing approaches

- **Integrated Assessment Models** (IAMs) that analyse the interactions between human activities and physical earth systems on an aggregate scale
- First studies on the economic implications of the resource nexus with **macroeconomic models**
- Growing number of **technology-focused, bottom-up nexus frameworks**: CLEWS, the WEF Nexus tool, PRIMA

Importance of the regional perspective for integrated nexus analyses

Hibbard and Janetos (2013) highlight the necessity of *"an integrated regional modelling approach that accounts for the dynamic interactions among physical, ecological, biogeochemical, and human processes and provides relevant information to regional decision makers and stakeholders"*

This analysis

Objective: analyse the 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 – The UK TIMES Model

- ***Overview***
  Integrated energy systems model - Least cost optimization - Partial equilibrium - Technology rich - sensitivity and uncertainty analysis

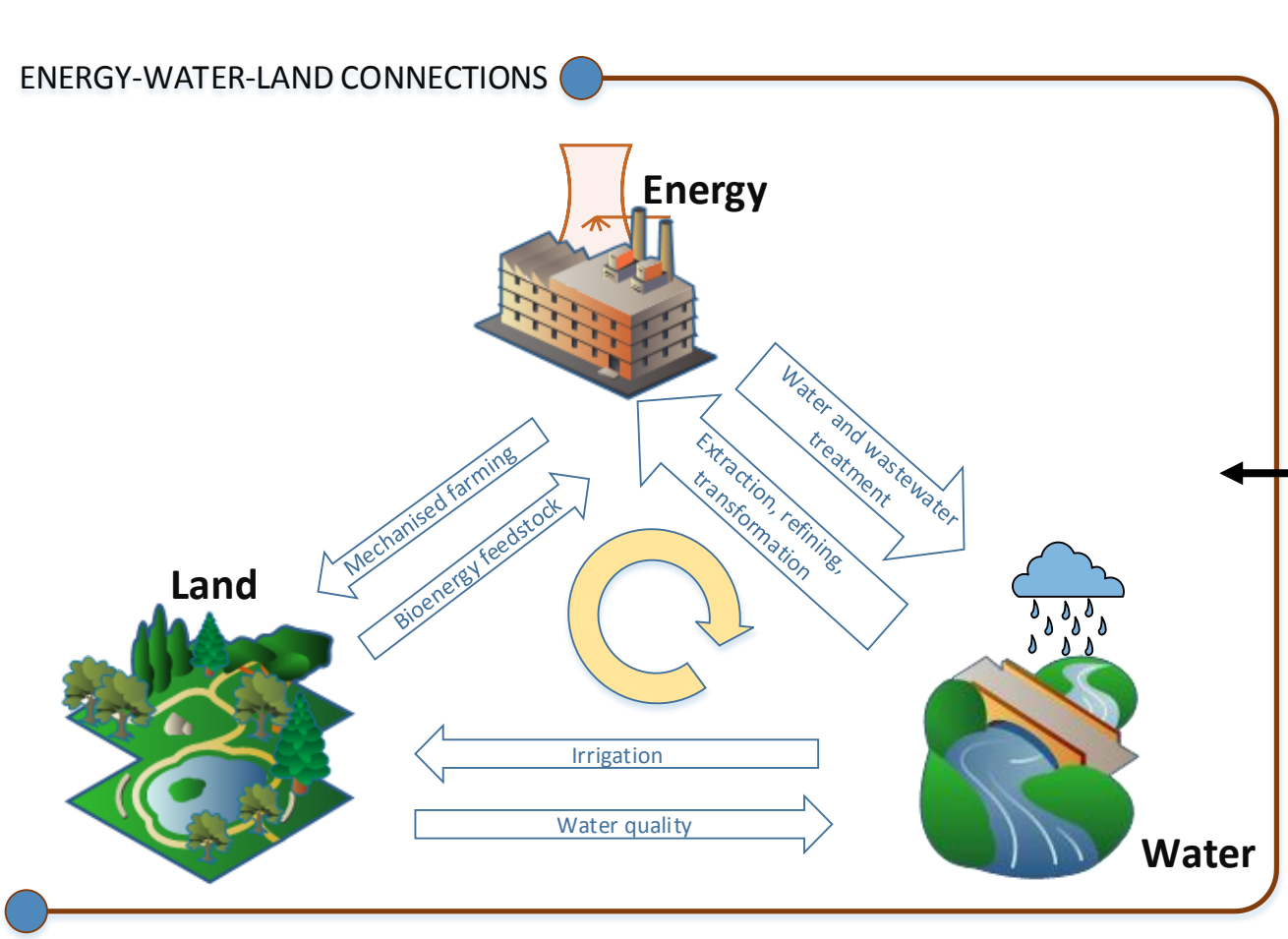
Successor of UK MARKAL

- ***New functionality of UKTM***
  - Higher temporal flexibility; storage
  - All GHG emissions & non-energy mitigation options;
  - Industrial & residential sector disaggregation;

- ***Open source modelling***
  - Transparency at the forefront of development
  - Full open source release in summer 2015
  - Strong policy engagement

- ***Ongoing research development***
  - Behaviour & fuel poverty
  - Land-Energy-Water nexus
  - Macro-economic impacts;
  - Spatial & temporal detail
  - Technology learning

The resource nexus model Foreseer UK



DEMAND DRIVERS

POPULATION GROWTH

Increased demand for
- Food
- Water
- Housing
- Energy

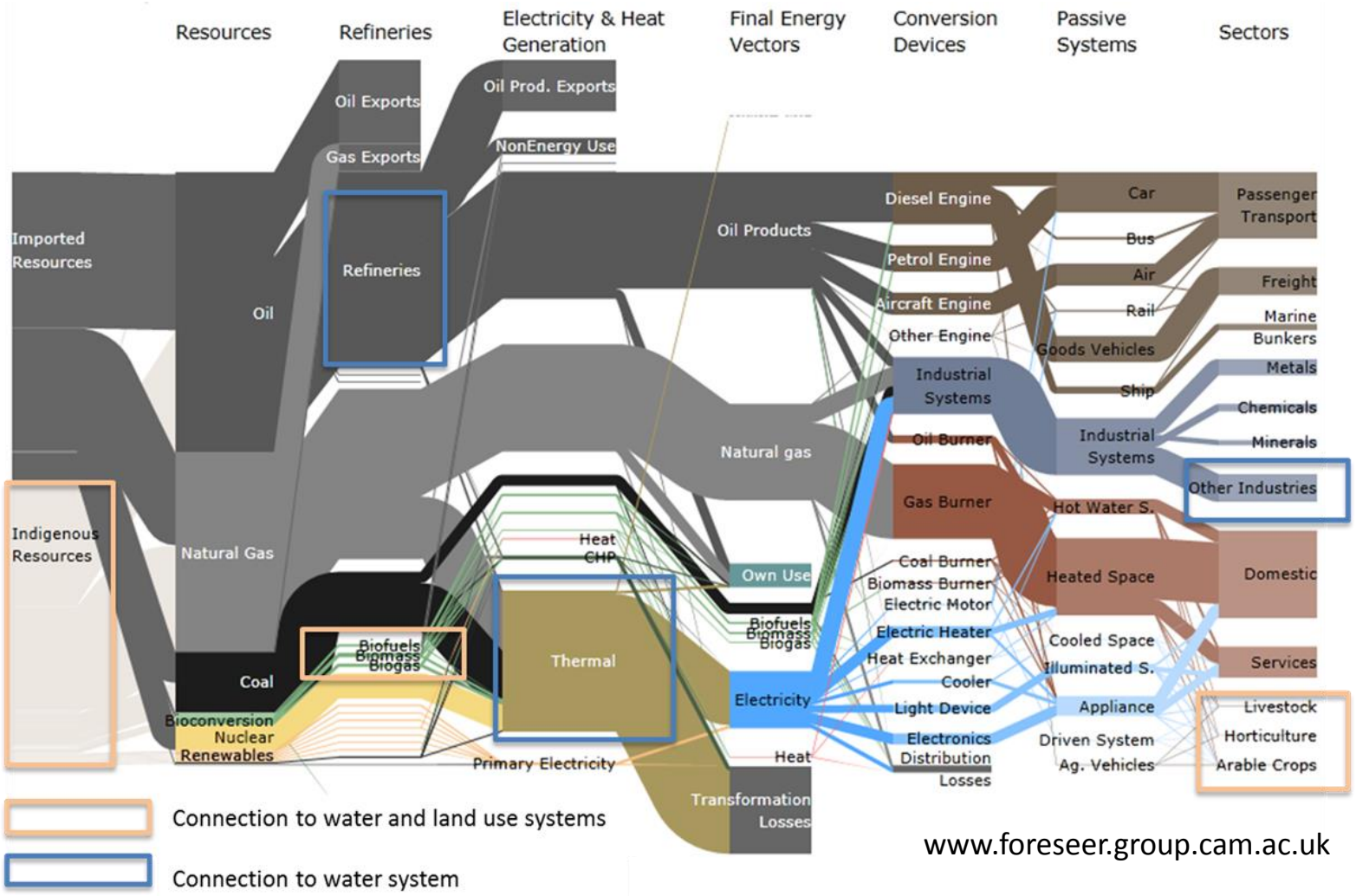
CLIMATE CHANGE

Increased
- Irrigation
- Drought
- Floods
- Cooling and heating

GHG REDUCTION

Demand for Low-carbon energy
- CCS
- Bioenergy

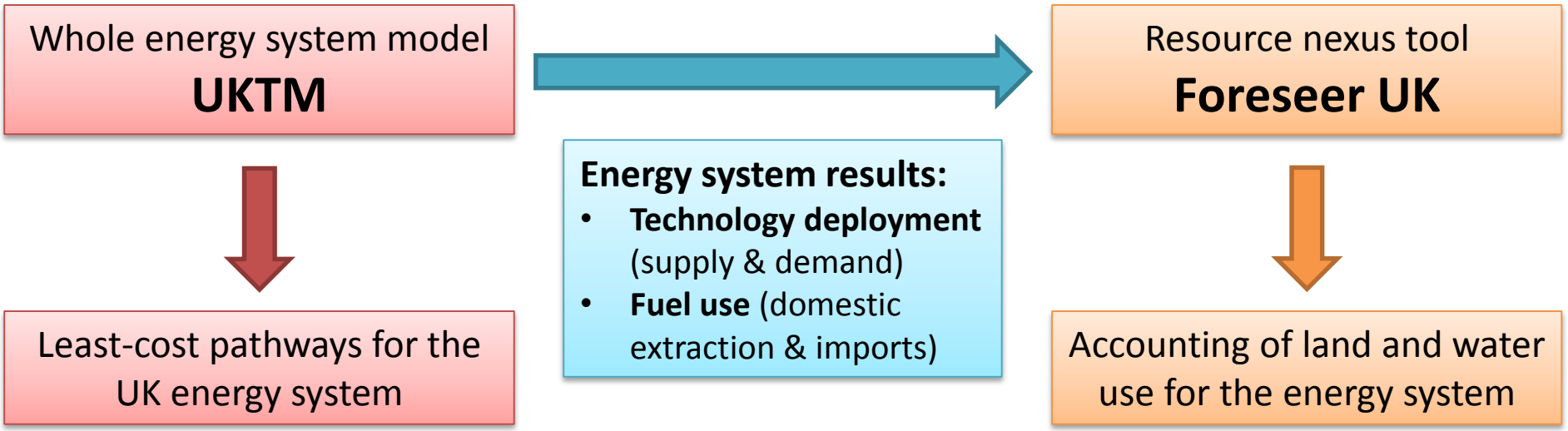
UK Energy System 2010 – main connections to Land & Water



www.foreseer.group.cam.ac.uk

Methodology for soft-linking

The analysis is triggered by UKTM
→ One-directional link of UKTM energy system results to Foreseer UK



Energy scenarios for UKTM

Two low-carbon scenarios (-80% GHG reduction until 2050)

→ alternative energy futures for the UK

→ with different availability of technologies and resources that are particularly sensible for water and land use

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

Land use scenarios for Foreseer UK

Three land scenarios (based on **change of energy crop yields to 2050**)

→ **LBAU** - Business-as-usual no change in yield relative to 2010

→ **YIELD10** - 10% improvement in bioenergy crop yield to 2050

→ **YIELD30** - 30% improvement in bioenergy crop yield to 2050

Two assessments were carried out:

A. Comparison with 900kha of "sustainable" land use change - according to the Bioenergy Review (DECC, 2012) - **physical feasibility**

B. Comparison with area of UK unused arable land – **availability of land**

Water scenarios for Foreseer UK

Two water scenarios (based on **cooling technology and future location of power plants**):

→ **WBAU** Business-as-usual - same cooling technology mix and distribution of sites power stations as current.

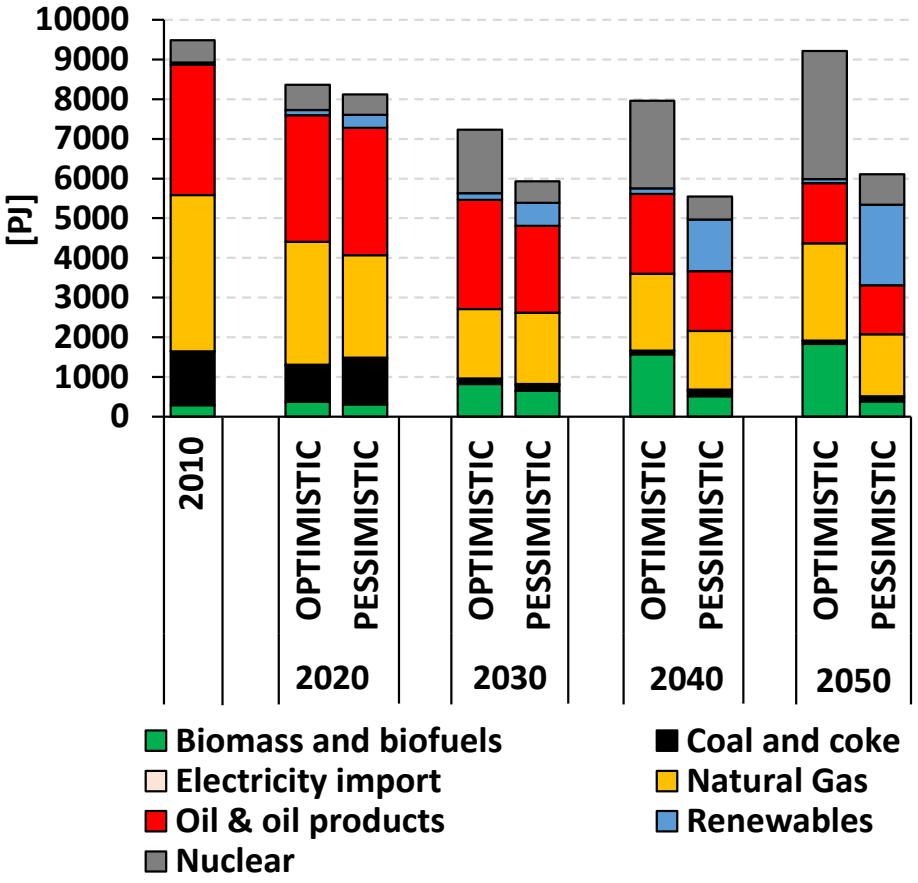
→ **CNUC** – Constrained Nuclear – total nuclear capacity on the coast limited to the currently licensed 16GWe to 2030.

Assessment:

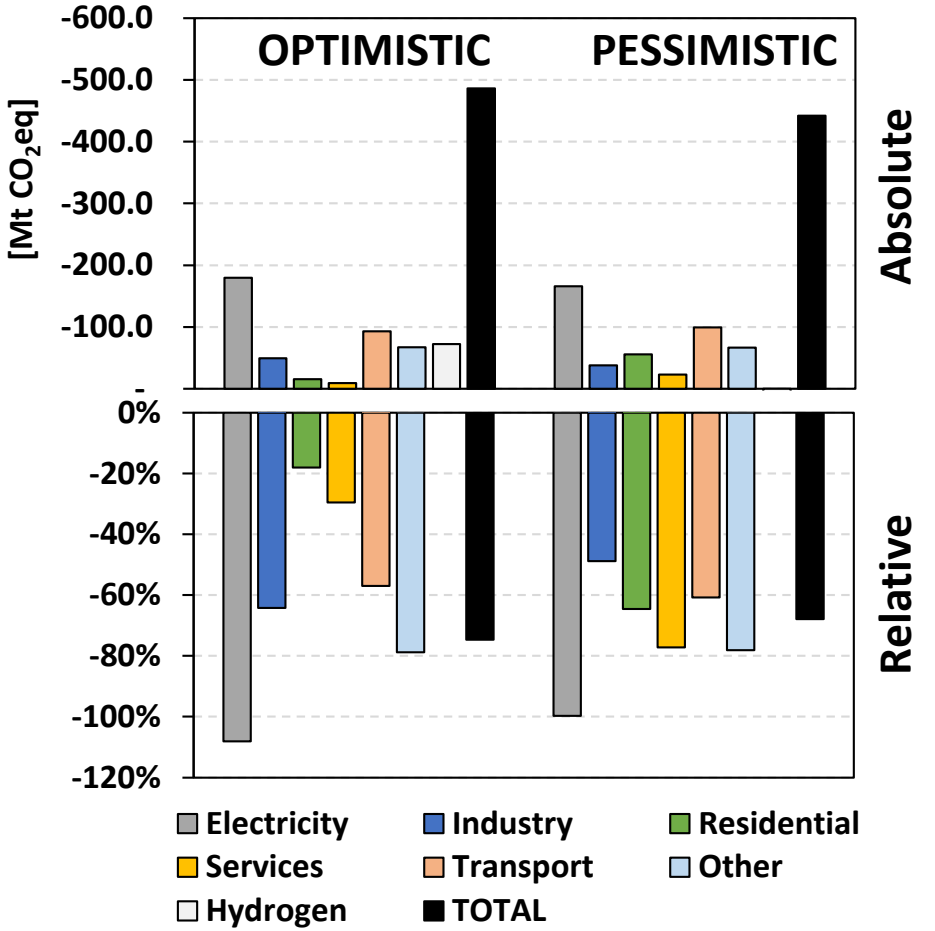
Comparison of water abstraction under each water scenario with current limits to total abstraction on a national basis – assessment of potential **conflicts between energy and water management policies** in UK.

UKTM results (1)

Primary energy consumption

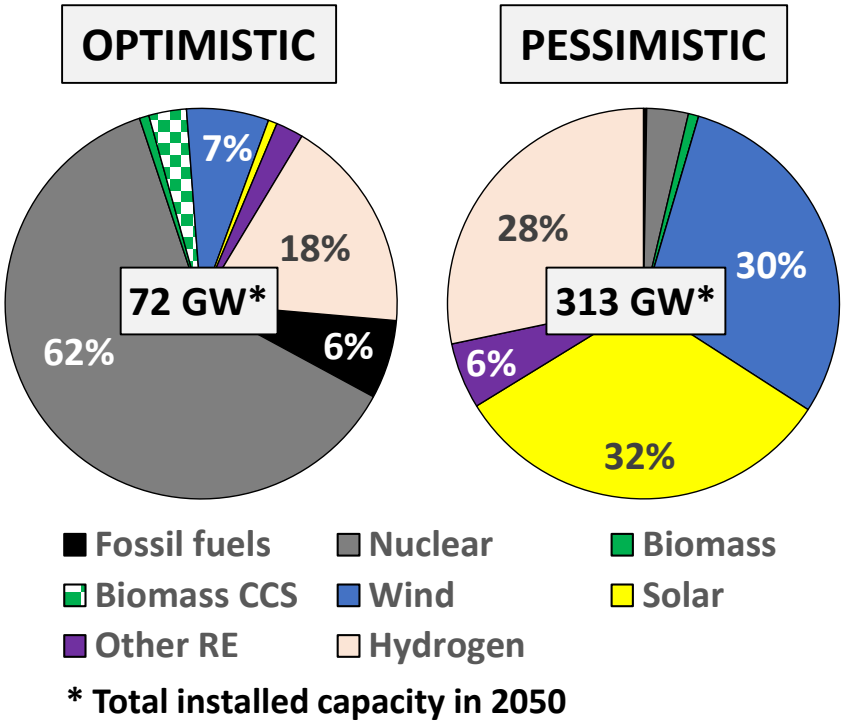


GHG emission reduction in 2050 (compared to 2010)



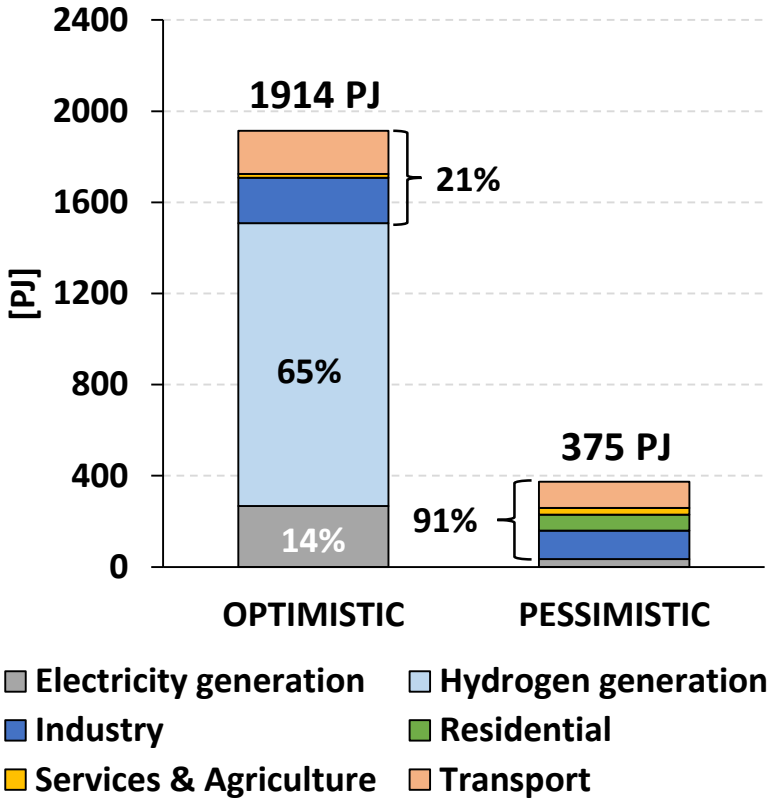
UKTM results (2)

Electricity capacity in 2050



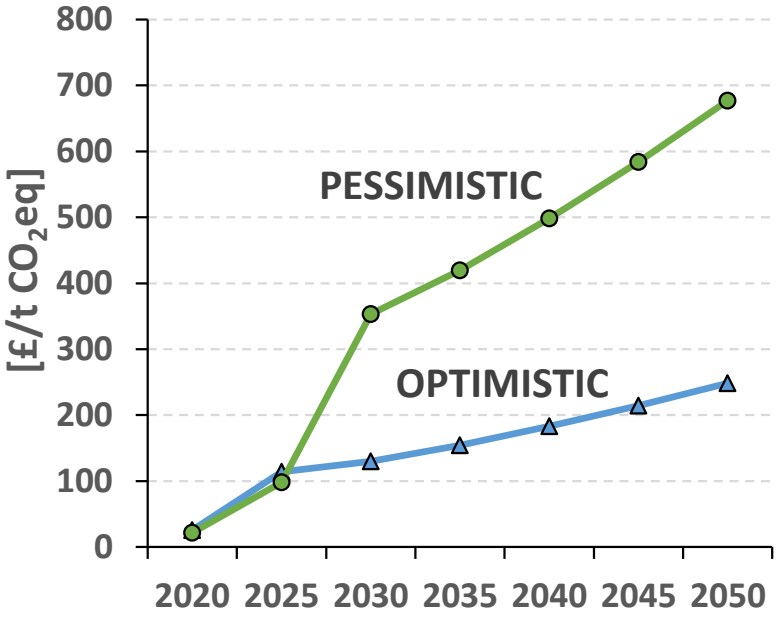
* Total installed capacity in 2050

Bioenergy use in 2050



UKTM results (3): Cost indicators

Carbon price

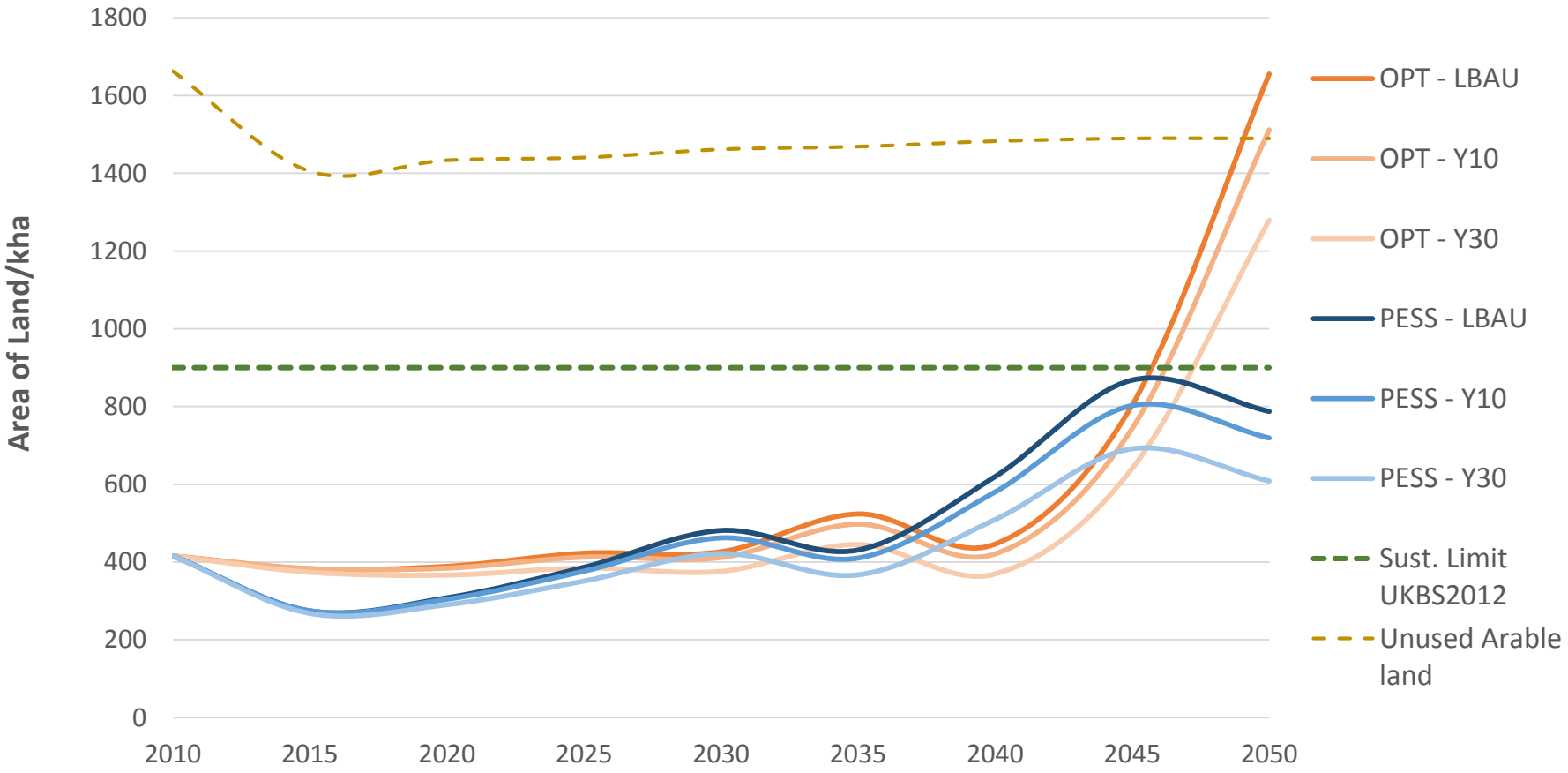


Difference in annual undiscounted welfare cost

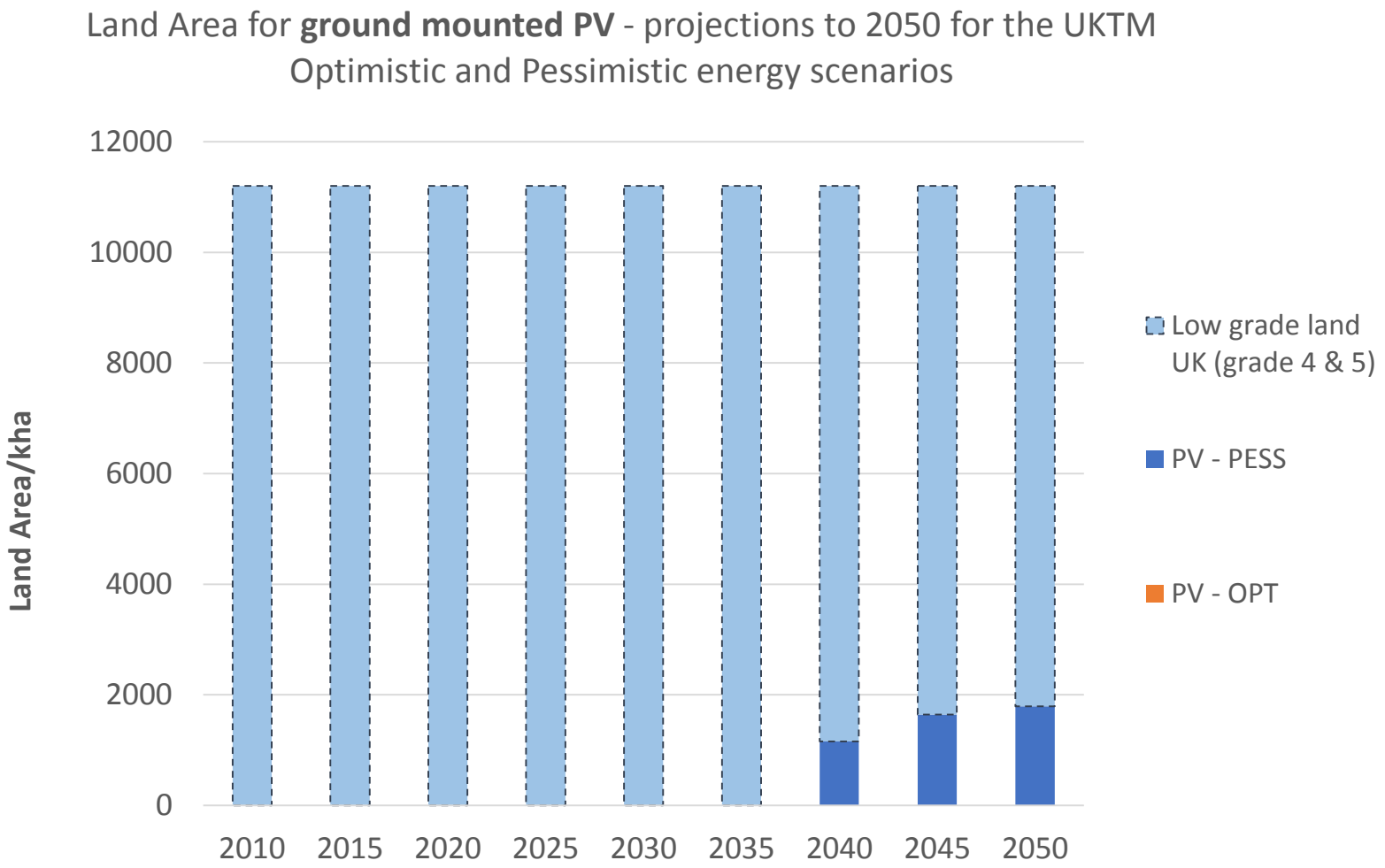
	2020	2030	2040	2050
PESSIMISTIC *vs.* OPTIMISTIC	0%	5%	7%	11%
	Cumulated 2010 - 2050			
	6% (£1080 Bn)			

Foreseer Land Impact Assessment (1) - Bioenergy

Land Area for **UK bioenergy feedstock production** - projections to 2050 for the UKTM Optimistic and Pessimistic energy scenarios

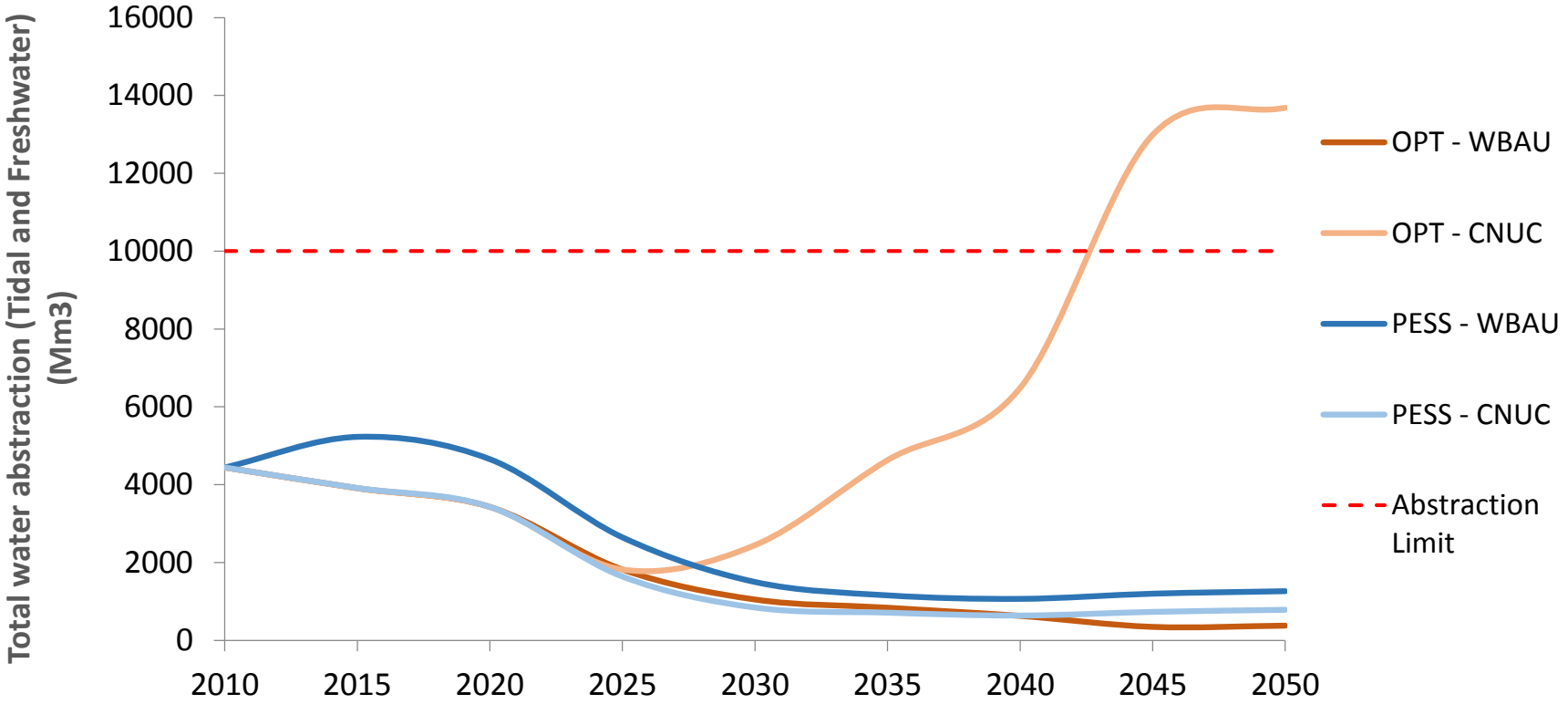


Foreseer Land Impact Assessment (2) – Solar PV



Foreseer Water Impact Assessment (3)

Total **water abstraction for UK energy system** - projections to 2050 for the UKTM Optimistic and Pessimistic energy scenarios



Summary of Foreseer analysis

→ **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

Conclusions

- Integrated nexus analyses highlighting the interactions between long-term decarbonisation strategies and the wider resource use will play an essential part in designing consistent and holistic environmental policy instruments
- Soft-linking an optimizing energy system model and a resource nexus model can help to highlight the trade-offs between least-cost decarbonisation pathways for the energy system and wider environmental impacts
- Not all decarbonisation strategies are automatically “no-regret” options for the environmental system!
- **Future work:**
  - Increase spatial disaggregation
  - Feedback link from Foreseer to UKTM to present environmental limits directly in the energy system analysis

Thank you for your attention!

UKTM

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Conclusions from Foreseer analysis - Land

→ **Pessimistic energy scenario has lower land use impact across all land scenarios.**

→ **Optimistic energy scenario** - land area requirements **above land use sustainability criterion** for all land yield improvement scenarios and could require **more than available unused arable land** in 2050

→ **Pessimistic energy cenario** – **meets** both **sustainability** criterion and **availability** of land in 2050

→ **Optimistic energy scenario** could face significant **deployment issues**, as rate of production after 2040 ramps up significantly – could be an issue for perennial crops.

→ **No substantial land availability issues for ground mounted PV –** max. of 16% of low quality land for PV in 2050 for Pessimistic energy scenario.

Conclusions from Foreseer analysis - Water

→ Generally both energy scenarios could have **impact on fresh and tidal wate**r resources **similar to current system** (actual 2010).

→ **Impact on coast could be significant for the Optimistic energy scenario** – as this requires more than 40GWe of nuclear generation on the coast – higher than the 16GWe currently licensed.

→ If new nuclear coastal sites limited to 16 GWe (**Constrained Nuclear scenario**) – fresh and tidal water abstractions substantially higher than 2010 levels – **Optimistic energy scenario** could have **significant water impacts and potential conflicts with water management policies**.