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Impact of bioenergy emission spatiotemporal factors on UK low carbon energy pathways

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WholeSEM Workshop:
Integrated energy systems models incorporating spatial and temporal detail
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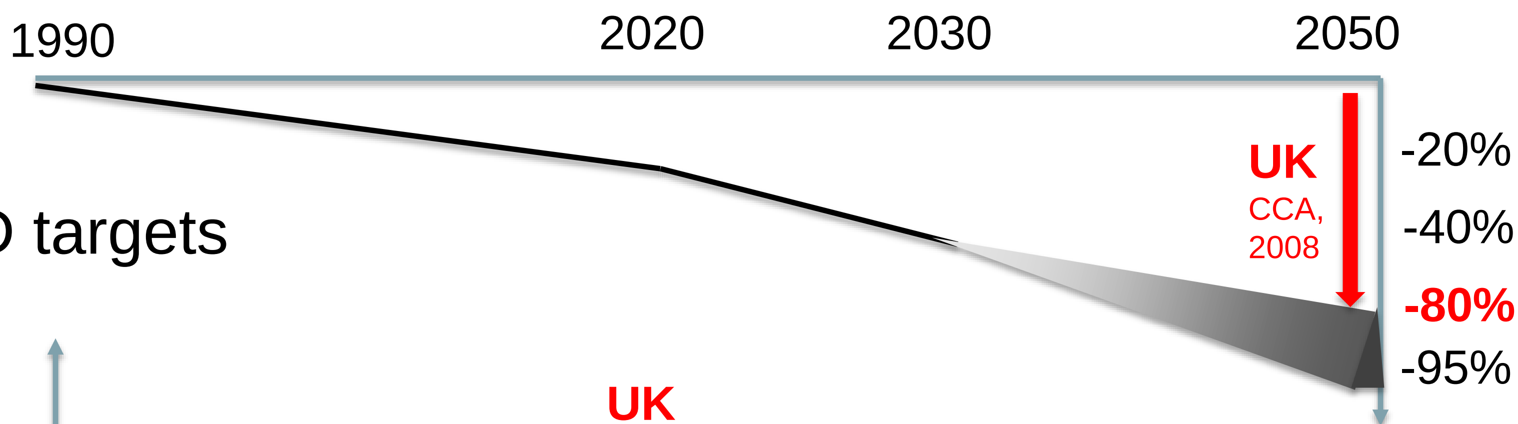
EPSRC
Engineering and Physical Sciences
Research Council

Bioenergy value chains
Whole systems analysis and optimisation

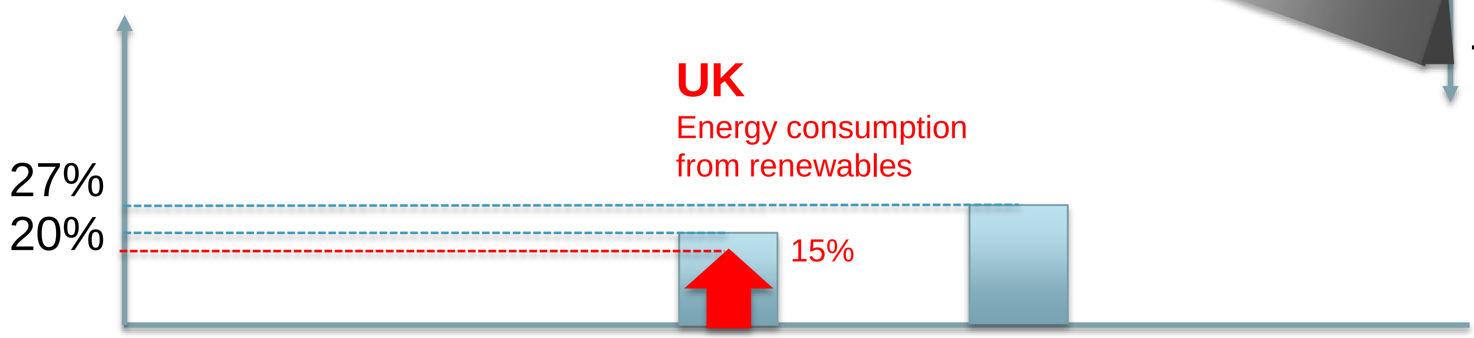
Context

International and UK policy landscape

- EU emission reduction targets



- EU RED targets



Role of bioenergy in the UK

- CCC bioenergy review 2012

  *It will be difficult to meet the overall 2050 emissions target unless bioenergy can account for around **10% (200 TWh)** of total **UK primary energy** (compared to the current 2%) and CCS is a feasible technology.*

- 5th Carbon Budget

  *Sustainable bioenergy can play an important role. However, there are limits to the sustainable supply (e.g. this could provide around **10%** of **primary energy in 2050**), so its role must be supplementary to other measures. Bioenergy should be allocated to options where it has the largest impact on reducing emissions.*

- ETI 'Delivering GHG emission savings through UK bioenergy value chains'

  *Bioenergy could be deployed to deliver net negative emissions of around -55MtCO2eq/yr in 2050 and meet around **10%** of **UK energy demand** (**≈130 TWh/yr in 2050**)*

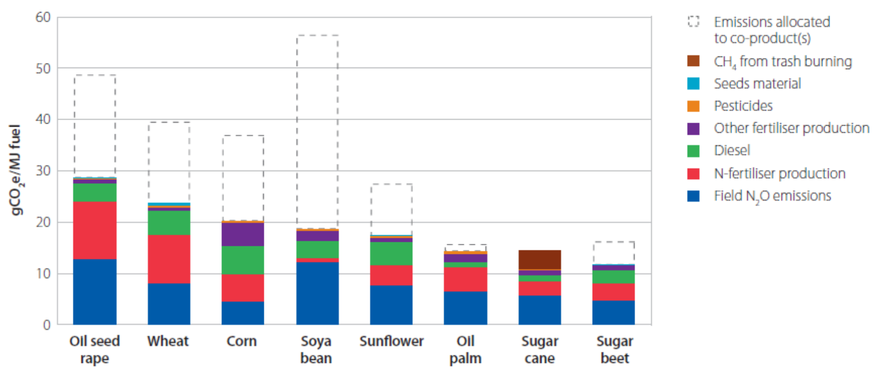
Motivation

- Bioenergy combined with CCS is a key vector in energy system decarbonisation pathways
- Advantages
  - Economic → Low cost
  - Technical → Easy to integrate in current infrastructure
  - Environmental → Potential for negative emissions
- Challenges
  - Land competition → Food, energy, non-market subsistence farming & biodiversity
  - Uncertain emissions → Direct emissions from combustion
    → dLUC arising from changes in land management practice associated to prior use
    → iLUC additional land use elsewhere when displaced agricultural activity

Modelling spatiotemporal bioenergy emission impacts (I)

- Resources
  RED Scope 1 and 2 life cycle emissions
  CCC iLUC average for biofuels
  BEAC LUC C stock change and land emissions (Imports)
  - Emissions from cultivation of food crops (CCC, 2012; RED/Biograce, E4Tech, Ecofys)

Figure 2.1: Cultivation emissions of food and fodder crops

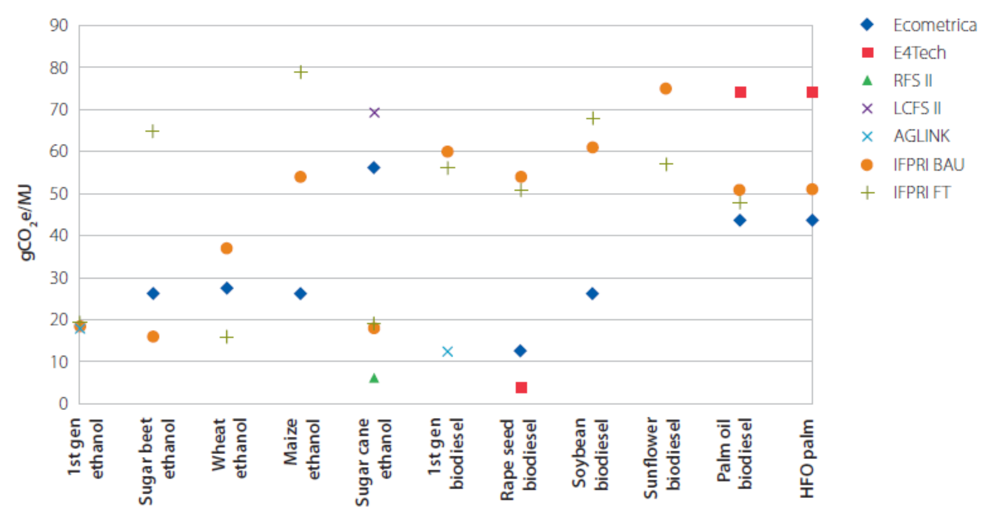


Source: Biograce.
Note: Biograce is an EU funded project which aims to harmonise calculations of GHG emissions that are performed in the EU under legislation implementing the Renewable Energy Directive and the Fuel Quality Directive. The EU-RED method for allocating emissions to co-products is based on energy content; soya meal is the main product and soya biofuel is the co-product, so in this exhibit the emissions in the lower section of the soya bar corresponds to the biofuel (the co-product) and emissions in the upper section to the soya meal.

Modelling spatiotemporal bioenergy emission impacts (II)

- Resources
  - Average indirect land use change estimates for biofuels

Figure 2.5: Range of estimates for ILUC emissions



Source: CE Delft (2010).

Modelling spatiotemporal bioenergy emission impacts (III)

UK Bioenergy strategy

- BEAC model → Soil and Land biomass C stock changes

  → Land emissions

  → Different harvest periods

  → Allows to investigate different GWP time horizons: 20, 40, 100 years

→ Does not account for changes in average forest carbon stock

→ Indirect impacts

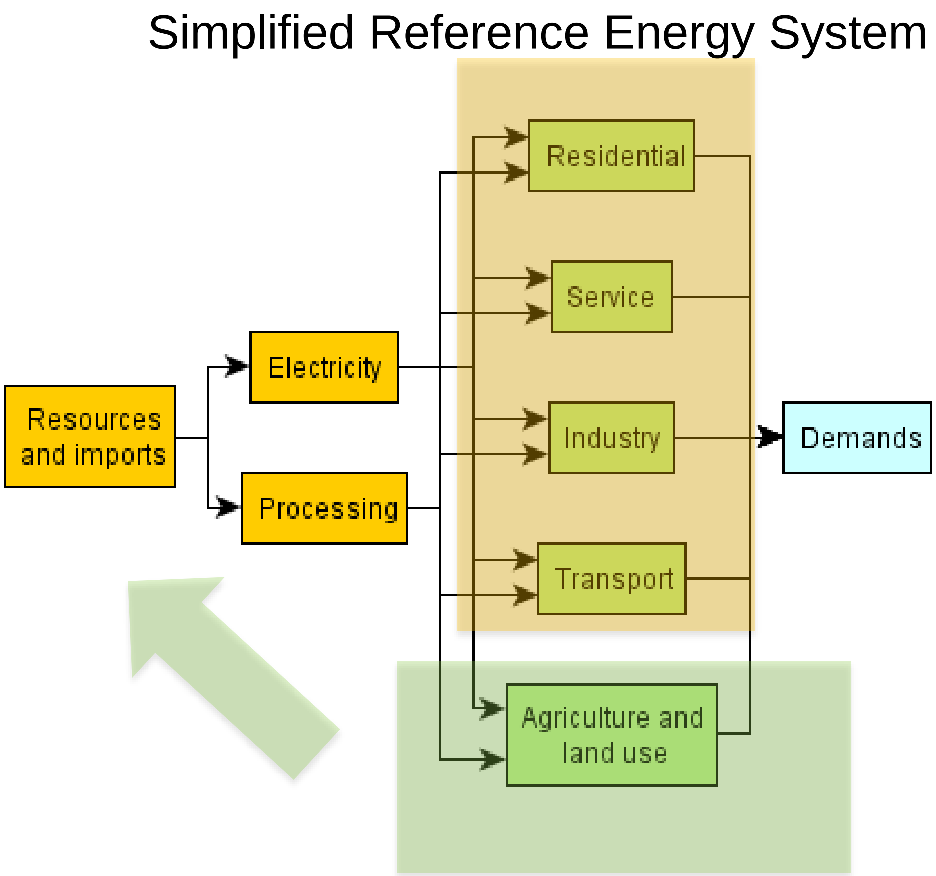
UKTM – The UK TIMES Model

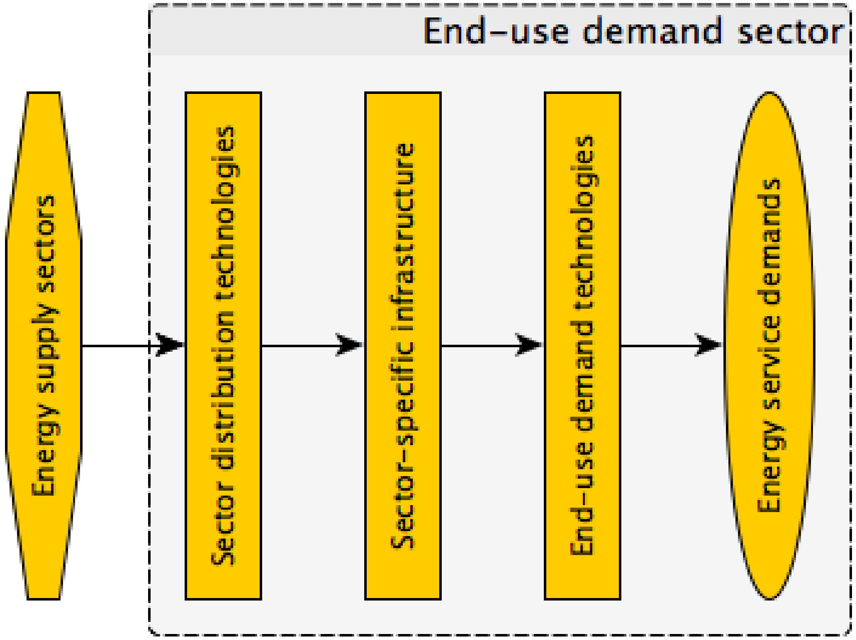
- *Overview*
  Integrated energy systems model - Least cost optimization - Partial equilibrium model - Technology rich - sensitivity and uncertainty analysis

- *History & future of policy analysis: Successor to UK MARKAL*
  - MARKAL's strong policy heritage
  - UKTM has a strong future in policy:
  - DECC have undertaken UKTM as core tool

- *New functionality of TIMES & UKTM*
  - All GHG emissions; storage; flexibility; bioenergy chains
  - Linkages with European & global TIMES models
  - Assumptions explicit
  - QA protocol at the heart of development

Structure of model and sectors





Bioenergy resources UKTM (I)

Domestic

1G

- **Arable crop**
  - Sugar crop
  - Starch crop
  - Oil crop

  - Sugar beet
  - Wheat, maize, potato
  - Rapeseed

2G

- **Woody energy crops**
  - Short rotation forestry (SRC)
  - UK energy crops
  - Stemwood

  - Poplar/willow
  - Miscanthus

- **Residues**
  - Sawmill co-product
  - Livestock manure
  - Waste wood
  - Arboricultural arisings
  - Tallow
  - Forestry residues
  - Dry agricultural residue

- **Waste**
  - Renewable fraction of waste
  - Non-renewable fraction of waste
  - Food waste
  - Used coking oil
  - Landfill gas
  - Sewage sludge

Bioenergy resources UKTM (II)

International imports

1G	Arable crop	Current oil crops
		Emerging oil crops
	Commodities	1 G Bioethanol
2G	Woody energy crops	Woody biomass
	Residues	Agricultural residues
		Tall oil

International exports

Commodities	Bioethanol

Bioenergy technologies UKTM

Domestic

Pre-treatment
- Straw waste pretreatment
- Wood waste pretreatment
- Oil crop pyrolysis

Pelletization
- High quality pellets
- Low quality pellets

Liquid biofuel
- Ethanol from starch
- Ethanol from grass
- Ethanol from sugar
- Ethanol from straw waste
- Ethanol from HQ pellets
- Methanol from HQ pellets
- Biodiesel 1G
- Biodiesel 2G
- Biokerosene 2G
- Biooil from pyrolysis oil

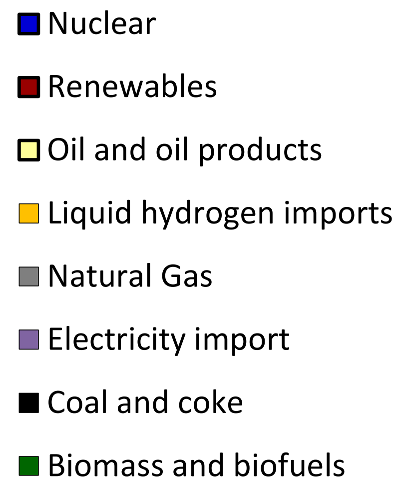
Gas
- Syngas from pellets
- Biogas from AD
- Biogas from landfill

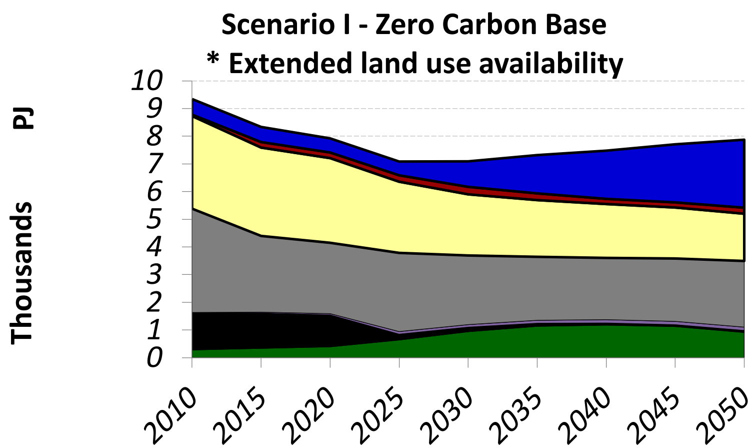
Upgrade
- Biomethane from syngas upgrade
- Biomethane from biogas upgrade
- Bio LFO from bioil upgrade

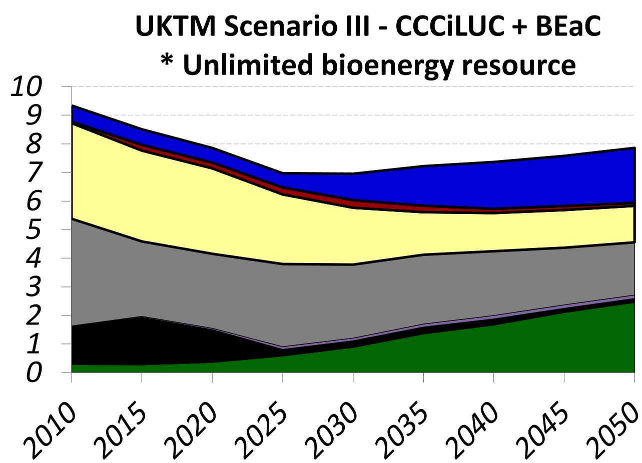
Results: Bioenergy scenarios

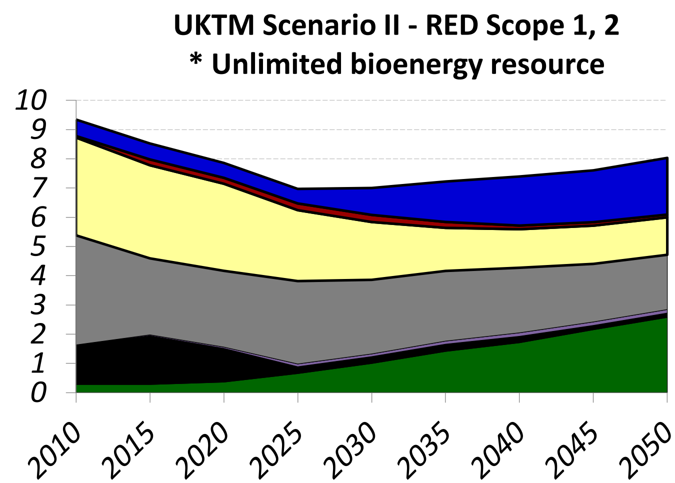
Scenario ID	Scenario Name	Emissions description	Resource availability	Constraints
Scenario I	Zero-Carbon Base	Bioenergy emissions offset during biomass growth	CCC (2011) 'Extended Land Use scenario assumptions	UK is constrained for a cumulative 80% emission reduction in 2050
Scenario II	RED (2009) Scope 1,2	Life cycle bioenergy emissions, dLUC, CH_4 and N_2O.	Unlimited bioenergy resource availability.	UK is constrained for a cumulative 80% emission reduction in 2050.
Scenario III	Scenario II + 1st generation iLUC + forestry carbon stock and land use (BEAC)	CCC (2011) iLUC factors for 1st generation bioethanol and biodiesel, and land biomass carbon stock change and land use emissions for forestry resource from Stephenson and McKay (2014) added.	Unlimited bioenergy resource availability.	UK is constrained for a cumulative 80% emission reduction in 2050.

Primary energy consumption

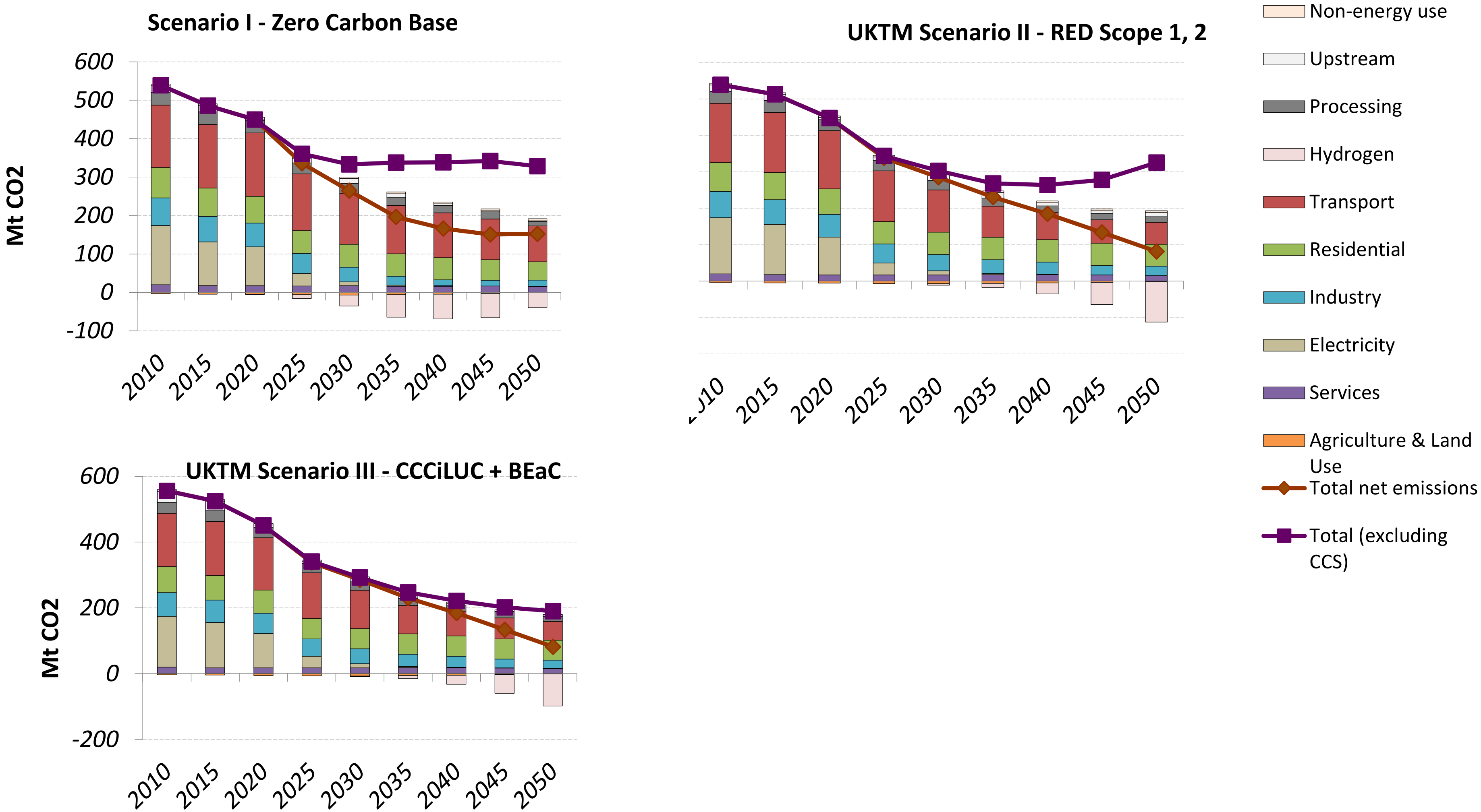




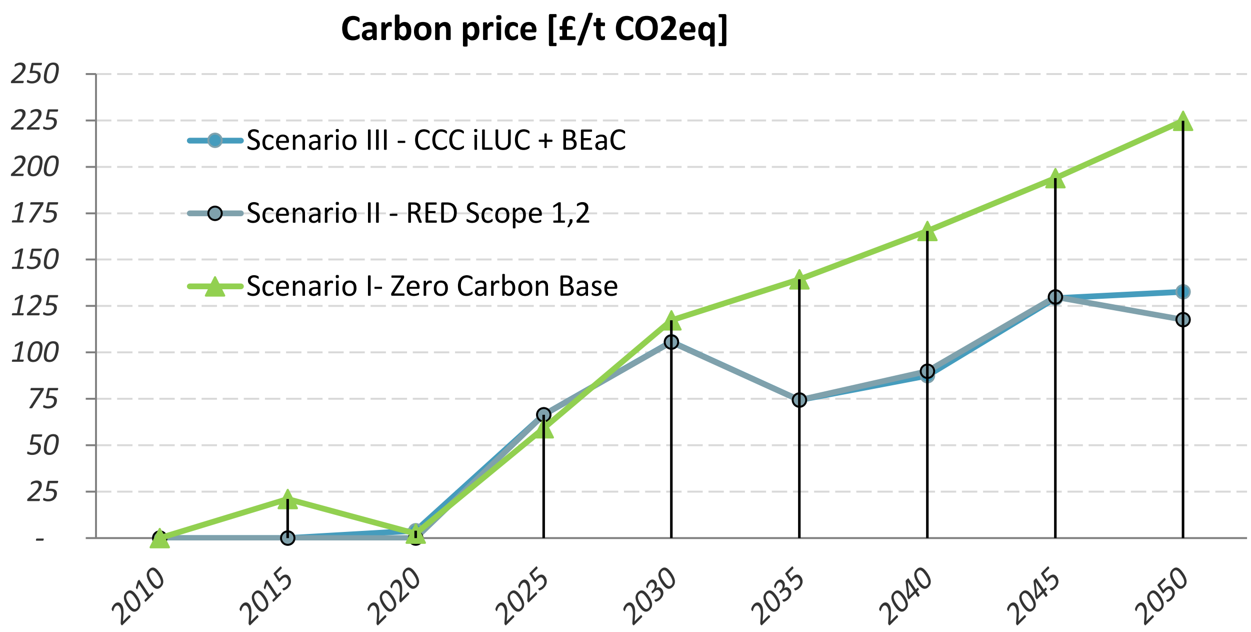




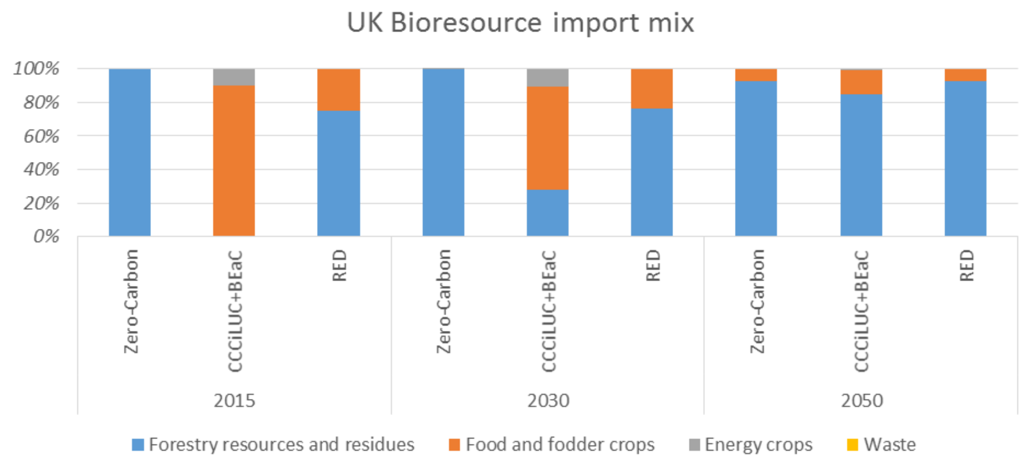
CO2 emissions by sector

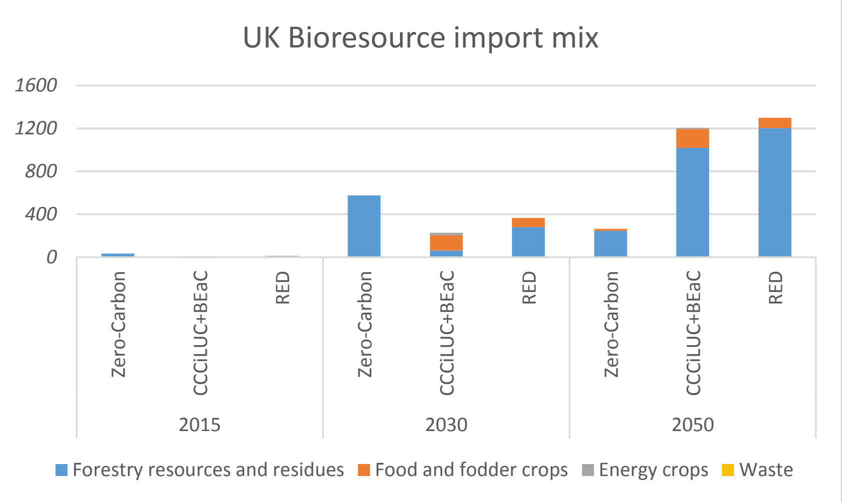


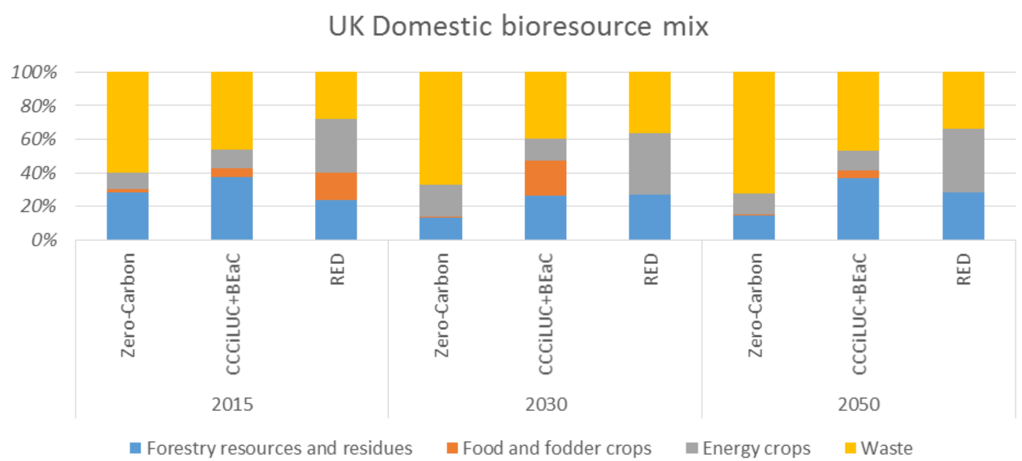
Carbon prices

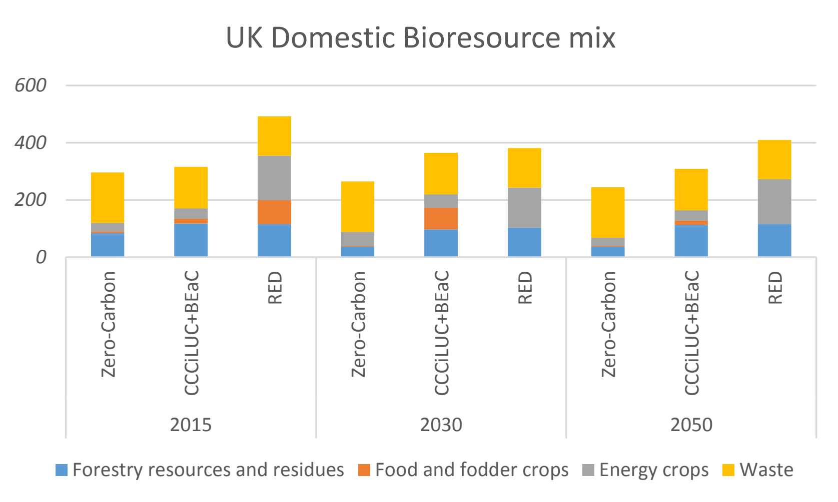


Bioenergy mix









Conclusions

- ❑ The model has not many other options to decarbonise the energy system and maximises the use of the available bioenergy resource
- ❑ The inclusion of indirect impacts shifts the bioenergy mix towards the use of more sustainable resources
- ❑ The real costs of indirect impacts are reflected in higher carbon prices
- ❑ The modelling of indirect impacts leads to less CCS needs and therefore provides a more wholistically optimal energy system
- ❑ Biofuel availability clearly benefits the decarbonisation of the transport sector.

Next steps

- ❑ Evaluate different GWP scenarios
- ❑ Model carbon stock changes
- ❑ Disaggregate further bioenergy classification for imports to account for geographical variations

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Bioenergy Value Chains:
Whole Systems Analysis and Optimisation
WP 2 – Technologies

Nagore Sabio, Miao Guo

THANKS FOR YOUR ATTENTION

UKTM Bioenergy technology routes

Existing

- Pretreatments
- Biodiesel production
- Bioethanol production
- Biogas production (landfill)

New

- Fermentation to ethanol
- Hydrolysis to ethanol
- Fermentation to methanol
- Hydrogenation and production of 1st generation biodiesel
- Gasification and FT 2nd generation biodiesel and biokerosene
- Gasification to biomethane
- Pellet pyrolysis to biooil
- AD to biogas

UKTM bioenergy products and market demands

- Bioenergy is consumed in the following sectors
  - Electricity
  - Processing
  - Services
  - Transport
  - Domestic
  - Industrial
  - Agriculture*
- In the form of
  - Food, Power, Fuel (biofuels or hydrogen), heat.
- Further whole system analysis…

Bioenergy mix