Bioenergy Review (2018) - Call for Evidence

<u>Question 1)</u> *What is the latest evidence on lifecycle GHG emissions of biomass and other biofuels imported into the UK? How could this change over time as a function of scaling up supply? We are particularly interested in evidence that considers the full range of relevant issues including changes to forest and land carbon stocks, direct and indirect land-use change and wider market effects.*

The EU imported 6.2 Mt of pellets in 2015, with over 90% of the supply coming from North America. Such a booming market, with expected growth from the Asian market, has questioned the alleged environmental benefits of using bio-based fuels in lieu of fossil fuels. In the context of investigating the potential of BECCS for climate change mitigation, we use the Modelling and Optimisation of Negative Emissions Technologies (MONET) tool[1] to evaluate the greenhouse gases implications of farming, pre-processing, transporting to the UK and converting different biomass feedstock in a pulverised combustion facility, combined with post-combustion CO_2 capture technology. Figure 1 shows the median carbon footprint of miscanthus pellets sourced from marginal land in different sub-regions of the world, and transported to the UK.

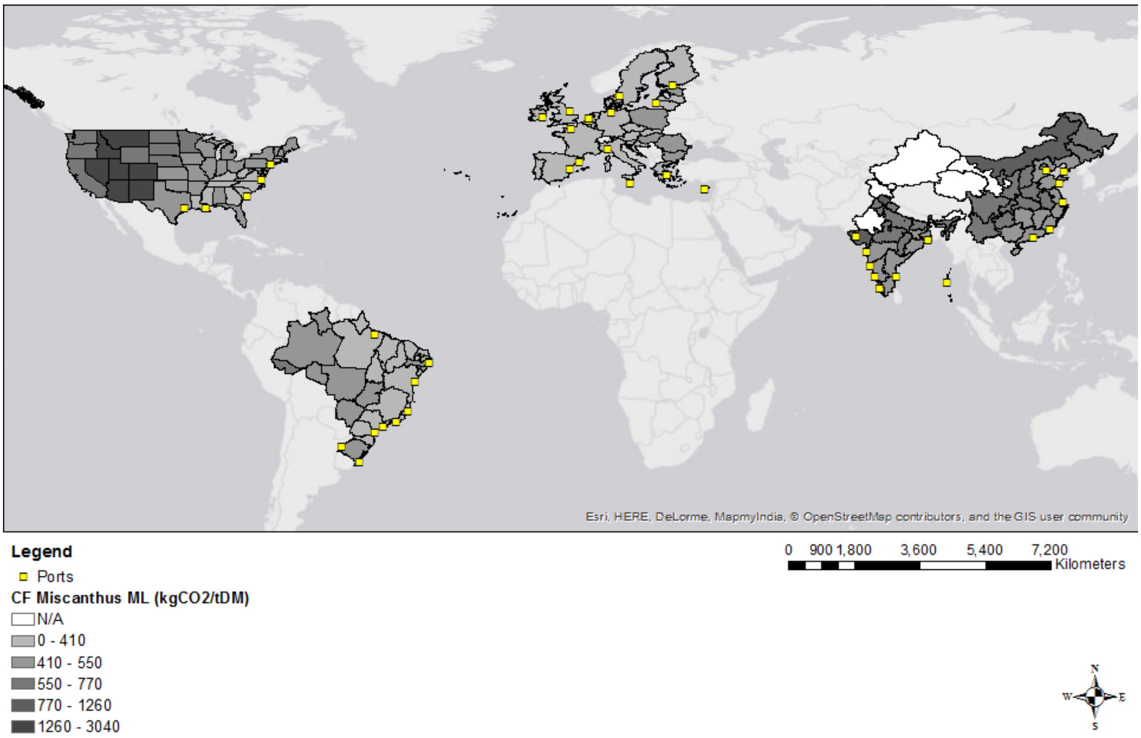

Figure 1: Median carbon footprint (CF) of miscanthus pellets sourced from different regions of the world (marginal land, ML) and transported to the UK [unpublished figure].

A key insight is that the carbon footprint is not necessarily proportional to the pellet transport distance. For example, biomass pellets from coastal regions in Brazil can show lower life cycle GHG emissions than domestic pellets. Factors such as yield and local electricity carbon intensity have a strong impact on the embodied emissions of the biomass. Regional marginal land availability is also a key factor, as it allows the cultivation of biomass for energy while limiting the GHG emissions from direct and indirect land use change.

As marginal land availability is constrained, "sustainable" biomass supply from each region is naturally limited. An increase in UK pellet imports could thus lead to two potential risks depending on the choices made along the supply chain: 1) if only marginal land is considered for biomass production, regions which could be characterised as "unsustainable" (*e.g.*, lower yields, or increased transport distance) would need to be considered to meet the increasing UK pellet demand; 2) if the option of growing biomass on other types of land (cropland, grassland, forests, etc.) is considered, importing biomass from the same "sustainable" region but using other types of land could potentially involve high direct and indirect land use change, as well as negatively impact the biodiversity. Figure 2 shows the increased carbon footprint of these same pellets when land use change from using cropland for bioenergy is considered.

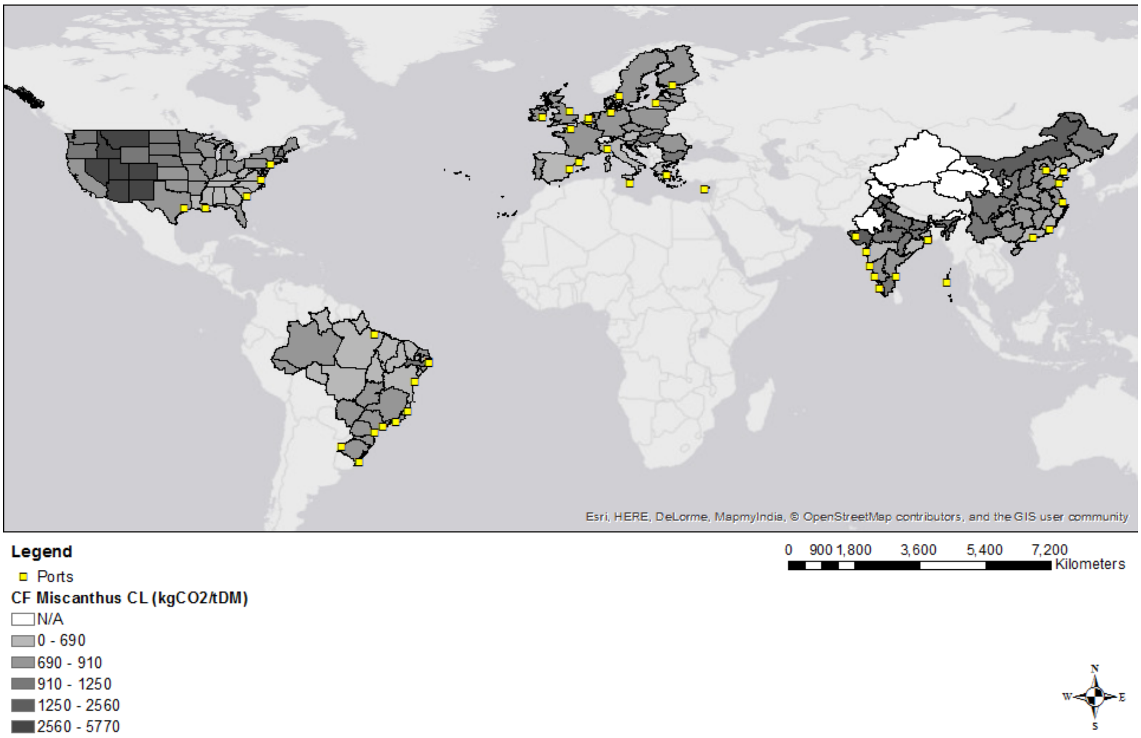

Figure 2: Median carbon footprint of miscanthus pellets sourced from different regions of the world (cropland) and transported to the UK [unpublished figure].

In the two options considered, an increase in the UK supply is likely to result in an increase in the life-cycle emissions of imported pellets.

<u>Question 4)</u> *Aside from GHG emissions, what evidence is there of other sustainability impacts associated with imported biomass or other biofuels? What evidence is there for how these might change as a function of scaling up supply (from the US, and internationally)?*

In addition to potential high GHG emissions, concerns have been raised around the resource cost – land, water and energy – of biomass. The MONET tool[1] also calculates the water footprint and embodied energy of the biomass pellets imported to the UK from different regions. Figure 3 shows the median marginal water footprint ("blue", i.e. fresh water, and "grey", i.e. polluted water, combined) of miscanthus pellets sourced from different regions.

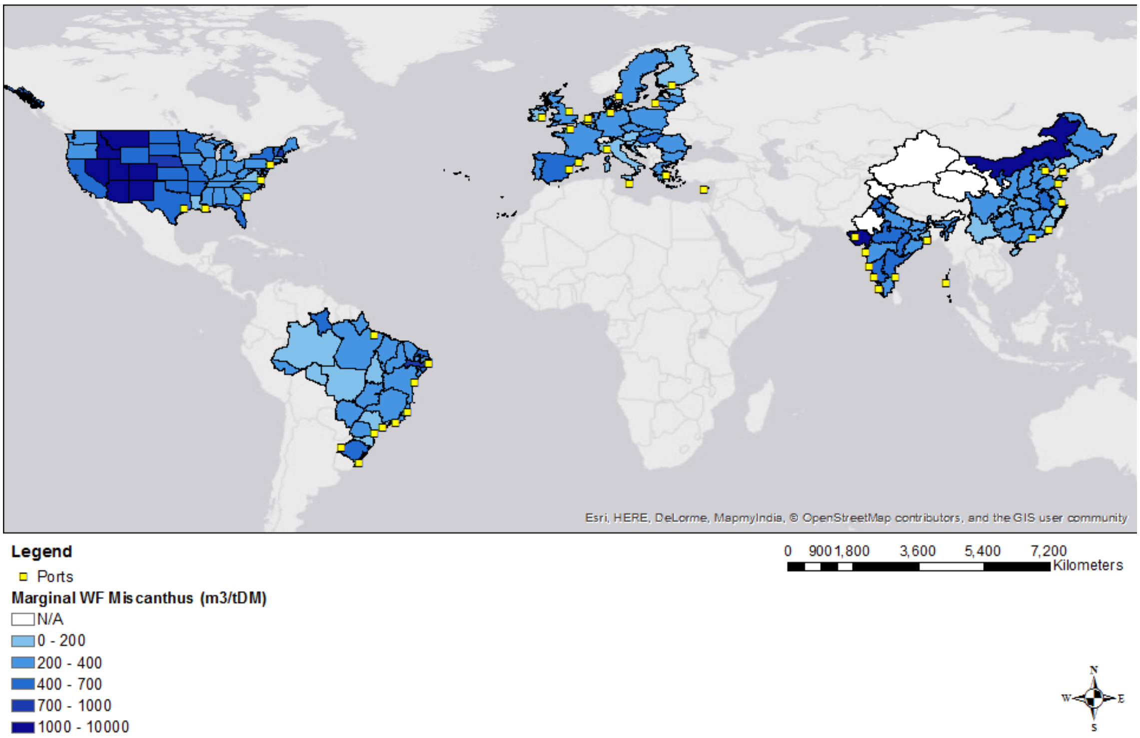

Figure 3: Median marginal water footprint (both blue and grey water) of miscanthus pellets.

Insights from this work are that 1) water footprint is strongly dependent on the regional climate, precipitation, biomass type and yield, hence very variable depending on the source of the biomass; 2) its impact on the bioenergy value chain water intensity is two orders of magnitude higher than the water intensity of biomass power plants[1]; and finally 3) regions with low water footprint biomass such as western Brazil for example, do not necessarily coincide with the regions with low carbon footprint biomass. This underlines the importance of considering the source of the biomass import carefully when assessing the sustainability of biomass, as well as the potential trade-offs between different sustainability criteria.

In a more recent contribution, we assessed the energy return on investment (EROI) of BECCS and of biomass pellets[2]. Results showed that biomass pellets EROI could be very variable depending on the regions of imports, and potentially lower than 1, and are observable on Figure 4.

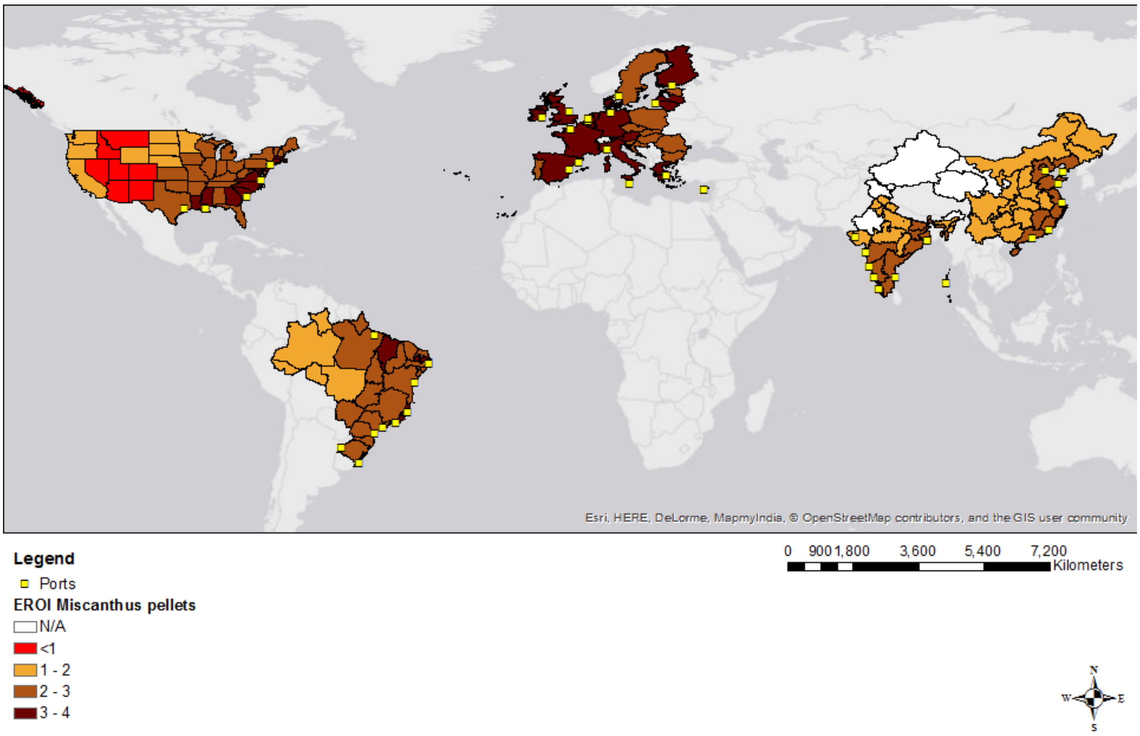

Figure 4: Median EROI of miscanthus pellets. Pellets from regions in red have an EROI lower than 1:1.

It is worth noting that conversion of the biomass pellet into energy would further decrease this EROI value depending on the conversion efficiency, and result in energy sources with a negative energy balance. As bioenergy demand rises, the risk of deploying low EROI bioenergy value chains becomes greater, potentially increasing the pressure on the world's energy security.

Other variables such as water footprint and embodied energy should therefore be included when refining biomass sustainability criteria.

Question 14) *What are the most credible and up-to-date estimates for the amount of bioenergy resource that could be produced from UK waste sources through to 2050?*

Energy recovery from waste converts the non-recyclable waste materials into usable energy through e.g. combustion and gasification. Combustion of municipal solid waste generates a renewable energy source and reduces carbon emissions, decreases the volume of solid waste destined for landfills and landfill methane generation (i.e., reducing methane emissions). Based on the statistics provided by Eurostat, the MSW generation rate for the UK is about 480 kg/Capita in 2015[1]. The principal projection population for 2050 from the UK Office for National Statistics is 77.6 million[2] as shown in Figure 5. The available MSW can be processed into fuel at the conversion rate of 28.6%,[3] while the remains are ferrous metals, glass/rubble and landfill etc.

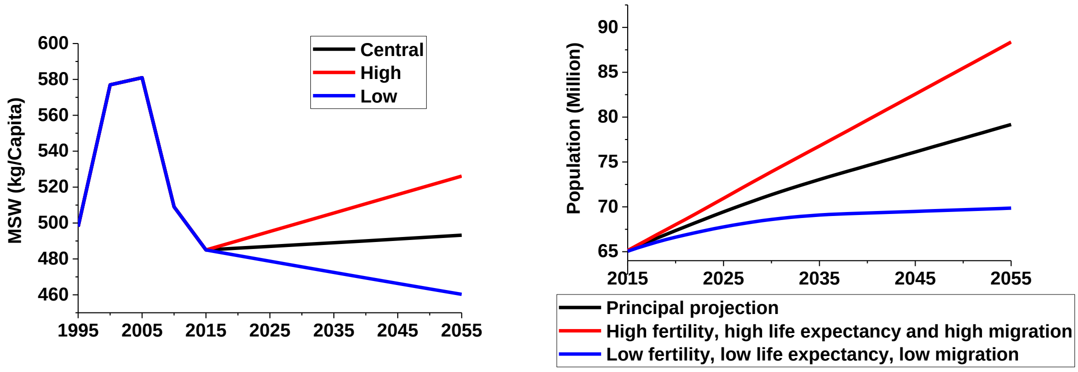

Figure 5: MSW availability and population projections for the UK.

Besides MSW, there are 3.3 Mt of timber waste from construction, wood processing and manufacturing, pallets and wooden packaging in 2011[3]. Its availability also has a strong correlation with population. According to the UK population principal projection, the potential recovery energy from waste is 34.6 TWh from MSW and 16.6 TWh from waste wood, respectively.

Question 24.a) *What are the potential timescales for commercial deployment of BECCS technologies?*

A number of things need to be achieved before BECCS can be deployed. First, we need to understand the way in which BECCS in power, heat, industry, and transport applications provide value, *i.e.*, what is the value proposition of BECCS, how can this be recognised, and how can this value accrue to the BECCS projects. Importantly, this may well be distinct (and significantly more complex) to simply assigning a value to "negative emissions". Second, we need to understand what we expect of BECCS in terms of quantity of CO_2 removed from the atmosphere over the project lifetime, and when this should start. This is important as, depending on iLUC/LUC emissions, it may be some time before a BECCS plant starts removing CO_2 from the atmosphere. This should, in turn, impact when it starts to receive payment for providing this service.

Taking this together, it implies (to me) that developing environmentally and economically viable BECCS projects will be more complex than "simply" developing CCS project. There are upstream cross chain risk elements associated with the biomass supply chain that are similarly complex to the downstream CO_2 transport and storage system, *e.g.*, if a BECCS operator procures a supply of ostensibly sustainable biomass which is subsequently found to have incurred significant carbon debt owing to iLUC/LUC emissions resulting in the system (biomass cultivation, harvest, transport, conversion, CO_2 transport and storage) being net carbon positive, who owns this liability?

Taking this together, I would expect that BECCS would be deployed *after* commercial scale CCS. The good news is that I do not see a specific technical impediment for this, and the delays are likely to arise from complexities surrounding the financing and insurance, *etc.*, and once this has been derisked for CCS, the additional complexity for BECCS should be marginal.

Therefore, the short answer is "I think that BECCS will come after CCS, but not long after"

Question 24.b) *What are likely to be the optimal uses of BECCS (e.g. electricity generation, hydrogen production)?*

The UK electricity system has seen reduced carbon intensity due to a shift from majority coal-fired to gas-fired generation, and increasing penetration of intermittent renewable energy sources (iRES). However, to achieve a decarbonised system, fossil fuel-derived generation must be abated using carbon capture and storage (CCS) and negative emissions to compensate for the residual emissions from CCS plants. The Electricity Systems Optimisation (ESO) model[1] was used to determine the potential role of negative emissions technologies (NETs) in decarbonising the UK energy system. In the absence of NETs, nuclear power and iRES (coupled with energy storage) dominated the system, with the total cost of electricity generation rising to £300 billion from 2015-2050[2].

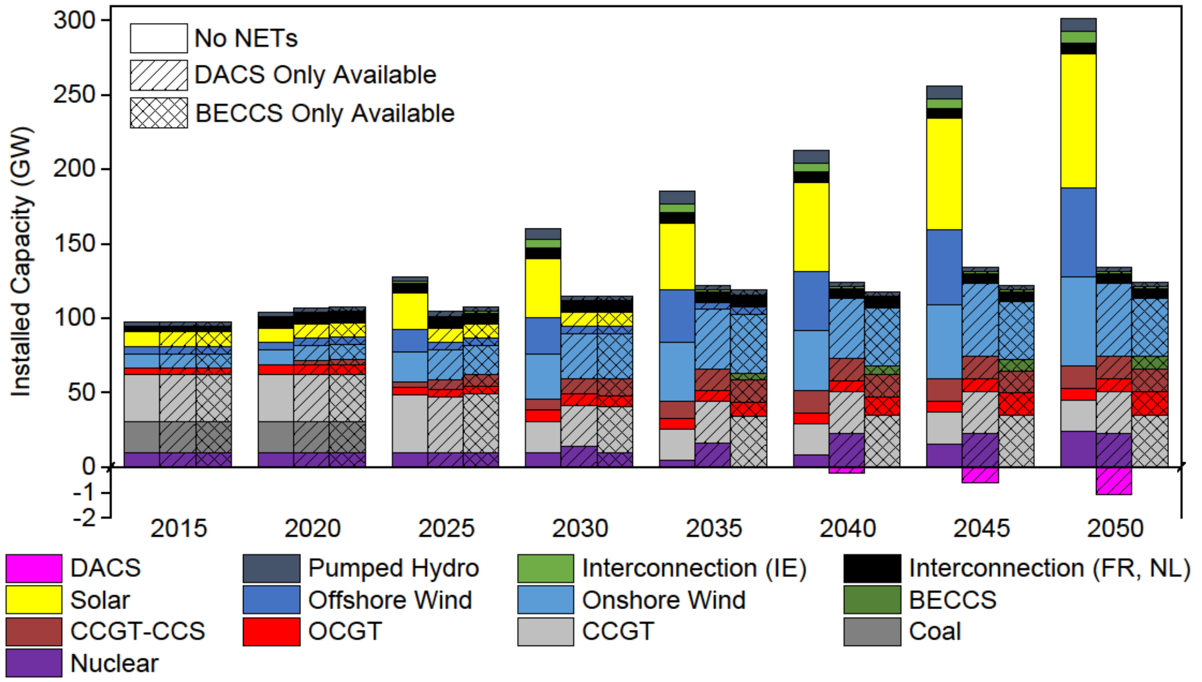

Figure 6: Optimal capacity mix for the UK from 2015 to 2050, given the availability of negative emissions technologies[2].

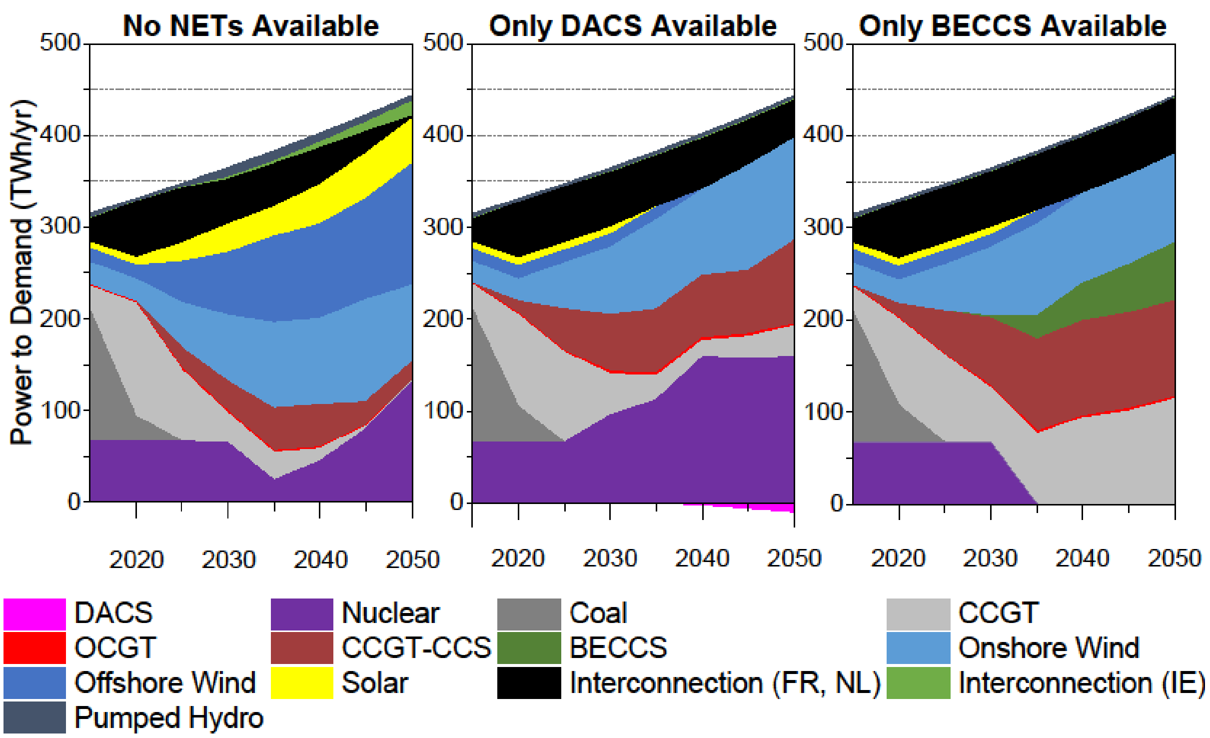

Figure 7: Optimal electricity generation mix for the UK from 2015-2050, given the availability of negative emissions technologies[2]

BECCS was found to reduce the cost of generation by 48%, as it displaced costly nuclear plants, iRES (except onshore wind) and energy storage from the system. The System Value metric (SV) quantifies the reduction in electricity system cost achieved by the deployment of a given technology[3]. On initial deployment, SV_{BECCS} total system cost by approximately £125,000/$kW_{installed}$. As BECCS reaches its economic limit of deployment of 8.5 GW in 2050, *i.e.*, the limit beyond which all the capacity made available is not deployed, SV_{BECCS} falls to approximately £20,000/kW. Based on estimates of UK grassland availability (excluding livestock production), the biomass demand for BECCS can be met locally.

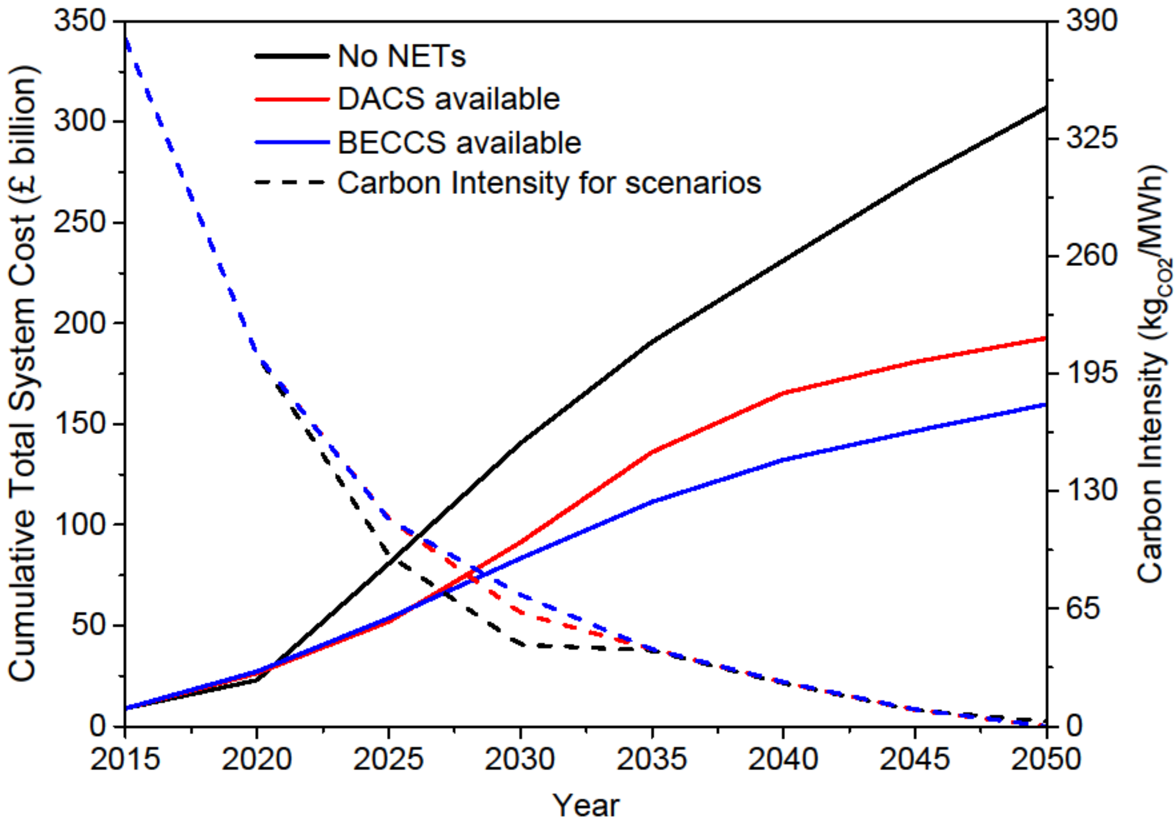

Figure 8: The cumulative total electricity system cost and carbon intensity for the UK from 2015-2050 given the availability of BECCS and DACS[2].

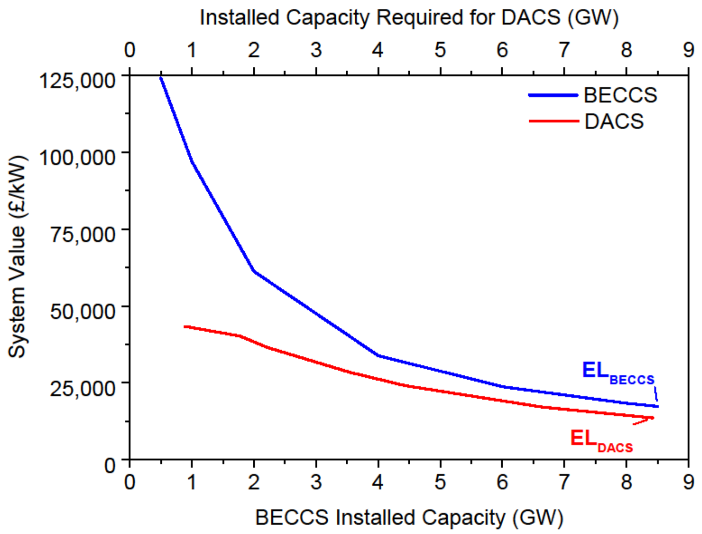

Figure 9: The system value of BECCS and DACS with increasing deployment within the UK electricity system[2].

In addition to the known services BECCS can provide – electricity generation and CO_2 removal – BECCS has been shown to allow for the increased operation of cheaper (abated and unabated) gas plants, especially combine cycle gas turbines (CCGTs). The resulting negative emissions offset gas-derived emissions, thereby allowing for continued CCGT operation in a decarbonised system. Increased utilisation results in greater revenues generated, hence BECCS operation accrues value to CCGTs. The value transferred from BECCS to CCGT plants has been estimated at £200/$t_{CO2\ removed}$[2].

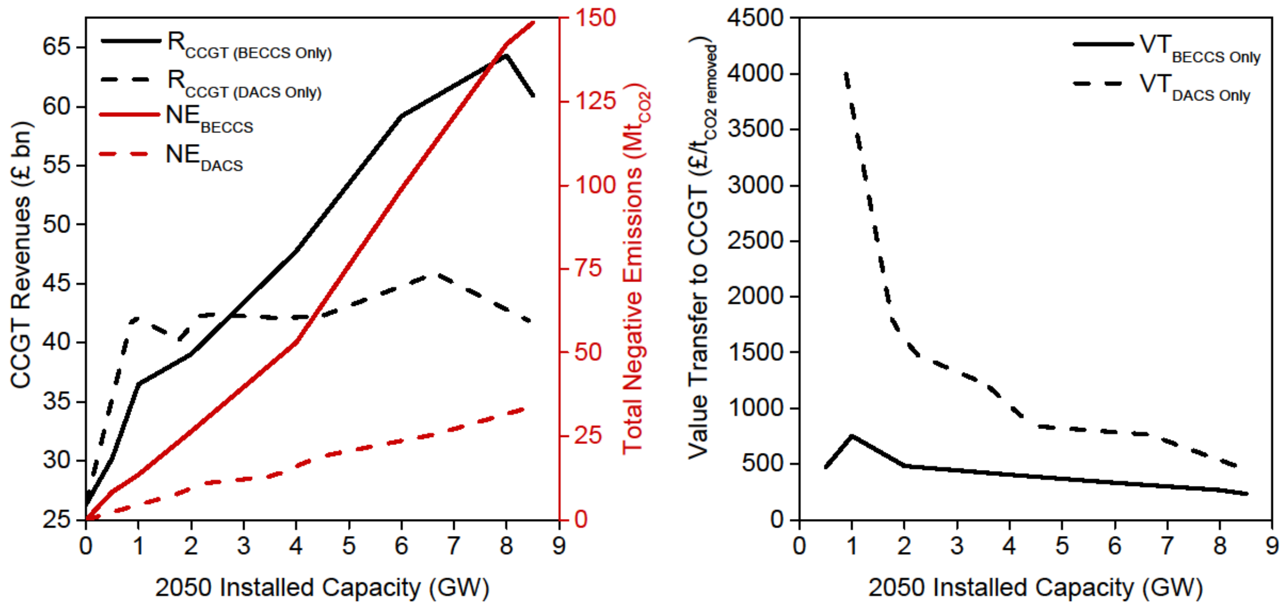

Figure 10: The variation in the revenues generated by CCGT power plants (black) and amount of negative emissions provided (red) with increasing deployment of BECCS and DACS (left). The value transferred to CCGT power plants with the increasing deployment of BECCS and DACS (right) [2].

BECCS therefore allows for the lowest cost pathway to power sector decarbonisation including negative emissions.

<u>Question 24.c)</u> *What efficiencies and costs are possible?*

The efficiency of BECCS depends on the power plant type, the CO_2 capture technology and biomass quality. Biomass-dedicated combustion power plants (without CCS) have net efficiencies ranging between 20% to 40%. Higher efficiencies are possible in plants over 100 MW_e or when biomass is co-fired with coal [4]. The net efficiency penalty due to CO_2 capture varies between 6–15 percentage points, depending on the capture technology considered[5]. The net efficiency of a dedicated biomass-fired plant reduces to 23–32% once integrated with an amine-based CO_2 capture plant. In contrast, biomass integrated gasification combined cycle (bio-IGCC) with physical absorption can achieve higher net efficiencies ranging between 33–45% (plants of 50 MW_e capacity)[5]. Further efficiency improvements to BECCS plants could reduce the marginal cost of electricity, enabling the power plant to operate at higher load factors[6, 7]. There are opportunities to improve the efficiency of BECCS systems. Power generation efficiency was found to increase from $31\%_{HHV}$ (conventional MEA solvent) to $38\%_{HHV}$ by using a high performance solvent with waste heat recovery[8, 9]. An important consideration is the complex trade-off between the system efficiency and carbon intensity. Increasing the efficiency of BECCS decreases the amount of CO_2 captured per MWh of electricity produced (consumes less biomass per MWh) [9]. Low efficiency BECCS plants (lower capital cost) are found to have superior environmental and economic performance compared to high efficiency facilities of higher cost[10]. Unit capital cost (CAPEX) for BECCS power plant decreases as the cumulative capacity increases. Figure 11 presents the CAPEX from power plants of 38% and 26% efficiency[8, 9] at three different learning rates.

At 1 GW of cumulative capacity, lower 26% efficiency BECCS has a unit cost of £1980/kW, whereas higher 38% efficiency BECCS has a unit of £2721/kW. The cost of BECCS may decrease significantly with higher learning rates. For high efficiency BECCS, the unit cost decreases to £2606 for the 1.1% learning rate, and £2182 for the 5.5% learning rate once cumulative capacity reaches 15 GW.

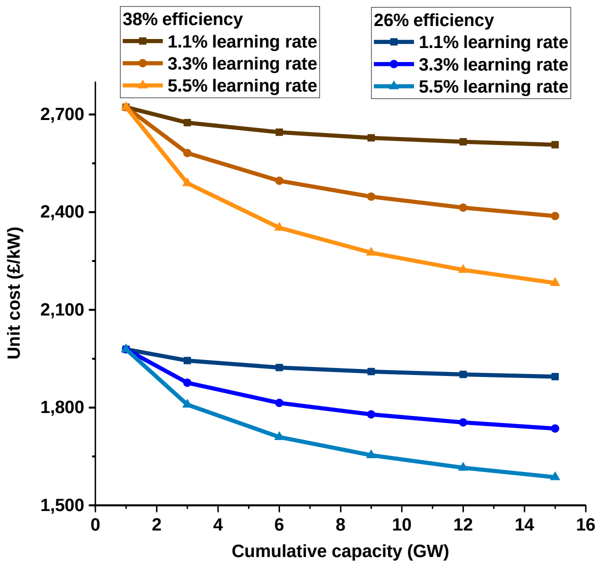

Figure 11: Unit capital cost of BECCS with high and low efficiency.

Question 24.d) *How will performance and cost differ according to feedstock type? What are likely to be the optimal feedstock types for BECCS? What are the implications for domestic supply vs imports (e.g. feasibility, considerations in scaling up over time)?*

The combustion performance depends on the moisture and ash content of the biomass. Biomass with higher moisture and lower ash content can achieve higher combustion temperature and improve efficiency[8, 9]. As the sulphur content of biomass is generally low, SO_X emissions from biomass combustion is significantly lower compared to coal. Additionally, biomass with ash that contains alkali oxides (e.g. CaO, MgO) can provide further reductions in SO_X emissions (specifically reacting with SO_2 and SO_3)[8, 9]. Selection of feedstock with characteristics of low content of moisture, ash and sulphur can improve combustion performance.

The costs of electricity generated from different feedstock vary according to the BECCS power plant efficiency, energy density, pellet price and material transportation cost. Pellet price includes the raw material prices, processing cost, pellet production capital cost and material transportation cost. Figure 12 shows the pellet price and annual energy availability of different feedstock in the UK for 2050 whilst considering biomass land availability of 1.22 Mha[4]. Imported pellets are assumed to have unlimited availability. Electricity prices of different feedstock shown in Figure 13 are calculated based on a BECCS power plant with 38% efficiency. Domestic supplies are cheaper than the imported pellets. By utilising domestic MSW and waste wood, the need for imported biomass pellet is reduced. However, the total domestic biomass supply can only fulfil one third of the BECCS reduction target of 47 Mt CO_2 in 2050 suggested by Committee on Climate Change[5]. Even if the biomass land availability is doubled, imported pellets are still needed unless alternative biomass resources become available.

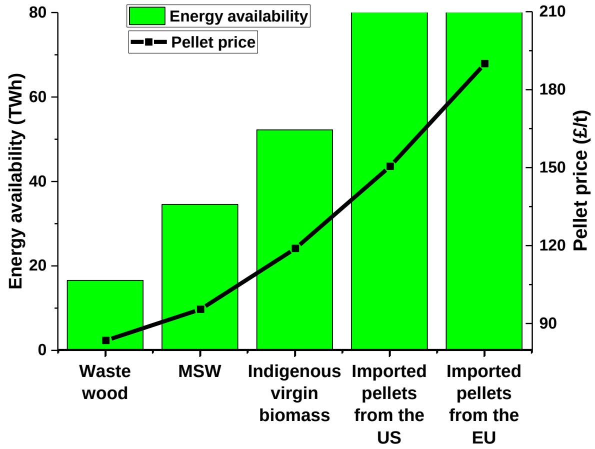

Figure 12: Biomass pellets energy availabilities and prices.

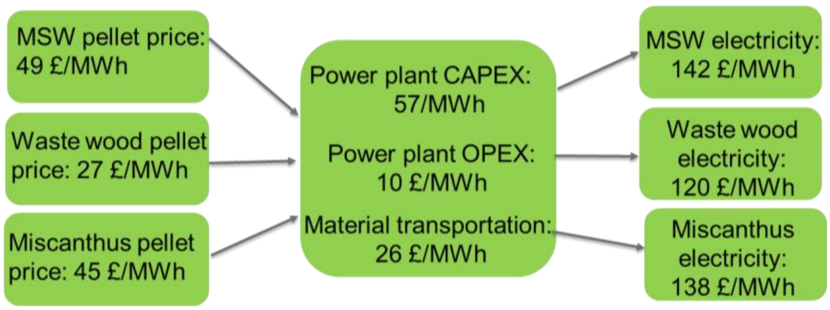

Figure 13: Example BECCS electricity prices from different feedstock.

<u>Question 24.e)</u> *What are the main barriers and uncertainties associated with the development, deployment and use of BECCS?*

BECCS faces sustainability, technical, economic and social challenges on both the bioenergy and the CCS fronts. On the one hand, supplying a bioenergy feedstock which guarantees BECCS to be energy positive, carbon negative, resource efficient, and provide CO_2 removal in a relevant time-frame, without competing with other markets, is the first set of challenges which hinders BECCS development and deployment at a large-scale. The main insights of our modelling work of BECCS value chain are that, depending on the conditions of BECCS deployment, BECCS can lead to scenarios that are both carbon negative and positive, energy positive and negative, resource efficient and intensive, and that can enable immediate and delayed carbon removal. Given the multiplicity of potential outcomes, the scope for unintended consequences when deploying BECCS for climate mitigation is vast [1, 2].

On the technical and financial fronts, the conversion of a biomass feedstock to bioenergy, in conjunction with CO_2 capture and sequestration, comes with efficiency penalties and higher capital and operating costs for the plant operator, as compared to fossil fuels. In a previous contribution, we showed that improvements in biomass pre-treatment, CO_2 capture processes and heat integration, could improve the system's energy efficiency[11]. However, it was also found that, providing a negative emissions credit is accrued by the BECCS facility operator, the carbon dioxide removal service of a BECCS facility could be more profitable than the energy generation service, thereby improving the economic viability of BECCS [12].

The absence of a regulatory framework monitoring the compliance of BECCS value chain to key sustainability metrics, as well as the right financial incentive schemes for CO_2 removal, are, to this point, crucial barriers to BECCS deployment.

Question 25) *Once developed BECCS is a technology that could be deployed in many different countries around the world. What principles and mechanisms should be used to determine where BECCS is deployed and how any associated negative emissions are accounted for? Should any UK participation in any international BECCS scheme be counted as additional to efforts to meet domestic carbon budgets?*

There is, in principle, no reason why a third country couldn't store CO_2 on behalf of the UK. If, for example, the US, moves rapidly to deploy BECCS, the UK could pay the US to remove CO_2 from the atmosphere on its behalf. The key point is that the limiting factor is access to derisked CO_2 storage infrastructure. Moving biomass around the work is not a limiting factor to its sustainability. Given that the UK has good potential access to extensive CO_2 storage capacity, providing a CO_2 storage service could be a potential source of long term revenue for the UK.

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