Imperial College London

BECCS deployment with MSW and waste wood in the UK

- supply chain modelling and network evolution

Di Zhang,[a,b] Mai Bui,[a,b] Mathilde Fajardy,[a,b] Niall Mac Dowell[a,b]

[a]Centre for Environmental Policy, Imperial College London, London SW7 1NA UK

[b]Centre for Process Systems Engineering, Imperial College London, London SW7 2AZ UK

7th September 2018

cep

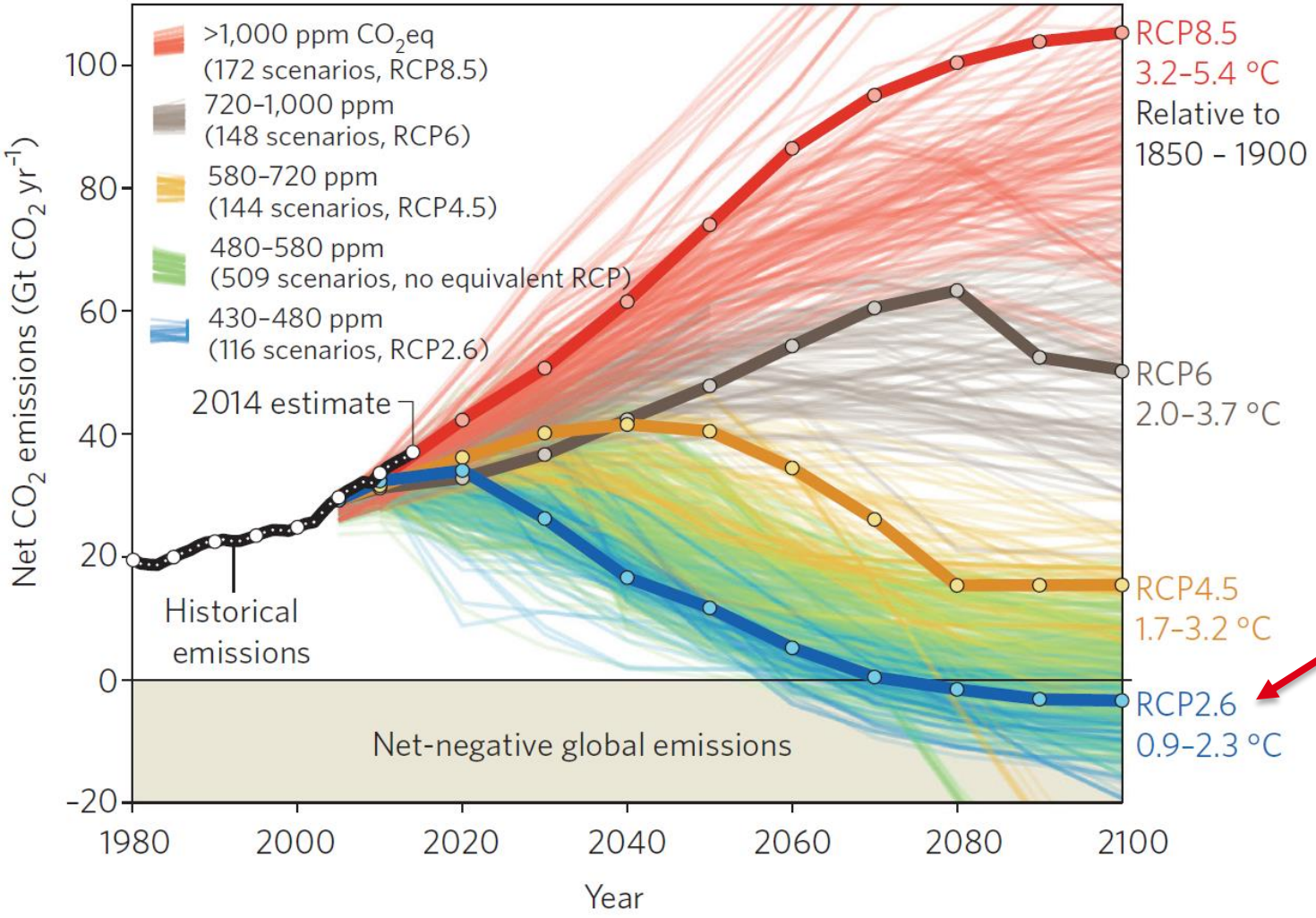
Centre for Process Systems Engineering

EPSRC

Engineering and Physical Sciences Research Council

Imperial College London

Meeting the 2°C IPCC and 1.5°C COP21 Targets



Most feasible scenarios substantially use BioEnergy with carbon capture and storage (BECCS).

Thus, BECCS is a key negative emissions technology.

Reference: IPCC Fifth Assessment Synthesis Report November 2014, Fuss, S., et al. (2014). Nature Climate Change, 4(10), 850–853

Bioenergy with CCS: Challenges and Opportunities

Challenges:

- Minimising emissions in the biomass supply chain (harvest, transport and processing).
- Need to ensure BECCS has a negative carbon balance.
- Competition for land when producing biomass for energy.

Opportunities:

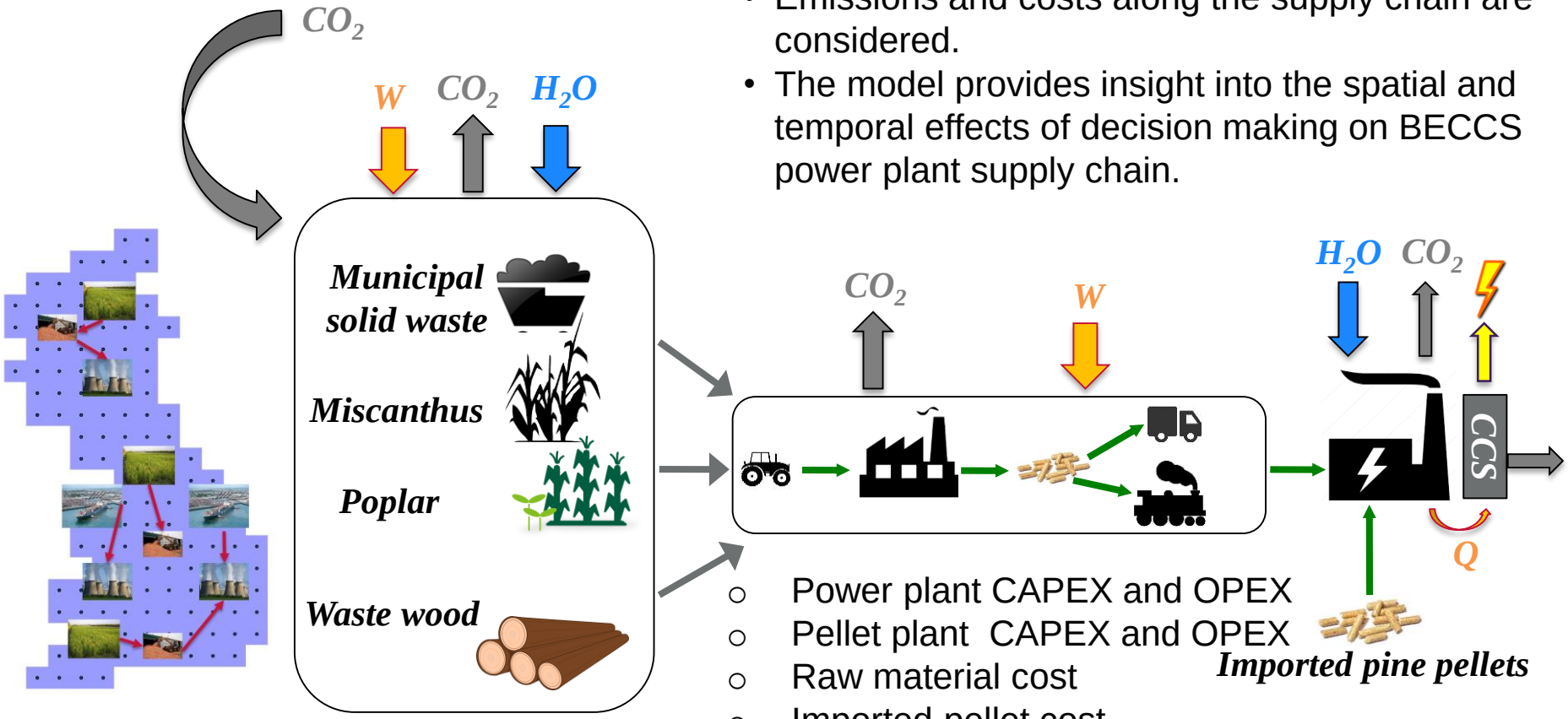
- Recovering energy from **waste wood and municipal solid waste (MSW)** has the potential to generate electricity and reduce CO_2 emissions – reducing requirements for land and imported fuels.

Objectives:

- Propose an optimal design of a BECCS power plant supply chain for the UK to achieve the emission reduction target for 2050.
- Conduct a sensitivity analysis of system negative CO_2 emission price.

Imperial College London

Biomass Supply Chain



- Emissions and costs along the supply chain are considered.
- The model provides insight into the spatial and temporal effects of decision making on BECCS power plant supply chain.

- Power plant CAPEX and OPEX
- Pellet plant CAPEX and OPEX
- Raw material cost
- Imported pellet cost
- Transportation cost

Reference: Fajardy, M. & Mac Dowell, N. (2017). Can BECCS deliver sustainable and resource efficient negative emissions, Energy and Environmental Science, 10 (6), 1389-1426.

Imperial College London

Biomass Sources

Virgin biomass fuels

- Miscanthus – farm locations based on land availability and yield
- Poplar – farm locations based on land availability and yield
- Pine pellets imported – shipped to Port of Tyne, Port of Hull, Port of Immingham and Port of Liverpool before transported.

Waste fuels

- Municipal Solid Waste (MSW) – total availability for UK is 33 Mt, distributed based on population density
- Waste wood – total availability for UK is 3.3 Mt, distributed based on population density

Reference: Jones, J. & Gudka, B. (2016), WP1 ONF report, Defra & Orchid Environmental, ECN Phyllis2 database

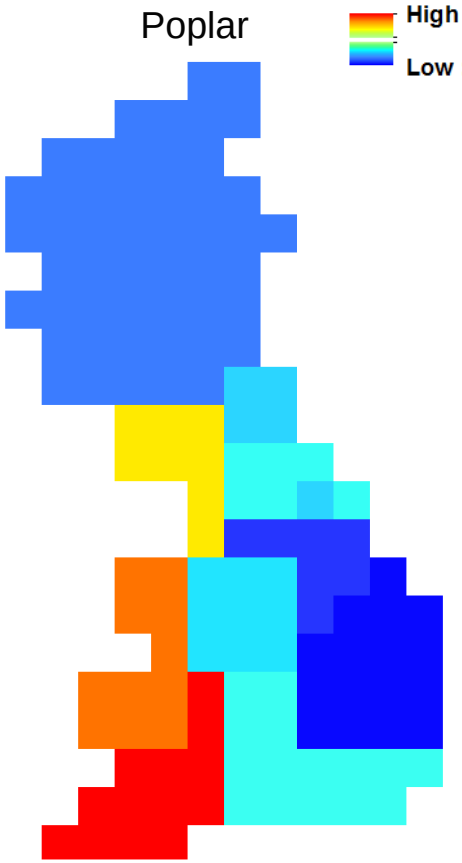
Imperial College London

Raw Material Availability

Dry mass yield of virgin biomass (t/ha)

Miscanthus

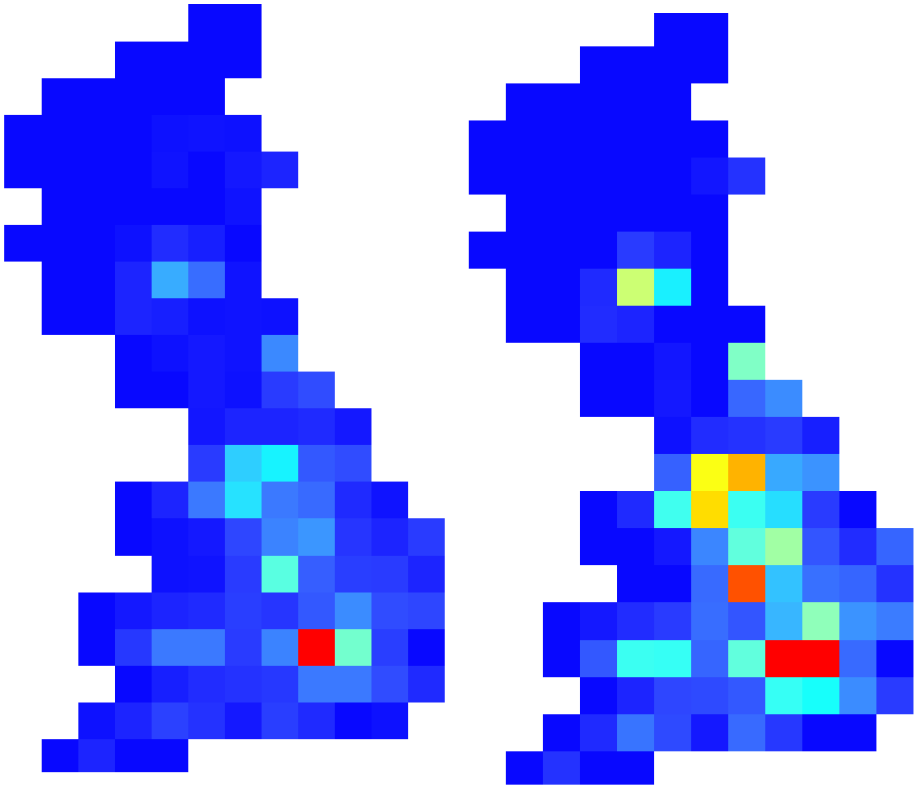
Poplar



Availability of waste biomass (t/ha)

Waste wood

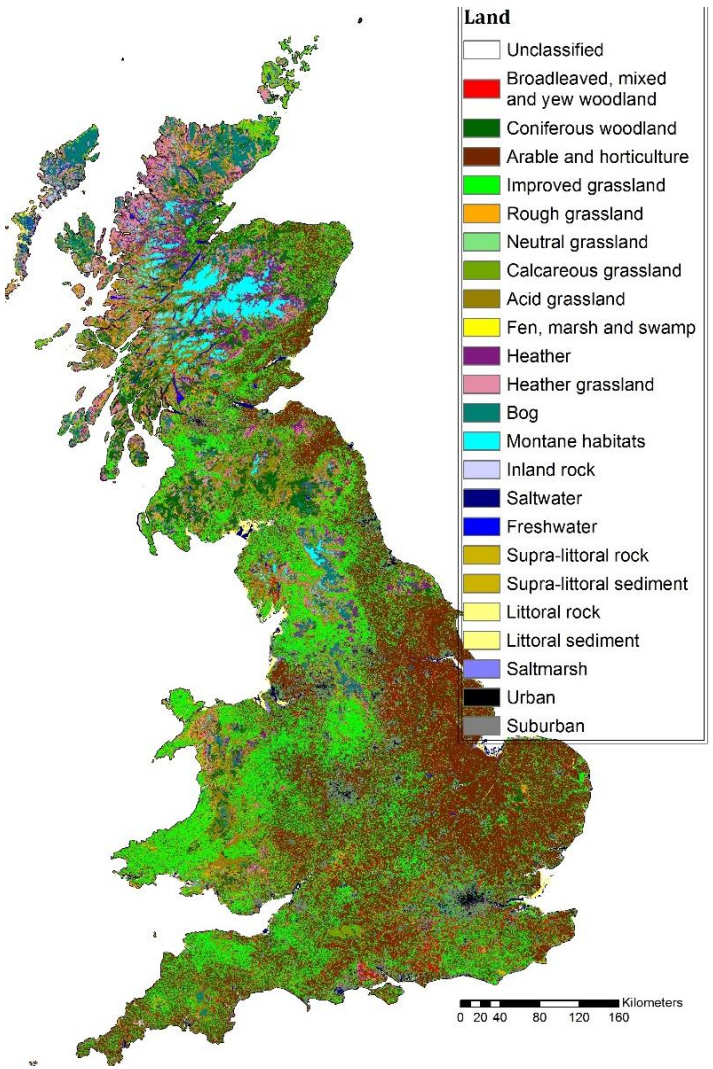
MSW

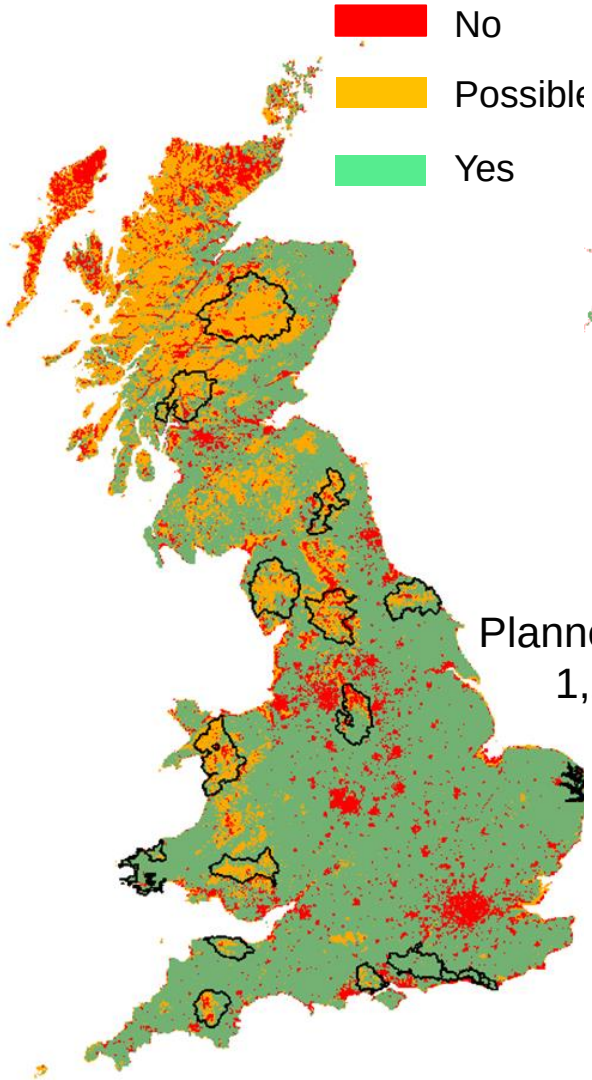


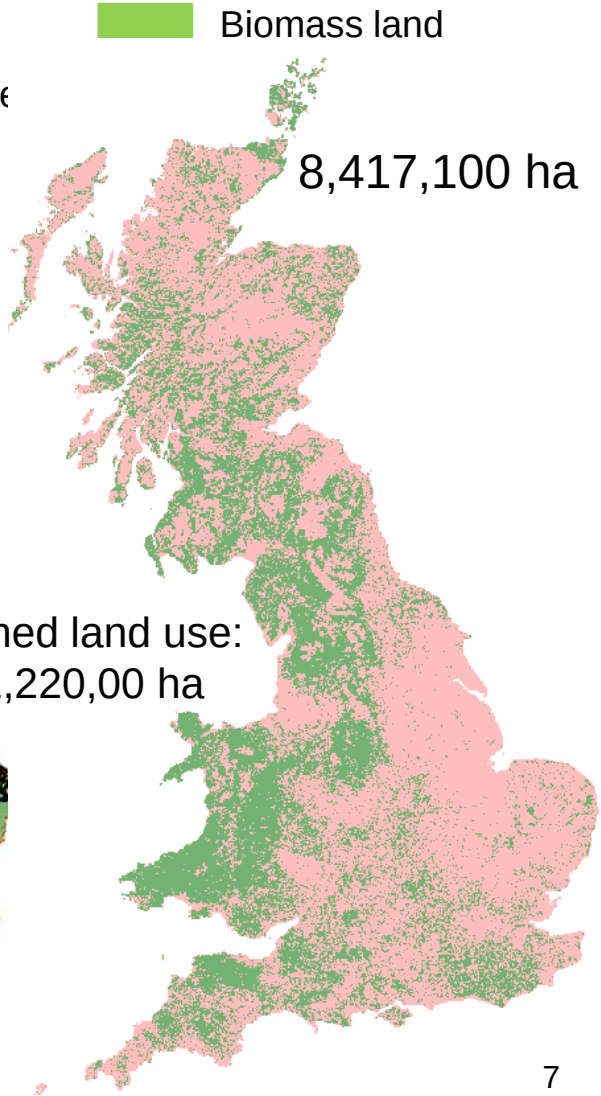
References: Euro statistics http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/tablea11principalprojectionuksummary
Hastings A. et.al. (2014) The technical potential of great Britain to produce lingo-cellulosic biomass for bioenergy in current and future climates. GCB Bioenergy, 6, 108-122.

Imperial College London

Biomass Land Availability







Planned land use: 1,220,00 ha

Reference: EDINA Environment Digimap Service. http://digimap.edina.ac.uk.

Imperial College London

Biomass Land Availability and Total Energy Availability

Biomass land availability (ha)

Total annual bioenergy potential (MWh/ha year)

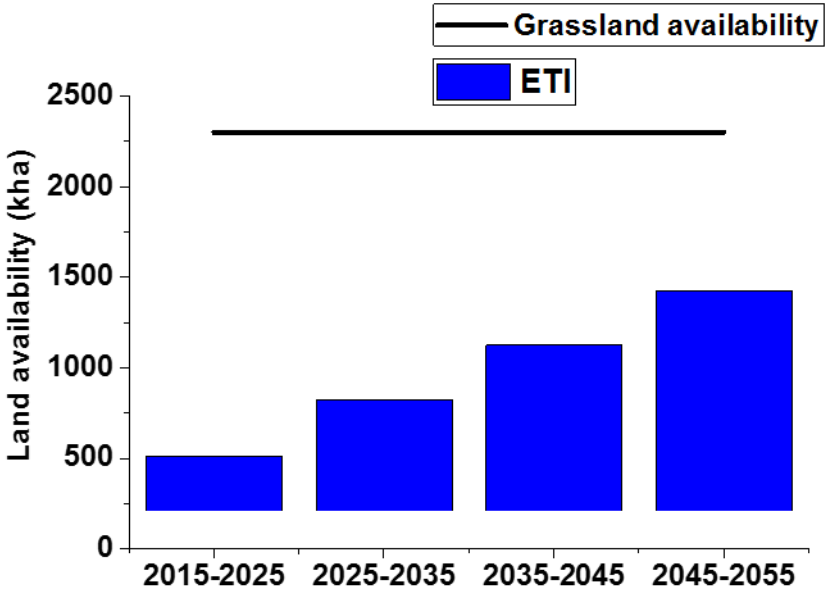
Imperial College London

Land Availability Summary

ETI suggests step increase in land availability over decades to a max of 1.22 Mha by 2055. Note: ETI considers land in different regions.

Based on our analysis:

- Available land considered is in zero competition with food production.
- All grasslands except land for food production are available for planting biomass, resulting in an upper bound of 2.3 Mha.



References:
http://www.eti.co.uk/library/delivering-greenhouse-gas-emission-savings-through-uk-bioenergy-value-chains
https://www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2016

Imperial College London

Costs of Processing Biomass

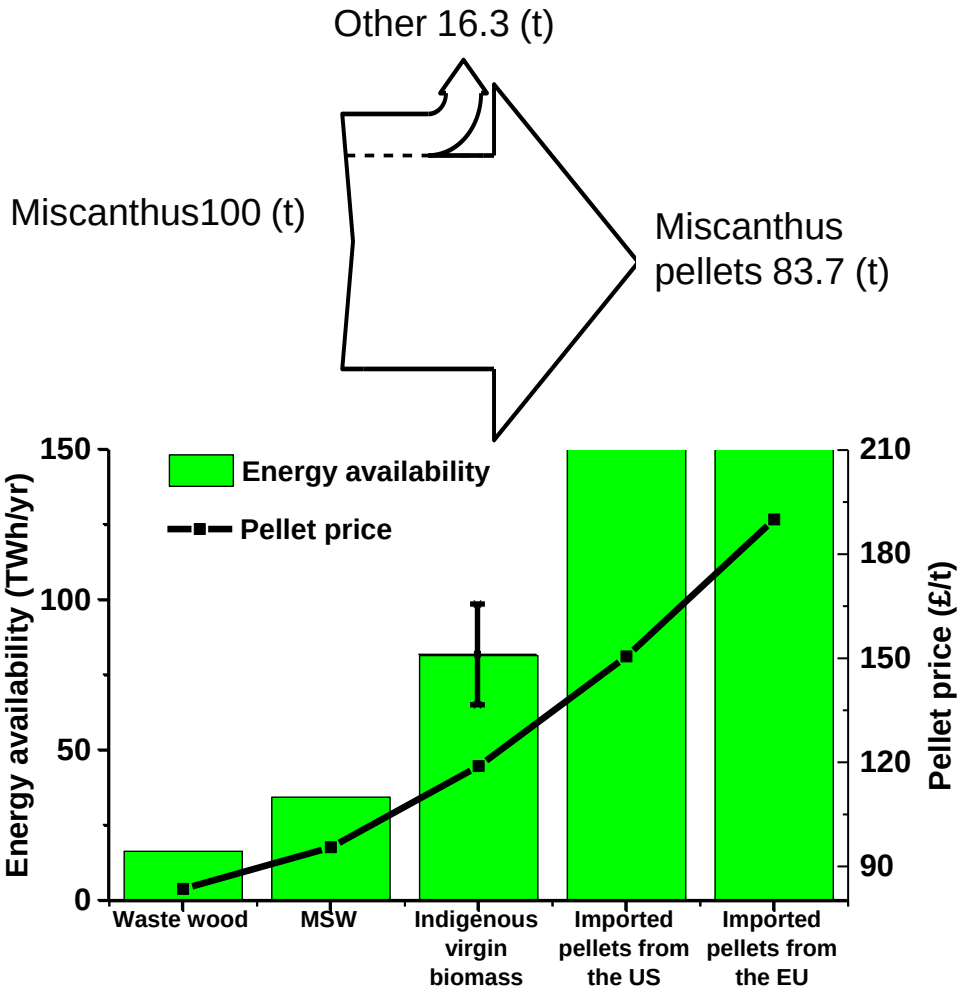
Miscanthus 49 £/t

Processing cost and personnel 18 £/t pellets

Annualised CAPEX 12 £/t pellets

Conversion rate 83.7%

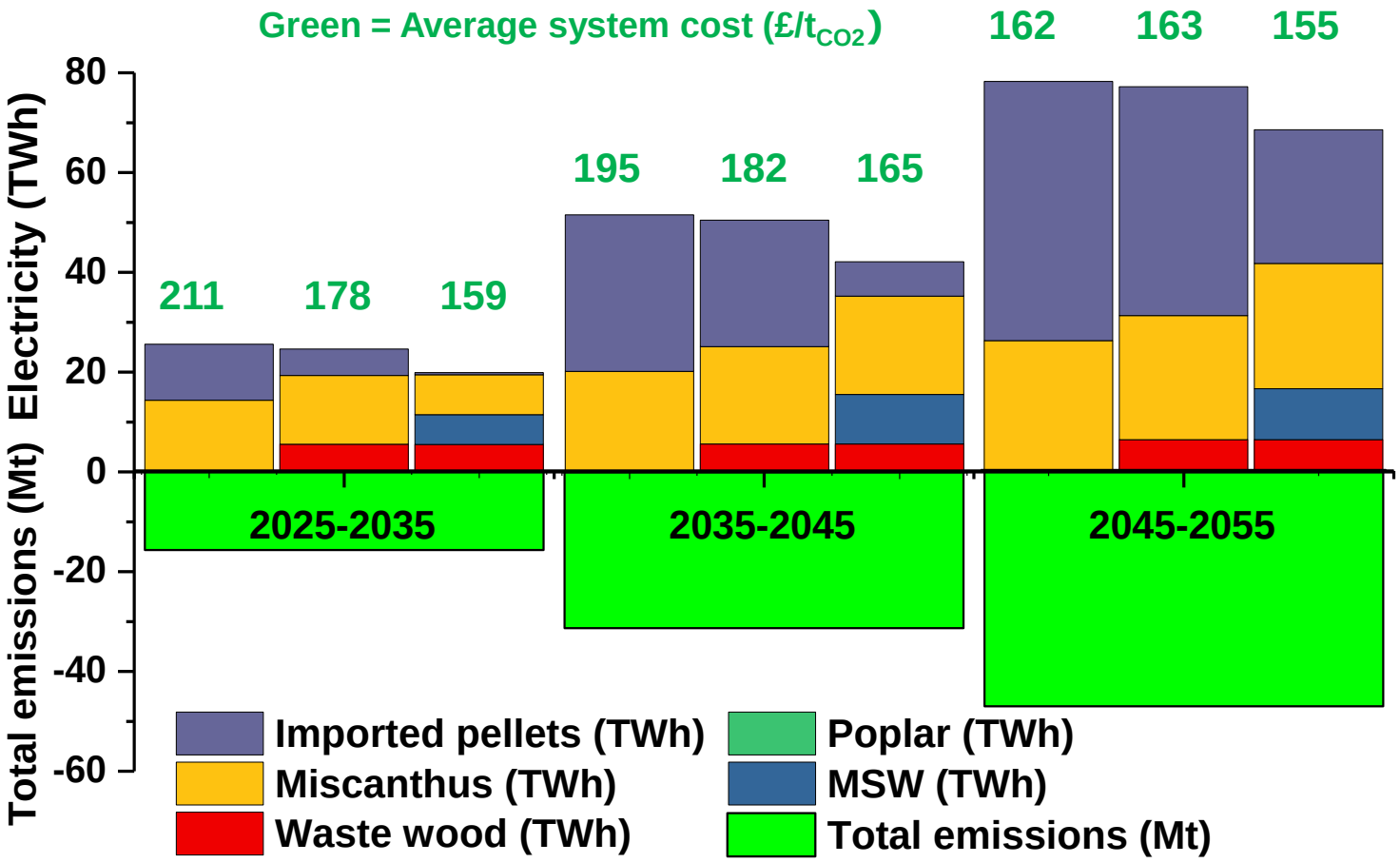
Miscanthus pellet price: 118.9 £/t



Reference: http://www.biomass-energy.org/wood-pellet-plant-cost

Imperial College London

BECCS Optimisation Results

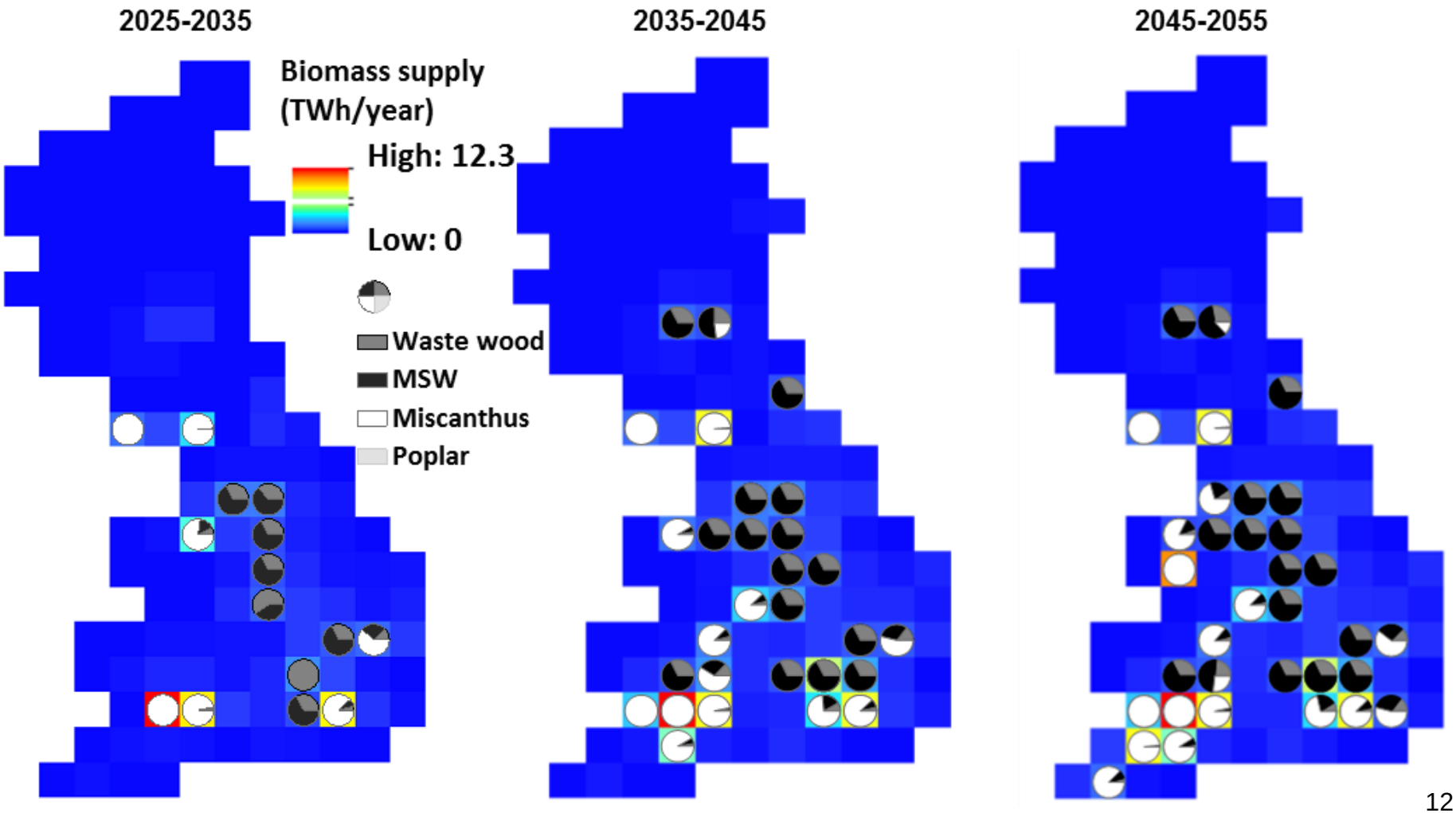


i. Indigenous virgin biomass + imports
ii. Indigenous virgin biomass + waste wood + imports
iii. Indigenous virgin biomass + waste wood + MSW + imports

Imperial College London

Evolution of the Biomass Supply Between 2025-2055

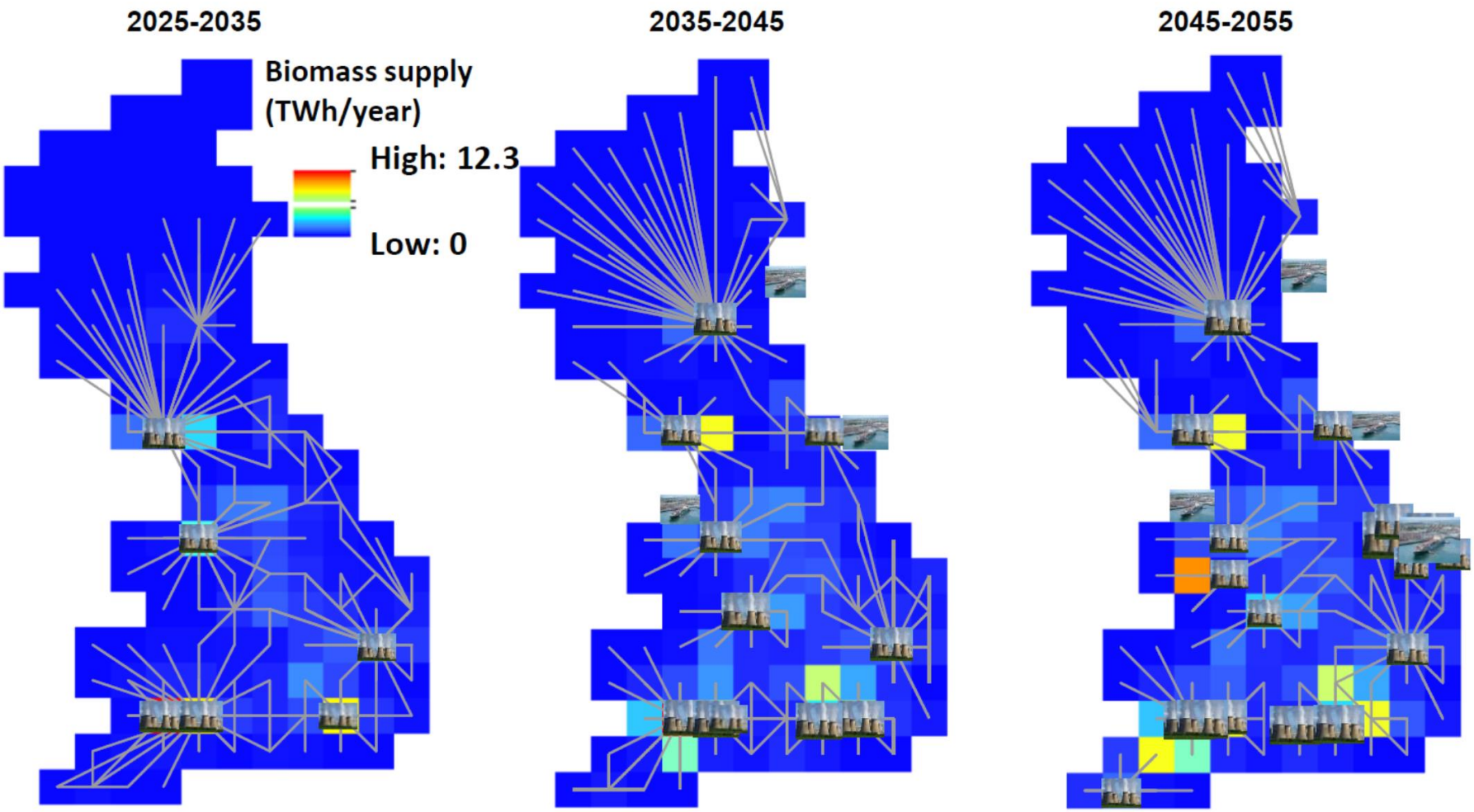
3) Indigenous virgin biomass + waste wood + MSW +imports



Imperial College London

Locations of Power Plants and Ports & Supply Chain Network Evolution between 2025-2055

3) Indigenous virgin biomass + waste wood + MSW +imports



Imperial College London

Negative Emission Price Sensitivity Analysis

Negative emission price: the price paid for reducing the amount of carbon emission from the atmosphere and storing it in a safe place. Five factors have be analysed:

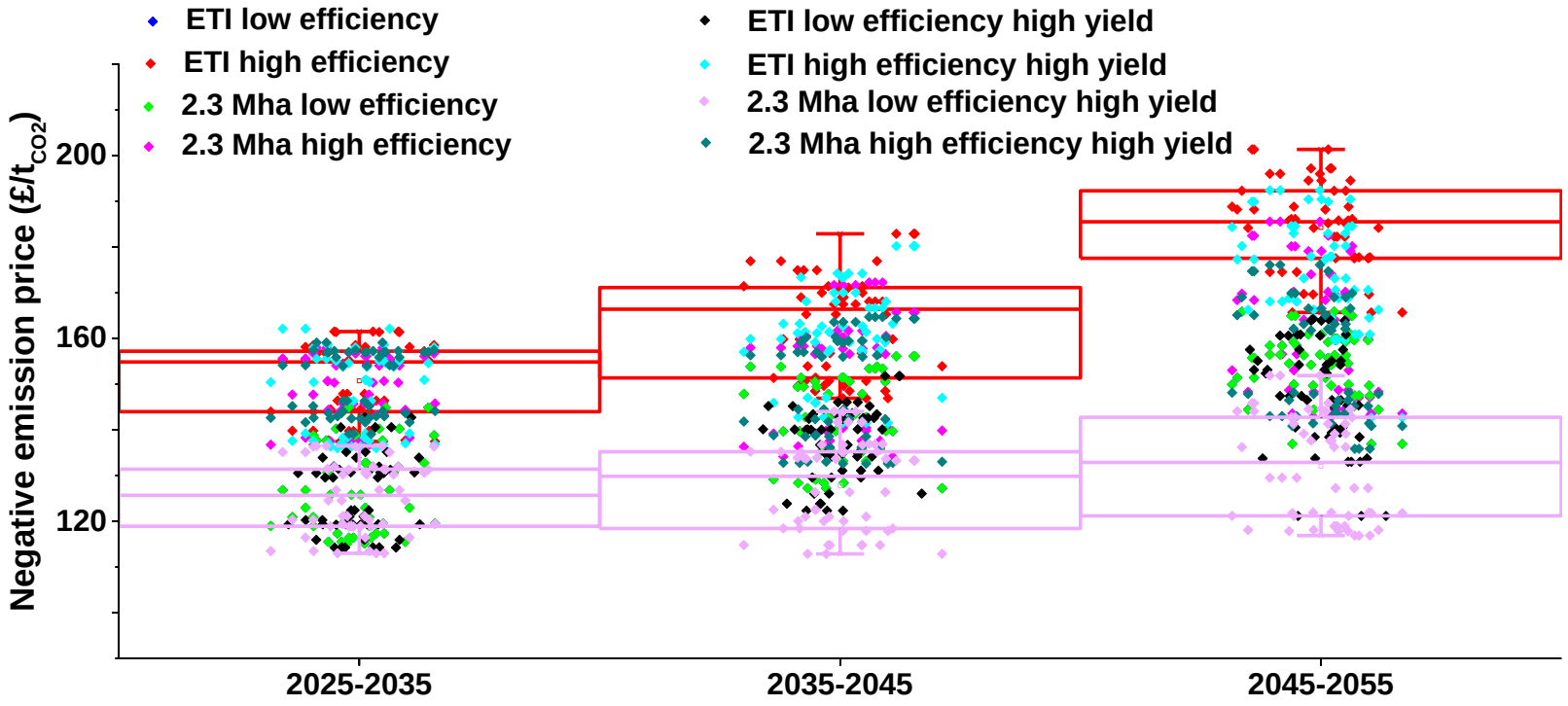
1. Plant efficiency:
   - Low: Subcritical post CCS power plant with conventional MEA ~26%
   - High: Ultra-supercritical post CCS power plant New solvent + heat recovery ~38%
2. Embodied emissions:
   - High: conventional drying process
   - Low : drying with biomass, biofuel, carbon neutral power, organic chemicals
3. MSW availability: High, Central or Low (+/-20%)
4. Land availability: High Central or Low (+/-20%)
5. CAPEX learning rate:
   - High: 5.5%
   - Central: 3.3%
   - Low: 1.1%

2*2*3*3*3=108 Scenarios

References: http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics
https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/tablea11principalprojectionuksummary

Imperial College London

Negative emission price under Sensitivity Analysis



- Power plant efficiency has greater impact on negative emission prices compared to other factors.
- For the power plants newly built in each period, the negative emission price increases because more expensive biomass with lower carbon content (virgin biomass, imported pellets) is consumed over the time periods.
- If the land availability is doubled, the negative emission price could be 10 £/t cheaper for the last period.
- No pellets need to be imported from abroad for the first two periods.

Conclusions

- Power plants locations tend to be near cities where waste wood/MSW are available.
- Domestic waste wood and MSW could play an important role in carbon emission reduction from BECCS, while reducing landfills
- Farm locations and areas of miscanthus have been optimised, which are close to power plants and have high yield.
- In order to reach the CO_2 reduction target in 2050, the UK will need a combination of domestic and imported pellets.
- Based on the sensitivity analysis, power plant efficiency has more influence on the negative emission prices than the other factors (compared to embodied emissions, MSW availability, farmland availability and CAPEX learning rate).